Optical phenomenon of peri-implant soft tissue. Part I. Spectrophotometric assessment of natural tooth gingiva and peri-implant mucosa

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Abstract
Objectives: The purpose of this study was to investigate the difference in optical appearance of the soft tissues labial to dental implants and to analyze the effects of titanium implant neck colors transmitted through the marginal mucosa.

Materials and methods: Fourteen patients with 15 Straumann single implant replacements in the maxillary anterior region were recruited. Color measurements of the peri-implant mucosa of test sites and the gingivae of contralateral or adjacent natural teeth as controls were made at the facial aspect of the teeth using a spectrophotometer. The color data (CIELAB color coordinates; \( L^* \), \( a^* \), \( b^* \) and \( C^* \)) in five incremental areas of 1 × 2 mm from the gingival margin toward the apical direction were obtained.

Results: A significant difference existed \((P<0.01)\) between the test site and the control site on the mean \( L^* \) and \( b^* \) values in all five incremental areas (area 1–5). In contrast, there was no significant difference in the mean \( a^* \) values. Discrepancies between color distributions of soft tissues were stronger in areas close to the gingival margin and decreased toward the apical direction. The mean color difference \( \Delta E \) between the test site and the control site was 7.7 in area 1 and decreased toward area 5 with a value of 6.5. However, there was no statistical difference in each of the mean values of differences in optical data, \( \Delta L^* \), \( \Delta a^* \) and \( \Delta b^* \), when five incremental areas of the control and the test sites were compared.

Conclusion: It was observed that the color of soft tissue around the titanium implant was significantly different compared with the gingiva of natural teeth. Significantly lower values of CIELAB color coordinates, \( L^* \) and \( b^* \) were found in the peri-implant soft tissue.

Basic and clinical research in implant dentistry in the early years focused mainly on the integration of endosseous dental implants in hard tissue and the re-establishment of masticatory function for patients with complete and partial edentulism (Brañemark et al. 1977; Adell et al. 1990; Buser et al. 1991; Chaytor et al. 1991; Lekholm et al. 1994; Avivi-Arber & Zarb 1996; Scheller et al. 1998; Haas et al. 2002). With the success of osseointegration based dental rehabilitation in these indications, the focus consequently shifted to the replacement of missing teeth in the esthetic region. In the maxillary anterior area, the esthetic outcome is a critical determinant in the overall success of implant therapy and yet remains a challenge.

An important role in achieving an esthetically optimal outcome is the morphology and appearance of peri-implant soft tissue associated with the implant and the resulting esthetics of the implant-supported restoration (Reikie 1993, 1995; Garber Date: Accepted 6 September 2006

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In natural teeth, a constant vertical dimension of healthy periodontal soft tissue, the biological width, is an essential factor in establishing gingival esthetics (Gargiulo et al. 1961; Vacek et al. 1994). Studies on the biology of peri-implant soft tissue indicated that supracrestal soft tissues of approximately 3–4 mm are always established following placement of an implant and suggested that the position of the peri-implant soft tissue margin may be related to the level of bone support around the implant (Berglundh et al. 1991; Abrahamsson et al. 1996; Berglundh & Lindhe 1996). The biological width is an important factor in achieving esthetic results of peri-implant soft tissue, especially for the non-submerged, one-piece titanium implants (Cochran et al. 1997; Hermann et al. 2000, 2001).

Understanding the existence of the biological width, the recession of the peri-implant soft tissue margin may result from an attempt to establish appropriate biological dimensions (Bengazi et al. 1996). It is clear that gingival recession can cause unacceptable soft tissue esthetics. Various prosthetic and surgical techniques have been proposed in an effort to overcome these occurrences following implant therapy, but the long-term success of these procedures has been inconclusive. Many surgical approaches have been used to enhance the esthetic appearance and gingival contour of peri-implant tissues (Israelson & Plemons 1993; Neale & Chee 1994; Palacci et al. 1995; Becker & Becker 1996; Conte et al. 2002). However, questions still remains regarding the viability and predictability of surgical approaches because the thickness of gingiva will often define how restorations will appear esthetically at the end of treatment (Kao & Pasquinelli 2002). Unlike thick gingiva, thin tissue is highly sensitive to trauma and inflammation and, thus, more susceptible to recession. In addition, thin gingival tissue tends to be delicate and almost translucent in appearance, contributing to an undesirable shine-through effect of the underlying titanium implants with a grayish appearance of the gingival cuff.

