Aesthetic analysis of natural anterior teeth and their restoration with resin composites

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CHAPTER 7

Quantitative clinical evaluation of aesthetic properties of incisors

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Quantitative clinical evaluation of esthetic properties of incisors.
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Abstract

Objective: to match perfectly the optical properties of natural teeth, a scientific approach is needed by using digital technology that excludes bias to quantitatively characterize the optical properties of populations’ teeth. The aim of this article is to present a method for a detailed clinical quantification of optical properties of front teeth.

Material and methods: A novel spectrophotometric approach was developed and applied on a preliminary group of subjects quantifying \( L^* \) (luminosity) \( a^* \) (quantity of green-red) and \( b^* \) (quantity of blue-yellow) of enamel and enamel-dentin complex against black and white background. Based on these in vivo data, CR (opacity) and opalescence (the ability to reflect blue wavelength when white light stroke the object perpendicularly) were also calculated.

Results: The mean values of \( L^* \) of the enamel-dentin complex against black and white background were 79.6 and 75.4, respectively. The mean values of \( a^* \) were 2.5 against black and 0.8 against white background, respectively. The mean values of \( b^* \) were 17.4 against black and 13.0 against white background, respectively. The mean contrast ratio was 86.7%. Opalescence value was 4.8. The mean values of \( L^* \) of enamel against black and white background were 79.0 and 64.2, respectively. The mean values of \( a^* \) were 2.1 against black and -0.3 against white background, respectively. The mean values of \( b^* \) were 15.2 against black and 8.7 against white background, respectively. The mean contrast ratio was 60.5%. Opalescence value was 7.4.

Conclusion: The described methodology, applied on a larger group of subjects, may serve as a database for a more exact characterization of optical properties of natural enamel and dentin.
Introduction

The demand of patients for imperceptible aesthetic restorations is steadily increasing [1]. Besides the restorations’ shape, a proper colour match is of main importance. Yet, the mostly used method to determine the optical properties of a tooth is by using shade tabs, a qualitative determination method which leads often to an imperfect colour match. Imperceptible restorative materials must in fact perfectly match optical properties of teeth. Even if almost every aesthetic restorative material sticks to the Vita scale of materials’ shades, this scale is only a rough approximation to the clinical reality of tooth colours. Furthermore, classic shade guide tabs are not systematically distributed in the colour space and they are not uniform in their colours over the entire tab [2]. That is why in 1996 Vita 3D Master was introduced to the profession as an attempt to improve the original Vita’s shade guide. A standardised ΔE = 4 was realised between the five subsequent groups of luminosity, making shade selection clinically much easier [3]. However, this approach is based on subjective human perception and is consequently subjected to bias. An approach that excludes this subjective bias by using an objective, quantitative colourimetric method was postulated and tested in vitro in the early nineties [4]. In the meantime spectrophotometers with build in photographic feature have been made available that can be used under routine clinical conditions [5, 6]. The quantitative data generated by these devices is converted by the devices’ software to porcelain shades (Vita, Ivoclar-Vivadent, Schaan, Liechtenstein). With certain modifications however, they may generate quantitative data not of the tooth’s colour only, but also of transparency and opalescence. These data may be used for the quantification of aesthetic properties of populations’ teeth. The aim of this study was therefore to develop a spectrophotometer and digital image-based quantitative method to measure CIE L*a*b*, transparency (CR) and opalescence of teeth in vivo that is rapid enough to be suitable for a large group of subjects.

Material and methods

After the approval of the study design by the ethical committee of the Dental School of the University of Geneva, 10 randomly chosen subjects from the Geneva region in the age range of 18 to 33 years gave their written informed consensus for a spectrophotometric and photographic analysis of their upper central incisors. Only patients with intact vital upper central incisors without malformations and significant intrinsic colourations, fissures or restorations were included into the study.

Prior to each measurement, the patient’s teeth were cleaned with a prophylaxis paste (Depurdent, Dr. Wild & Co. AG, Basel, Switzerland) and rinsed with water
spray to avoid bias due to extrinsic colourations. Care was taken not to dehydrate the teeth before the measurements to avoid changes in their opacity due to intrinsic humidity loss.

