

University of Groningen

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

van Brakel, Ralph; Noordmans, Herke Jan; Frenken, Joost; de Roode, Rowland; de Wit, Gerard C.; Cune, Marco

Published in:
CLINICAL ORAL IMPLANTS RESEARCH

DOI:
[10.1111/j.1600-0501.2010.02082.x](https://doi.org/10.1111/j.1600-0501.2010.02082.x)

IMPORTANT NOTE: You are advised to consult the publisher's version (publisher's PDF) if you wish to cite from it. Please check the document version below.

Document Version
Publisher's PDF, also known as Version of record

Publication date:
2011

[Link to publication in University of Groningen/UMCG research database](#)

Citation for published version (APA):

van Brakel, R., Noordmans, H. J., Frenken, J., de Roode, R., de Wit, G. C., & Cune, M. S. (2011). The effect of zirconia and titanium implant abutments on light reflection of the supporting soft tissues. *CLINICAL ORAL IMPLANTS RESEARCH*, 22(10), 1172-1178. DOI: [10.1111/j.1600-0501.2010.02082.x](https://doi.org/10.1111/j.1600-0501.2010.02082.x)

Copyright

Other than for strictly personal use, it is not permitted to download or to forward/distribute the text or part of it without the consent of the author(s) and/or copyright holder(s), unless the work is under an open content license (like Creative Commons).

Take-down policy

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

Downloaded from the University of Groningen/UMCG research database (Pure): <http://www.rug.nl/research/portal>. For technical reasons the number of authors shown on this cover page is limited to 10 maximum.

Ralph van Brakel
Herke Jan Noordmans
Joost Frenken
Rowland de Roode
Gerard C. de Wit
Marco S. Cune

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

Authors' affiliations:

Ralph van Brakel, Department of Oral-Maxillofacial Surgery, Prosthodontics and Special Dental Care, University Medical Centre, Utrecht, The Netherlands
Herke Jan Noordmans, Rowland de Roode, Department of Medical Technology, University Medical Center, Utrecht, The Netherlands
Joost Frenken, Marco S. Cune, Department of Oral-Maxillofacial Surgery, Prosthodontics and Special Dental Care, St Antonius Hospital, Nieuwegein, The Netherlands
Gerard C. de Wit, Bartiméus, Zeist, The Netherlands
Marco S. Cune, Department of Fixed and Removable Prosthodontics, University Medical Center Groningen/Center for Dentistry and Oral Hygiene, Groningen, The Netherlands

Corresponding author:

R. van Brakel
University Medical Centre Utrecht
PO Box 85.060
3508 AB, Utrecht, The Netherlands
Tel.: +31 88 7568025
fax: +31 88 7568043
e-mail: rbrakel@umcutrecht.nl

Key words: aesthetics, implant, spectrophotometry

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. Haemoglobin peaks in the reflection spectrum can be observed and make hyper-spectral imaging a practical and useful tool for measuring soft tissue health.

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. 2005). 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; Bortoluzzi et al. 2007; Watkin & Kerstein 2008).

In the past, titanium (Ti) abutments were the standard of care for implant restorations through-

out 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

Date:

Accepted 31 August 2010

To cite this article:

van Brakel R, Noordmans HJ, Frenken J, de Roode R, de Wit GC, Cune MS. The effect of zirconia and titanium implant abutments on light reflection of the supporting soft tissues. *Clin. Oral Impl. Res.* 22, 2011; 1172–1178.
doi: 10.1111/j.1600-0501.2010.02082.x

be too white, and it is suggested that more tooth coloured abutment materials are to be preferred (Nakamura et al. 2010).

It was demonstrated *in vitro* that the thickness of the overlying mucosa plays an important 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 & Gotfredsen 2010). Yet, when rated more objectively by means of spectrophotometric measurements at 1 mm below the gingival margin, no statistically significant differences in the discernable amount of discoloration between customized ZrO₂ and Ti abutments with either all-ceramic or metal–ceramic crowns could be revealed after 1 and 3 years (Zembic et al. 2009; Sailer et al. 2009b). The authors used a commercially available device originally intended for the determination of tooth shades. They stress the need for more controlled clinical trials to study the influence of the abutment material on the colour of the soft tissues. Indeed, criteria need to be defined to decide under what particular circumstances patients may benefit most from ZrO₂ or Ti abutments. This is of interest, also, considering the fact that the latter ones are usually more affordable and have a longer track record.

