CLINICAL ORAL IMPLANTS RESEARCH

*Raluca Cosgarea*
*Cristina Gasparik*
*Diana Dudea*
*Bogdan Culic*
*Bettina Dannewitz*
*Anton Sculean*

# Peri-implant soft tissue colour around titanium and zirconia abutments: a prospective randomized controlled clinical study

**Authors' affiliations:**
*Raluca Cosgarea,* Department of Periodontology, Philipps University Marburg, Marburg, Germany
*Raluca Cosgarea,* Department of Prosthodontics, University Iuliu Hatieganu, Cluj-Napoca, Romania
*Cristina Gasparik, Diana Dudea, Bogdan Culic,* Department of Propedeutics and Aesthetic Dentistry, University Iuliu Hatieganu, Cluj-Napoca, Romania
*Bettina Dannewitz,* Section of Periodontology, Department of Conservative Dentistry, Clinic for Oral, Dental and Maxillofacial Diseases, Ruprecht-Karl University Hospital Heidelberg, Heidelberg, Germany
*Bettina Dannewitz,* Department of Periodontology, Center of Dentistry and Oral Medicine (Carolinum), Johann Wolfgang Goethe-University, Frankfurt/Main, Germany
*Raluca Cosgarea, Anton Sculean,* Department of Periodontology, Dental School, University of Bern, Bern, Switzerland

**Corresponding author:**
Prof. Dr *Anton Sculean*
Department of Periodontology
University of Bern
Freiburgstrasse 7, 3010 Bern, Switzerland
Tel.: +41 (0) 31 632 25 77
Fax: +41 (0) 31 632 49 15
e-mail: anton.sculean@zmk.unibe.ch

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**Key words:** implant abutments, mucosa colour, peri-implant soft tissue, titanium, zirconia

**Abstract**

**Objectives:** To objectively determine the difference in colour between the peri-implant soft tissue at titanium and zirconia abutments.

**Materials and methods:** Eleven patients, each with two contralaterally inserted osteointegrated dental implants, were included in this study. The implants were restored either with titanium abutments and porcelain-fused-to-metal crowns, or with zirconia abutments and ceramic crowns. Prior and after crown cementation, multi-spectral images of the peri-implant soft tissues and the gingiva of the neighbouring teeth were taken with a colorimeter. The colour parameters $L^*$, $a^*$, $b^*$, $c^*$ and the colour differences $\Delta E$ were calculated. Descriptive statistics, including non-parametric tests and correlation coefficients, were used for statistical analyses of the data.

**Results:** Compared to the gingiva of the neighbouring teeth, the peri-implant soft tissue around titanium and zirconia (test group), showed distinguishable $\Delta E$ both before and after crown cementation. Colour differences around titanium were statistically significant different ($P = 0.01$) only at 1 mm prior to crown cementation compared to zirconia. Compared to the gingiva of the neighbouring teeth, statistically significant ($P < 0.01$) differences were found for all colour parameter, either before or after crown cementation for both abutments; more significant differences were registered for titanium abutments. Tissue thickness correlated positively with $c^*$-values for titanium at 1 mm and 2 mm from the gingival margin.

**Conclusions:** Within their limits, the present data indicate that: (i) The peri-implant soft tissue around titanium and zirconia showed colour differences when compared to the soft tissue around natural teeth, and (ii) the peri-implant soft tissue around zirconia demonstrated a better colour match to the soft tissue at natural teeth than titanium.

Aesthetic and functional replacement of missing teeth with dental implants has been well documented and high long-term success rates have been reported (Berglundh et al. 2002; Manso & Wassal 2010; Dierens et al. 2012). A predictable long-term aesthetic and functional outcome with a natural, healthy tooth-like appearance is the goal in implant dentistry (Belser et al. 2004); this is the result of a correct diagnosis, proper treatment planning, accurate surgical techniques and prosthetical restoration. A major role in aesthetics plays the peri-implant soft tissue and the implant-supported restoration (Reikie 1993, 1995; Garber 1996). Therefore, the peri-implant tissue thickness, its architecture, surface texture, contour and colour influence the esthetical and "natural" appearance of a healthy peri-implant mucosa (Furhauser et al. 2005; Jung et al. 2007). Histologically, factors like the intensity of tissue melanogenesis, the degree of epithelial keratinisation, the depth of epithelisation and the density and size of capillaries have been reported to have an impact on the gingival colour (Dummett 1960; Kleinheinz et al. 2005). Furthermore, factors like the colour of the underlying root, restorative materials such as crown margins, MTA, implant abutments also influence the gingiva colour (Bortoluzzi et al. 2007; Ishikawa-Nagai et al. 2007; Jung et al. 2007; Watkin & Kerstein 2008).

Titanium (Ti) abutments are commonly used for prosthetical dental implant restoration. In situations with thin peri-implant mucosa, this material shimmers blue-greyish, hindering a successful esthetical outcome. Studies have shown a noticeable colour

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difference between the mucosa overlying Ti abutments and natural teeth (Park et al. 2007; van Brakel et al. 2011; Bressan et al. 2011). Therefore, materials with better aesthetical properties have been introduced for abutments: alumina and oxide or yttrium-stabilized zirconium oxide (Heydecke et al. 2002; Rompen et al. 2007; Watkin & Kerstein 2008). As compared to alumina, where occasional fracture of the abutment was recorded (Andersson et al. 2001, 2003), stabilized zirconia shows high bending strength and toughness, as well as good biocompatibility and aesthetics (Manicone et al. 2007; Sailer et al. 2009a). Furthermore, the use of all-ceramic crowns has been used increasingly on teeth and implants in aesthetical demanding anterior regions (Andersson et al. 2001; Glauser et al. 2004).

At present, the literature comparing the colour properties of the soft tissue around implants restored with titanium and zirconia abutments is still sparse. Jung and colleagues have compared in 30 patients the effect of aluminium-oxide based abutments restored with all-ceramic crowns to titanium or gold abutments restored with porcelain-fused-to-metal (PFM) crowns on the colour-change of the soft tissues (Jung et al. 2007). Connective tissue grafting was performed in cases where the mucosa displayed a thickness <2 mm. The results have indicated that compared to the colour of natural teeth, the all-ceramic group has shown statistically significantly less visible colour change compared to the PFM group. The colour differences (e.g. ΔE) between the abutments did not show statistically significant differences.