**Tooth colour determination by shade tab selection**

A digital photo (FinePix S2 Pro, Fujifilm Switzerland, Dielsdorf, Switzerland) with a macro lens (105 mm Macro lens, Nikon, Zurich, Switzerland) and a macro flash (SB-29 Macro flash, Nikon, Zurich, Switzerland) documented the Vita 3D Master tab’s shade selection (Vita, Bad Säckingen, Germany), aligned edge to edge with the upper right central incisor (Figure 1a). Two calibrated dentists independently chose the tab’s shade. In case of a difference, an agreement was reached by consensus between the two operators.

**Tooth shape determination**

A vinyl polysiloxane impression (Express fast set light body, 3M ESPE Dental Products, St Paul, MN, USA) of upper front teeth was taken and poured with plaster to enable registration of 3D tooth dimensions. The oro-facial thickness and the length of the tooth was measured on the model by using a dental calliper (Figure 1b).

**Figure 1a** Digital photograph “edge to edge” with a Vita 3D master tab
Figure 1b  Upper front incisor thickness measurements by using a dental calliper on the stone model

Spectrophotometer measurements

A calibrated reflectance spectrophotometer (SpectroShade, Handy Dental Type 713000, Serial No. HDL0090, MHT, Arbizzano di Negar, Verona, Italy) was used in this study. With this device CIE \( L^*a^*b^* \) measurements of the central upper incisors of each subject were executed by using a white as well as a black background. The device has a build-in aiming routine that enables a reproducible positioning perpendicular to the facial tooth surface to ensure equal measurement conditions for all teeth evaluated (Figure 1c). The device is equipped with a D65 light source (6500 °K) that is transformed into monochromatic light by means of a grating. This light is splinted in order to have each tooth illuminated simultaneously from two sides at 45° angle. The reflected light is directed at 0° on both the system’s two detector areas (both 18 x 13 mm\(^2\)). One detector is a colour CCD chip that generates the colour video image. The other, black and white CCD detector records the spectrophotometric data. Polarization filters are used to eliminate surface gloss. The data are stored in a proprietary image file format which is used to create detailed CIE \( L^*a^*b^* \) data.
Validation of spectrophotometric measurements

To validate and reconfirm the efficiency of the spectrophotometric analysis [7], L*a*b* data of the entire surface of the upper right and of the upper left central incisor obtained on the white background in separate measurements, were used to calculate the colour difference between both teeth. The difference was expressed in $\Delta E$ and calculated with the MHT analysis software (SpectroShade, Dental software version 2.41, MHT, Arbizzano di Negar, Verona, Italy).

On the stored images the vertical length of the upper right central incisor was then divided in six equal zones along the median axis. In each zone a round spot was
Quantitative clinical evaluation of aesthetic properties of incisors

defined (preset diameter 40 measuring points (Figure 2a)) by using the device’s software. L*a*b* values on white and black background were then recorded and also converted into Yxy values to obtain information about opacity as well. The mathematical formulas used for these calculations are described in Table 1.

**Table 1**  
Formulas used for the calculations of Yxy, opalescence and contrast ratio (CR) out of CIE L*a*b* measurements

---

### CIE-L*ab —> XYZ

\[
\begin{align*}
\text{var}_Y &= (\text{CIE-L*} + 16) / 116 \\
\text{var}_X &= \text{CIE-a*} / 500 + \text{var}_Y \\
\text{var}_Z &= \text{var}_Y - \text{CIE-b*} / 200 \\
\text{if } (\text{var}_Y^3 > 0.008856) & \text{ var}_Y = \text{var}_Y^3 \\
\text{else} & \quad \text{var}_Y = (\text{var}_Y - 16 / 116) / 7.787 \\
\text{if } (\text{var}_X^3 > 0.008856) & \text{ var}_X = \text{var}_X^3 \\
\text{else} & \quad \text{var}_X = (\text{var}_X - 16 / 116) / 7.787 \\
\text{if } (\text{var}_Z^3 > 0.008856) & \text{ var}_Z = \text{var}_Z^3 \\
\text{else} & \quad \text{var}_Z = (\text{var}_Z - 16 / 116) / 7.787 \\
\end{align*}
\]

\[\begin{align*}
X &= \text{ref}_X \times \text{var}_X \\
Y &= \text{ref}_Y \times \text{var}_Y \\
Z &= \text{ref}_Z \times \text{var}_Z \\
\end{align*}\]