The present investigation focuses on the effect of ZrO₂ and Ti implant abutments on light reflection of the supporting soft tissues in man, as it relates to the thickness of the peri-implant mucosa. A novel method for the assessment of the colour of perimucosal or gingival tissues is presented.

Material and methods

A cross-over, within subject comparison study was designed.

Patient population and implant placement

Eleven consecutive Caucasian subjects (six males, five females; mean age 32.5 years; range 20.3–46 years) scheduled to receive a total of 15 implants in the anterior region of the maxilla were included in the study after they had provided informed consent. Twelve out of 15 implant sites had been augmented before implant placement with autologous bone originating from the retromolar region. Soft tissue augmentations were not performed.

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 flap was 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 (OsseoSpeed[®], Astra Tech, Mölndal, 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.

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.

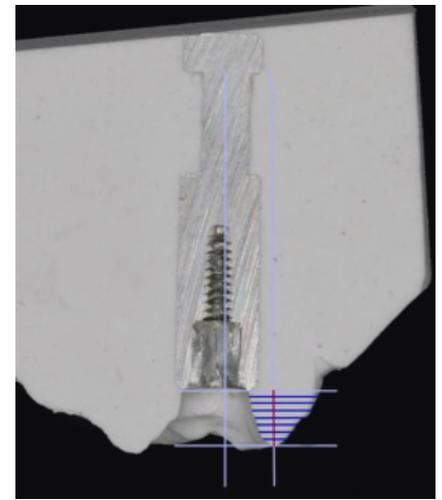


Fig. 1. A plaster model is sectioned through the middle of the implant with reference lines for the measurement of soft-tissue height and thickness. Soft-tissue height is measured along the interrupted red line. Soft-tissue thickness is measured at 0.2 mm intervals along the dark blue lines, commencing at the most caudal point.

In addition, the height of the perimucosal 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 perimucosal 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 min was allowed for settling of the perimucosal 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 $I_{n,t}(x, y, \lambda)$ 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-

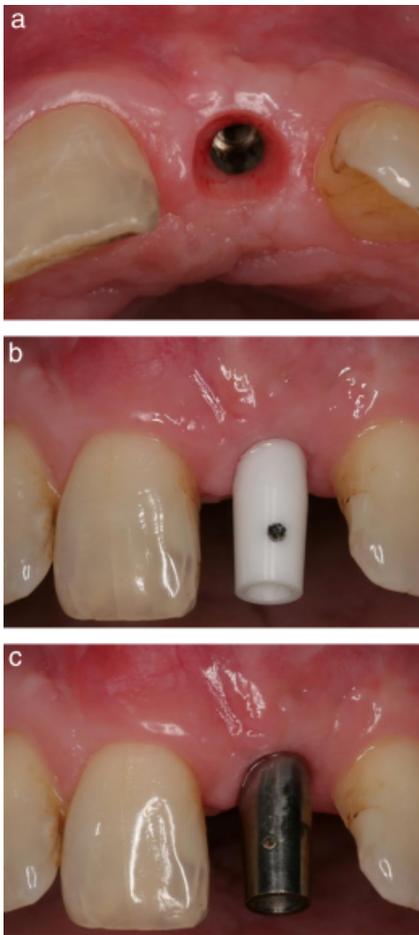


Fig. 2. (a) Implant with healing abutment removed (patient no. 6). (b) Implant with the zirconia test abutment. (c) Implant with the titanium test abutment.

