Aesthetic analysis of natural anterior teeth and their restoration with resin composites
Ardu, S.

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CHAPTER 8

Pilot in vivo image spectrophotometric evaluation of optical properties of pure enamel and enamel-dentin complex

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Pilot in vivo image spectrophotometric evaluation of optical properties of pure enamel and enamel-dentin complex
Abstract

**Objective:** The aim of this in vivo study is to investigate the L*a*b* and the opacity (CR) of front teeth by means of an image spectrophotometer and to evaluate the eventual influence of the background colour on the results. The second aim is to investigate if there is a relationship between tea, coffee, red wine drinking habits or smoking habits of the test subjects and tooth colour.

**Material and methods:** A novel image based spectrophotometric approach was developed and applied on a Swiss Army recruits group quantifying L*a*b* of pure enamel as well as of enamel-dentin complex against black and white background together with CR.

**Results:** When 2mm thick pure enamel was considered, the values obtained were (mean (SD)) L*(76.3 (3.4)), a*(3.4 (1.2)) and b*(17.2 (2.4)) against white background and L*(63.5 (4.2)), a*(0.8 (1.3)) and b*(10.7 (2.7)) against black background. The opacity (CR) of 2mm thick pure enamel was (64.4 (0.1)).

When 3mm thick enamel-dentin complex was considered, the values obtained were L*(79.0 (2.6)), a*(3.9 (1.3)) and b*(20.4 (3.0)) against a white background and L*(74.9 (3.0)), a*(1.8 (1.2)) and b*(16.7 (3.1)) against a black background. The opacity (CR) of 3 mm thick enamel-dentin complex was (87.4 (0.1)).

**Conclusion:** The application of this method on a larger group of subjects of different ages may serve as a database for a more exact characterization of optical properties of natural enamel and dentin.
**Introduction**

The need for imperceptible aesthetic restorations is steadily increasing due to the rise of very demanding patients [1]. In modern society, in fact, aesthetic is one of the major pillars and dental appearance is an important factor, especially in front teeth. In the modern trend of minimal invasiveness, veneers and crowns are only indicated when acceptable aesthetic results can not be reached by the direct restorative approach, i.e. the use of free-hand bonded composite restorations.

Even if composite resins have proved to give satisfactory results in the hands of excellent practitioners, the invisible restoration is still a chimera for the majority of dentists. Besides the restorations’ shape, a proper colour match is of main importance and it is difficult to achieve with today’s composites. There is, in fact, an evident mismatch between shades of available restorative materials [2] and teeth. Furthermore a large part of the available composites still sticks to the Vita shade guide where the shade selection is done by mixing the colour information of enamel and dentin. Due to this outdated concept the majority of epidemiologic tooth colour studies have been done by measuring the colour of the entire tooth. This approach has already been criticized and shade selection based on the separate choice of enamel and dentin colour has been proposed [3-5]. Anyway, no study has, so far, tried to measure in vivo on a larger number of subjects the optical properties of enamel and dentin. The only few available data in this field are, in fact, available from in vitro measurements [6, 7] and limited to a low number of samples.

The aim of this in vivo study is therefore to investigate the L*a*b* values and opacity (CR) of front teeth by means of an image spectrophotometer and to evaluate the eventual influence of the background colour on the results. The second aim is to investigate if there is a relationship between tea, coffee, red wine drinking habits or smoking habits of the test subjects and tooth colour.

**Material and Methods**

Sixty-two randomly chosen recruits from the Swiss Army coming from the German Swiss region in the age of 20-21 years gave their written informed consensus for a spectrophotometric analysis and the stone reproduction through a polysiloxane impression 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.

After answering a questionnaire on their drinking and smoking habits, their front teeth were cleaned with 70 RDA toothpaste on a toothbrush (Colgate Total, Colgate-Palmolive, Thalwil, Switzerland).
**Spectrophotometer measurements**

A calibrated reflectance image 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 entire surface of the central upper incisors of each subject were performed against 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. 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 18mm x 13mm). 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.

