The effect of zirconia and titanium implant abutments on light reflection of the supporting soft tissues

**Abstract**

**Objectives:** To determine the difference in light reflection of oral mucosa covering titanium (Ti) or zirconia (ZrO2) abutments as it relates to the thickness of the covering mucosa.

**Material and methods:** Fifteen anterior implants (Astra Osseo speed) in 11 patients were fitted with a Ti or a ZrO2 abutment (cross-over, within-subject comparison). Hyper-spectral images were taken with a camera fitted on a surgical microscope. High-resolution images with 70 nm interval between 440 and 720 nm were obtained within 30 s (1392 × 1024 pixels). Black- and white-point reference was used for spatial and spectral normalization as well as correction for motion during exposure. Reflection spectra were extracted from the image on a line mid-buccal of the implant, starting 1 mm above the soft tissue continuing up to 3 mm apically.

**Results:** Median soft tissue height is 2.3 mm (min: 1.2 mm and max: 3.1 mm). The buccal mucosa rapidly increases in the thickness, when moving apically. At 2.2 mm, thickness is 3 mm. No perceivable difference between the Ti and ZrO2 abutment can be observed when the thickness of the mucosa is 2 ± 0.1 mm (95% confidence interval) or more.

**Conclusion:** It is expected that the difference in light reflection of soft tissue covering Ti or ZrO2 abutments is no longer noticeable for the human eye when the mucosa thickness exceeds 2 mm. 

**The ultimate challenge of restorative and implant dentistry is to replace all lost hard and soft structures, restore function and aesthetics, thus mimicking the unrestored, healthy tooth and its bony and soft tissue surroundings.** With respect to the latter, the architecture, contour, surface texture and colour of the permucosal tissue are important determinants of the appearance of the restoration. Not much research is available with respect to the colour of the gingiva or peri-implant mucosa and its influencing factors, but it is presumed to depend primarily upon the intensity of melanogenesis, the degree of epithelial cornification, the depth of epithelialization and the arrangement of gingival vascularization (Dummett 1960; Kleinheinz et al. 2003). However, the colour of underlying root surfaces or restorative materials such as implant abutments, crown margins or even MTA are also considered to be of influence on gingival colour (Takeda et al. 1996; Jung et al. 2007; Bortoluzza et al. 2007; Watkin & Kerstein 2008).

In the past, titanium (Ti) abutments were the standard of care for implant restorations throughout the mouth. Unfortunately, blue-greyish shimmering of such abutments may hamper the aesthetic outcome in cases with thin overlying mucosal tissues and cause a noticeable colour difference with the gingival tissues of neighbouring teeth (Park et al. 2007). This is why initially alumina abutments were introduced, but the occasional fracture of abutments made from alumina was observed (Prestipino & Ingber 1993a, 1993b; Andersson et al. 2001, 2003). The use of partially stabilized zirconia (ZrO2) abutments has become more popular in recent years, especially in regions of high aesthetic demand (Watkin & Kerstein 2008). Such abutments combine high bending strength and toughness with good biocompatibility and the limited amount of available data suggests that the clinical performance is comparable with that of Ti abutments [Manicone et al. 2007; Sailer et al. 2009a]. As with alumina abutments, the white colour of ZrO2 is considered aesthetically advantageous (Glauser et al. 2004; Tan & Dunne 2004; Canullo 2007; Ishikawa-Nagai et al. 2007; Park et al. 2007; Bae et al. 2008). Although it is considered by some to...
be too white, and it is suggested that more tooth colored abutment materials are to be preferred (Nakamura et al. 2010).

It was demonstrated in vitro that the thickness of the overlying mucosa plays an import role on discoloration and the aesthetic appearance of soft tissues (Jung et al. 2007). Randomized controlled clinical trials are needed to demonstrate the optical effect of ZrO₂ and Ti materials when placed subgingivally. On visual inspection and graded on a four-item scale, less discoloration of the buccal mucosa was seen at all ceramic crowns on ZrO₂ abutments at 1–2 months after crown cementation when compared with porcelain-fused-to-metal crowns on Ti abutments (Hosseini & Gottfredsen 2010). Yet, when rated more objectively by means of spectrophotometric measurements at 1 mm below the gingival margin, no statistically significant differences in the measurements at 1 mm below the gingival margin were reported. Yet, when rated more objectively by means of spectrophotometric measurements at 1 mm below the gingival margin, no statistically significant differences in the measurements at 1 mm below the gingival margin were reported.