---

### XYZ —> Yxy

\[
\begin{align*}
\text{Y} &= \text{Y} \\
x &= X / (X + Y + Z) \\
y &= Y / (X + Y + Z) \\
\end{align*}
\]

---

**OPALESCEENCE**

1. \[\{(a_w-a_b)^2 + (b_w-b_b)^2\}^{1/2}\]

2. \[\{(b_w-b_b)^2\}^{1/5}\]

**CR** (opacity): \(Y_b/Y_w\)

---

1: first formula proposed taking in count a and b parameters  
2: second formula proposed taking in account only the b parameter  
w = white background  
b = black background
**Figure 2a**  Example of L*a*b* measurements of the six different zones on an upper central incisor

**Figure 2b**  The gloss mode of the spectroshade MHT version 2.41 software allows an easier identification of “pure enamel zones”
Opalescence and opacity determination

Areas of pure enamel with 2 mm thickness were identified by comparing optical data of the MHT device in gloss mode (Figure 2b) with the plaster models, where a digital calliper was used to measure their thickness in oro-facial direction (Figure 1b). Once the area detected, CIE L*a*b* measurements were performed on the corresponding SpectroShade images with white and black background (Figure 2c). Areas of 3 mm thickness consisting of an equal amount of enamel and dentin [8] (according to Schillingburg & Scott 1973) were then detected and CIE L*a*b* values on white and black background were obtained through the same methodology as described for enamel. No direct measurements on pure dentin samples were possible due to the absence of exposed dentin in intact teeth.

The CIE L*a*b* values of enamel and enamel-dentin were used to calculate opalescence and opacity. Opalescence [9] was calculated out of the ΔE of a* and b* data against white and black background according to the formula in Table 1. CIE L*a*b* values of 2 mm thick enamel and 3 mm thick enamel-dentin with white and black background were then converted to Yxy scale to obtain contrast ratio (CR) values.

Figure 2c Example of L*a*b* measurement of a 2 mm thick enamel zone on white and black background
**Results**

Upper front incisor thickness of each patient at gingival and incisal level as well as the respective vertical lengths are presented in Table 2a.

### Table 2a

Dimensions of the upper incisors evaluated in the study

<table>
<thead>
<tr>
<th>Patient No.</th>
<th>Incisal Thickness (mm)</th>
<th>Gingival Thickness (mm)</th>
<th>Length (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.9</td>
<td>7.0</td>
<td>10.7</td>
</tr>
<tr>
<td>2</td>
<td>1.9</td>
<td>6.5</td>
<td>9.0</td>
</tr>
<tr>
<td>3</td>
<td>1.9</td>
<td>6.1</td>
<td>9.0</td>
</tr>
<tr>
<td>4</td>
<td>2.0</td>
<td>6.5</td>
<td>10.0</td>
</tr>
<tr>
<td>5</td>
<td>1.7</td>
<td>6.8</td>
<td>10.8</td>
</tr>
<tr>
<td>6</td>
<td>2.0</td>
<td>7.0</td>
<td>10.5</td>
</tr>
<tr>
<td>7</td>
<td>2.0</td>
<td>6.5</td>
<td>10.0</td>
</tr>
<tr>
<td>8</td>
<td>2.1</td>
<td>7.6</td>
<td>10.5</td>
</tr>
<tr>
<td>9</td>
<td>2.0</td>
<td>7.3</td>
<td>10.5</td>
</tr>
<tr>
<td>10</td>
<td>2.1</td>
<td>7.6</td>
<td>9.0</td>
</tr>
<tr>
<td><strong>Mean ± SD</strong></td>
<td><strong>2.0 ± 0.1</strong></td>
<td><strong>6.9 ± 0.5</strong></td>
<td><strong>10.0 ± 0.7</strong></td>
</tr>
</tbody>
</table>

The comparison between L*a*b* data on white background and ΔE of the entire surface of the upper right and of the corresponding upper left central incisor is presented in Table 2b.

