

COLOR MASKING MEASUREMENT FOR CERAMIC COATING OF TITANIUM USED IN DENTAL IMPLANTS

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ABSTRACT

Statement of problem: The dark metal color showing through the periimplant soft tissue as a result of poor implant placement or thin gingiva and progressive bone resorption is a common problem in implant dentistry.

Purpose: The purpose of this study was to test the color masking effect of porcelain applied on titanium used in fabricating the polished collar of tissue level implants to solve this problem.

Material and Methods: Type 4 commercially pure titanium disks and five porcelain dentin shades (A2, A3, B2, C2, and D3) were used. Ten titanium disk specimens per porcelain shade were air abraded and ultrasonically cleaned. Porcelain was condensed directly on the specimens, then fired and finished (1200 grit SiC paper). The color ($L^*a^*b^*$ values) of the polished specimens were measured using reflective spectrophotometer. The specimens were then ground and polished in 0.1 mm increments. Color was measured and ΔE values were calculated at each increment until the thickness at which the color coordinates start to change. ΔE greater than 3.3 was considered as a significant color mismatch detectable by the human eye. The data (n=10) was statistically analyzed by ANOVA/Tukey test at the 95% confidence level ($\alpha = .05$).

Results: ΔE was less than 3.3 as long as the ceramic thickness was ≥ 0.5 mm for A2, A3, B2, and C2 shades. For D3, ΔE was less than 3.3 as long as the ceramic thickness was ≥ 0.4 mm.

Conclusions: The minimum ceramic thickness required to block the underlying titanium color is 0.5 mm for all shades except D3 which only needs 0.4 mm ceramic thickness. L^* decreased with thickness increase. Redness a^* and yellowness b^* increased with thickness increase.

INTRODUCTION

Dental implants have become an integral part of today's modern dentistry. According to a report on the Global dental market released by Persistence

Market Research in September 2014 , the global dental implants market was valued at USD 4,508.9 million in 2014 and is expected to grow to reach an estimated value of USD 7,879.5 in 2020 with an estimated cumulated annual growth rate (CAGR)

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of 9.7% from 2014 to 2020. Globally, some of the major drivers which help increase the demand for dental implant treatment are rising aging population and growing concern for oral healthcare and the rising demand for esthetic dentistry (Persistence Market Research. Global market study on dental implants: Asia Pacific to witness fastest growth by 2020. Sep 2014).

Currently, tooth replacement with dental implants has a high success rate. However, restoring anterior teeth with implants remains a technique sensitive task. In the anterior region the surgical and restorative team is challenged with esthetic as well as functional success.^{1,2} Any impairment in the esthetic outcome may be considered to be a failure of the whole reconstruction.³

Titanium is the preferred material for dental implants, because of its biocompatibility, fatigue resistance, high elastic limit and low elastic modulus.⁴ However, with the current systems in the market, it is common for the implant neck to show through the gums as a black or dark grey line and/or as a grayish discoloration of the periimplant soft tissue.⁵ This is a major esthetic dilemma in implant dentistry today when unfavorable soft tissue conditions (thin periimplant mucosa, soft tissue recessions) are present. It has been reported that during the first year of function of an endosseous implant, a vertical loss of 1 mm is usually observed, at the alveolar crest, followed by an additional 0.1 mm for every subsequent year.^{6,7} Recession will result in progressive exposure of the implant with the unsightly exposure of the dark metal surface.