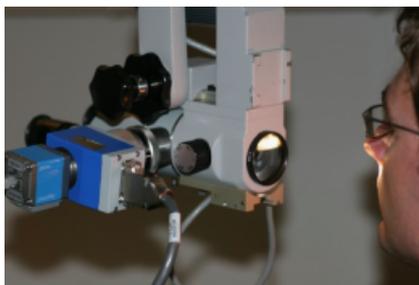


Fig. 3. Experimental set-up. The spectrophotometric device consisting of a high-resolution monochrome camera (PCO) and an electronically tuneable colour filter (Cri) is connected to a microscope (Zeiss). A hyper-spectral image is made, the abutment is switched and the procedure is repeated.

ence/object and in total darkness, the image can be corrected spatially and spectrally with the following formula:

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

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-



Fig. 4. Hyper-spectral image normalization to remove motion, and spatial and spectral inhomogeneities.

ject, 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 its real physical value. Second, the distance axis along the central line was converted to a mucosa 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):

$$\begin{bmatrix} X(D) \\ Y(D) \\ Z(D) \end{bmatrix}_{n,t} = \int_{\lambda} \begin{bmatrix} \bar{x}(\lambda) \\ \bar{y}(\lambda) \\ \bar{z}(\lambda) \end{bmatrix} \cdot R_{n,t}(D, \lambda) S(\lambda) d\lambda / \int_{\lambda} \bar{y}(\lambda) S(\lambda) d\lambda \quad (2)$$



Fig. 5. Definition of distance along the central axis of abutment. Along this axis, the reflection spectra are extracted. The circle denotes the averaged pixel spectra at each distance.

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

$$\begin{pmatrix} L^*(D) \\ a^*(D) \\ b^*(D) \end{pmatrix}_{n,t} = \begin{pmatrix} 116 f_{Y(D)_{n,t}} - 16 \\ 500 (f_{X(D)_{n,t}} - f_{Y(D)_{n,t}}) \\ 200 (f_{Y(D)_{n,t}} - f_{Z(D)_{n,t}}) \end{pmatrix} \quad (3)$$

where $f_{P(D)_{n,t}} =$

$$\begin{cases} P(D)_{n,t}^{1/3} & \text{if } P(D)_{n,t} > 0.009 \\ \frac{903.3 P(D)_{n,t} + 16}{116} & \text{if } P(D)_{n,t} \leq 0.009 \end{cases} \quad P \in \{X, Y, Z\} \quad (4)$$

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

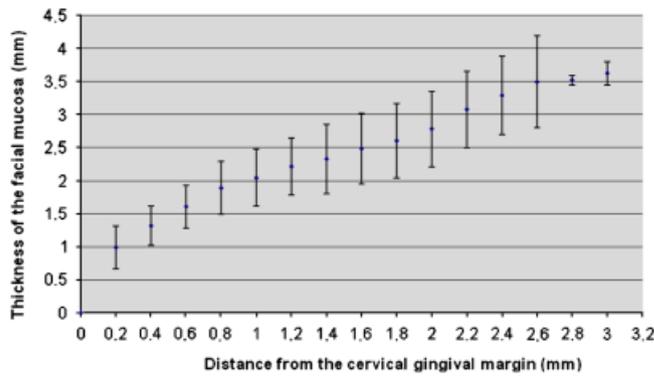


Fig. 6. Mean facial soft-tissue thickness (and SD) in relation to the distance from the soft-tissue margin at 0.2 mm intervals, $n = 15$ implants in 11 patients.



Fig. 7. Difference in appearance of patient 3: (a) zirconia abutment, (b) titanium abutment, (c) ratio image.

divided by each other, resulting in a ratio image. A small, dark region in the area of the emergence 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 shown in Fig. 8. Starting from $d = -1$ mm, the spectra still represent the spectrum of the abutment 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 to 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 ± 0.1 mm (95% confidence interval).

To observe the effect of this thickness threshold 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 substantial 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; Furhauer 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 having 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 reflect the height from the cervical mucosal margin to the edge of the implant, which is not necessarily also the location of the facial bone, although implants were originally placed “at bone level”. Because the latter in most cases will be positioned 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 implant is installed at bone level, the maximum thickness of the overlying mucosa never exceeds 3.1 mm. This has implications for the ideal implant 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 neighbouring 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 maximum thickness seen in the 15 implant sites is 3.2 mm. Other studies also report on the thickness 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. Anaesthetics 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 margin. 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 originating from the same research group, the average soft tissue thickness around ZrO_2 and Ti abutments was only 1.9 mm (Sailer et al. 2009b). This