A subsequent study by the same group determined the colour of the peri-implant mucosa at titanium and zirconia abutments restored with metal-ceramic or alumina or zirconia ceramic crowns and reported similar amounts of tissue discoloration at both abutment materials (Sailer et al. 2009b). Also in that study, gingival grafting was performed at the implant sites if needed. The results reported at 1 year were comparable to those obtained after 3 years in function (Zembic et al. 2009). However, in both studies the implants were placed in different patients and thus, it cannot be excluded that possible differences between the gingiva colour of the patients may have influenced the outcomes.

Bressan and colleagues determined in 20 patients the colour properties of the mucosa at titanium, gold and zirconia abutments without performing any gingival grafting at the implant sites (Bressan et al. 2011). The abutments were consecutively inserted on the same implant and provisionally fixed with the same all-ceramic crown. Colour measurements were performed after each abutment insertion and compared with the contra-lateral tooth. Statistically significantly higher colour differences were found at titanium abutments compared to zirconia and gold ($P < 0.05$), however without any correlation between tissue thickness and colour difference.

Other studies have only investigated the colour properties of peri-implant mucosa at either titanium abutments (Park et al. 2007), or zirconia abutments (Happe et al. 2013) as compared to natural teeth, but without any comparison between the two abutment materials. A recent study has related the light-reflection of the oral mucosa which covered titanium or zirconia abutments to the mucosa thickness, but no evaluation of the mucosa colour was made (van Brakel et al. 2011).

Thus, at present there is still limited data evaluating the differences in colour between the peri-implant soft tissues at titanium and zirconia abutments and the possible influence of the peri-implant soft tissue thickness on colour parameters.

Therefore, the aim of the present prospective, randomized, controlled clinical study was to objectively determine in a split-mouth design the difference in colour between the peri-implant soft tissue at titanium and zirconia abutments and to assess the influence of the peri-implant tissue thickness on colour parameters.

## Material and methods

### Study population

Eleven Caucasian patients from the University Clinic of Cluj-Napoca, Department of Prosthetic Dentistry, were enrolled in this prospective randomized controlled clinical trial. In order to be included in the study, patients had to be partially edentulous with at least two osteointegrated dental implants (Seven®, MIS Technologies ltd., Shlomi, Israel). The implants had to be located in two different mouth quadrants in lateral regions (premolars or molars) and be prior to final prosthetic restoration. Patients had to be without any ongoing systemic diseases or infections, not pregnant or lactating. All patients underwent comprehensive dental and, if needed, periodontal care; they were instructed to maintain a high level of oral hygiene (plaque control record <30% (O'Leary et al. 1972)). The study was conducted according to the Declaration of Helsinki (1964, revision 2008) and approved by the Ethical Committee of the Faculty of Medicine and Pharmacy of Cluj-Napoca, Romania (Application #177/20.10.2010). All patients gave their informed written consent to participate in the study.

### Prosthetic suprastructure and soft tissue thickness assessment

For every patient, the two implants included in the study were randomly assigned according to a computer generated randomisation list, to an either titanium or zirconiumoxid abutment (MIS Technologies ltd., Shlomi, Israel). The randomisation was realized with the Proc Plan procedure of the statistic system SAS, version 9.1 for Windows (SAS System for Windows, Cary, NC, USA). The zirconia abutment received an all-ceramic crown (CC) on a zirconia core (Fig. 1), while the titanium abutment was prosthetically restored with a PFM crown (Fig. 2). The restorations were cemented with a temporary dental cement (TempBond NE, Kerr, West Collins, CA, USA). All restorations were performed by the same dental technician, and one single clinician (RC).

### Assessment of the peri implant soft tissue thickness

In order to determine the correlation between colour assessment and soft tissue dimensions, the soft tissue thickness around implants and their corresponding mesial neighbouring teeth was determined. The soft tissue was pierced mid-facially at one, two and three millimetres apical to the gingival margin with an endodontic file (Hedstroem Nr. 20; Kerr Endodontics, Gilbert, AZ, USA, Fig. 1 and 2).

### Colour measurements

Multi-spectral images of the soft tissues around implants (test site) and the mesial neighbouring teeth (control sites) were taken for all 11 patients, by one single experienced clinician (CG) (Fig. 3). A colourimeter (ShadeVision System, X-Rite Inc., Neu-Isenburg, Germany) attached with a disposable light-focusing cone was used to record the images (Joiner 2004; Hugo et al. 2005; Kim-Pusateri et al. 2009; Chu et al. 2010; Lehmann et al. 2010). The cone was placed perpendicularly in careful contact with the area of interest, with the aperture centred on the region of interest: the peri-implant mucosa or the gingiva of the neighbouring tooth respectively (Fig. 3). Measurements were performed twice for each patient, twenty minutes after placing the implant abutment; the mean of the two measurements was considered for statistical


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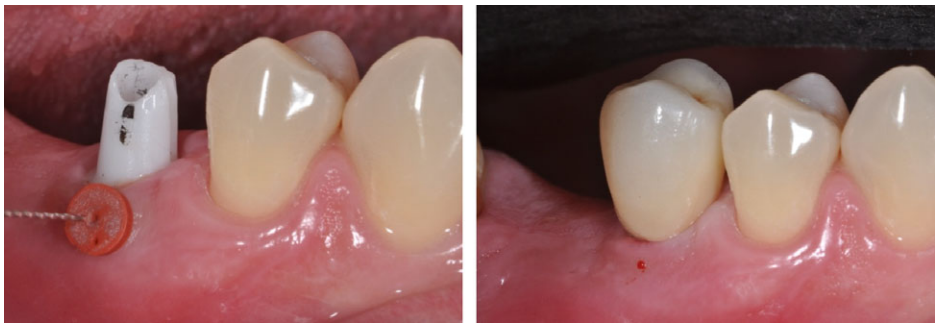

*Fig. 1.* Measuring tissue thickness at a zirconia abutment (left). Zirconia abutment restored with a porcelain-fused-to-metal crown (right).

