Fluorescent Properties of Porcelain-Restored Teeth and Their Discrimination

Kazutoshi Tani1*, Fumio Watari2, Motohiro Uo2 and Manabu Morita1

1Division of Preventive Dentistry, Department of Oral Health Science, Graduate School of Dental Medicine, Hokkaido University, Sapporo 060-8586, Japan
2Division of Dental Materials and Engineering, Department of Oral Health Science, Graduate School of Dental Medicine, Hokkaido University, Sapporo 060-8586, Japan

The differentiation of porcelain from tooth using fluorescence emission was investigated as a basic research for the visual detection of porcelain-restored teeth in mass dental health examinations. The fluorescence spectra were taken from the extracted human maxillary central incisors and five types of porcelain by excitation using the light 380-470 nm. There was a clear difference in fluorescence intensity between tooth and porcelain using excitation longer than 400 nm. Tooth and porcelain could be successfully distinguished on an image photographed by fluorescent light.

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1. Introduction

Various aesthetic restorative materials such as composite resin1–5 and porcelain6–10 are widely used in dental clinics. Detection of the teeth restored with aesthetic materials has become very difficult for dentists in a mass dental health examination due to the improvement of their aesthetics. The visual inspection of color difference between restorative materials and tooth or exploring of tactile difference of surface quality have been used widely as detection methods of teeth restored with aesthetic materials. However, these detection methods do not have a high degree of reliability, depending on the restored spots of aesthetic materials and examiner’s skills and experience. If a clear method for the differentiation of aesthetic materials from tooth with a high reproducibility could be attained, it would be possible to determine easily and precisely the state of the oral health condition of individuals. Our previous study showed that the discrimination of composite resin from the tooth in a resin-restored tooth was possible using the fluorescent properties.11 In this study, the differentiation of porcelain from tooth was investigated using the fluorescent properties.

2. Materials and Methods

2.1 Measurement of fluorescence spectra

2.1.1 Porcelain samples

Five types of dentin and enamel porcelains were used for the present research (Table 1). All porcelain powders were formed using a steel mold with the dimensions of 10 mm in diameter and a height of 5 mm. Powder compacts were fired according to each manufacturer’s recommended firing schedule in a vacuum in a porcelain furnace (CERAMIMAT FA-IV, GC). For enamel porcelain, firing was performed at atmospheric pressure.

2.1.2 Teeth

Four tooth specimens from the human maxillary central incisors without caries or coloring, and tetracycline fluorescence, which had been extracted and stored in 10%-neutral buffer formalin, were prepared.

Table 1 Porcelains used for measurement of fluorescence.

<table>
<thead>
<tr>
<th>Porcelain</th>
<th>Brand name</th>
<th>Manufacture</th>
<th>Shade</th>
<th>Abbreviation</th>
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<tbody>
<tr>
<td>Super porcelain AAA</td>
<td>Noritake</td>
<td></td>
<td></td>
<td>NTA</td>
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<tr>
<td>VITA</td>
<td>GC</td>
<td>EN1, A1</td>
<td></td>
<td>VITA</td>
</tr>
<tr>
<td>ZEOCELIGHT</td>
<td>YAMAMOTO</td>
<td>E3, DA3</td>
<td></td>
<td>ZOC</td>
</tr>
<tr>
<td>VINTAGE UNIBOND</td>
<td>SHOFU</td>
<td>59, A1B</td>
<td></td>
<td>VT-U</td>
</tr>
<tr>
<td>VINTAGE Halo</td>
<td>SHOFU</td>
<td>59, A1B</td>
<td></td>
<td>VT-H</td>
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The measurement of fluorescence spectra was done with a fluorescence spectrophotometer (F-2500, HITACHI) using the 6 mm × 6 mm frame mask for both the polished surface of porcelain and the flat plane of the labial side of the natural teeth. The fluorescence spectra were measured for the excitation wavelengths of 380, 400, 430, 450 and 470 nm (scan speed 300 nm/min, photo multiplier voltage 700 V, slit width 2.5 nm).

2.2 The fluorescence image

2.2.1 Porcelain restored tooth specimen

After four sound premolar teeth were cut at the root area parallel to the occlusal surface, a cavity of about 3 mm depth was formed using a diamond point (SHOFU 301, 311). An impression of the cavity-formed teeth was taken with silicone rubber impression materials. Four refractory models were made with refractory die materials (Nori-Vest, Noritake). Four porcelain inlays were made by applying a refractory cast according to the manufacturer’s recommended methods. Each inlay was fixed in the cavities of the teeth using resin cement (Super bond, SUN MEDICAL).

2.2.2 Excitation light

Excitation light applied to the porcelain-restored tooth was formed with the combination of a halogen lamp as a light source and various filters. The spectral distribution curve is shown in Fig. 1, which was obtained by multiplying the spectral distribution curve of a light source and the transmission curve of each filter. Filters were fixed on the visible
light-curing unit (JETLITE 3000, J. MORITA) with the wavelength set in the 380–520 nm range, peaking at 480 nm. The excitation light with the peak wavelengths of 400, 430, 450 nm, abbreviated as 40, 43, 45, was formed using the filters HOYA color-glass filter BP-40, FUJIFILM OPTICAL BP-43, HOYA color-glass filter BP-45, respectively. The excitation light L47 used the visible light-curing unit with a blue LED (Radius, OSADA) peaked at 470 nm.