### Table 2b

Comparison of L*a*b* and ΔE of the entire surface of the upper left and of the upper right incisor

<table>
<thead>
<tr>
<th>Patient No.</th>
<th>Tooth number 11</th>
<th>Tooth number 21</th>
<th>ΔE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>L: 80.58 a: 2.83 b: 16.66</td>
<td>L: 80.17 a: 3.38 b: 17.02</td>
<td>0.77</td>
</tr>
<tr>
<td>2</td>
<td>L: 81.28 a: 4.42 b: 19.02</td>
<td>L: 79.63 a: 4.29 b: 17.54</td>
<td>2.22</td>
</tr>
<tr>
<td>3</td>
<td>L: 78.12 a: 4.14 b: 17.32</td>
<td>L: 78.67 a: 4.13 b: 17.41</td>
<td>0.54</td>
</tr>
<tr>
<td>4</td>
<td>L: 77.39 a: 4.15 b: 17.25</td>
<td>L: 76.82 a: 3.73 b: 16.72</td>
<td>0.88</td>
</tr>
<tr>
<td>5</td>
<td>L: 76.55 a: 4.43 b: 18.72</td>
<td>L: 77.90 a: 2.91 b: 18.50</td>
<td>2.04</td>
</tr>
<tr>
<td>6</td>
<td>L: 76.13 a: 3.28 b: 18.36</td>
<td>L: 75.71 a: 4.08 b: 18.53</td>
<td>0.99</td>
</tr>
<tr>
<td>7</td>
<td>L: 76.55 a: 2.42 b: 15.94</td>
<td>L: 76.26 a: 3.24 b: 17.08</td>
<td>1.50</td>
</tr>
<tr>
<td>8</td>
<td>L: 81.14 a: 3.60 b: 15.53</td>
<td>L: 81.80 a: 3.52 b: 14.43</td>
<td>1.28</td>
</tr>
<tr>
<td>9</td>
<td>L: 79.24 a: 4.35 b: 18.83</td>
<td>L: 79.26 a: 4.85 b: 18.20</td>
<td>0.80</td>
</tr>
<tr>
<td>10</td>
<td>L: 78.80 a: 4.17 b: 17.90</td>
<td>L: 79.31 a: 4.33 b: 17.71</td>
<td>0.56</td>
</tr>
<tr>
<td><strong>Mean</strong></td>
<td><strong>L: 78.58 a: 3.78 b: 17.55</strong></td>
<td><strong>L: 78.55 a: 3.85 b: 17.31</strong></td>
<td><strong>1.15</strong></td>
</tr>
</tbody>
</table>

Mean L*a*b* data with standard deviations on white background as well as contrast ratio of the six spot measurements along the vertical axis of upper right incisors are summarised in Table 2c.
### Table 2c

L*a*b*, Contrast Ratio (CR) and tooth thickness at each of the six measuring spots
(Data of each of the 10 subjects & means)

<table>
<thead>
<tr>
<th>Measuring spot</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tooth thickness</td>
<td>7.0 mm</td>
<td>6.0 mm</td>
<td>4.5 mm</td>
<td>3.0 mm</td>
<td>2.5 mm</td>
<td>2.0 mm</td>
</tr>
<tr>
<td>L 1</td>
<td>75.84</td>
<td>81.07</td>
<td>82.79</td>
<td>83.04</td>
<td>80.85</td>
<td>80.59</td>
</tr>
<tr>
<td>L 2</td>
<td>75.80</td>
<td>79.83</td>
<td>80.84</td>
<td>83.41</td>
<td>83.85</td>
<td>83.81</td>
</tr>
<tr>
<td>L 3</td>
<td>73.81</td>
<td>78.62</td>
<td>79.32</td>
<td>80.60</td>
<td>81.10</td>
<td>81.05</td>
</tr>
<tr>
<td>L 4</td>
<td>71.01</td>
<td>75.64</td>
<td>78.10</td>
<td>79.54</td>
<td>79.64</td>
<td>82.39</td>
</tr>
<tr>
<td>L 5</td>
<td>71.56</td>
<td>77.57</td>
<td>79.28</td>
<td>80.74</td>
<td>80.34</td>
<td>77.84</td>
</tr>
<tr>
<td>L 6</td>
<td>70.84</td>
<td>77.57</td>
<td>78.88</td>
<td>78.18</td>
<td>77.92</td>
<td>79.13</td>
</tr>
<tr>
<td>L 7</td>
<td>74.55</td>
<td>78.13</td>
<td>79.15</td>
<td>78.61</td>
<td>76.90</td>
<td>74.79</td>
</tr>
<tr>
<td>L 8</td>
<td>74.07</td>
<td>80.46</td>
<td>81.04</td>
<td>81.43</td>
<td>82.32</td>
<td>82.09</td>
</tr>
<tr>
<td>L 9</td>
<td>76.61</td>
<td>79.90</td>
<td>80.20</td>
<td>80.17</td>
<td>80.21</td>
<td>80.42</td>
</tr>
<tr>
<td>L 10</td>
<td>75.30</td>
<td>79.55</td>
<td>80.53</td>
<td>81.77</td>
<td>81.55</td>
<td>79.53</td>
</tr>
<tr>
<td>Mean L</td>
<td>73.94</td>
<td>78.83</td>
<td>80.11</td>
<td>80.75</td>
<td>80.47</td>
<td>80.16</td>
</tr>
</tbody>
</table>