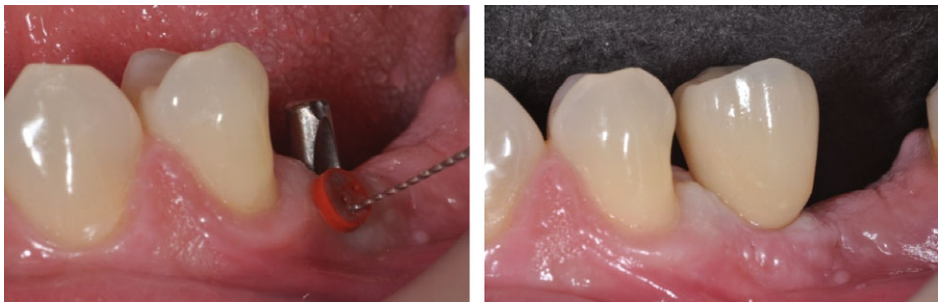

*Fig. 2.* Measuring tissue thickness at a titanium abutment (left). Titanium abutment restored with a porcelain-fused-to-metal crown (right).

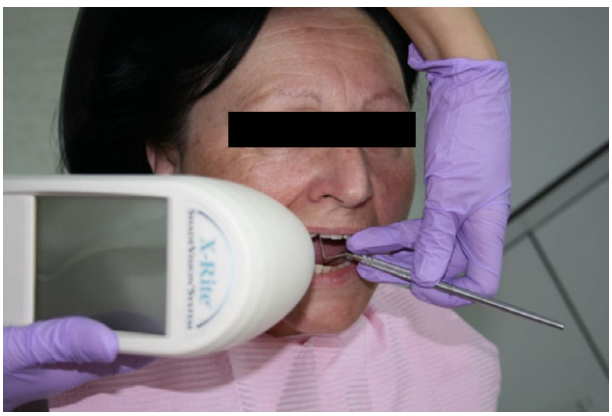

*Fig. 3.* Acquirement of multispectral images with a colourimeter (X-Rite, Schade Vision System).

analysis. Measurements were repeated 1 week after cementation of the crowns.

Images were analysed using a colour analysis software and colour parameters of the *Commission Internationale de l'Éclairage* (CIE) were obtained: $L^*$ = lightness, $a^*$ = chroma along red–green axis and $b^*$ = chroma along yellow–blue axis. These parameters were determined for three regions of interest, 1 mm$^2$ each located on the buccal gingival aspect of the abutments/crowns/tooth at 1 mm, 2 mm, 3 mm from the gingival margin (Fig. 4). Mean values of $L^*$, $a^*$ and $b^*$ parameters were used to calculate the colour difference ($\Delta E_{(1,2)} = [(L_2 - L_1)^2 + (a_2 - a_1)^2 + (b_2 - b_1)^2]^{1/2}$) between the peri-implant soft tissue and the marginal gingiva of the neighbouring teeth as well as the metric chroma $c^*[\sqrt{(a^{*2} + b^{*2})}]$ (Paul et al. 2002).

### Statistical analysis

To describe the distribution and differences of colour differences ΔE, as well as ΔL-, Δa-, Δb-, Δc-values between test and control sites, descriptive analysis was conducted including calculation of means, standard deviations, minima, maxima as well as 95% confidence intervals. Pairwise comparisons between groups were carried out using the two-sided paired Wilcoxon-Test, as well as pairwise comparisons between both time-points were carried out using the two-sided Mann–Whitney *U*-Test. The interrelationship between tissue thickness and chroma (c*) or lightness (L*) was calculated using Spearman rank correlation coefficients. Due to the exploratory nature of the study, no adjustment was made for multiple testing, and test results surpassing a 5% confidence level were interpreted as statistically significant. All statistical analyses were run on the Statistics Package SAS version 9.1.

This study is a feasibility study with pilot character. Based on the existing literature regarding peri-implant gingival colour (Park et al. 2007; Jung et al. 2008; van Brakel et al. 2011; Bressan et al. 2011; Happe et al. 2013), we recruited consecutively in the first 6 months of 2011, the given number of patients that fulfilled the inclusion criteria.

## Results

Eleven subjects (mean age 30.27 years, seven female) with 22 osteointegrated dental implants prior to prosthetic loading were enrolled in this study. Half of the implants ($n = 11$) were restored with Ti abutments and PFM crowns (Fig. 2), and the other half with Zr abutments and CC crowns (Fig. 1). For all patients, image and data acquisition, as well as gingival thickness measurement were uneventful. All implants were placed in the molar or premolar region, five of them (22.7%) had been placed in the upper jaw.

### Colour of the peri-implant mucosa

Both Ti and Zr abutments (test sites) revealed significant colour differences ($\Delta E$ values) of the peri-implant mucosa in relation to the gingiva around the natural teeth (control sites); this difference could be observed both before (timepoint 1) and after (timepoint 2) crown cementation (Table 1). Furthermore, higher mean $\Delta E$ values between timepoint 1 and 2 were obtained for Ti as compared to Zr (Table 1); prior to crown placement, the mean colour difference $\Delta E$ between Ti and its control site ranged between 11.98 and 8.13 for the three analysed areas, while the colour difference between Zr and the corresponding control showed lower mean values, ranging between 8.25 and 6.77 (Table 1). At timepoint 2, lower mean colour differences as compared to baseline (timepoint 1) were registered for both Ti and Zr abutments, with values between 8.60 and 6.69 for Ti and 8.00 and 6.38 for Zr. Statistical significant

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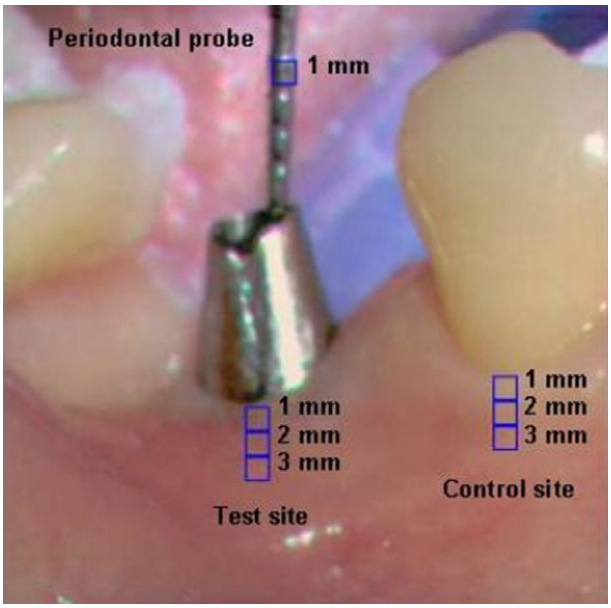


*Fig. 4.* Establishment of the regions of interest at 1-, 2- and 3 mm from the gingival margin.