2.2.3 Fluorescent image

Four kinds of porcelain-restored teeth (NTA, VITA, VT-U, VT-H) were set in a dark environment, and were irradiated with the excitation light 40, 43, 45, 47 at a distance of 100 mm and an incident angle of 80°. The filter (HOYA color filter SC-50) with permeability over 500 nm was fixed on the camera (Canon EOS100QD). The reversal color film (FUJIFILM PROVIA400) was used to evaluate the efficiency for the discrimination of the porcelain part from the tooth. A monochrome film (NEOPAN SS FUJIFILM) was used to measure the luminance ratio of porcelain and tooth with the filter (HOYA color filter SC-50). A negative film was read as a digital image into a personal computer using the flat scanner, and luminance was measured using image analysis software (Scion-Image). The contrast was calculated as the luminance ratio of porcelain to tooth.

3. Results

3.1 Excitation spectra

The excitation spectra for the 500 nm fluorescence wavelength were shown for dentin and enamel porcelains with the shade A3, the most frequently used color tone in clinics, and tooth in Fig. 2. Tooth showed a broader peak than all other porcelains, peaking around 370 nm. The fluorescence of tooth was stronger than porcelain for the excitation with the wavelengths longer than 380 nm. For excitation less than 380 nm in wavelength, the intensity emitted from tooth was in a similar range as most porcelains.

3.2 Fluorescence spectra

3.2.1 Tooth

The fluorescence spectra of six maxillary incisors at 400 nm excitation were similar, especially for wavelengths longer than 500 nm. This indicated that the conditions for differentiation were constant and reliable in this range.

3.2.2 Dependence of fluorescence spectra on shade of porcelain

In Fig. 3, fluorescence spectra at 400 nm excitation for tooth and different shades of super porcelain triple A (NTA, Noritake) were shown: all the three kinds of shades for enamel porcelain (E1, E2, E3) and eight shades selected from sixteen colors for dentin porcelain (A1B, A3B, A4B, B1B, B4B, C1B, C4B, D4B). The fluorescence of tooth was shown as the average intensity of six teeth. The difference in fluorescence was seen depending on each shade in wavelengths lower than 380 nm, and became very small for wavelengths longer than 500 nm.

3.2.3 Comparison of fluorescence of porcelain and tooth

Based on the results of Fig. 3, A3 shade porcelain, most frequently used in clinics, was used as representative in the following. The spectra of tooth and each A3 porcelain at excitation wavelengths of 380, 400, 470 nm are shown in Figs. 4–6. For the 380 nm excitation (Fig. 4), the strongest fluorescence intensity of enamel porcelain showed a similar intensity to tooth, and dentin porcelain was smaller than tooth. The absolute fluorescence intensity of tooth and porcelain at 400 nm excitation decreased compared with
380 nm excitation (Fig. 5). However the relative fluorescence intensity of porcelain was much lower than tooth. As the excitation wavelength becomes longer, reaching 470 nm (Fig. 6), porcelain had very little fluorescence in comparison with 400 nm excitation, although the absolute fluorescence of tooth declined considerably. Fluorescence of porcelain and tooth at 430, 450 nm excitation had the intensity between Fig. 5 and Fig. 6.

3.3 Fluorescent image

Based on the fluorescence spectra, the fluorescent images of porcelain-restored tooth for wavelengths over 500 nm were photographed under the excitation light 40, 43, 45, L47 (Fig. 7). Porcelain ① of Fig. 7 is NTA, ② is VT-U, ③ is VITA, ④ is VT-H. The fluorescence emission of porcelain was weaker than tooth, so that discrimination was possible.

3.4 Contrast evaluation

Monochromatic images for the fluorescence over 500 nm and the luminance ratio of porcelain to tooth are shown for the excitation light 40, 43, 45, L47 in Fig. 8. Under excitation light L47 using the blue the LED, fluorescence intensity of tooth was the strongest. As for the luminance contrast of porcelain to tooth, the excitation light 40 was better than 43, 45, L47.

4. Discussion

4.1 Detection of porcelain-restored teeth in the mass dental examinations

In the mass dental health examinations, the evaluation of accurate oral health status is useful not only for the planning of oral health and welfare programs but also for the appropriate oral health guidance and care of individuals. These evaluations would greatly contribute to the progress of Quality of Life for people from the viewpoint of preventive dentistry. The procedure to make porcelain restorations requires much more time and labor which results in much more prominent aesthetics compared with other esthetic materials like composite resin. Thus, it is very difficult to detect the teeth restored with porcelain. To obtain more reliable survey results, we need a more accurate detection method for porcelain-restored teeth.