| Mean a | 7.03 | 4.54 | 3.48 | 2.87 | 2.43 | 2.11 |
| a 1 | 5.70 | 3.45 | 2.47 | 2.08 | 2.08 | 2.03 |
| a 2 | 7.74 | 5.42 | 4.29 | 3.49 | 3.06 | 2.86 |
| a 3 | 7.25 | 4.59 | 3.80 | 2.98 | 2.52 | 2.47 |
| a 4 | 9.32 | 6.44 | 4.30 | 2.97 | 2.24 | 1.38 |
| a 5 | 8.84 | 5.44 | 4.03 | 2.99 | 2.15 | 1.31 |
| a 6 | 6.06 | 3.85 | 2.63 | 2.30 | 1.93 | 1.20 |
| a 7 | 4.25 | 2.76 | 1.98 | 1.88 | 1.25 | 1.13 |
| a 8 | 7.07 | 4.44 | 4.05 | 3.70 | 3.00 | 2.85 |
| a 9 | 6.63 | 4.40 | 3.80 | 3.55 | 3.59 | 3.10 |
| a 10 | 7.45 | 4.60 | 3.47 | 2.75 | 2.51 | 2.73 |
| Mean b | 20.01 | 19.76 | 18.91 | 17.77 | 17.18 | 16.51 |
| b 1 | 21.97 | 20.43 | 18.46 | 15.95 | 15.33 | 15.07 |
| b 2 | 20.47 | 21.44 | 20.50 | 18.92 | 17.99 | 18.35 |
| b 3 | 17.00 | 17.26 | 17.64 | 17.23 | 18.55 | 17.82 |
| b 4 | 23.83 | 21.65 | 18.05 | 16.06 | 15.54 | 15.81 |
| b 5 | 20.81 | 21.89 | 20.31 | 18.62 | 17.02 | 15.49 |
| b 6 | 21.79 | 21.22 | 18.83 | 17.73 | 17.64 | 16.35 |
| b 7 | 18.11 | 18.89 | 17.76 | 17.57 | 15.98 | 14.69 |
| b 8 | 16.32 | 16.28 | 18.37 | 18.02 | 16.76 | 17.20 |
| b 9 | 19.22 | 19.79 | 19.61 | 19.31 | 19.43 | 18.37 |
| b 10 | 20.57 | 18.72 | 19.55 | 18.24 | 17.61 | 15.92 |
| Mean CR | 96.8 | 95.2 | 92.8 | 87.8 | 80.1 | 66.5 |
Mean L*a*b* data with standard deviations on black and on white background as well as contrast ratio and opalescence for 2 mm thick enamel and for 3 mm thick enamel-dentin are shown in Tables 2d and 2e.

Table 2f shows the Vita 3D Master shade selection proposed by the MHT spectrophotometer software on white and black background, respectively, and the subjective shade choice by the two operators as well.