***Table 1.*** **Mean ΔE values and standard deviations (SD) in mm for titanium (Ti) and zirconia (Zr) abutments calculated in relation to the adjacent tooth**

| | | 1 mm Mean ± SD | 2 mm Mean ± SD | 3 mm Mean ± SD |
|---|---|---|---|---|
| Ti | 1 | 11.98 ± 3.54 | 9.33 ± 3.57 | 8.13 ± 2.08 |
| | 2 | 8.60 ± 2.73 | 8.37 ± 2.76 | 6.69 ± 2.71 |
| Zr | 1 | 8.25 ± 2.97 | 7.08 ± 2.65 | 6.77 ± 2.26 |
| | 2 | 8.00 ± 2.22 | 7.53 ± 2.39 | 6.38 ± 2.32 |

1 = prior to cementation; 2 = 1 week after cementation.

differences for the colour difference *ΔE* for Ti and Zr were obtained only at 1 mm from the gingival margin, prior to crown fixture (timepoint 1, Wilcoxon test, $P = 0.01$, Table 2). However, all obtained mean *ΔE* values were above the critical threshold of 3.7 for colour distinction by the naked eye (Ruyter et al. 1987; Ishikawa et al. 1988; Johnston & Kao 1989).

Furthermore, test sites (Ti/Zr) showed lower mean values for L*, a*, b* and c* than their corresponding control sites in all three incremental areas (Table 3 and 4). Statistical significant colour differences between Ti and the control tooth were recorded only for c* values in all incremental areas at both timepoints,

***Table 2.*** ***P*-values of Wilcoxon test for detecting statistical significances for differences between ΔE values for titanium and zirconia per timepoint (prior [Timepoint 1] and 1 week after [Timepoint 2] crown cementation)**

| Timepoint | 1 mm | 2 mm | 3 mm |
|---|---|---|---|
| 1 | 0.01* | 0.07 | 0.15 |
| 2 | 0.64 | 0.64 | 0.7 |

*Statistical significant value.

while L*, a* and b* values demonstrated significant differences mostly prior crown placement, and not in all areas (Table 3). Compared to Ti, there were fewer statistical significant colour differences registered for Zr; however, these were mainly registered at 1 and 2 mm for a*, b* and c* values. No significant differences were registered for Zr abutments regarding L* values (Table 4).

#### Correlation between peri implant soft tissue thickness and tissue colour

The peri-implant soft tissue thickness measured at 1 mm was 1.31 ± 0.61 mm (mean ± SD) for Ti and 1.24 ± 0.35 mm for Zr, at 2 mm 1.79 ± 0.73 mm (Ti) and 1.95 vs. 0.35 mm (Zr), and at 3 mm 2.27 ± 0.35 mm for Ti and 2.20 ± 0.55 mm for Zr respectively (Table 5). C* values demonstrated a significant positive Spearman rank correlation coefficient registered only for titanium at 1 mm ($P = 0.03$) and 2 mm ($P = 0.02$) prior to crown placement (Table 6). No significant positive correlations for L* were obtained at none of the timepoints, neither for Ti nor for Zr abutments (Table 6).

## Discussion

The present study has evaluated the colour difference of the peri-implant soft tissue at titanium and zirconia abutments prior and after crown placement. By evaluating *ΔE*, the goal was to achieve small values, which correspond more precisely to optimal colour matches with the soft tissue (e.g. gingiva) at natural teeth. The present results have shown statistically significantly higher colour differences between the test and the control sites (*ΔE* values) than the critical threshold of 3.7 (Johnston & Kao 1989). This value represents the colour difference between natural and restored teeth for the intraoral colour distinction of the naked eye, and thus, it has only a limited value for an objective colour analysis of the gingiva. Despite the fact that a similar reference value for soft tissue is lacking, it is still the most frequently reported reference related to prosthetic reconstructions.

Our findings are in agreement with those reported previously by others (Park et al. 2007; Jung et al. 2008; Sailer et al. 2009b; Zembic et al. 2009; Bressan et al. 2011), and indicate that substantial colour differences of the soft tissue around natural teeth and peri-implant mucosa are present, independent of the abutment material. Bressan et al. (2011) obtained *ΔE* values for the peri-implant mucosa at titanium, gold and zirconia abutments as compared to the gingiva around natural teeth higher than 8.5, with a statistical significant difference for titanium (11 ± 0.4) vs. zirconia (8.5 ± 0.4) abutments. Similar values were also reported by Park et al. (mean *ΔE* between 7.7 at 1 mm and 6.5 at 5 mm from the gingival margin) and Sailer et al. ($\Delta E_{zr} = 8.1 \pm 3.9$, $\Delta E_{Ti} = 7.8 \pm 4.3$) at 1 year, as well as at 3 years ($\Delta E_{zr} = 9.3 \pm 3.8$, $\Delta E_{Ti} = 6.8 \pm 3.8$) after implant loading (Park et al. 2007; Sailer et al. 2009b; Zembic et al. 2009). Moreover, in the study by Jung et al. (2008) titanium and gold abutments were loaded with PFM crowns and aluminium-oxide based abutments received all ceramic crowns. They reported colour differences of 7.4 ± 2.7 in the ceramic crown group and of 7.6 ± 2.8 in the PFM group. Taking together, these findings indicate that comparable values in terms of colour differences (*ΔE)* can be obtained for both Ti and Zr abutments.