L*a*b* values on white (L* 96.6; a* -0.7; b* 2.6) and black (L* 0.4; a* 0.1; b* -0.1) background were then recorded and also converted into Yxy values to obtain information about opacity as well. The mathematic formulas used for these calculations are described in Table 1.
### Table 1

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

#### CIE-L*ab —> XYZ

\[
\begin{align*}
\text{var}_Y &= \frac{\text{CIE-L}* + 16}{116} \\
\text{var}_X &= \frac{\text{CIE-a}*}{500} + \text{var}_Y \\
\text{var}_Z &= \text{var}_Y - \frac{\text{CIE-b}*}{200}
\end{align*}
\]

\[
\begin{align*}
\text{if} \ ( \text{var}_Y^3 > 0.008856 ) \ & \text{var}_Y = \text{var}_Y^3 \\
\text{else} \ & \text{var}_Y = \frac{\text{var}_Y - 16/116}{7.787}
\end{align*}
\]

\[
\begin{align*}
\text{if} \ ( \text{var}_X^3 > 0.008856 ) \ & \text{var}_X = \text{var}_X^3 \\
\text{else} \ & \text{var}_X = \frac{\text{var}_X - 16/116}{7.787}
\end{align*}
\]

\[
\begin{align*}
\text{if} \ ( \text{var}_Z^3 > 0.008856 ) \ & \text{var}_Z = \text{var}_Z^3 \\
\text{else} \ & \text{var}_Z = \frac{\text{var}_Z - 16/116}{7.787}
\end{align*}
\]

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

#### XYZ —> Yxy

\[
\begin{align*}
\text{X} &= \text{ref}_X \times \text{var}_X \quad /\text{ref}_X = 95.047 \quad \text{Observer:} \ 2^\circ, \ \text{Illuminant:} \ D65 \\
\text{Y} &= \text{ref}_Y \times \text{var}_Y \quad /\text{ref}_Y = 100.000 \\
\text{Z} &= \text{ref}_Z \times \text{var}_Z \quad /\text{ref}_Z = 108.883
\end{align*}
\]

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

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

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\(w = \) white background  \\
\(b = \) black background

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**Observer. = 2°, Illuminant = D65**

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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 were measured on the model by using a dental calliper.

Opacity determination

Areas of pure enamel with 2 mm thickness were identified by comparing optical data of the MHT device in gloss mode (Figure 1) with the plaster models, where a digital calliper was used to measure their thickness in oro-facial direction. Once the area was detected, CIE L*a*b* measurements were performed on the corresponding SpectroShade images with white and black background. Areas of 3 mm tooth thickness consisting of an equal amount of enamel and dentin according to Shillingburg & Scott 1973 [8] 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 young teeth.

The CIE L*a*b* values of enamel and enamel-dentin were used to calculate opacity. CIE L*a*b* values of 2 mm thick enamel and 3 mm thick enamel-dentin complex with white and black background were then converted to Yxy scale to obtain contrast ratio (CR) values.

An exhaustive description of the whole methodology was reported in a preceding publication [9].


Results

When the 2 mm thick pure enamel was considered, the values obtained were $L^*$ (76.3 (3.4)), $a^*$ (3.4 (1.2)) and $b^*$ (17.2 (2.5)) against a white background and $L^*$ (63.5 (4.2)), $a^*$ (0.8 (1.3)) and $b^*$ (10.7 (2.7)) against a black background. The opacity (CR) of 2 mm pure enamel was (64.4 (0.1)).

When the 3 mm thick enamel-dentin complex was considered, the values obtained were $L^*$ (79.0 (2.6)), $a^*$ (3.9 (1.3)) and $b^*$ (20.4 (3.0)) against a white background and, $L^*$ (74.9 (3.0)), $a^*$ (1.8 (1.2)) and $b^*$ (16.7 (3.1)) against a black background. The opacity (CR) of 3 mm thick enamel-dentin complex was (87.4 (0.1)).

In order to investigate the influence of the background on $L^*$, $a^*$ and $b^*$ values on 2 mm thick pure enamel a Kruskall Wallis test was employed due to the fact that the data were not normally distributed (Shapiro Wilk test). This analysis showed that the background had a significant influence on $L^*$, $a^*$ and $b^*$ values ($p<0.05$).

To investigate the influence of smoking, tea, coffee and wine on $L^*$, $a^*$ and $b^*$ values against white and black background a Multifactorial Anova was used. It was shown that smoking, tea, coffee and wine did not affect $L^*$, $a^*$ and $b^*$ values significantly ($p>0.05$) when analysed against white background. When analysed
against black background, only tea had a significant influence, by decreasing L* values (p<0.05).

In order to investigate the influence of the background on L*a*b* values of the 3 mm thick enamel-dentin complex a Kruskall Wallis test was employed due to the fact that the data were not normally distributed (Shapiro Wilk test). This analysis showed that background had a significant influence on L*, a* and b* values (p<0.05).

To investigate the influence of smoking, tea, coffee and wine on L*a*b* values against white and black background a Multifactorial Anova was used. From this analysis it was shown that smoking, tea, coffee and wine did not affect (p>0.05) L*, a* and b* values when analysed against white background and black background as well. The complete representation of the data distribution is showed in Table 2.