### Table 2d

L*a*b* on black (b) and white (w) background, Contrast Ratio in percent (CR%) and opalescence (Opal) calculated according to the two formulas represented in Table 1 for 2 mm thick enamel

<table>
<thead>
<tr>
<th>Subject</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>L<em>b</em></td>
<td>80.4</td>
<td>83.46</td>
<td>79.27</td>
<td>81.84</td>
<td>74.95</td>
<td>76.86</td>
<td>72.94</td>
<td>82.2</td>
<td>81.75</td>
<td>76.04</td>
<td>78.97</td>
</tr>
<tr>
<td>L<em>a</em></td>
<td>82.61</td>
<td>70.76</td>
<td>65.02</td>
<td>65.35</td>
<td>61.57</td>
<td>66.37</td>
<td>61.78</td>
<td>66.12</td>
<td>63.55</td>
<td>58.87</td>
<td>64.20</td>
</tr>
<tr>
<td>a*</td>
<td>2.12</td>
<td>3.15</td>
<td>2.53</td>
<td>1.24</td>
<td>0.15</td>
<td>0.97</td>
<td>1.6</td>
<td>2.5</td>
<td>2.42</td>
<td>3.92</td>
<td>2.06</td>
</tr>
<tr>
<td>a<em>b</em></td>
<td>-0.98</td>
<td>0.76</td>
<td>-0.88</td>
<td>-1.33</td>
<td>-0.87</td>
<td>0.24</td>
<td>0.03</td>
<td>-0.58</td>
<td>-1.05</td>
<td>1.81</td>
<td>-0.31</td>
</tr>
<tr>
<td>b*</td>
<td>15.27</td>
<td>17.12</td>
<td>14.69</td>
<td>12.21</td>
<td>12.31</td>
<td>15.98</td>
<td>15.45</td>
<td>17.44</td>
<td>15.1</td>
<td>16.72</td>
<td>15.23</td>
</tr>
<tr>
<td>b<em>b</em></td>
<td>4.5</td>
<td>8.83</td>
<td>9.58</td>
<td>5.32</td>
<td>9.34</td>
<td>11.4</td>
<td>10.64</td>
<td>8.41</td>
<td>6.74</td>
<td>12</td>
<td>8.68</td>
</tr>
<tr>
<td>Cr%</td>
<td>54.2</td>
<td>66.6</td>
<td>61.5</td>
<td>57.5</td>
<td>62</td>
<td>69.8</td>
<td>66.9</td>
<td>58.5</td>
<td>53.9</td>
<td>53.8</td>
<td>60.50</td>
</tr>
<tr>
<td>Opal¹</td>
<td>11.2</td>
<td>8.62</td>
<td>10.01</td>
<td>7.35</td>
<td>3.14</td>
<td>4.63</td>
<td>5.05</td>
<td>9.54</td>
<td>9.05</td>
<td>5.17</td>
<td>7.38</td>
</tr>
<tr>
<td>Opal²</td>
<td>10.77</td>
<td>8.28</td>
<td>9.41</td>
<td>6.89</td>
<td>2.97</td>
<td>4.58</td>
<td>4.8</td>
<td>9.02</td>
<td>8.36</td>
<td>4.72</td>
<td>6.98</td>
</tr>
</tbody>
</table>

### Table 2e

L*a*b* on black (b) and white (w) background, Contrast Ratio in percent (CR%) and opalescence (Opal) calculated according to the two formulas represented in Table 1 for 3 mm thick enamel-dentin complex