To solve this esthetic problem the surgeon or periodontist may attempt tissue augmentation and grafting to increase the tissue thickness and cover the metal exposure or showing through. Again, this is very costly to the patient and the immediate and long term esthetic outcome is not predictable. It is also common for the tissue graft to fail or to have a different color and texture from the surrounding tissue resulting in compromised esthetics.⁸

Another solution to this problem was the introduction of ceramic abutments. The whitish color of zirconia abutments offers favorable esthetics compared to the grayish color of titanium abutments.^{9,10} Lesser gingival discoloration was reported for zirconium abutments.¹¹ Nonetheless, zirconia has greater opacity, making it difficult to achieve natural tooth color. There was no evidence for difference in patient's esthetic satisfaction between zirconia and metal abutments.^{11,12} Therefore, lithium disilicate abutments were suggested to replace metal abutments. While lithium disilicate abutments were originally thought to have the potential to withstand the physiological occlusal forces in the anterior region⁹ more anterior abutment fractures were reported for ceramic abutments when compared to metal abutments.¹¹

A recent solution was introduced by Wadhvani et al. where they developed a laboratory technique using readily available household items that can alter the titanium abutment color by anodization.¹³

A new solution is suggested by the investigators of the current study. The implant body is made of type 4 commercially pure titanium. Titanium provides adequate strength, is biocompatible and allows the osseointegration of the bone to the implant surface. The top 1.0-3.0 mm of the neck of the tissue level implants is made of a polished titanium collar which could be covered with a ceramic shell. This ceramic shell is the key component that will mask the dark color of the metal and will give a whitish color (similar to a natural tooth color) underneath the soft tissues, which closely mimics nature and gives the patient a more pleasing result.

This suggested design is aimed at improving the esthetic outcome of the implant treatment and offering a more natural looking dental prosthesis that will optimally blend-in with the surrounding dentition and oral structures, the added ceramic coating will also help with achieving a favorable tissue response due to the proven track record of positive soft tissue response to ceramic surfaces¹⁴⁻²²

The null hypothesis in this study is “dental porcelain will not be able to mask the color of titanium at thickness less than 1.0 mm”. The aim of the study was to investigate this hypothesis and determine the minimum porcelain thickness that is needed to mask the color of titanium used in dental implant.

The resulting information should provide insight into the question of whether the ceramic shell can provide adequate color masking while maintaining low thickness.

MATERIAL AND METHODS

Grade 4 commercially pure titanium disks and five porcelain system shades (Dentin shades A2, A3, B2, C2, and D3) were used in this study. Ten specimens were fabricated from each porcelain shade. This resulted in a total of 50 specimens (five groups of ten specimens each).

Titanium plates fabrication: Disk-shaped specimens of 18-mm diameter and 2-mm thickness were cut from titanium rod (ASTM Grade 4 titanium; Titanium Industries) using a low speed water cooled diamond saw (Isomet; Buehler). The specimens’ surfaces where porcelain is to be fired were air abraded with 110 μm Al₂O₃ particles (Korox®; Bego) on a dental air-abrasion unit (Blastmate II; Ney). Air pressure for the air abrasion was maintained at 2.5 bars or 30 psi, and the distance between the nozzle and surface was maintained at approximately 1 cm during sandblasting of 20 seconds. Air abrasion was done at a 45 degree angle. Specimens were then steam cleaned and let dried on a tissue for 5 minutes to naturally oxidize. A thin coating of bonder (GC Titanium Bonder; GC America Inc.) was then applied on titanium surface. Properly fired bonder had a very slight sheen under lighting.

Porcelain application: Five porcelain shades (Dentin shades A2, A3, B2, C2, and D3) were used (GC Initial Ti; GC America Inc.). GC Initial Ti is a specifically adapted ceramic for titanium frameworks (Table 1).

TABLE (1) Specifications of GC Initial Ti used porcelain

Property	Value
Dentin Firing (°C)	780
CTE (25-500°C 10 ⁻⁶ x K ⁻¹)	2 nd firing 8.6, 4 th firing 8.6
Glass Transition Temperature (°C)	572
Solubility (μg/cm ²)	11
Density (g/cm ²)	2.4
Flexural Strength (MPa)	70
Mean Particle size (μm; D %50)	22.2

A thin opaque layer (GC Titanium Opaque; GC America Inc.) was applied by a glass rod and fired according to manufacturer’s recommendations. Porcelain powders from each shade were mixed with deionized water and condensed under vibration in a plastic ring 1.2 mm in height and 18 mm in diameter. In each of these groups the porcelain was condensed directly; excess moisture was removed with absorbent paper tissue to minimize porosity. Each specimen was then removed and placed on a honeycomb firing tray (Round Tray 680050; National Keystone Products Co.). For each porcelain group, the ten specimens were fired together according to the manufacturer’s recommendations in a porcelain furnace (Multimat Touch & Press; Dentsply Ceramco), which was calibrated at the melting point of silver (962°C) using silver foils (foil 267449; Sigma-Aldrich Inc.).