4.2 Excitation spectra

To examine the difference of fluorescence properties between porcelain and tooth, the excitation spectra was measured for the fluorescence at the wavelength of 500 nm. The broad wavelength was observed in the full width of half maximum (FWHM) for the fluorescence at 500 nm (Fig. 2), and there was a clear difference in the fluorescence intensity with an excitation light over 400 nm. This suggested that the fluorescence emission of tooth was brighter than all the porcelains at excitation light longer than 400 nm. Fluorescence spectra of tooth obtained from six teeth showed that the individual difference is small for peak wavelength, intensity and width, especially in the longer wavelength side. These suggest that the discrimination of porcelain from tooth was possible using the fluorescent properties.

4.3 Dependence of fluorescence on shade difference

Various colors are supplied for porcelain to correspond with teeth so that restoration is not conspicuous. Therefore,
Fig. 7 Fluorescence image of the porcelain-restored tooth with different excitation lights 40(a), 43(b), 45(c), L47(d).

Fig. 8 Fluorescence image (>500 nm) of the porcelain-restored tooth with excitation lights 40, 43, 45, L47, and the corresponding luminance of porcelain and tooth.
the fluorescence spectra were studied for each shade. As shown in Fig. 3, the fluorescence spectra were similar with nearly the same peak position and similar intensity. Therefore, one could conclude that the shade of porcelains does not practically affect the fluorescent properties.

4.4 The optimum discrimination condition
Fluorescence spectra of each A3 shade porcelain and tooth were compared for the 380, 400, 430, 450 and 470 nm excitation wavelengths. The fluorescence of tooth is stronger than all the porcelains at excitation light, over 400 nm, as shown in the excitation spectra of tooth and porcelain (Fig. 2). In the fluorescence spectra excited by 380 nm wavelength, fluorescence intensities of each enamel porcelain were similar to tooth. For the 400, 430, 470 nm excitation, the fluorescence intensity of tooth was stronger than all the porcelains of both enamel and dentin in the range longer than 500 nm. Under these conditions, discrimination is possible.

4.5 Fluorescence image
To examine if the discrimination is visually feasible, the fluorescence image of porcelain-restored tooth was photographed under the conditions suggested from spectroscopy. For the excitation light 40, 43, 45 and L47, the tooth part of the porcelain-restored tooth was brighter and discrimination was possible in correspondence with the fluorescence spectra of Fig. 5 and Fig. 6. The degree of difference was also quantitatively evaluated by comparing the luminance of porcelain and tooth. Fig. 8 showed that tooth emitted the strongest fluorescence by excitation light L47 with the blue LED. This may be because the LED produced the strongest light intensity compared to that of excitation lights 40, 43 and 45 (Fig. 1). Regarding the luminance ratio of tooth to porcelain, the excitation light 40 provided the highest as shown in Fig. 8. This is in agreement with the fact that the difference of fluorescence emission between tooth and porcelain was larger than others as shown in the spectra by the 400–470 nm excitations (Fig. 5, 6).

4.6 The possibility on clinical application
Discrimination of tooth from aesthetic materials close, in luster and shades, to natural tooth was difficult in mass dental examinations. The present detection methods of teeth restored with aesthetic materials using visual inspection or palpation with explorers have not been very accurate detection methods, and take a long time. Furthermore, palpation using explorers with sharp tips carry the risk of tooth damage. If accurate, easy and non-contact visual detection methods with reproducibility were made possible, efficient examination without the early incidence of caries by exploring could be carried out. This fluorescence study found that the suitable range of excitation light for discrimination is 400–450 nm in order to give a good luminance contrast. The previous study for composite resin showed that excitation light 430–460 nm provided a good luminance contrast. Therefore the excitation light of wavelengths ranging from 430 to 450 nm would satisfy the discrimination in the cases of both composite resin and porcelain. The observation of fluorescence image was obtained only in a dark environment in these studies. A stronger light source is necessary for use in a bright place, since fluorescence emission is in proportion to the intensity of excitation light. As an excitation light source, LED seems suitable for clinical application because of its high emission intensity, and convenience because a filter is not necessary.13) Long life and small electricity consumption are also appropriate as a light source for mass dental health examinations. However, as a light source for differentiation, it is not currently optimal since the peak wavelength of a marketable LED is 470 nm. The detection ability may be increased with the improvement of higher intensity and suitable wavelengths for LED’s in the future. In addition, the amplifying system of fluorescence image is desirable to enhance the visual detection ability of teeth restored with aesthetic material.

5. Conclusions
As a basic research for the visual detection of porcelain-restored teeth in mass dental health examinations, the discrimination of porcelain from tooth was examined using the fluorescent properties, and the following findings were obtained.

(1) Fluorescence difference by color shade of porcelain is small at 400 nm excitation.
(2) Fluorescence of tooth is stronger than porcelain by excitation with wavelengths over 400 nm.
(3) The optimum condition (430–450 nm) for discrimination of tooth from porcelain in the fluorescence image is in agreement with the condition suggested by the fluorescence spectra.
(4) As an excitation light source, the high brightness and operability provided by LED is more suitable.
(5) The fluorescence difference can successfully discriminate the porcelain from tooth and recognize the restored tooth, which suggests the possibility of a non-contact detection method in mass dental health examinations without having to use the exploring method.

REFERENCES