<table>
<thead>
<tr>
<th>Subject</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>L<em>b</em></td>
<td>82.57</td>
<td>82.53</td>
<td>79.39</td>
<td>79.5</td>
<td>81.07</td>
<td>77.5</td>
<td>77.81</td>
<td>82.49</td>
<td>80.73</td>
<td>82.15</td>
<td>79.60</td>
</tr>
<tr>
<td>L<em>a</em></td>
<td>77.94</td>
<td>77.6</td>
<td>75.93</td>
<td>73.46</td>
<td>76.14</td>
<td>72.83</td>
<td>73.63</td>
<td>75.12</td>
<td>75.6</td>
<td>75.04</td>
<td>75.36</td>
</tr>
<tr>
<td>a*</td>
<td>1.87</td>
<td>3.1</td>
<td>2.53</td>
<td>2.33</td>
<td>2.66</td>
<td>2.2</td>
<td>1.75</td>
<td>3.17</td>
<td>3.25</td>
<td>2.43</td>
<td>2.53</td>
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<tr>
<td>a<em>b</em></td>
<td>0.16</td>
<td>1.6</td>
<td>1.54</td>
<td>0.45</td>
<td>0.62</td>
<td>0.71</td>
<td>1.04</td>
<td>0.38</td>
<td>0.56</td>
<td>0.48</td>
<td>0.75</td>
</tr>
<tr>
<td>Cr%</td>
<td>86.5</td>
<td>85.7</td>
<td>89.5</td>
<td>92.2</td>
<td>85.5</td>
<td>85.7</td>
<td>87.2</td>
<td>79.2</td>
<td>85.3</td>
<td>79.8</td>
<td>86.70</td>
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<tr>
<td>Opal¹</td>
<td>4.12</td>
<td>3.38</td>
<td>4.41</td>
<td>5.64</td>
<td>4.25</td>
<td>4.38</td>
<td>3.26</td>
<td>6.21</td>
<td>6.28</td>
<td>5.66</td>
<td>4.76</td>
</tr>
<tr>
<td>Opal²</td>
<td>3.75</td>
<td>3.04</td>
<td>4.3</td>
<td>5.32</td>
<td>3.73</td>
<td>4.12</td>
<td>3.19</td>
<td>5.54</td>
<td>5.67</td>
<td>5.31</td>
<td>4.40</td>
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</table>
Table 2f  Comparison between the subjective shade selection by two dentists and the SpectroShade shade selection on white and black background

<table>
<thead>
<tr>
<th>Subject</th>
<th>MHT white background</th>
<th>MHT black background</th>
<th>Dentists</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
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<td>2L1,5</td>
<td>2L1,5</td>
</tr>
<tr>
<td>2</td>
<td>2M2</td>
<td>2R1,5</td>
<td>2M1</td>
</tr>
<tr>
<td>3</td>
<td>1M2</td>
<td>1M2</td>
<td>1M2</td>
</tr>
<tr>
<td>4</td>
<td>1M2</td>
<td>1M2</td>
<td>1M1</td>
</tr>
<tr>
<td>5</td>
<td>1M2</td>
<td>1M2</td>
<td>2M1,5</td>
</tr>
<tr>
<td>6</td>
<td>1M2</td>
<td>1M1</td>
<td>2M1</td>
</tr>
<tr>
<td>7</td>
<td>1M2</td>
<td>1M1</td>
<td>1M1</td>
</tr>
<tr>
<td>8</td>
<td>1M2</td>
<td>1M1</td>
<td>1M1</td>
</tr>
<tr>
<td>9</td>
<td>1M2</td>
<td>2L1,5</td>
<td>3M1</td>
</tr>
<tr>
<td>10</td>
<td>1M2</td>
<td>1M2</td>
<td>2M1</td>
</tr>
</tbody>
</table>

**Discussion**

Only little is known about the exact optical properties of vital teeth of a specific population in their natural surrounding. This is especially true if a separate information is required for enamel and for dentin. Separate optical properties of enamel and dentin, in fact, have only been measured in vitro on a very limited number of samples [10]. Clinical studies on a larger group of patients are scarce and only basic colour of the entire tooth has been measured in these studies so far [11, 12], without any attempt to discriminate enamel and dentin or to characterize opacity and opalescence. In contrast to this, the method developed in this study takes all these parameters into consideration. According to the experience of the authors, less than 20 min are needed for the clinical data acquisition. Thus the method may easily be used in vivo on a large group of subjects.

We decided to investigate the aspect that we believe to be the most important for colour perception i.e. L*, a* and b*. L* gives the information on the luminosity onto a scale from 0 (black) to 100 (white). The a* value tells the quantity of green (whenever it is negative) or red (whenever it is positive). The b* value furnishes the quantity of blue (if the value is negative) or yellow (if the value is positive). Through these values measured against white and black background the opacity, that is the capacity not to allow to see through the object, can be calculated. We decided to take also into account opalescence. This is the capacity of giving a material a bluish appearance under reflected light and orange under transmitted light. The decision of using a spectrophotometer is based on the numerous advantages of this technology in comparison to colourimeter devices. A colourimeter analysis relies on the colours of the three human eye receptors, being red, green and blue, while a spectrophotometer
Chapter 7

analyzes every 1-10 nm of the visible spectrum. The result of the spectrophotometric analysis is a transmittance curve of the visible spectrum and obviously the obtained data are more accurate.