Wet silicon carbide coated papers (240, 320, 400, 600, 1000, and 1200 grit; Allied High Tech Products Inc.) were used to make opposing faces parallel and polished at 1.0 mm porcelain thickness. The specimens were not glazed because glazing may introduce inconsistent thickness and thus increased variation within groups.

Color coordinates (CIELAB) of polished specimens were measured using a portable reflective spectrophotometer (spectrophotometer model RM200QC; X-Rite). The aperture size was set to 4 mm and the specimens were exactly aligned with the device. A white background was selected and measurements were made according to the CIE $L^*a^*b^*$ color space relative to the CIE standard illuminant D65.

The specimens were ground using silicon carbide coated papers (600, 1000, and 1200 grit in grinder-polisher (EcoMet 250 Grinder-Polisher; Buehler) in 0.1 mm increments and color measured at each increment until the thickness at which the color coordinates start to change. Color coordinates (CIELAB) of polished specimens before grinding was used as a control. The color changes (ΔE) of the specimens were evaluated using the following formula²³:

$$\Delta E_{CIELAB} = (\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2})^{1/2}$$

Where: L^* color coordinate ranges from 0 to 100 and represents lightness; the a^* color coordinate ranges from -90 to 70 and represents greenness on the positive axis and redness on the negative; the b^* color coordinate ranges from -80 to 100 and represents yellowness (positive b^*) and blueness (negative b^*).²⁴

Thickness was controlled with a digital thickness gauge (± 0.001 mm, 543-452B; Mitutoyo). In dental color science, $\Delta E = 3.3$ is the acceptability limit in the color difference for observers (the clinical detectable value).²⁵

A repeated measures analysis of variance was used to identify significantly different L^* , a^* , and b^* between groups. ΔE values were calculated. ΔE greater than 3.3 was considered as inability of porcelain to mask titanium color which is detectable by the human eye. Tukey's multiple-comparison test was used to determine which groups differed. All statistical tests were performed at the 95% confidence level ($\alpha = .05$).

RESULTS

Means and standard errors (means \pm SE) of CIE L^* , a^* , b^* values for each shade at the different ceramic thicknesses are presented in Tables 2-4. The ANOVA showed a statistical significance in two factors (shade and color parameters) but not in the third factor (thickness). The interaction between the three factors was statistically significant ($F = 1.7$).

The interaction between the shade and color parameters was statistically significant ($F = 14.3$ and $P < .001$). This means that the average color parameters (L^* , a^* , b^*) were significantly different among the shades studied.

Additionally, the interaction between the thickness and color parameters was statistically significant ($F = 49.7$ and $P < .001$). L^* decreased with thickness increase (Table 2). Redness a^* increased with thickness increase (Table 3) and yellowness b^* increased with thickness increase (Table 4).

Means and standard errors (means \pm SE) of ΔE values for each shade at the different ceramic thicknesses are presented in Table 5. The CIELAB for all specimens was measured before incrementally grinding the ceramic surface. Then, it was measured again after removing each 0.1mm of ceramic thickness. ΔE decreased with thickness increase. For A2, A3, B2, and C2 dentin shades, the average of ΔE became greater than 3.3 (clinical detectable value) when 0.6mm of ceramic thickness was removed (i.e. at 0.4 mm ceramic thickness). This means that the minimum ceramic thickness of any one of those shades required to block the underlying titanium color is 0.5mm. At 0.4mm ceramic thickness, ΔE was 4.1, 3.8, 4.6, and 4.02 for A2, A3, B2, and C2. For D3 shade, the average of ΔE became greater than 3.3 when 0.7 mm of ceramic thickness was removed (i.e. at 0.3 mm ceramic thickness). This means that the minimum ceramic thickness of D3 shade required to block the underlying titanium color is 0.4 mm.