Table 2  L*, a*, b*and CR graphical representation of 2 mm pure enamel and 3mm enamel-dentin complex

<table>
<thead>
<tr>
<th>Background</th>
<th>L* Means</th>
<th>95,0 Percent LSD Intervals</th>
</tr>
</thead>
<tbody>
<tr>
<td>White</td>
<td>62</td>
<td></td>
</tr>
<tr>
<td>Black</td>
<td>65</td>
<td></td>
</tr>
<tr>
<td>White</td>
<td>68</td>
<td></td>
</tr>
<tr>
<td>Black</td>
<td>71</td>
<td></td>
</tr>
<tr>
<td>White</td>
<td>74</td>
<td></td>
</tr>
<tr>
<td>Black</td>
<td>77</td>
<td></td>
</tr>
</tbody>
</table>
Background

Means and 95.0 Percent LSD Intervals on Enamel Complex

\[ a^* \]

White | Black

Means and 95.0 Percent LSD Intervals on Enamel-Dentin Complex

\[ L^* \]

White | Black
Chapter 8

Means and 95.0 Percent LSD Intervals on Enamel-Dentin Complex

Box-and-Whisker Plot
Discussion

Only little is known about quantitative optical properties of vital teeth of a specific population in their natural surrounding. This is especially true if specific data are required for enamel and for enamel-dentin complex. Optical properties of enamel and dentin, in fact, have only been measured in vitro on a very limited number of samples [5]. 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 [10-12], without any attempt to discriminate enamel and dentin or to characterize opacity. In contrast to this, the method developed in this study takes all these parameters into consideration [9].

The decision of using an image spectrophotometer is based on 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 analyzes every 1-10nm 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 [9]. The MHT spectrophotometer samples every 8nm and incorporates a “tool mode” which allows a standardized angle of measurement. As it measures the entire surface and combines the measurement with a live colour image of the tooth, specific local measurements on the tooth surface are possible. Furthermore, as the device was developed for clinical measurements, the 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 in fact important due to the different optical characteristics of enamel and dentin. Enamel is more translucent and in respect to tooth colour plays only a minor role through scattering at wavelengths in the blue range. On the other hand dentin is more opaque and, according to ten Bosch and Coops [14] it is this tissue that determinates mainly the colour of the tooth.

In the 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 young human teeth. That is why we chose to evaluate L*a*b* values of pure enamel of 2mm thickness, which can be found in all patients at the periphery of the tooth, and to measure the 3 mm thick enamel-dentin complex [9] in the incisal third of the front teeth. In this zone according to measurements of Shillingburg 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 for a “sandwich” with 1.5mm thickness of enamel and 1.5mm thickness of dentin.

The localization of “pure” enamel of 2mm thickness was possible due to the visual determination of enamel on MHT images in gloss mode (Figure 1) and a parallel measurement of the enamel thickness on the dye stone model of the respective anterior teeth [9]. Through this approach quantitative in vivo L*a*b* measurements were possible on black and white background in order to calculate opacity values (CR) according to formulas presented in Table 1.

Enamel results were more dependent on the background than the dentin-enamel complex. This could be due to the lower opacity of enamel which comes from its intrinsic higher transparency and the lower thickness (2mm) if compared to the thicker dentin-enamel complex (3mm). L* values, in fact, were similar on a white background, while on a black background enamel values became lower than those of the enamel-dentin complex. a* and b*, on the other hand, were higher for the enamel-dentin complex when analysed against the two backgrounds showing a shift towards yellow and red, maybe due to the presence of dentin which has a higher chroma than enamel [7].

Surprisingly, only tea consumption affected the enamel luminosity significantly by lowering its values on black background. All the other habits evaluated, did not show any significant influence neither on enamel nor on enamel-dentin complex. A possible explanation could be that in the young population the exposure to the staining agents like smoke, red wine, coffee or tea is not long enough to produce a significant effect. Another factor which has not been taken into account in this study is the frequency of dental recalls which could have modified the influence of the potential staining agents. The low influence of the potential staining agents could also be due to the relative low number of samples analysed.

Conclusions

In this in vivo study L*a*b* and opacity (CR) of a young population of recruits in the Swiss Army were evaluated. The influence of background on the results was significant while only a marginal influence of the drinking habits (only tea showed to decrease L* values in pure enamel when analysed against black background) could be found.

Future studies with higher number of subjects of different range of age and of different origins are needed in order to confirm the present data and to be able to create
a database of aesthetic parameters of the teeth, which may be useful for further developments of aesthetic restorative materials

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References