The present study has shown lower *ΔE* – values for zirconia abutments compared to titanium abutments both prior to as well as after crown cementation (Table 1). A statistically significant discrepancy in soft


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***Table 3.*** **$L^*$-, $a^*$-, $b^*$-, $c^*$- values (mean ± standard deviation, in mm) for titanium (Ti) and its adjacent tooth (control tooth = C-Ti), prior (timepoint 1) and after (timepoint 2) crown cementation**

| | | 1 mm | | *P*-value (group | 2 mm | | *P*-value (group | 3 mm | | *P*-value (group |
|---|---|---|---|---|---|---|---|---|---|---|
| | Time | Ti | C-Ti | difference) | Ti | C-Ti | difference) | Ti | C-Ti | difference) |
| $L^*$ | 1 | 48.94 ± 4.30 | 56.47 ± 3.35 | <0.01† | 50.81 ± 3.46 | 55.50 ± 3.33 | <0.01† | 50.67 ± 2.85 | 53.05 ± 4.18 | 0.05 |
| Mean ± SD | 2 | 52.63 ± 3.30 | 54.71 ± 2.96 | 0.15 | 51.85 ± 3.13 | 53.29 ± 2.72 | 0.33 | 50.11 ± 2.33 | 52.31 ± 3.32 | 0.24 |
| *P*-value (time difference) | | 0.07 | 0.58 | | 0.76 | 0.45 | | 0.97 | 0.85 | |
| $a^*$ | 1 | 15.83 ± 5.24 | 18.37 ± 4.43 | 0.22 | 18.01 ± 4.27 | 20.85 ± 4.74 | 0.38 | 20.52 ± 3.67 | 24.04 ± 5.00 | 0.04† |
| Mean ± SD | 2 | 18.73 ± 4.16 | 22.83 ± 2.49 | 0.01† | 21.34 ± 4.29 | 25.52 ± 3.11 | 0.21 | 23.53 ± 3.32 | 26.25 ± 3.17 | 0.14 |
| *P*-value (time difference) | | 0.83 | 0.06 | | 0.75 | 0.04† | | 0.06 | 0.23 | |
| $b^*$ | 1 | 8.89 ± 2.34 | 16.06 ± 2.56 | <0.01† | 9.92 ± 2.54 | 14.97 ± 2.84 | <0.01† | 10.76 ± 2.75 | 15.19 ± 2.43 | <0.01† |
| Mean ± SD | 2 | 12.29 ± 2.00 | 16.31 ± 2.88 | <0.01† | 11.62 ± 1.98 | 14.75 ± 2.89 | 0.12 | 11.69 ± 2.53 | 14.84 ± 2.82 | 0.08 |
| *P*-value (time difference) | | <0.01† | 0.96 | | 0.45 | 0.95 | | 0.43 | 0.76 | |
| $c^*$ | 1 | 18.40 ± 4.79 | 24.72 ± 3.00 | <0.01† | 20.76 ± 3.98 | 25.98 ± 3.61 | <0.01† | 23.35 ± 3.49 | 28.65 ± 4.17 | <0.01† |
| Mean ± SD | 2 | 22.53 ± 3.91 | 28.19 ± 2.51 | <0.01† | 24.42 ± 4.02 | 29.59 ± 3.27 | <0.01† | 26.36 ± 2.27 | 30.27 ± 3.27 | <0.01† |
| *P*-value (time difference) | | 0.02† | 0.04† | | 0.04† | 0.01† | | 0.13 | 0.42 | |

†Statistical significance.

***Table 4.*** **$L^*$-, $a^*$-, $b^*$-, $c^*$- values (mean ± standard deviation, in mm) for zirconia (Zr) and its adjacent tooth (control tooth = C-Zr), prior (timepoint 1) and after (timepoint 2) crown cementation**

| | | 1 mm | | *P*-value (group | 2 mm | | *P*-value (group | 3 mm | | *P*-value (group |
|---|---|---|---|---|---|---|---|---|---|---|
| | Time | Zr | C-Zr | difference) | Zr | C-Zr | difference) | Zr | C-Zr | difference) |
| $L^*$ | 1 | 54.21 ± 5.67 | 54.48 ± 4.46 | 0.12 | 53.39 ± 4.26 | 53.43 ± 3.57 | 0.98 | 50.88 ± 3.77 | 52.39 ± 3.90 | 0.37 |
| Mean ± SD | 2 | 52.85 ± 1.24 | 54.52 ± 2.84 | 0.93 | 51.89 ± 3.16 | 53.97 ± 2.67 | 0.11 | 50.16 ± 3.31 | 52.97 ± 3.54 | 0.07 |
| *P*-value (time difference) | | 0.77 | 0.03† | | 0.75 | 0.89 | | 0.64 | 0.72 | |
| $a^*$ | 1 | 18.08 ± 6.15 | 20.54 ± 3.62 | 0.27 | 20.56 ± 4.79 | 23.67 ± 3.10 | 0.09 | 24.02 ± 3.67 | 25.04 ± 3.52 | 0.51 |
| Mean ± SD | 2 | 18.83 ± 2.44 | 22.95 ± 2.71 | <0.01† | 20.61 ± 3.30† | 24.19 ± 2.99 | <0.01† | 22.88 ± 2.84 | 24.79 ± 3.20 | 0.15 |
| *P*-value (time difference) | | 0.71 | 0.09 | | 0.98 | 0.7 | | 0.43 | 0.86 | |
| $b^*$ | 1 | 11.22 ± 2.34 | 15.68 ± 3.26 | <0.01† | 11.44 ± 2.42 | 14.85 ± 3.21 | 0.01† | 12.27 ± 3.17 | 14.47 ± 3.77 | 0.15 |
| Mean ± SD | 2 | 12.76 ± 2.85 | 15.88 ± 2.48 | <0.01† | 11.83 ± 2.49 | 14.04 ± 2.57 | 0.05 | 11.79 ± 2.50 | 13.50 ± 2.61 | 0.13 |
| *P*-value (time difference) | | 0.18 | 0.87 | | 0.98 | 0.79 | | 0.7 | 0.49 | |
| $c^*$ | 1 | 21.64 ± 5.12 | 26.09 ± 3.15 | <0.01† | 23.80 ± 3.85 | 28.14 ± 2.82 | <0.01† | 27.17 ± 3.49 | 29.12 ± 3.72 | 0.22 |
| Mean ± SD | 2 | 22.91 ± 2.49 | 28.11 ± 1.23 | <0.01† | 23.96 ± 2.61 | 28.10 ± 2.77 | <0.01† | 25.92 ± 2.20 | 28.36 ± 3.00 | 0.04† |
| *P*-value (time difference) | | 0.49 | 0.06 | | 0.86 | 0.96 | | 0.32 | 0.6 | |

†Statistical significance.