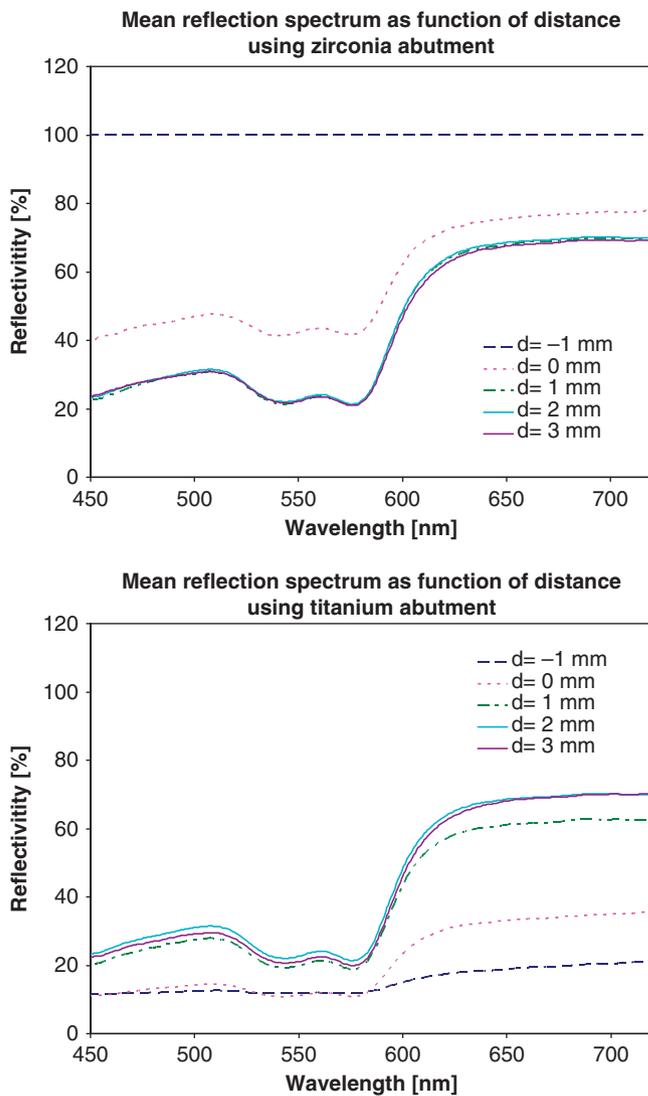


Fig. 8. Mean reflection spectra of zirconia and titanium abutments, between 1 mm coronal of the cervical gingival margin and 3 mm apically. Note the particular shape of the reflection spectrum of oxygenated haemoglobin.

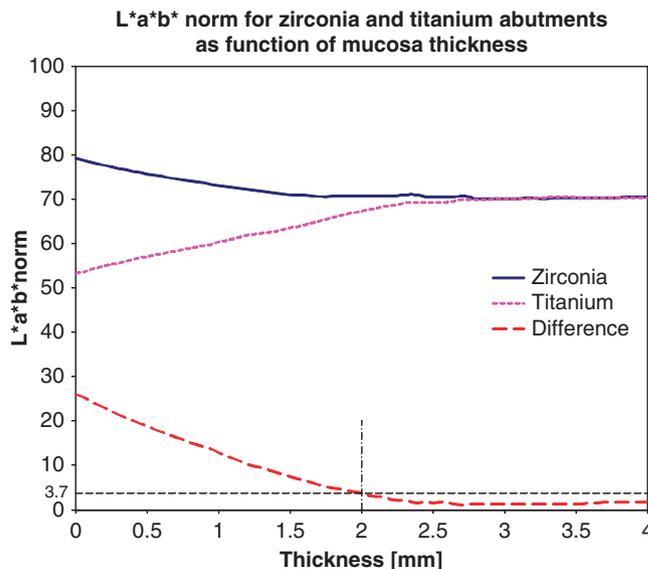


Fig. 9. $L^*a^*b^*$ norms and difference as function of mucosa thickness to determine at which thickness no perceived difference is expected.