Preformed abutments are the stainless steel abutments that are available for most dental implant systems and are essentially free of gingival discoloration. Yet, when rated more objectively by means of spectrophotometric measurements at 1 mm below the gingival margin, no statistically significant differences in the measurements at 1 mm below the gingival margin were reported. Yet, when rated more objectively by means of spectrophotometric measurements at 1 mm below the gingival margin, no statistically significant differences in the measurements at 1 mm below the gingival margin were reported.

Specular properties of ZrO₂ abutments are similar to those of the cementoenamel junction of the contralateral tooth. In all situations, primary stability could be achieved. When the implants were placed in a submerged manner (seven implants), a cover screw was utilized. In all other situations (eight implants), a perimucosal healing abutment of appropriate dimensions was placed (non-submerged healing). Wound closure was performed with Gore-Tex™ sutures (W.L. Gore & Associates, Newark, DE), which were removed after 2 weeks.

Assessment of soft tissue thickness and height
At least 3 months after implant placement, or when applicable, at least 3 weeks after second-stage implant surgery, the healing abutments were disconnected. A standard open tray impression registering the implant position and the surrounding soft tissues was made (Impregum, 3M Espe, Germany). Subsequently, an implant analogue was connected to the impression post and a plaster model was poured. The model was ground in a mesial-distal direction, in a plane parallel to the implant until the mid-buccal plane of the implant was reached (Fig. 1). The specimen were photographed using a Canon EOS 20D (Japan) photo camera with a 100 mm macro lens and a ring flash (8.2 mega pixels).

A line parallel to the implant was drawn. Perpendicular to this line, a series of lines was drawn with 0.2 mm intersections, starting at the most coronal point of the peri-implant mucosa. Along these lines, the facial soft tissue thickness was measured in a commercially available computer program that allows image analysis (Adobe Photoshop CS3 extended). The images were calibrated, for which the known dimensions of (sections of) the implant analogue or a ruler that was photographed in the same plane were used.

Under local anaesthesia, a full-thickness flap was raised with a crestal incision located approximately 2–3 mm toward the palatal aspect. Small relieving incisions were placed into the gingival sulcus of the adjacent teeth and extended to the mesio-buccal site of these teeth.

The palatal and buccal mucoperiosteal flaps were elevated and the alveolar crest was inspected. When a bone augmentation procedure had been performed before implant placement, a small vertical incision was made in the mucosa overlying the bone graft at the position of the fixation screw. In this way, the screw could be removed easily with little exploration and trauma, preventing disturbance of the vascularization.

A surgical template was used to assure the proper placement of the implant. The implants (Ossospeed™, Astra Tech, Möhndal, Sweden) were 3.5 or 4 mm in diameter, placed at bone level, mostly in a position 1 mm apical to the cemento-enamel junction of the contralateral tooth. In all situations, primary stability could be achieved. When the implants were placed in a submerged manner (seven implants), a cover screw was utilized. In all other situations (eight implants), a perimucosal healing abutment of appropriate dimensions was placed (non-submerged healing). Wound closure was performed with Gore-Tex™ sutures (W.L. Gore & Associates, Newark, DE), which were removed after 2 weeks.

In addition, the height of the permucosal tissues covering the implants was determined from the implant shoulder to the cervical margin (Fig. 1).

Spectrophotometric measurements
Specially prepared dimensionally identical ZrO₂ or Ti abutments were placed in random order. The dimensions of the permucosal section of these abutments were similar to those of the healing abutment. The abutments had been provided with markers to allow for the calibration of linear measurements (Fig. 2a–c). A time span of 15 mm was allowed for settling of the permucosal tissues.

The subject was seated in a chair with a head rest. His head was positioned perpendicular to the objective of the microscope and subsequently strapped to the head rest with a band of Velcro tape. A hyper-spectral image was made, the abutments were switched and the measurements were repeated.

High-resolution images 1392 × 1024 pixels were made using a hyper-spectral camera (Fig. 3) (Noordmans et al. 2007b, 2009). Using an electronically tuneable optical bandfilter (vis-LCTF, Cri, Woburn, MA, USA), images were captured from a wavelength of 440–720 nm with a stepsize of 4 nm. In this hyper-spectral image, the intensity I₀, (x, y, λ) was determined for each pixel coordinate x, y and wavelength λ for implant n and abutment type t. Subsequently, the hyper-spectral images were corrected in two ways (Fig. 4):

1. **White balance and vignetting:** By making a hyper-spectral image of both a white refer-
subject, the reflection image was subsequently normalized by the reflection spectrum of ZrO$_2$ extracted 1 mm coronal of the mucosal margin. The validity of ZrO$_2$ being a good white reference was confirmed by spectral reflection measurements using a halogen light bulb and a calibrated Ocean Optics spectrometer QE65000 (Dunedin, FL, USA).

