Discrimination between Composite Resin and Teeth using Fluorescence Properties

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The differentiation of composite resin from teeth using fluorescence emission was investigated as basic research for the visual detection of resin filled teeth in mass dental health examinations. Fluorescence spectra were taken from extracted human maxillary central incisors and 12 types of light-cured composite resins with a maximum of 15 shades via excitation using light with wavelengths of 400 – 500 nm. The fluorescence intensity ratio of resin to tooth was lowest around 500 nm for all the resins. The fluorescent images were taken based on spectroscopic results, which confirmed discrimination between the resin part and the tooth in the resin filled tooth.

Key words: Fluorescence, Composite resin, Tooth

INTRODUCTION

Light-cured composite resins have been widely used as an aesthetics restorative material in dental clinics and are preferred by patients¹ - ⁵. Unfortunately, the progress of composite resin aesthetics has made quick and accurate mass dental health examinations more and more difficult for dentists. Fig. 1 is a typical example of aesthetic

Fig. 1 Example of second molar tooth restored with composite resin.
restoration. Visual inspection of such restored teeth is very difficult due to the lack of light in the mouth and the insufficient difference in shades between resin restorations and surrounding teeth. Noting the difference of color between resin and tooth surface or exploring the tactile difference in surface quality has been used widely as a detection method. However, palpation with the sharp tip of the explorer may cause the breakage of the remineralized layer and initiate caries. These detection methods also do not have a high reliability, depending on the filling spots of resin and the examiner’s skills and experience. If a non-contact and clear discrimination of resin from teeth with high reproducibility could be attained, it would greatly help make oral health conditions of individuals easily and precisely known without the risk of tooth damage. Accurate oral health conditions provide allow appropriate oral health guidance to be given to individuals, solving part of the present problem. These facts would better the quality of people’s lives in the view of preventive dentistry and greatly contribute to the epidemiologist community and public welfare. In this study, we focused on the difference of optical characteristics as a method to detect resin filled teeth, and the possibility of applying fluorescence properties was examined to discriminate resin from tooth.

MATERIALS AND METHODS

Sample
1) Resin samples
Nationally marketed light-curing composite resins of 6 companies with a maximum of 12 types were used in the research (Table 1). An acrylic mold 10×10×5 mm was filled in with composite resin on a slide glass board and pressed with another slide glass from above. Photo-curing was done from both top and bottom sides via irradiation for 60 seconds using a visible light curing unit (JETLITE 3000, J.MORITA, Kyoto, Japan). After setting, samples were detached from the molds and polished with waterproof abrasive paper of #1200.

Table 1 Light-cured composite resins used for measurement of fluorescence

<table>
<thead>
<tr>
<th>Brand Name</th>
<th>Manufacturer</th>
<th>Shade</th>
<th>Abbreviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Z100</td>
<td>3M</td>
<td>All color (15 colors)</td>
<td>Z100</td>
</tr>
<tr>
<td>Z250</td>
<td>3M</td>
<td>All color (15 colors)</td>
<td>Z250</td>
</tr>
<tr>
<td>ESTELITE LV (Low Flow)</td>
<td>TOKUYAMA</td>
<td>A1, A3, A4</td>
<td>ELV</td>
</tr>
<tr>
<td>ESTELITE PASTE</td>
<td>TOKUYAMA</td>
<td>A1, A3, A3.5, A4, B3, C2</td>
<td>EP</td>
</tr>
<tr>
<td>TOUGH WELL</td>
<td>TOKUYAMA</td>
<td>All color (9 colors)</td>
<td>TW</td>
</tr>
<tr>
<td>ESTIO LC</td>
<td>GC</td>
<td>All color (12 colors)</td>
<td>ELC</td>
</tr>
<tr>
<td>UniFil S</td>
<td>GC</td>
<td>All color (11 colors)</td>
<td>YU-S</td>
</tr>
<tr>
<td>UniFil Flow</td>
<td>GC</td>
<td>A3</td>
<td>YU-F</td>
</tr>
<tr>
<td>PROGRESS</td>
<td>Kanebo</td>
<td>All color (8 colors)</td>
<td>PRO</td>
</tr>
<tr>
<td>CLEARFIL AP-X</td>
<td>KURARA</td>
<td>A2, A3, A3.5, A4, XL, B2, C3, OA3</td>
<td>KUR</td>
</tr>
<tr>
<td>LITE-FIL ll</td>
<td>SHOFU</td>
<td>B2, A2, A3</td>
<td>LIT II</td>
</tr>
<tr>
<td>Buty Fil</td>
<td>SHOFU</td>
<td>A2, A3, A3.5</td>
<td>BUTY</td>
</tr>
</tbody>
</table>
2) Teeth
Four teeth specimens which had been extracted and stored in 10%-neutral buffer formalin were prepared from sound human maxillary central incisors without caries, coloring or tetracycline fluorescence.