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 deduced 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; Stamatias & Kollias 2007; Vogel et al. 2007; Noordmans et al. 2007a, 2007b; Mallia et al. 2008, 2010; Stamatias 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 *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

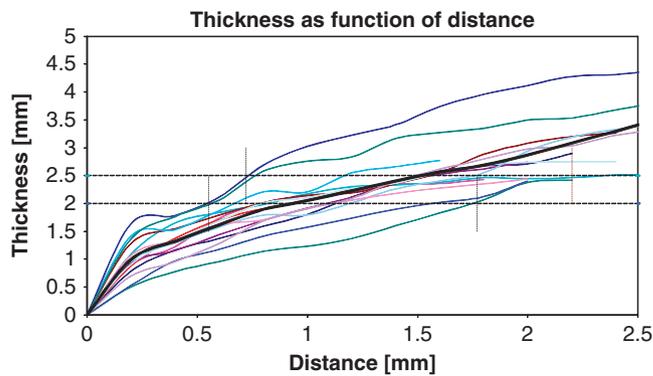


Fig. 10. Variability in distance from the cervical margin per implant ($n = 15$ implants) at which it is expected that a difference between zirconia and titanium abutments can be perceived.

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 perimucosal tissue of a sound tooth, one could compare the perceptible differences between perimucosal 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 $L^*a^*b^*$ 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.

Acknowledgements: The authors wish to thank Mathieu Steijvers for the preparation of the plaster casts.

References

- Andersson, B., Glauser, R., Maglione, M. & Taylor, A. (2003) Ceramic implant abutments for short-span FPDs: a prospective 5-year multicenter study. *The International Journal of Prosthodontics* **16**: 640–646.
- Andersson, B., Taylor, A., Lang, B.R., Scheller, H., Schärer, P., Sorensen, J.A. & Tamow, D. (2001) Alumina ceramic implant abutments used for single-tooth replacement: a prospective 1- to 3-year multicenter study. *The International Journal of Prosthodontics* **14**: 432–438.
- Bae, K.H., Han, J.S., Seol, Y.J., Butz, F., Caton, J. & Rhyu, I.C. (2008) The biologic stability of alumina-zirconia implant abutments after 1 year of clinical service: a digital subtraction radiographic evaluation. *International Journal of Periodontics and Restorative Dentistry* **28**: 137–143.
- Belser, U.C., Grutter, L., Vailati, F., Bornstein, M.M., Weber, H.P. & Buser, D. (2009) Outcome evaluation of early placed maxillary anterior single-tooth implants using objective esthetic criteria: a cross-sectional, retrospective study in 45 patients with a 2- to 4-year follow-up using pink and white esthetic scores. *Journal of Periodontology* **80**: 140–151.
- Belser, U.C., Schmid, B., Higginbottom, F. & Buser, D. (2004) Outcome analysis of implant restorations located in the anterior maxilla: a review of the recent literature. *The International Journal of Oral & Maxillofacial Implants* **19** (Suppl.): 30–42.
- Bortoluzzi, E.A., Araujo, G.S., Guerreiro Tanomaru, J.M. & Tanomaru-Filho, M. (2007) Marginal gingiva discoloration by gray MTA: a case report. *Journal of Endodontology* **33**: 325–327.
- Canullo, L. (2007) Clinical outcome study of customized zirconia abutments for single-implant restorations. *The International Journal of Prosthodontics* **20**: 489–493.
- Chang, M., Wennstrom, J.L., Odman, P. & Andersson, B. (1999a) Implant supported single-tooth replacements compared to contralateral natural teeth. Crown and soft tissue dimensions. *Clinical Oral Implants Research* **10**: 185–194.
- Chang, M., Wennstrom, J.L., Odman, P. & Andersson, B. (1999b) Implant supported single-tooth replacements compared to contralateral natural teeth. Crown and soft tissue dimensions. *Clinical Oral Implants Research* **10**: 185–194.
- Dummett, C.O. (1960) Oral pigmentation. *Journal of Periodontology* **31**: 356–360.
- Furhauser, R., Florescu, D., Benesch, T., Haas, R., Mailath, G. & Watzek, G. (2005) Evaluation of soft tissue around single-tooth implant crowns: the pink esthetic score. *Clinical Oral Implants Research* **16**: 639–644.
- Glauser, R., Sailer, I., Wohlwend, A., Studer, S., Schibli, M. & Schärer, P. (2004) Experimental zirconia abutments for implant-supported single-tooth restorations in esthetically demanding regions: 4-year results of a prospective clinical study. *The International Journal of Prosthodontics* **17**: 285–290.
- Hosseini, M. & Gotfredsen, K. A randomized, clinical study of implant-supported all ceramic crowns and abutments. 88th General session & exhibition of the IADR, Abstract nr. 1313, Barcelona, Spain, July 14–17, 2010.
- Ishikawa-Nagai, S., Da Silva, J.D., Weber, H.P. & Park, S.E. (2007) Optical phenomenon of peri-implant soft tissue. Part II. Preferred implant neck color to improve soft tissue esthetics. *Clinical Oral Implants Research* **18**: 575–580.