***Table 5.*** **Gingiva/peri-implant mucosa thickness values at titanium(Ti)/zirconia (Zr) abutments and at their neighbouring teeth (C-Ti/C-Zr)**

| | 1 mm Mean ± SD | 2 mm Mean ± SD | 3 mm Mean ± SD |
|---|---|---|---|
| Ti | 1.31 ± 0.69 | 1.79 ± 0.74 | 2.27 ± 0.34 |
| C-Ti | 1.02 ± 0.36 | 1.32 ± 0.51 | 1.50 ± 0.49 |
| Zr | 1.24 ± 0.35 | 1.95 ± 0.35 | 2.20 ± 0.56 |
| C-Zr | 1.05 ± 0.52 | 1.26 ± 0.45 | 1.36 ± 0.39 |

tissue colour around Ti and Zr abutments was only recorded prior to crown placement at 1 mm from the gingival margin (*P = 0.01*, Table 2). On the other hand, there were no further statistically significant differences between the two materials at any other more apically located region (ROI at 2 and 3 mm) or even at 1 week after crown cementation. One possible explanation for this finding may be due to the fact that the peri-implant soft tissue covered the abutment material only in the coronal area. Furthermore, it cannot be excluded that the apical increase of the soft-tissue thickness may have also influenced the outcomes.

In the study by Happe et al. (2013) loaded titanium implants with zirconia abutments were veneered with fluorescent ceramic and full-ceramic crowns. Contrary to our findings, they obtained $\Delta E$ values <3.7 at 1 and 2 mm from the gingival margin in almost half of the patients (6 out of 12 patients). Nonetheless, medians of $\Delta E$ were higher than 3.7 in all incremental areas (at 1, 2, 3, 4 and 5 mm). In their study, the implants were placed in the maxillary anterior region, where the amount of keratinized soft tissue is thicker compared to the molar and premolar

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***Table 6.*** **Correlation coefficients (CC) and *P*-values (*P*) for the correlation between *L**, *c** and gingival thickness (G) at 1-, 2- and 3- mm from the gingival margin (Spearman rank correlation coefficients)**

| | | | 1 mm | | 2 mm | | 3 mm | |
|---|---|---|---|---|---|---|---|---|
| | | Timepoint | Ti | Zr | Ti | Zr | Ti | Zr |
| *C** | CC | 1 | 0.62 | <0.01 | 0.69 | 0.34 | 0.33 | −0.23 |
| | | 2 | −0.6 | −0.1 | −0.39 | −0.13 | 0.22 | 0.3 |
| | *P* | 1 | 0.03† | 0.99 | 0.02† | 0.31 | 0.32 | 0.49 |
| | | 2 | 0.05 | 0.77 | 0.23 | 0.69 | 0.50 | 0.38 |
| *L** | CC | 1 | −0.46 | −0.15 | −0.43 | 0.26 | 0.31 | 0.58 |
| | | 2 | 0.59 | 0.74 | 0.53 | 0.39 | 0.03 | 0.25 |
| | *P* | 1 | 0.15 | 0.41 | 0.19 | 0.43 | 0.36 | 0.08 |
| | | 2 | 0.06 | 0.24 | 0.1 | 0.22 | 0.94 | 0.34 |

†Statistical significant differences.

area where the implants in the study had been placed (Muller et al. 2000).

Soft tissue discoloration on natural teeth has been reported after prosthetic treatment with metal ceramic and resin-veneered crowns (Takeda et al. 1996). "Noticeable" ($\Delta E$ = 3.26–6.51) and "very noticeable" ($\Delta E$ = 6.52–13.04) colour differences of the gingiva around these types of restorations as compared to unrestored natural teeth have been recorded. Mean $\Delta E$ values in our study can all be considered as "very noticeable" (Table 1), both before and after crown cementation. However, due to the differences in study design and in the types of used restorations, no direct comparisons between the present results and those reported by Takeda et al. (1996) be made.

In the present study all colour parameters L*, a*, b* and c*, irrespective of the timepoint of measurement and of the abutment material, were smaller compared to the values obtained around natural teeth, most of the differences being statistically significant (Table 3 and 4). This is in agreement with other data reported in the literature (Jung et al. 2008; Bressan et al. 2011). Their results showed better colour matches of the peri-implant soft tissue around zirconium-oxide abutments as compared to the natural teeth, than titanium and gold abutments vs. gingiva at natural teeth. When comparing different abutment types, Bressan et al. (2011) obtained no statistically significant differences on the red and green scale values (a*); however, significant differences were registered for L* and b* values. This is in line with the results of our study where titanium abutments showed significant differences for b* and c* values in all incremental areas (Table 3 and 4), before crown placement; chroma was statistically significant different also after crown placement in all areas (Table 3). The corresponding values for zirconia abutments were statistically significant mostly at 1 and 2 mm from the gingival margin, with values higher than those of titanium. Our results suggest that neither titanium nor zirconia abutments offers good matching to the gingiva around natural teeth regarding the chroma along the yellow–blue axis. The use of full ceramic or metal-fused-to ceramic crowns did not change this fact (timepoint 2 values, Tables 3 and 4).

In a recent study by Paniz et al., a threshold of $\Delta E$ = 8.74 was set for the distinction of peri-implant soft tissue colour differences between perfect ($\Delta E$ = 6.63) or good colour matching ($\Delta E$ = 8.54) vs. clinically distinguishable matching ($\Delta E$ = 15.54) (Paniz et al. 2013). They correlated the subjective colour matching made by five examiners with the objective method using a spectrophotometer. Our data demonstrated for zirconia "good matching" both before and after crown cementation; as for titanium, this showed "good matching" at 3 mm prior to crown cementation and in all incremental areas after cementation (Table 1, (Paniz et al. 2013)).