Excitation and fluorescence spectra
Measurements of excitation and fluorescence spectra were done with a fluorescence spectrophotometer (F-2500, Hitachi, Tokyo, Japan) using a 6×6 mm frame mask for both the polished surface of resin and the flat plane of the labial side of natural teeth. Excitation spectra were measured using the fluorescent wavelength 500 nm (scan speed 300/min, photo multiplier voltage 700 V, slit 2.5 nm). The fluorescence spectra were measured for the excitation wavelengths 400, 430, 450 and 470 nm (scan speed 300/min, photo multiplier voltage 700 V, slit 2.5 nm).

The fluorescence image
1) Specimens
After four sound molar teeth were cut at the root part parallel to the occlusal surface, a cavity of about 3 mm depth was formed using a diamond point (No 3202 and 3102R, SHOFU, Kyoto, Japan), filled with 4 types of resin (KUR, EP, PRO, Z100), and polished using a white point (No 25 and 28, SHOFU, Kyoto, Japan).

2) Exciting light
Exciting light applied to the resin filled teeth is summarized in Table 2. A filter was fixed on a visible light curing unit (JETLITE 3000) with wavelengths ranging 380~520 nm and peaking at 480 nm. The exciting light 40, 43, 45, 46 was formed using the filters shown in Table 2. The exciting light L47 was used in the visible light curing unit with a blue LED (Radius, OSADA, Tokyo, Japan).

<table>
<thead>
<tr>
<th>Exciting Light</th>
<th>Light Source</th>
<th>Filter Type</th>
<th>Peak Wavelength (nm)</th>
<th>Full Width of Half Maximum (nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>40</td>
<td>Halogen</td>
<td>HOYA COLOR FILTER GRASS BP-40</td>
<td>400</td>
<td>10</td>
</tr>
<tr>
<td>43</td>
<td>Halogen</td>
<td>FUJIFILM OPTICAL BP-43</td>
<td>430</td>
<td>50</td>
</tr>
<tr>
<td>45</td>
<td>Halogen</td>
<td>FUJIFILM OPTICAL BP-45</td>
<td>450</td>
<td>59</td>
</tr>
<tr>
<td>46*</td>
<td>Halogen</td>
<td>FUJIFILM OPTICAL BP-45+COLOR FILTER GLASS Y-44</td>
<td>456</td>
<td>37</td>
</tr>
<tr>
<td>L47</td>
<td>Blue LED</td>
<td>–</td>
<td>470</td>
<td>35</td>
</tr>
</tbody>
</table>
3) Fluorescent image observation
Four kinds of resin filled teeth (KUR, EP, PRO, Z100) were set in a dark place and irradiated with the exciting lights 40, 43, 45 and L47 at a distance of 100 mm and incident angles of 80°. A filter (Color filter SC-50, HOYA, Tokyo, Japan) with a permeability over 500 nm was fixed on the camera (EOS100QD, Canon, Tokyo, Japan). Reversal color film (PROVIA400, FUJIFILM, Tokyo, Japan) was used, and the efficiency for the discrimination of resin part from tooth was quantitatively evaluated. To measure the luminance of resin filled teeth, monochrome film (NEOPAN SS, FUJIFILM, Tokyo, Japan) was used with a filter (Color filter SC-50). A negative piece film was incorporated as a digital image into a personal computer using a flat scanner, then luminance was measured using image analysis software (Scion-Image). Finally, the contrast (luminance ratio of resin to tooth) was calculated.