The predictability of an esthetic implant outcome can be achieved by overcoming this optical problem at the marginal peri-implant mucosa of titanium implants. Few studies exist in terms of color properties of soft tissue around titanium dental implants. Previous research on colorimetric solutions to improve the esthetic appearance of peri-implant soft tissue has not been thoroughly performed and has remained of subjective nature. The specific aims of this study were to: (1) investigate the difference in optical properties of the soft tissues labial to dental implants and the marginal gingivae of natural teeth, and (2) analyze the effects of titanium implant neck colors transmitted through the marginal mucosa in terms of areas. In this study, the hypothesis that the peri-implant soft tissue would exhibit a difference in color compared with that of natural tooth was verified, as measured by a color spectrophotometer.

Materials and methods

Color measurements of the peri-implant mucosa of test sites and the gingivae of contralateral or adjacent natural teeth as controls were made at the facial aspect of the teeth on five incremental areas in 1-mm increments [Fig. 1].

Human subjects and implants

Subjects who had already received Straumann® implants [Institut Straumann AG, Waldenburg/BL, Switzerland] during the past 5 years for single-implant replacements in the maxillary anterior region were recruited from the patient pool at the Harvard School of Dental Medicine. At the first visit, an initial examination including the location of the soft tissue margin, plaque index, bleeding on probing, probing depth and implant mobility was performed. The patients who met the study eligibility criteria were invited to a second visit for color measurement. Fifteen sites from 14 patients were included in this study. This study was approved by the Institutional Review Board (IRB) at Harvard Medical School.
Table 1. Optical data of five incremental areas for the control (C) and test (T) sites

<table>
<thead>
<tr>
<th>Area</th>
<th>Site</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C</td>
<td>T</td>
<td>C</td>
<td>T</td>
<td>C</td>
<td>T</td>
</tr>
<tr>
<td>$L^*$</td>
<td>Mean</td>
<td>56.2</td>
<td>49.9</td>
<td>55.7</td>
<td>50.8</td>
<td>54.4</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>6.7</td>
<td>4.9</td>
<td>6.7</td>
<td>4.2</td>
<td>6.3</td>
</tr>
<tr>
<td>$a^*$</td>
<td>Mean</td>
<td>17</td>
<td>15.7</td>
<td>18.6</td>
<td>16.3</td>
<td>20.1</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>3.2</td>
<td>4.3</td>
<td>3.8</td>
<td>3.3</td>
<td>3.9</td>
</tr>
<tr>
<td>$b^*$</td>
<td>Mean</td>
<td>17.2</td>
<td>12.7</td>
<td>14.7</td>
<td>11.2</td>
<td>15</td>
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<tr>
<td></td>
<td>SD</td>
<td>3</td>
<td>4.2</td>
<td>3.1</td>
<td>2.8</td>
<td>3.1</td>
</tr>
<tr>
<td>$C^*$</td>
<td>Mean</td>
<td>24.1</td>
<td>20.4</td>
<td>23.6</td>
<td>19.8</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>3.6</td>
<td>5.2</td>
<td>4.2</td>
<td>3.9</td>
<td>4.4</td>
</tr>
</tbody>
</table>

C, control site; T, test site.

Color measurements
Spectrophotometric measurements were made using a multi-spectral camera system [Handy-MSC, Olympus Co., Tokyo, Japan] as shown in Fig. 2. This spectrophotometer (Handy-MSC) uses a new technique of multi-band image acquisition with a built-in light-emitting diode (LED) lamp in the measuring head as a light source. The acquired multiband image data perform estimation of a spectrum and colorimetric values with original algorithm by exclusive software. Eight LED lamps (Olympus Co.) are used as a source of illumination. The area of illuminations is 20 mm in diameter with a central area of 15 mm in diameter for measurement. Spectral data acquisition requires about 0.2 s. The spectrophotometer used in this study has a 45°/0° geometry and is accurate to <0.1 ΔE for repeated measurements. Before specimen color measurement, a calibration was performed with a standardized calibration tile (Olympus Co.). The measuring head was placed on the surface of the object, and the display confirmed the object and the area to be measured.