TABLE (2) CIE L* values (means ± SE) of tested specimens (n=10)

	Control	Remove 0.1 mm	Remove 0.2 mm	Remove 0.3 mm	Remove 0.4 mm	Remove 0.5 mm	Remove 0.6 mm
A2	78.6 ±0.1	80.2 ±.06	80.2 ±0.2	80.5 ±0.2	80.5 ±0.2	80.6 ±0.1	81.4 ±0.1
A3	77.5 ±0.1	79.2 ±0.1	79.4 ±0.1	79.5 ±0.1	79.6 ±0.1	79.7 ±0.1	80.1 ±0.1
B2	78.7 ±0.1	78.9 ±0.1	79 ±0.1	79.3 ±0.1	79.4 ±0.1	79.4 ±0.1	80.2 ±.07
C2	78.3 ±0.2	78.9 ±0.2	79.3 ±0.2	79.5 ±0.2	80.1 ±0.2	80.6 ±0.2	81.4 ±0.2
D3	77.3 ±0.1	77.6 ±0.1	77.8 ±0.1	78.3 ±0.1	79 ±0.1	79.3 ±0.1	79.7 ±0.1

TABLE (3) CIE a* values (means ± SE) of tested specimens (n=10)

	Control	Remove 0.1 mm	Remove 0.2 mm	Remove 0.3 mm	Remove 0.4 mm	Remove 0.5 mm	Remove 0.6 mm
A2	0.7 ±.07	0.6 ±.07	0.4 ±.05	0.3 ±.03	0.3 ±.04	0.2 ±.03	-.04 ±.06
A3	0.9 ±.06	0.8 ±.05	0.6 ±.04	0.4 ±.03	0.3 ±.02	0.1 ±.04	-0.1 ±.05
B2	1 ±.07	0.8 ±.05	0.6 ±.02	0.4 ±.03	0.3 ±.03	0.2 ±.02	-0.1 ±.05
C2	1.2 ±.06	1 ±.04	0.8 ±.03	0.5 ±.03	0.3 ±.03	0.2 ±.02	0.08 ±.03
D3	1.4 ±.06	1.2 ±.05	0.9 ±.03	0.8 ±.03	0.6 ±.03	0.4 ±.03	0.2 ±.02

TABLE (4) CIE b* values (means ± SE) of tested specimens (n=10)

	Control	Remove 0.1 mm	Remove 0.2 mm	Remove 0.3 mm	Remove 0.4 mm	Remove 0.5 mm	Remove 0.6 mm
A2	12.4 ±0.4	11.1 ±0.2	11 ±0.3	10.3 ±0.2	10 ±0.2	9.9 ±0.2	9.5 ±0.1
A3	13 ±0.3	12.3 ±0.2	11.7 ±0.2	11.5 ±0.1	11 ±0.1	10.9 ±0.1	10.4 ±0.1
B2	14.5 ±0.2	13 ±0.1	12.6 ±0.1	12.2 ±0.1	12.1 ±0.1	12 ±0.1	11 ±0.1
C2	10.1 ±0.3	9.4 ±0.2	9.2 ±0.1	9 ±0.1	8.7 ±0.1	8.5 ±0.1	8 ±0.1
D3	11 ±0.3	10.6 ±0.3	10.3 ±0.2	10 ±0.2	9.9 ±0.1	9.7 ±0.1	9.5 ±0.3

TABLE (5) ΔE values (means ± SE) of tested specimens (n=10)