Patient- and material-related biases could be avoided, as measurements were performed for both abutment and crown materials in each patient. However, the different types of used crowns (CC and PFM), may influence the colour change of the soft tissue around the investigated abutment materials.

The available data from the literature suggest that mucosa thickness plays an important role in tissue discoloration and aesthetic appearance caused by different restorative materials (Jung et al. 2007; Park et al. 2007; van Brakel et al. 2011). Most of the available studies have evaluated tissue discoloration in anterior regions, which are the areas of major aesthetic requirements. However, when interpreting the present findings it needs to be pointed out that the areas investigated in the present study were located in premolar and molar regions, which, in certain patients, are also of aesthetic demands. Furthermore, it has been shown that the lateral dental areas present may differ from the anterior regions in terms of soft tissue thickness (Muller et al. 2000). Thus, it cannot be excluded that, at least in certain clinical situations, differences in tissue-thickness and -discoloration between lateral and frontal areas are present.

Jung et al. demonstrated *in vitro*, a significant colour change of the peri-implant mucosa in cases with a thickness below 2 mm when titanium abutments were compared to zirconia (Jung et al. 2007). Since the authors investigated the colour change as related to tissue thickness in an *in vitro* setting, we aimed at evaluating the same issue in *in vivo* conditions. Their results are in agreement with the results of our study where a statistically significant positive correlation between the soft tissue thickness and the chroma values (c*) for Ti-abutments at the marginal aspect of the soft tissue (at 1 and 2 mm) were found. This colour difference could not be noticed neither after the crown insertion nor at zirconia abutments. Furthermore, our data also confirmed the results of van Brakel et al. (2011), where no perceivable colour differences between Ti and Zr abutments could be obtained for a gingiva thicker than 2.0 ± 0.1 mm. In a clinical study, Jung et al. (2008) showed no significant colour changes after cementation of PFM or CC crowns at implants with a peri-implant soft-tissue thickness above 2.9 ± 0.9 mm. It has, however, to be pointed out that in our study the mean values for mucosa thickness, both at Ti and Zr abutments, were below 2.2 ± 0.56 mm indicating the presence of a "thin" biotype according to Jung et al. (Jung et al. 2007): the values obtained at natural teeth were smaller than those at implants (Table 4). However, this difference was smaller compared to that reported in the literature (Chang et al. 1999; Jung et al. 2007, 2008), where the gingiva at natural teeth was approximately 1 mm thinner compared to that at implants. This discrepancy might be explained by different methods used for soft tissue measurement, implant position and diameter, clinical procedures and sample size (Jung et al. 2007, 2008; Sailer et al. 2007, 2009b; van Brakel et al. 2011; Bressan et al. 2011; Paniz et al. 2013).

Visual determination of colour is considered highly subjective. External light conditions, experience, age and fatigue of the human eye are variables that influence this process (Barna et al. 1981). Computerised colourimetry and spectrophotometry have been shown to be more accurate and reproducible


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than the human visual tooth colour determination (Paul et al. 2002). This relies on the assessment of the CIE colour parameters and enables a direct mathematical colour comparison (Seghi et al. 1989). Several methods of visual colour determination of the human gingiva have been described in the literature (Furhauser et al. 2005; Heydecke et al. 2005). Some studies described gingiva colour assessment by means of a spectrophotometer (Park et al. 2007; Jung et al. 2008). In the present study, a colourimeter was used to capture gingival images, which were analysed for the CIE colour parameters using a computer software. One disadvantage of this method is the direct contact of the colourimeter tube with the gingiva, which in turn might have influenced the colour by pressure effects, despite the fact that this step was carefully performed. On the other hand, no spectrophotometric or colourimetric device has yet been validated for the colour measurement of the gingiva (Schnitzer et al. 2004; Heydecke et al. 2005; Jung et al. 2007; Park et al. 2007).

## Conclusions

Taken together, within their limits, the present data indicate that: (i) The peri-implant soft tissue around titanium and zirconia showed colour differences when compared to the soft tissue around natural teeth, and (ii) the peri-implant soft tissue around zirconia demonstrated a better colour match to the soft tissue at natural teeth than titanium.

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## Conflict of interests

The authors declare to have no conflict of interest regarding the present study.

## 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., Scharer, P., Sorensen, J.A. & Tarnow, 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.

Barna, G.J., Taylor, J.W., King, G.E. & Pelleu, G.B., Jr. (1981) The influence of selected light intensities on color perception within the color range of natural teeth. *Journal of Prosthetic Dentistry* **46**: 450–453.

Belser, U., Buser, D. & Higginbottom, F. (2004) Consensus statements and recommended clinical procedures regarding esthetics in implant dentistry. *International Journal of Oral and Maxillofacial Implants* **19**(Suppl): 73–74.

Berglundh, T., Persson, L. & Klinge, B. (2002) A systematic review of the incidence of biological and technical complications in implant dentistry reported in prospective longitudinal studies of at least 5 years. *Journal of Clinical Periodontology* **29**(Suppl 3): 197–212; discussion 232-193.

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 endodontics* **33**: 325–327.

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**: 1172–1178.

Bressan, E., Paniz, G., Lops, D., Corazza, B., Romeo, E. & Favero, G. (2011) Influence of abutment material on the gingival color of implant-supported all-ceramic restorations: a prospective multicenter study. *Clinical Oral Implants Research* **22**: 631–637.

Chang, M., Wennstrom, J.L., Odman, P. & Andersson, B. (1999) Implant supported single-tooth replacements compared to contralateral natural teeth. Crown and soft tissue dimensions. *Clinical Oral Implants Research* **10**: 185–194.

Chu, S.J., Trushkowsky, R.D. & Paravina, R.D. (2010) Dental color matching instruments and systems. Review of clinical and research aspects. *Journal of Dentistry* **38**(Suppl 2): e2–e16.

Dierens, M., Vandeweghe, S., Kisch, J., Nilner, K. & De Bruyn, H. (2012) Long-term follow-up of turned single implants placed in periodontally healthy patients after 16-22 years: radiographic and peri-implant outcome. *Clinical Oral Implants Research* **23**: 197–204.