RESULTS

Fluorescence properties
1) Excitation spectra
The excitation spectra of each resin (shade A3) and natural teeth for the 500 nm fluorescence wavelength are shown in Fig. 2. Most resins have a narrow peak width compared with teeth, and teeth showed an excitation intensity higher than all resins at wavelengths over 430 nm. The fluorescence of teeth was stronger than that of resin for excitation with wavelengths longer than 430 nm.

2) Natural tooth
Fluorescence spectra of 4 maxillary central incisors at 400 nm excitation are shown in Fig. 3. The fluorescence curves were similar for all the teeth, especially for wavelengths longer than 500 nm. This indicated that the condition for discrimination was
Fig. 3 Fluorescence spectra of natural teeth at the 400 nm excitation wavelength.

Fig. 4 Difference of fluorescence spectra by color tone of resin (Z100) for the 430 nm excitation wavelength.

more constant and reliable in this range.

3) Dependence of fluorescence spectra on shade of resin
Fluorescence spectra at 430 nm excitation were shown for each shade of Z100 resin and tooth in Fig. 4. Seven shades of each of the 15 kinds of colors were selected based on reflectivity difference in the visible region. C4 had the lowest reflectivity, P and UD the highest, and A2, 3, 3.5, 4 were fundamental shades. The fundamental and C4 shade resins showed very little difference in fluorescence intensity. The P and UD shade was stronger than the other resin materials, but the fluorescence intensity
DISCRIMINATION BETWEEN COMPOSITE RESIN AND TEETH

Fig. 5 Fluorescence spectra of tooth and composite resin (Z100) for different wavelengths of exciting light.

Fig. 6 Fluorescence spectra of tooth and composite resin for the 400 nm excitation wavelength.

Fig. 7 Fluorescence spectra of tooth and composite resin for the 430 nm excitation wavelength.

of resin was much smaller than that of the teeth irrespective of shade difference.

4) Comparison of A3 shade resin and natural teeth
Based on the result of Fig. 4, the A3 shade, most frequently used in clinics, was representative of the following. Fluorescence spectra of each resin at excitation wavelengths of 400, 430, 450, 470 nm were compared with that of teeth. Fig. 5 shows the comparison of tooth and resin (Z100) fluorescence intensity for each excitation wavelength. The fluorescence spectrum of natural teeth as the average intensity of four teeth and the A3 resin at each excitation wavelength are shown in Figs. 6~9. For the 400 nm excitation, there was considerable difference in the peak position and the spectrum waveform among resins (Fig. 6). The absolute fluorescence intensity of
tooth and resin at 430 nm excitation was lower compared with the 400 nm excitation as seen Fig. 5. The relative fluorescence intensity of resin was much lower than that of teeth and the difference was larger around 500 nm. As the excitation wavelength became longer at 450 nm excitation (Fig. 8) and 470 nm excitation (Fig. 9), the absolute fluorescence intensity of resin and tooth declined considerably. The relative difference, however, became much larger around wavelengths over 500 nm.
Observation of fluorescence image

Based on the fluorescence spectra, the fluorescent images of resin filled teeth over 500 nm were photographed under the exciting lights 40, 43, 45 and L47 (Fig. 10). Composite resin 1 of Fig. 10 is KUR, 2 is EP, 3 is PRO, and 4 is Z100. Under the exciting light 40, the fluorescence emission of resin was stronger than it was in teeth for KUR. For Z100, discrimination was difficult since the fluorescence emission of resin was equivalent to that of teeth. For PRO and EP, fluorescence emission was weaker than that of teeth so that discrimination was possible. Under the exciting light 43, the fluorescence intensity for KUR and Z100 was weaker than that of teeth, and discrimination was possible. For the exciting lights 45 and L47, the relative difference in fluorescence intensity was larger, and discrimination was clearer. From these results, wavelengths longer than 430 nm for exciting light is suitable for discrimination using fluorescence over 500 nm.