	Remove 0.1 mm	Remove 0.2 mm	Remove 0.3 mm	Remove 0.4 mm	Remove 0.5 mm	Remove 0.6 mm
A2	2.1 ±0.2	2.1 ±0.1	2.9 ±0.2	3.1 ±0.2	3.1 ±0.3	4.1 ±0.4*
A3	1.8 ±0.2	2.3 ±0.2	2.5 ±0.2	3 ±0.3	3.1 ±0.2	3.8 ±0.3*
B2	1.5 ±0.1	2.5 ±0.1	3.1 ±0.1	3.2 ±0.1	3.2 ±0.1	4.6 ±0.2*
C2	1 ±0.03	1.5 ±0.06	1.8 ±0.06	2.4 ±0.03	3.1 ±0.09	4 ±0.06*
D3	0.5 ±0.01	0.9 ±0.06	1.5 ±0.09	2.2 ±0.1	2.6 ±0.1	3.1 ±0.2

*Indicates ΔE value that became greater than 3.3 (clinical detectable value) in same row for each shade.

DISCUSSION

The dark metal color exposure or showing through the periimplant soft tissue as a result of poor implant placement or thin gingival biotype and progressive bone resorption is a common problem in implant dentistry.⁵ In the present study, in order to test the null hypothesis we evaluated the color masking effect of porcelain to determine the minimum thickness required to block the underlying color of titanium. Based on the results of this study we can reject the null hypothesis, and we can accept the alternative hypothesis “porcelain thickness below 1.0 mm can mask the color of underlying titanium”.

Color is not an intrinsic characteristic of an object, but is rather a perception of the reflected light that enters the eye.²⁵ In order to precisely describe and communicate color in restorative dentistry, scientists have attempted to use color science and color theory to express color parameters (hue, chroma, and value) numerically, in much the same way length and weight are expressed. The Commission International de l'Eclairage (CIE) developed a system, which enabled color perception to be quantified.²⁶

Spectrophotometers collect spectral data from reflected light and automatically translate these data into the three color coordinates (L*, a*, b*). According to CIE L* a* b* system, these three coordinates can be defined out of three original color stimuli, X Y, and Z, to compensate for the human standard color space. In the L* a* b* color space, the difference between two colors can be mathematically calculated with a formula known as ΔE which is expressed as a positive value:²³

$$\Delta E = [(L1 - L2)^2 + (a1 - a2)^2 + (b1 - b2)^2]^{.5}$$

Color difference (ΔE^*) represents the difference in color's parameters between the compared objects.²⁷ In another meaning, the Euclidean distance ΔE^* is a measure of color difference between two

points in three dimensional color space.²⁸ Moreover, the degree of human visual perceptibility for materials can also be expressed with ΔE^* , which has been evaluated by several studies.^{29,30} Most authors have adopted ΔE^* values between 2.6 and 3.7 as the threshold for acceptability in their clinical research indicating acceptable color match, whereas higher values indicate color mismatch between the two objects or surfaces which are compared. Ruyter and others³¹ reported a threshold for visually acceptable color change to be up to 3.3. Therefore, the color measurements in the present study were made according to the CIE L*a*b* color space and the clinical detectable value $\Delta E = 3.3$ was used as the acceptability limit in the color.

Spectrophotometer was used for color measurement in the current study because of its advantages such as compact structure, easy handling and a multitude of recorded data.¹⁷ On the other hand, some studies mentioned a main disadvantage associated with this type of instruments: edge – loss error generated by the contact of the plain surface of the recording system to the convex portion of the tooth (which will cause a fraction of the light entering tooth to be lost). These previous studies concluded that these types of instruments are originally designed for flat surfaces, not for curved ones, such as labial dental surfaces.^{32,33} In this study the use of a spectrophotometer was appropriate since all specimens had flat porcelain with parallel opposing faces.