Dummett, C.O. (1960) Dental health problems of the negro population. *Journal of the American Dental Association* **61**: 308–314.

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.

Garber, D.A. (1996) The esthetic dental implant: letting restoration be the guide. *The Journal of Oral Implantology* **22**: 45–50.

Glauser, R., Sailer, I., Wohlwend, A., Studer, S., Schibli, M. & Scharer, 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.

Happe, A., Schulte-Mattler, V., Fickl, S., Naumann, M., Zoller, J.E. & Rothamel, D. (2013) Spectrophotometric assessment of peri-implant mucosa after restoration with zirconia abutments veneered with fluorescent ceramic: a controlled, retrospective clinical study. *Clinical Oral Implants Research* **24**(Suppl A100): 28–33.

Heydecke, G., Schnitzer, S. & Turp, J.C. (2005) The color of human gingiva and mucosa: visual measurement and description of distribution. *Clinical Oral Investigations* **9**: 257–265.

Heydecke, G., Sierraalta, M. & Razzoog, M.E. (2002) Evolution and use of aluminum oxide single-tooth implant abutments: a short review and presentation of two cases. *The International Journal of Prosthodontics* **15**: 488–493.

Hugo, B., Witzel, T. & Klaiber, B. (2005) Comparison of in vivo visual and computer-aided tooth shade determination. *Clinical Oral Investigations* **9**: 244–250.

Ishikawa, S., Nemoto, F., Furukawa, K. & Ishibashi, K. (1988) Colorimetric studies of the gingiva. Color variation of the gingiva in the upper anterior region. *Nihon Hotetsu Shika Gakkai Zasshi* **32**: 821–828.

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 Dental Research* **68**: 819–822.

Joiner, A. (2004) Tooth colour: a review of the literature. *Journal of Dentistry* **32**(Suppl 1): 3–12.

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. *The International Journal of Periodontics & 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. *The International Journal of Periodontics & Restorative Dentistry* **27**: 251–257.

Kim-Pusateri, S., Brewer, J.D., Davis, E.L. & Wee, A.G. (2009) Reliability and accuracy of four dental shade-matching devices. *Journal of Prosthetic Dentistry* **101**: 193–199.

Kleinheinz, J., Buchter, A., Fillies, T. & Joos, U. (2005) Vascular basis of mucosal color. *Head & Face Medicine* **1**: 4.

Lehmann, K.M., Igiel, C., Schmidtmann, I. & Scheller, H. (2010) Four color-measuring devices

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compared with a spectrophotometric reference system. *Journal of Dentistry* **38**(Suppl 2): e65–e70.

Manicone, P.F., Rossi Iommetti, P., Raffaelli, L., Paolantonio, M., Rossi, G., Berardi, D. & Perfetti, G. (2007) Biological considerations on the use of zirconia for dental devices. *International Journal of Immunopathology and Pharmacology* **20**: 9–12.

Manso, M.C. & Wassal, T. (2010) A 10-year longitudinal study of 160 implants simultaneously installed in severely atrophic posterior maxillas grafted with autogenous bone and a synthetic bioactive resorbable graft. *Implant Dentistry* **19**: 351–360.

Muller, H.P., Schaller, N., Eger, T. & Heinecke, A. (2000) Thickness of masticatory mucosa. *Journal of Clinical Periodontology* **27**: 431–436.

O'Leary, T.J., Drake, R.B. & Naylor, J.E. (1972) The plaque control record. *Journal of Periodontology* **43**: 38.

Paniz, G., Bressan, E., Stellini, E., Romeo, E. & Lops, D. (2013) Correlation between subjective and objective evaluation of peri-implant soft tissue color. *Clinical Oral Implants Research*: 1–5. doi: 10.1111/clr.12201

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.

Paul, S., Peter, A., Pietrobon, N. & Hammerle, C.H. (2002) Visual and spectrophotometric shade analysis of human teeth. *Journal of Dental Research* **81**: 578–582.

Reikie, D.F. (1993) Esthetic and functional considerations for implant restoration of the partially edentulous patient. *Journal of Prosthetic Dentistry* **70**: 433–437.

Reikie, D.F. (1995) Restoring gingival harmony around single tooth implants. *Journal of Prosthetic Dentistry* **74**: 47–50.

Rompen, E., Raepsaet, N., Domken, O., Touati, B. & Van Dooren, E. (2007) Soft tissue stability at the facial aspect of gingivally converging abutments in the esthetic zone: a pilot clinical study. *Journal of Prosthetic Dentistry* **97**: S119–S125.

Ruyter, I.E., Nilner, K. & Moller, B. (1987) Color stability of dental composite resin materials for crown and bridge veneers. *Dental Materials* **3**: 246–251.

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., Hammerle, C.H. & Mattiola, A. (2007) Single-tooth implant reconstructions: esthetic factors influencing the decision between titanium and zirconia abutments in anterior regions. *The European Journal of Esthetic Dentistry* **2**: 296–310.

Sailer, I., Zembic, A., Jung, R.E., Siegenthaler, D., Holderegger, C. & Hammerle, C.H. (2009b) Randomized controlled clinical trial of customized zirconia and titanium implant abutments for canine and posterior single-tooth implant reconstructions: preliminary results at 1 year of function. *Clinical Oral Implants Research* **20**: 219–225.

Schnitzer, S., Turp, J.C. & Heydecke, G. (2004) Color distribution and visual color assessment of human gingiva and mucosa: a systematic review of the literature. *The International Journal of Prosthodontics* **17**: 327–332.

Seghi, R.R., Hewlett, E.R. & Kim, J. (1989) Visual and instrumental colorimetric assessments of small color differences on translucent dental porcelain. *Journal of Dental Research* **68**: 1760–1764.

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.

Watkin, A. & Kerstein, R.B. (2008) Improving darkened anterior peri-implant tissue color with zirconia custom implant abutments. *The Compendium of Continuing Education in Dentistry* **29**: 238–240, 242.

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.

## Supporting Information

Additional Supporting Information may be found in the online version of this article:

**Appendix S1.** CONSORT 2010 checklist of information to include when reporting a randomised trial*


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