This machine generates a multi-spectral image, that is, a digital image of an entire object that features spectral data for each pixel, and saves it to a computer (CF-W2J, Panasonic, Tokyo, Japan) to be used for analysis. The image is expanded on the computer, where areas of interest for spectral analysis can be selected. Actual measurement is performed for each area chosen from the display image. Reflectance values ranged from 380 to 780 nm at 1 nm intervals. CIELAB color coordinates $L^*$ (lightness), $a^*$ (redness), $b^*$ (yellowness) and $C^*$ (chroma) were provided. The total $\Delta E$ between the colors being compared was determined by the following equation: $\Delta E = (\Delta L^* + \Delta a^{*2} + \Delta b^{*2})^{1/2}$ (Ishikawa-Nagai et al. 2005).

The multi-spectral images of soft tissues for the implant crown [test site] and the natural tooth [control] were taken and saved to the computer. The color data (CIELAB color coordinates, $L^*$, $a^*$, $b^*$ and $C^*$) in five incremental areas of $1 \times 2$ mm from the gingival margin toward the apical direction were calculated based on the reflectance values from the wavelength of 400–700 nm. Triplet color measurement was performed, and the average of these measurements was considered to be as the measured data. Color difference $\Delta E$ values and its components ($\Delta L^*$, $\Delta a^*$, $\Delta b^*$ and $\Delta C^*$) were analyzed in each of five incremental areas. According to the CIELAB units, close color mismatches were in the range of 2–4 $\Delta E$ units. A $\Delta a^*$ value in the mean was determined by the following equation: $\Delta a^* = \sqrt{(\Delta a^1)^2 + (\Delta a^2)^2 + \ldots + (\Delta a^n)^2}$ (Ishikawa-Nagai et al. 2005).

Statistical analysis
Statistical analyses were performed using Statcel computer software [OMS Ltd., Saitama, Japan] and data were expressed as the mean ± 1 SD. Outcome values ($\Delta E$, $L^*$, $\Delta a^*$, $\Delta b^*$) were plotted and skewness and kurtosis values were computed to evaluate the normality of the distributions. Those distributions with confirmed normality were analyzed using parametric methods [one-way ANOVA]. Scheffe’s test was chosen a priori as a test for multiple comparisons.

Results
The color of the test site [peri-implant mucosa] demonstrated lower mean values of $L^*$, $a^*$, $b^*$ and $C^*$ than the control site (gingiva of adjacent or contralateral natural tooth) in all five areas (Table 1 and Fig. 3). There was a significant difference ($P<0.01$) between the test site and control site in the mean $L^*$ and $b^*$ values in all five incremental areas, and in the mean $C^*$ values in all areas except for area 5. In contrast, there was no significant difference in the mean $a^*$ values. Both the $L^*$–$C^*$ map and the $a^*$–$b^*$ map showed discrepancies between color distributions of soft tissues measured in the test and control sites (Fig. 4). Lower $L^*$–$C^*$ and $a^*$–$b^*$ values for the test site were observed compared with those of the control site. The color coordinates showed lower values of $L^*$, $a^*$, $b^*$ and $C^*$ for the peri-implant mucosa compared with those of the control site, indicating darkness, less redness, less yellowness and less chroma, respectively. The discrepancies were stronger in areas close to the gingival margin and decreased toward the apical direction.

The mean color difference $\Delta E$ between the test and control site was 7.7 in area 1 and decreased toward area 5, which was 6.5 (Fig. 5). In addition, the mean $\Delta E$ value in area 5 was >5, which is a much greater value than the clinical perceptual threshold of 3.6. A trend toward decrease in color coordinates $L^*$, $a^*$ and $b^*$ between the test site and control site was observed toward the apical aspect [Fig. 6]. Area 1 (gingival) showed the greater mean values of $L^*$, $a^*$ and $b^*$ and these values decreased toward area 5 (apical). However,
there was no statistical difference at $P < 0.05$ on each of the mean values of differences in optical data, $\Delta L^*$, $\Delta a^*$ and $\Delta b^*$, when five incremental areas of the control and the test sites were compared.