Evaluation of fluorescence image

Fluorescent monochrome images over 500 nm and their luminance ratio of resin to teeth are shown for the exciting lights 45, 46 and L47 in Fig. 11. Under exciting light L47 using the blue LED, the fluorescence intensity of teeth was the strongest. As for the luminance contrast of resin and teeth, the exciting light 46 was better than 45 and L47.
DISCUSSION

1. Detection of resin filled teeth in the mass dental health examinations

Information on oral health status obtained during mass dental health examinations is used for oral health surveys as basic data to plan oral health programs and to guide oral health properly\(^6\). As a high reliability is required, the results of this investigation might provide a large profit for the mass dental service. Light-cured composite resin is widely used because of its superior mechanical and aesthetic properties. Inspections are usually done using color differences and palpations are usually done using tactile differences between resin and tooth surface. The recent improvement of aesthetics in light-cured composite resins has made the detection of resin restored teeth much more difficult. The accurate detection of resin filled tooth depends greatly on the experience, intuition and skills of the examiner. The detection of resin filled into the palatal and molar occlusal surface is particularly difficult. To obtain more reliable survey results, we need a more accurate method to detect resin filled tooth.

2. Optical discrimination between resin and teeth

Preliminarily, we aimed to investigate the non-contact detection method of resin filled teeth using optical means in mass dental health examinations. The reflectivity and fluorescence properties were studied to discriminate between resin and tooth. The ultraviolet ray (under 380 nm) was excluded because of its harmful effect on human body\(^8\). The reflectivity of resin of shade A3 and teeth was measured for visible regions. The reflectivity difference was around 25% at maximum for light over 700 nm. To visualize reflectivity, resin filled teeth were photographed using infra-red film (INFRARED 760, Nikon, Tokyo, Japan) with spectral sensitivity in the 750–860 nm range. However, clear discrimination was difficult with the picture. Detection methods using reflectivity difference need further investigation. Then we focused on the use of fluorescence properties.

3. Excitation spectra

To examine the difference of fluorescence properties between resin and teeth, we measured excitation spectra for the fluorescence of the wavelengths 700, 650, 600, 550 and 500 nm. For the fluorescence in the 550–700 nm range, the difference in excitation spectra between resin and teeth could hardly be seen. A remarkable difference was observed in the full width of half maximum for fluorescence at 500 nm (Fig. 2), and there was a clear difference in the fluorescence intensity caused by exciting light over 430 nm. This suggested that the fluorescence emission of teeth was brighter than all the resins at excitation light wavelengths over 430 nm. Fluorescence spectra of teeth obtained from four teeth (Fig. 3) showed that individual differences are small where the differences in peak wavelength, intensity and width are small. Moreover, the fluorescence intensity of the longer wavelength side was similar.

These results suggest that discrimination between resin and tooth was possible
using their fluorescence properties.

4. Dependence of fluorescence on shade difference
Various colors are supplied for resin so that it will correspond with teeth color and make restoration inconspicuous. Therefore, fluorescence spectra were studied for each shade. As shown in Fig. 4, fluorescence spectra of the highest reflectivity (P, UD shade), the lowest reflectivity (C4 shade) and the middle fundamental color (A2, 3, 3.5, 4 shade) were studied in all 15 shades of Z100 resin using 430 nm excitation. The fluorescence spectra for these shades were similar, having nearly the same peak position and similar intensity. Among all the resins in Table 1, only LIT II had a considerable difference for shades. However, there was little difference in fluorescence emission in the spectrum range greater than 500 nm for excitation at 430, 450 and 470 nm. Therefore, the shade of resins does not having a significant affect on fluorescence properties if a fluorescence over 500 nm is used.