- Johnston, W.M. & Kao, E.C. (1989) Assessment of appearance match by visual observation and clinical colorimetry. *Journal of Dentistry Research* **68**: 819–822.
- Jung, R.E., Holderegger, C., Sailer, I., Khraisat, A., Suter, A. & Hammerle, C.H. (2008) The effect of all-ceramic and porcelain-fused-to-metal restorations on marginal peri-implant soft tissue color: a randomized controlled clinical trial. *International Journal of Periodontics and Restorative Dentistry* **28**: 357–365.
- Jung, R.E., Sailer, I., Hammerle, C.H., Attin, T. & Schmidlin, P. (2007) In vitro color changes of soft tissues caused by restorative materials. *International Journal of Periodontics and Restorative Dentistry* **27**: 251–257.
- Kan, J.Y., Morimoto, T., Rungcharassaeng, K., Roe, P. & Smith, D.H. (2010) Gingival biotype assessment in the esthetic zone: visual versus direct measurement. *International Journal of Periodontics and Restorative Dentistry* **30**: 237–243.
- Kan, J.Y., Rungcharassaeng, K., Umezu, K. & Kois, J.C. (2003) Dimensions of peri-implant mucosa: an evaluation of maxillary anterior single implants in humans. *Journal of Periodontology* **74**: 557–562.
- Klaessens, J.H.G.M., Noordmans, H.J., de Roode, R. & Verdaasdonk, R.W. (2009) Non-invasive skin oxygenation imaging using a multi-spectral camera system: effectiveness of various concentration algorithms applied on human skin. *Proceedings of SPIE* **7174**: 717408.
- Kleinheinz, J., Buchter, A., Fillies, T. & Joos, U. (2005) Vascular basis of mucosal color. *Head and Face Medicine* **1**: 4.
- Mallia, R., Thomas, S.S., Mathews, A., Kumar, R., Sebastian, P., Madhavan, J. & Subhash, N. (2008) Oxygenated hemoglobin diffuse reflectance ratio for in vivo detection of oral pre-cancer. *Journal of Biomedical Optics* **13**: 041306.
- Mallia, R.J., Narayanan, S., Madhavan, J., Sebastian, P., Kumar, R., Mathews, A., Thomas, G. & Radhakrishnan, J. (2010) Diffuse reflection spectroscopy: an alternative to autofluorescence spectroscopy in tongue cancer detection. *Journal of Applied Spectroscopy* **64**: 409–418.
- Manicone, P.F., Rossi, I.P. & Raffaelli, L. (2007) An overview of zirconia ceramics: basic properties and clinical applications. *Journal of Dentistry* **35**: 819–826.
- Nakamura, K., Kanno, T., Milleding, P. & Ortengren, U. (2010) Zirconia as a dental implant abutment material: a systematic review. *The International Journal of Prosthodontics* **23**: 299–309.
- Noordmans, H.J., de Roode, R. & Verdaasdonk, R.M. (2007a) Compact multi-spectral imaging system for dermatology and neurosurgery. *Proceedings of SPIE* **6510**: 165100.
- Noordmans, H.J., de Roode, R. & Verdaasdonk, R.M. (2007b) Fast interactive elastic registration of 12-bit multi-spectral images with subvoxel accuracy using display hardware. *Proceedings of SPIE* **6512**: 65121Z.
- Noordmans, H.J., Kuijter, E., de Groot, I., de Roode, R., Rem, A.I., de Boorder, T. & Verdaasdonk, R.M. (2009) Evaluation of the response and healing effect after laser hair removal using a multi-spectral dermatoscope. *Proceedings of SPIE* **7161**: 171610T.
- Park, S.E., Da Silva, J.D., Weber, H.P. & Ishikawa-Nagai, S. (2007) Optical phenomenon of peri-implant soft tissue. Part I. Spectrophotometric assessment of natural tooth gingiva and peri-implant mucosa. *Clinical Oral Implants Research* **18**: 569–574.