Five different porcelain system shades (Dentin shades A2, A3, B2, C2, and D3) were tested in this study. These shades were selected to represent most commonly used hues that are commercially pure and could be clinically used. Two chroma degrees in the same hue (A2 and A3) were selected because they are the most commonly seen shades in natural dentition and hence most frequently used.^{34,35}

The color of a material is determined by a complex combination of its optical properties. The

light transmission and reflection characteristics have an important influence on the color of esthetic materials.³⁶ Color may be determined from the transmitted light through a material, where the light source and detector are on opposite sides of the object, or from the reflected light where the light source and detector are on the same sides of the object (as in this study). It was reported that spectral reflectance decreased with increasing chroma number when compared within the same hue³⁷ which explains our findings that the masking ability (guided by ΔE^*) of A3 shade was more than A2 shade.

It has been reported that chroma (related to a^* and b^* values) increased from light to dark shades (e.g. A1 to A4).³² This is in agreement with our results that a^* and b^* values of A3 was more than those of A2.

The results of the present study demonstrated that the minimum ceramic thickness needed for shades A2, A3, B2, and C2 to mask the underlying titanium substructure color was 0.5 mm. Meanwhile, it was 0.4 mm for D3 porcelain shade. This could be attributed to the fact that a significant correlation exists between the masking power of porcelain and its opacity, as more opaque ceramics were more successful in blocking the underlying color of the substructure.³⁸ In addition, if the tested porcelain shades is arranged according to the value (from the highest value to the lowest), it would be as: B2, A2, C2, A3, D3. The value is the amount of light returned from an object. Lowering the value means less light returns from the illuminated object and the remaining light is being absorbed or scattered elsewhere, which is another explanation for this result.³⁹ From a composition point of view, the higher masking power of D3 shade is referred to the more concentrations of opacifying oxides incorporated in the composition of more opaque porcelain shades.

As more dye is added, the mixture appears darker; thus, the increase in chroma has a corresponding

change in value. As chroma is increased, the value is decreased.⁴⁰ Therefore, the results of this study are in accordance with many studies revealing that the increase in chroma saturation results in decreased ceramic translucency.^{34,41} In other words, the more opaque the porcelain, the more chromatic it is.⁴²

In addition to opacity and porcelain shade, the thickness of ceramic material determines the final shade of an esthetic restoration.²⁴ Our results revealed that redness a^* and yellowness b^* increased with the increase in thickness of porcelain for all shades. This is in agreement with the results of other studies.^{24,43,44} However, these results are not consistent with those of another study by Shono and Al Nahedh⁴⁴ where a^* and b^* values decreased when ceramic thickness increased. This disagreement may be attributed to the difference in specimen fabrication. The majority of the studies, including our study, fabricated the specimens in two combinations (substrate and veneer), whereas the study by Shono and Al Nahedh used only veneering ceramics in the fabrication of the specimens.

The results of the current study also revealed that L^* values decreased for all ceramic shades as their thickness increased. As mentioned in the literature, this may be explained by the fact that more light is absorbed with thicker specimens and less is reflected; hence; lower L^* values are recorded. Our results are in agreement with two previous studies that have shown that as the ceramic thickness increased, L^* values decreased for different types of ceramic systems.⁴³⁻⁴⁵

The current study is in agreement with other studies which found that the increase in ceramic thickness results in lower ΔE values for all ceramic shades, which implies an increased masking ability.^{45,46}

The current study provided the minimum thickness of the ceramic shell that is needed to mask the color of the underlying titanium surface which is 0.5 mm. This thickness will be used in the

future fabrication of the suggested ceramic neck implants in order to facilitate the development and optimization of the novel design for future clinical use and function.

CONCLUSIONS

The minimum ceramic thickness required to block the underlying titanium color is 0.5 mm for all shades except D3 which only needs 0.4 mm ceramic thickness. L^* decreased with thickness increase. Redness a^* and yellowness b^* increased with thickness increase. ΔE decreased with ceramic thickness increase.