2. Movement during acquisition and matching of the images. As the capture sequence takes about 10–30 s, small movements occur during acquisition. Fast GPU-based image matching software was used to re-align the spectral slices based on rigid deformations and image correlation [Noordmans et al. 2007a]. This software was also used to match the hyper-spectral images of the ZrO$_2$ and Ti abutments.

Spectra were extracted starting 1 mm coronal until 3 mm apical of the soft tissue margin in 0.05 mm steps (Fig. 5). For each step, spectra were acquired in a small circular region to reduce noise and small highlights. The mean reflection spectrum along the ZrO$_2$ and Ti abutment was then calculated by averaging over the spectra of all patients.

Subsequently, they were processed as follows. First, calibration of the distance axis along the central line was performed by setting the distance from the marker and the edge of the abutment to the central line was performed by setting the distance to the cervical margin is presented in Fig. 6. The median value of ZrO$_2$, extracted 1 mm coronal of the mucosal thickness axis. Values for mucosa thickness D as a function of the distance to the cervical margin of the mucosa were obtained from the measurements on the plaster model. Then, the resulting spectra were converted to XYZ-colour space and finally to L’ a’ b’ colour space using the following functions [Wyszecki & Stiles 2000]:

$$R_{a,b}(x, y, \lambda) = \frac{I_{a,b}(x, y, \lambda) - D(x, y, \lambda)}{W(x, y, \lambda)} \quad (1)$$

where $I$ represents the captured image, $D$ and $W$ the dark and white reference and $R$ the reflection image. To compensate for differences in distance between camera and sub-

$$\begin{bmatrix} X(D) \\ Y(D) \\ Z(D) \end{bmatrix}_{a,b} = \int \begin{bmatrix} x(\lambda) \\ y(\lambda) \\ z(\lambda) \end{bmatrix} \cdot R_{a,b}(D, \lambda)S(\lambda)d\lambda.$$  

$$\begin{bmatrix} 116f_Y(D) - 16 \\ 1 \quad f_X(D) - f_Y(D) \\ f_Y(D) - 2f_Z(D) \end{bmatrix} \quad (3)$$

where $f_X(D) = \begin{cases} P(D)_{n_{90}} & \text{if } P(D)_{n_{90}} > 0.009 \\ 90 \cdot P(D)_{n_{90}} + 16 & \text{if } P(D)_{n_{90}} \leq 0.009 \end{cases}$}

Results

Soft tissue thickness and height

The mean thickness of the buccal mucosa covering the abutment surface in the midline in relation to the distance from the cervical gingival margin is presented in Fig. 6. The median value for the height of the mucosa to the edge of the implant is 2.3 mm (mean 2.4 SD 0.5 mm, min: 1.2 mm and max: 3.1 mm).

Spectral analysis

As an example of the colour reconstructions, the processed images of patient 3 are presented following white balancing, vignetting, correction of movement and matching of the images of both abutment types [Fig. 7]. To enhance the difference in appearance of the mucosa, the images are corrected spatially and spectrally with the following formula:

$$L'(D) = \begin{cases} L(D) &= \frac{116f_Y(D) - 16}{500} \\ a'(D) &= \frac{f_X(D) - f_Y(D)}{200} \\ b'(D) &= \frac{f_Y(D) - 2f_Z(D)}{16} \end{cases}$$

where $\bar{x}, \bar{y}, \bar{z}$ denote the colour matching functions and $S(\lambda)$ the spectral power density of a D50 light source.

The mean thickness of the buccal mucosa covering the abutment surface in the midline in relation to the distance from the cervical gingival margin is presented in Fig. 6. The median value for the height of the mucosa to the edge of the implant is 2.3 mm (mean 2.4 SD 0.5 mm, min: 1.2 mm and max: 3.1 mm).
of the abutment can be perceived hinting that the
influence of the abutment does not extend that
far apically.

The mean spectrum at different distances from
the mucosal margin for both abutment types is
demonstrated in Fig. 8. Starting from \( d = -1 \) mm,
the spectra still represent the spectrum of the abut-
ment material itself, and further apically the
spectra become increasingly similar to that of
mucosa tissue. Note that the absorption peaks of
oxygenated haemoglobin are clearly visible. It
was demonstrated in the optical literature that
such data can be used to quantify the functional
properties of tissue (Vogel et al. 2007).

To determine at which thickness of mucosa
differences can be perceived by human observers,
the distance axis is converted to a thickness axis
using the measurements of Fig. 6. The \( L^a'b' \) norms for both abutment types as a function
of the mucosa thickness are shown in Fig. 9.
To determine at which thickness no difference
can be perceived, the norm of the difference
between the \( L^a'b' \) vectors is calculated and a
threshold is set at a difference of 3.7 (Johnston &
Kao 1989). This corresponds with a mucosa
thickness of \( 2 \pm 0.1 \) mm (95% confidence inter-
val).