Specifically, the MHT spectrophotometer samples every 8 nm and incorporates a “tool mode” which allows a standardized angle of measurement (Figure 1a). As it records the entire tooth surface, a large number of different representations of the data on specific tooth locations becomes possible. Furthermore, this kind of approach has the advantage of taking into consideration all the clinical factors that may influence aesthetic appearance of the teeth such as the pulpal blood supply and the surrounding gingival tissues, which by scattering phenomenon can influence tooth colour perception [13].

A careful examination of well defined areas is important due to the different optical characteristics of enamel and dentin which cause the not uniform shade of the tooth [14]. Enamel is, in fact, more translucent and in respect to tooth colour plays only a minor role through scattering at wave lengths in the blue range. On the other hand dentin is more opaque and, according to ten Bosch and Coops [15] it is this tissue that determinates mainly the colour of the tooth.

According to Shillingburg & Scott Grace [8] at different level of the teeth along the vertical axe different thicknesses of enamel and dentin are present and different whole thicknesses are considered. That is why we think it is of little interest to analyze optical and spectrophotometric data of vertical thirds or sixths of the tooth due to the inhomogeneity of the substrate. Anyway from the observation of the present study some considerations can be drawn. As tooth thickness increases, opacity and a * values increase, too, while luminosity (L* values) decreases. At gingival level significantly higher a * values are detected maybe due to the scattering effect of the surrounding tissues and the presence of the subjacent pulp blood; b* values slightly increase with thickness, too in a constant and linear way.

Considering the main two components of tooth in a clinical situation, it is impossible to analyze separately the same thickness of enamel and dentin because no uncovered dentin can be found on sound natural human teeth. That’s why we chose to evaluate  L*a*b* values of 2 mm thick of “pure “enamel, that can be found in all patients at the incisal edge or in the interproximal area, and to measure the 3mm thick enamel/dentin complex at the incisal third. In this zone according to measurement of Schillingburg and Scott Grace [8], on 3 mm oro-facial thickness of incisor teeth in this area 50% of the thickness is formed by enamel and 50% by dentin. The obtained data of the dentin-enamel complex are thus representative of a “sandwich” with 1,5 mm thickness of enamel and 1,5 mm thickness of dentin.
The localization of “pure” enamel of 2 mm thickness was possible due to a visual determination of enamel on MHT images in gloss mode (Figure 2b) and a parallel measurement of the enamel thickness on the dye stone model of the respective anterior teeth (Figure 2a). Through this approach a quantitative in vivo L*a*b* measurement was possible on black and white background in order to calculate opacity values (CR) according to formulas presented in Table 1.

No attempt was made to determine fluorescence of enamel and dentin as it may not relevantly contribute to aesthetic properties of teeth under usual lightning conditions [15].

In course of this study the agreement between human perception and spectrophotometric colour selection based on Vita 3D Master was also checked, because only a 29.1% agreement was reported in a previous investigation [16]. In the present study an agreement of about 40% was found between SpectroShade measurements on black background and human perception. This is better than the values of Hugo et al. [16] but still quite low. The mismatch might be due to the fact that the algorithms used by the spectrophotometer to match the Vita 3D master tabs data need further optimization. Another explanation may be the fact that shade guides are not uniform in their colours so that the shade guide used in this investigation might have been different from the shade guide used for calibration of the spectrophotometer software [17]. So even if the L*a*b* measurements are precise [5], the device may still have some drawbacks if used as a routine shade determination method for restorations. Finally, it is also interesting to notice that if white background data were taken into consideration, the percentage of agreement with human perception decreased to 10% which shows the important influence of background colour on the outcome.

**Conclusions**

A novel quantitative in vivo approach for characterization of aesthetic tooth parameters such as colour, opacity and opalescence was developed in course of this study and proved its feasibility on a limited number of patients. The application of this method on a larger group of subjects may allow for creation of a database of aesthetic parameters of the teeth, which may be useful for further developments of aesthetic restorative materials.
Acknowledgements

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Quantitative clinical evaluation of aesthetic properties of incisors

References