5. The optimum discrimination condition
Fluorescence spectra of each A3 shade resin and tooth were compared at the 400, 430, 450 and 470 nm excitation wavelengths. The fluorescence of teeth is stronger than all the resins at excitation light over 430 nm as shown in the excitation spectra of tooth and resin (Fig. 2). In the fluorescence spectra excited by the 400 nm wavelength in Fig. 6, the spectral form and the intensity of each resin varied. It was difficult to discriminate between resin and teeth. For the 430, 450, 470 nm excitation wavelengths, the fluorescence intensity of teeth was stronger than all the resins in the range longer than 500 nm. Under these conditions, discrimination would be possible.

6. Fluorescent image
To determine if discrimination is visually possible, the fluorescent images of resin filled teeth were photographed using a camera equipped with a filter transmitting light over 500 nm under various exciting lights. A filtered halogen lamp and blue LED was used as the excitation light source. Discrimination between each tooth and resin was difficult for the exciting light wavelength of 400 nm (Fig. 10, a), which was in accordance with the fluorescence spectra analysis (Fig. 6). For exciting lights 43, 45 and L47, the tooth part of the resin filled tooth was brighter and discrimination was possible in correspondence to the fluorescence spectra (Figs. 7~9) where tooth was stronger than resin. In the picture, discrimination with exciting light 43 was less clear compared with exciting lights 45 and L47. It seems that the fluorescence emission of the resin part with exciting light 43 was stronger than that with excitation lights 45 and L47, because exciting light 43 contained part of the spectrum under 420 nm where resin had stronger fluorescence than tooth. The degree of discrimination was also quantitatively evaluated by comparing the luminance of resin and teeth. Exciting light 46 removed the wavelengths below 420 nm from exciting light 45. The resin EP filled teeth were used for samples because discrimination with them was the most difficult of all the 12 resins as shown in Figs. 7~9. Fig. 11 showed
that the tooth emitted the strongest fluorescence by exciting light L47 with blue LED among exciting lights 45, 46 and L47. This is because the LED produced the strongest light intensity compared to that of exciting lights 45 and 46. Exciting light 46 had the highest luminance ratio of tooth to resin as shown in Fig. 11. This is because the fluorescence of resin decreased further since exciting light 46 did not include the spectrum part under the wavelength of 420 nm.

7. The possibility of clinical application

The observation of fluorescence images was possible only in dark places in the present study. The fluorescence intensity was too small in light places and stronger excitation light is necessary. As an excitation light source, LED seems suitable for clinical application because of its high emission intensity, sharp wavelength, long life, small size without a filter and light electric consumption. Our research showed that the suitable exciting light range for discrimination is 430~460 nm due to the good luminance contrast found in the range. However, the peak wavelength of blue LED available at present is 470 nm. A detector with a higher efficiency, equipment to amplify fluorescent images and a more intense LED with a suitable wavelength is desirable for further improvement.

CONCLUSION

As basic research for the visual detection of resin filled teeth in mass dental health examinations, discrimination between resin and teeth was examined using fluorescence properties.

1. The excitation spectra of teeth have a broader peak than composite resin. Tooth emits stronger fluorescence than resin in excitation wavelengths longer than 430 nm.
2. For fluorescence over 500 nm, the intensity difference of each resin by shade difference was small at 430, 450 and 470 nm excitation.
3. Fluorescence intensity of each resin in relation to teeth varied at the 400 nm excitation wavelength.
4. The fluorescence intensity of teeth was stronger than all resin at excitation wavelengths over 430 nm.
5. Although the absolute fluorescence intensity became weaker for excitation wavelengths longer than 400 nm, the relative difference in fluorescence intensity between resin and tooth increased.
6. The optimum condition for discriminating between teeth and resin in the fluorescent image was in agreement with the condition suggested by the fluorescence spectra.
7. As an excitation light source, the LED with a high brightness was excellent concerning operability and efficiency.
8. The present study suggested possibilities for further development of accurate methods detection resin filled tooth without the damage cause by explorers and also reducing misunderstandings of results by examiners in mass dental health
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