To observe the effect of this thickness thresh-
old on the distance at which differences may still
be perceivable, the thresholds are transferred to
the thickness/distance plots (Fig. 10). One can
observe that the range in distance is rather sub-
stantial from 0.5 to 2 mm.

Discussion

The appearance of the permucosal tissue is an
important determinant of the overall aesthetic
outcome of an implant–bone restoration. It has
proven difficult to mimic all aspects of the gingival
appearance of the neighbouring teeth (Chang et al. 1999a; Belser et al. 2004, 2009; Furhauser et al. 2005). When the mucosa is thin
and frail, it is prone for recession and underlying
restorative materials will cause discoloration of
the mucosa. Only little information is available
regarding the dimensions, which is height and
thickness, of the peri-implant mucosa in men.

Kan and colleagues measured the mid-facial
height of the peri-implant mucosa in two-stage
anterior implants by means of bone probing with a
periodontal probe after anaesthesia. They found
an average height of 3.6 mm, with shallower
values for subjects that were categorized as hav-
ing a “thin biotype” (Kan et al. 2003). In the
present study in which also two-stage implants
were used, the median facial soft tissue height
was 2.3 mm (minimum: 1.2 mm and maximum:
3.1 mm). It should be noted however that the
height measurements on the plaster models re-
fect the height from the cervical mucosal margin
to the edge of the implant, which is not necessa-
riely the location of the facial bone, although
implants were originally placed “at bone level”.
Because the latter in most cases will be posi-
tioned more apically, this would explain the
small difference with the clinical findings from
Kan and colleagues. It is interesting and clinically
relevant to observe that when a two-stage im-
plant is installed at bone level, the maximum
thickness of the overlying mucosa never exceeds
3.1 mm. This has implications for the ideal im-
plant placement in relation to the neighbouring
teeth, especially with respect to the position of
the implant shoulder. It underlines the clinical
experience that implant placement too far below
the cementum–enamel junction of the neigh-
bouring teeth will result in a non-harmonic
soft-tissue architecture and a relatively long
tooth, which will be difficult to correct.

From Fig. 6, it can be observed that the
mucosal thickness swiftly increases with the
distance from the cervical gingival margin. At
1 mm apical from the cervical margin, the mean
thickness is approximately 2 mm. The maxi-
mum thickness seen in the 15 implant sites is
3.2 mm. Other studies also report on the thick-
ness of the permucosal tissues around implants.
Some used an ultrasonic device to measure the
thickness of the mucosa at the bottom of the
probeable pocket around an implant. Anaes-
thetics were not used. They measured an average
soft tissue thickness of 2 mm (Chang et al.
1999b). Although this seems an elegant non-
 invasive measurement technique, its reliability
was never verified and the exact distance from
the cervical margin was not disclosed. Others
used endodontic files to measure the mid-facial
soft tissue thickness at 1 mm apical to the mar-
gin. Jung et al. (2008) report on 2.9–3.4 mm at
all-ceramic and porcelain-fused to metal implant
crowns, respectively. In another report originat-
ing from the same research group, the average soft
tissue thickness around ZrO2 and Ti abutments
was only 1.9 mm (Sailer et al. 2009b). This

Fig. 6. Mean facial soft-tissue thickness [and SD] in relation to the distance from the soft-tissue margin at 0.2 mm intervals, \( n = 15 \) implants in 11 patients.

Fig. 7. Difference in appearance of patient 3: (a) zirconia abutment, (b) titanium abutment, (c) ratio image.
corresponds well with the measurements from the present study, although an explanation for the difference with the study of Jung and colleagues is not given. Ishikawa-Nagai denote that they measured gingival thickness around implants in a study on the shine-through effects of implants on the peri-implant mucosa, but do not report on the actual data [Ishikawa-Nagai et al. 2007]. In a recent study, the facial gingival thickness of anterior teeth at 2 mm below the cervical gingival margin was measured immediately after extraction by means of callipers. The average gingival thickness was approximately 1 mm [Kan et al. 2010]. From Fig. 6, it can be deducted that the corresponding thickness at implant sites in the present study averages at approximately 2.8 mm, and hence is considerably thicker.