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REFERENCES

1. Touati B and Guez G. Immediate implantation with provisionalization: from literature to clinical implications. *Pract Proced Aesthet Dent* 2002; 14: 699-707.
2. Sadan A, Blatz MB, Salinas TJ, Block MS. Single-implant restorations: a contemporary approach for achieving a predictable outcome. *J Oral Maxillofac Surg* 2004; 62:73-81.
3. Kohal RJ, Klaus G, Strub JR. Zirconia-implant-supported all-ceramic crowns withstand long-term load: a pilot investigation. *Clin Oral Impl Res* 2006; 17:565-71.
4. Adell R, Lekholm U, Rockler B, Brånemark PI. A 15-year study of osseointegrated implants in the treatment of the edentulous jaw. *Int J Oral Surg* 1981; 10: 387-416.
5. Heydecke G, Kohal R, Gläser R. Optimal esthetics in single-tooth replacement with the re-implant system: a case report. *Int J Prosthodont* 1999; 12: 184-9.
6. Adell R, Lekholm U, Rockler B, Brånemark PI, Lindhe J, Eriksson B, et al. Marginal tissue reaction at osseointegrated titanium fixtures (I). A 3-year longitudinal prospective study. *Int J Oral Max Surg* 1986; 15: 39-52.
7. Quirynen M, Naert I, van Steenberghe D, Dekeyser C, Callens A. Periodontal aspects of osseointegrated fixtures supporting a partial bridges. An up to 6-years retrospective study. *J Clin Periodontol* 1992;19: 118-26
8. Bosco AF, Bonfante S, Luize DS, Bosco JM, Garcia VG. Periodontal plastic surgery associated with treatment for the removal of gingival overgrowth. *J Periodontol* 2006; 77:922-8.
9. Elsayed A, Wille S, Al-Akhali M, Kern M. Comparison of fracture strength and failure mode of different ceramic implant abutments. *J Prosthet Dent* 2016 Oct 18. pii: S0022-3913(16)30289-X. doi: 10.1016/j.prosdent.2016.06.018. [Epub ahead of print]
10. Dede DÖ, Armağanci A, Ceylan G, Çelik E, Çankaya S, Yılmaz B. Influence of implant abutment material on the color of different ceramic crown systems. *J Prosthet Dent* 2016 Jul 8. pii: S0022-3913(16)30076-2. doi: 10.1016/j.prosdent.2016.04.004. [Epub ahead of print]
11. Bidra AS, Rungruanant P. Clinical outcomes of implant abutments in the anterior region: A systematic review. *J Esthet Restor Dent* 2013; 25: 159-76.
12. Kim A, Campbell SD, Viana MA, Knoernschild KL. Abutment material effect on peri-implant soft tissue color and perceived esthetics. *J Prosthodont* 2015 Sep 23. doi: 10.1111/jopr.12360. [Epub ahead of print]
13. Wadhvani CP, O'Brien R, Kattadiyil MT, Chung KH. Laboratory technique for coloring titanium abutments to improve esthetics. *J Prosthet Dent* 2016;115:409-11.
14. Gallucci GO, Grütter L, Chuang SK, Belser UC. Dimensional changes of peri-implant soft tissue over 2 years with single-implant crowns in the anterior maxilla. *J Clin Periodontol* 2011; 38:293-9.
15. Nothdurft F, Pospiech P. Prefabricated zirconium dioxide implant abutments for single-tooth replacement in the posterior region: evaluation of peri-implant tissues and superstructures after 12 months of function. *Clin Oral Implants Res* 2010; 21:857-65.
16. Linkevicius T, Apse P. Influence of abutment material on stability of peri-implant tissues: a systematic review. *Int J Oral Maxillofac Implants* 2008; 23:449-56.
17. Andersson B, Glauser R, Maglione M, Taylor A. Ceramic implant abutments for short-span FPDs: a prospective