**Discussion**

The results of the present study revealed a significant difference between the color of soft tissue in natural tooth (control site) and around the implant (test site). It was reported that color differences between the soft tissues of contralateral natural teeth were within 2.7 [Ishikawa 1988]. Therefore, the color difference obtained in this study between a test site and the corresponding control site was much larger than the color difference that can be observed in soft tissues surrounding the natural dentition.

The color differences between the soft tissue of natural teeth and the soft tissue around the titanium implant revealed a greater amount of discrepancy in color closer to the gingival margin (area 1), which subsequently decreased toward the apical direction (area 5). This finding further supports the effect of optical phenomenon of peri-implant soft tissue compared with that of natural teeth. The overall restorative esthetic outcome is frequently dependent upon the quality and color of soft tissue at or near the gingival margin [Garber 1996; Chang et al. 1999]. It is in this region that significant esthetic impairment can occur, especially in patients with a high smile line [Chang et al. 1999].

Changes in the position of the soft tissue margin, especially at the facial aspect, can be detrimental from an esthetic perspective possibly leading to exposure of the titanium implant below the crown margin [Führhauser et al. 2005]. The relationship between soft tissue thickness and changes in the level of the soft tissue margin in terms of recession has been investigated in previous research, and it was suggested that the thickness of the peri-implant mucosa appears to be an important factor for the height of the soft tissue [Warrer et al. 1995; Wennström 1996].

Soft tissue thickness can also influence the shine-through effect of the underlying titanium implant, consequently compromising the overall esthetics of the peri-implant soft tissue [Ochsenbein & Ross 1969; Moberg et al. 1999]. In these instances, if conventional titanium abutments are selected and an implant is not submerged, there exists a risk of metallic gray tint becoming visible through thin soft tissue. This darker coloring effect could produce an unfavorable overall esthetic result,
especially in the esthetically sensitive maxillary anterior region. In the current study, the larger difference in color at the gingival margin area indicates the possibility of the shine-through effect of the implant neck of one-piece non-submerged titanium implants. For two-piece non-submerged or two-piece submerged implants, the dark coloring effect of conventional transmucosal metal abutment could have a detrimental impact on the esthetic appearance of patients with a fragile gingival tissue [Moberg et al. 1999]. Ceramic abutments or gold color abutments have been developed to help resolve this soft tissue problem. Andersson et al. [2001] demonstrated the advantages of using ceramic implant abutments for single-tooth replacement in esthetically sensitive areas.

It is critical to understand how the gingival tissue would respond to restorative margins and gingival inflammation to ensure predictable peri-implant esthetics. Moreover, subsequent recession of the soft tissue margin following crown placement has been reported in previous studies [Adell et al. 1986; Apsø et al. 1991; Jemt et al. 1994; Bengazi et al. 1996]. In addition to the position and quality of the labial margin of the peri-implant mucosa, the optical effect of soft tissue may be a contributing factor to the final esthetic outcome.

The use of a spectrophotometer in the present study provided an objective and predictable method to obtain reliable color measurements. The color measurement of the soft tissue is extremely sensitive to the effects of pressure, especially for a measurement of a small area such as marginal gingiva. Therefore, measurements must be acquired without soft tissue contact. The color measurement instrument used in this study can capture the relatively large area of 15 mm diameter without any contact on the surface of the measured object. As an actual measurement is performed for each area chosen from the display image, any small area can be measured. This feature conferred accuracy and consistency to this study in color measurement.

In the current study, it was observed that the soft tissue color around titanium implant was significantly different compared with that of natural teeth as measured by a spectrophotometer. This seems to indicate that the surface characteristics of the implant and abutment may influence the color effect. Further investigation measuring the thickness of peri-implant mucosa and its relationship with color analysis is underway. Approaches to change the optical appearance at the marginal peri-implant mucosa are of great interest and may offer an important option to achieve the desired soft tissue esthetics.

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References


Park et al. Optical phenomenon of peri-implant soft tissue


Ishikawa, S. [1988] Colorimetric study of marginal gingiva inflammatory effects on color difference analyses from the standpoint of gingival tissue inflammatory effects on color difference analyses from the standpoint of gingival tissue. *Journal of Periodontology* 32: 829-838.