In this study, the \(L^*a^*-b^*\) norm could also have been measured using commercially available calibrated RGB cameras, but using a hyper-spectral camera one obtains the full reflection spectrum for every point in the image. In combination with the Match software, subtle changes in the reflection spectrum can be tracked accurately over time. It has been demonstrated in the optical literature that such data can be used to quantify functional tissue properties like blood perfusion, tissue oxygenation and the longitudinal evaluation of healing response or disease progression of infections or tumour growth, also in the mouth, in a non-invasive, non-contact manner [Sorg et al. 2005; Subhash et al. 2006; Stamatas & Kollias 2007; Vogel et al. 2007; Noordmans et al. 2007a, 2007b; Mallia et al. 2008, 2010; Stamatas et al. 2008; Klaessens et al. 2009]. Such estimations are based on the principle that erythema of the skin [and also of the gingiva and oral mucosa] is associated with an increase in blood perfusion that is linked to the relative concentration of oxygenated haemoglobin. For example, blood perfusion can be perceived by determining the amount of haemoglobin present in the reflection spectrum and oxygenation by looking at the difference between the oxy- and deoxygenated haemoglobin spectra. Because our method not only yields the spectral information along the central line of the implant but also provides the full spectral information for the entire image, one could do tissue calculations for the entire image and assess the extent of tissue abnormalities. This opens an array of opportunities for a more objective evaluation of soft tissue health around oral implants \textit{in vivo}, as has been proposed for gingival tissues before [Zakian et al. 2008].

Although the study shows a satisfactory result, a number of improvements may be included in the measurement setup: (1) Perform a dark and white reference before each measurement. In this study, we made a dark and white reference only once, but it appeared that the camera set-up

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**Fig. 8.** Mean reflection spectra of zirconia and titanium abutments, between 1 mm coronal of the cervical gingival margin and 3 mm apically. Note the particular shape of the reflection spectrum of oxygenated haemoglobin.

**Fig. 9.** \(L^*a^*-b^*\) norms and difference as function of mucosa thickness to determine at which thickness no perceived difference is expected.
varied too much over time that we finally had to make a white reference again using the zirconium abutment itself. [2] Include the ultra-violet range to study the fluorescence effects of abutments and crowns. [3] Use of a polarizer in the illumination path perpendicular to the polarizing axis of the tuneable filter to suppress specular highlights (Noordmans et al. 2007b). In this study, we choose not to use this cross-polarization approach as it removes 80% of the light resulting in longer exposure times or larger motion errors. In addition, we are studying the visual differences between Ti and ZrO2 abutments and our eyes are not equipped with polarisers and thus see the reflected light. [4] Also, if one were able to measure the thickness of permucosal tissue of a sound tooth, one could compare the perceptible differences between permucosal tissue on sound teeth or that on implants. The method used to measure mucosa thickness on plaster models is not feasible for mucosa covering teeth.

Others have also focussed on the thickness of the mucosa as it relates to soft tissue aesthetics. Data from an in vitro experiment in sacrificed pig's maxillae using spectrophotometry suggest that when the thickness of the mucosa exceeds 3 mm, both Ti and ZrO2 do not cause a noticeable colour change of the mucosa (Jung et al. 2007). The authors used a L’ab* norms difference of 3.7, which is used in the literature as a threshold for perceivable colour differences (Johnston & Kao 1989). It would have to be determined how perceivable differences relate to clinical relevance or acceptability of a slight, but noticeable mismatch of mucosal appearance. From our in vivo data, it can be expected that a noticeable difference between Ti and ZrO2 abutments occurs when the thickness of the facial mucosa is approximately 2 mm or less. There is considerable individual variance with respect to the depth at which this will be the case and therefore the choice of abutment material remains a decision that should be based on the clinical situation at hand. However, as a general rule of thumb, Ti implant abutments are best avoided in aesthetically critical areas when the desired location of the crown margin does not exceed 1 mm submucosally.

Conclusion

The labial mucosa covering an implant abutment rapidly increases in thickness when moving apically and is approximately 1 mm thick at 0.2 mm and 2 mm thick at 1 mm below the cervical margin on average. On theoretical grounds, it can be expected that the difference in light reflection between tissues covering ZrO2 and Ti implant abutments is no longer noticeable for the human eye when the mucosa thickness exceeds 2 mm. Haemoglobin peaks are clearly visible in the reflection spectrum, which may render hyper-spectral imaging a practical and objective tool for monitoring soft tissue health. This could be the focus of further research.

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References


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van Brakel et al. - Light reflection of peri-implant mucosa

Fig. 10. Variability in distance from the cervical margin per implant (n = 15 implants) at which it is expected that a difference between zirconia and titanium abutments can be perceived.

Table 1. Variability in distance from the cervical margin per implant (n = 15 implants) at which it is expected that a difference between zirconia and titanium abutments can be perceived.