- Prestipino, V. & Ingber, A. (1993a) Esthetic high-strength implant abutments. Part I. *Journal of Esthetic Dentistry* **5**: 29–36.
- Prestipino, V. & Ingber, A. (1993b) Esthetic high-strength implant abutments. Part II. *Journal of Esthetic Dentistry* **5**: 63–68.
- Sailer, I., Philipp, A., Zembic, A., Pjetursson, B.E., Hammerle, C.H. & Zwahlen, M. (2009a) A systematic review of the performance of ceramic and metal implant abutments supporting fixed implant reconstructions. *Clinical Oral Implants Research* **20** (Suppl. 4): 4–31.
- Sailer, I., Zembic, A., Jung, R.E., Siegenthaler, D., Holderegger, C. & Hammerle, C.H.F. (2009b) Randomized controlled clinical trial of customized zirconia and titanium implant abutments for canine and posterior single-tooth implant reconstructions at 1 year function. *Clinical Oral Implants Research* **20**: 219–225.
- Sorg, B.S., Moeller, B.J., Donovan, O., Cao, Y. & Dewhirst, M.W. (2005) Hyperspectral imaging of hemoglobin saturation in tumor microvasculature and tumor hypoxia development. *Journal of Biomedical Optics* **10**: 44004.
- Stamatas, G.N. & Kollias, N. (2007) In vivo documentation of cutaneous inflammation using spectral imaging. *Journal of Biomedical Optics* **12**: 051603.
- Stamatas, G.N., Zmudzka, B.Z., Kollias, N. & Beer, J.Z. (2008) In vivo measurement of skin erythema and pigmentation: new means of implementation of diffuse reflectance spectroscopy with a commercial instrument. *British Journal of Dermatology* **159**: 683–690.
- Subhash, N., Mallia, J.R., Thomas, S.S., Mathews, A., Sebastian, P. & Madhavan, J. (2006) Oral cancer detection using diffuse reflectance spectral ratio R540/R575 of oxygenated hemoglobin bands. *Journal of Biomedical Optics* **11**: 014018.
- Takeda, T., Ishigami, K., Shimada, A. & Ohki, K. (1996) A study of discoloration of the gingiva by artificial crowns. *The International Journal of Prosthodontics* **9**: 197–202.
- Tan, P.L. & Dunne, J.T. Jr (2004) An esthetic comparison of a metal ceramic crown and cast metal abutment with an all-ceramic crown and zirconia abutment: a clinical report. *Journal of Prosthetic Dentistry* **91**: 215–218.
- Vogel, A., Chernomordik, V.V., Riley, J.D., Hassan, M., Amyot, F., Dasgeb, B., Demos, S.G., Pursley, R., Little, R.F., Yarchoan, R., Tao, Y. & Gandjbakhche, A.H. (2007) Using noninvasive multispectral imaging to quantitatively assess tissue vasculature. *Journal of Biomedical Optics* **12**: 051604.
- Watkin, A. & Kerstein, R.B. (2008) Improving darkened anterior peri-implant tissue color with zirconia custom implant abutments. *Compendium of the Continuing Education in Dentistry* **29**: 238–40, 242.
- Wyszecki, G. & Stiles, W.S. (2000) *Concepts and Methods, Quantitative Data and Formulae*. 2nd edition. New York: Wiley.
- Zakian, C., Pretty, I., Ellwood, R. & Hamlin, D. (2008) In vivo quantification of gingival inflammation using spectral imaging. *Journal of Biomedical Optics* **13**: 054045.
- Zembic, A., Sailer, I., Jung, R.E. & Hammerle, C.H. (2009) Randomized-controlled clinical trial of customized zirconia and titanium implant abutments for single-tooth implants in canine and posterior regions: 3-year results. *Clinical Oral Implants Research* **20**: 802–808.