- 5-year multicenter study. *Int J Prosthodont* 2003; 16: 640-6.
18. Henriksson K, Jemt T. Evaluation of custom-made proceera ceramic abutments for single-implant tooth replacement: a prospective 1-year follow-up study. *Int J Prosthodont* 2003; 16:626-30.
 19. Andersson B, Taylor A, Lang BR, Scheller H, Schärer P, Sorensen JA, et al .Alumina ceramic implant abutments used for single-tooth replacement: a prospective 1- to 3-year multicenter study. *Int J Prosthodont* 2001; 14:432-8.
 20. Andersson B, Schärer P, Simion M, Bergström C. Ceramic implant abutments used for short-span fixed partial dentures: a prospective 2-year multicenter study. *Int J Prosthodont* 1999; 12:318-24.
 21. Köndell PA, Söder PO, Landt H, Frithiof L, Anneroth G, Engström PE, et al. Gingival fluid and tissues around successful titanium and ceramic implants. A comparative clinical, laboratory, and morphologic study. *Acta Odontol Scand* 1991;49:169-73.
 22. Sailer I, Philipp A, Zembic A, Pjetursson BE, Hämmerle CH, Zwahlen M. A systematic review of the performance of ceramic and metal implant abutments supporting fixed implant reconstructions. *Clin Oral Implants Res* 2009; 20 Suppl 4:4-31.
 23. Johnston WM. Color measurement in dentistry. *J Dent* 2009; 37 Suppl 1:e2-6.
 24. Dozić A, Kleverlaan CJ, Meegdes M. The influence of porcelain layer thickness on the final shade of ceramic restorations. *J Prosthet Dent* 2003; 90: 563-70.
 25. Dudea D, Culic B, Prejmerean V, Colosi H, Alb C, Botos A, et al. Comparison of two instrumental methods for dental color selection. *Optoelectron Adv Mater* 2010; 4: 102-9.
 26. Ishikawa-Nagai S, Ishibashi T, Tsuruta O, Weber HP. Reproducibility of tooth color gradation using a computer color-matching technique applied to ceramic restorations. *J Prosthet Dent* 2005; 93:129-37.
 27. Paravina RD. New shade guide for tooth whitening monitoring: visual assessment. *J Prosthet Dent* 2008; 99:178-84.
 28. Kim J, Paravina R, Chen JW. In vivo evaluation of color of primary teeth. *Pediatr Dent* 2007; 29:383-6.
 29. Ragain JC Jr, Johnston WM. Accuracy of Kubelka-Munk reflectance theory applied to human dentin and enamel. *J Dent Res* 2001; 80: 449-52.
 30. Douglas RD, Brewer JD. Variability of porcelain color reproduction by commercial laboratories. *J Prosthet Dent* 2003; 90: 339-46.
 31. Ruyter IE, Nilner K, Moller B. Color stability of dental composites resin materials for crown and bridge veneers. *Dent Mater* 1987; 3: 246-51.
 32. Paravina RD, Majkic G, Imai FH, Powers JM. Optimization of tooth color and shade guide design. *J Prosthodont* 2007; 16: 269-76.
 33. Paravina RD, O'Keefe KL, Kuljic BL, et al. Color of permanent teeth: A prospective clinical study. *Balkan J Stomatol* 2006; 10: 93-6.
 34. Dietschi D, Ardu S, Krejci I. A new shading concept based on natural tooth color applied to direct composite restorations. *Quintessence Int* 2006; 37:91–102.
 35. Hasegawa A, Ikeda I, Kawaguchi S. Color and translucency of in vivo natural central incisors. *J Prosthet Dent* 2000; 83:418-23.
 36. Ota M, Ando S, Endo H, Ogura Y, Miyazaki M, Hosoya Y. Influence of refractive index on optical parameters of experimental resin composites. *Acta Odontol Scand* 2012; 70: 362-7.
 37. Shiraishi T, Wood DJ, Shinozaki N, van Noort R. Optical properties of base dentin ceramics for all-ceramic restorations. *Dent Mater* 2011; 27: 165-72.
 38. Chu FC, Sham AS, Luk HW. Threshold contrast ratio and masking ability of porcelain veneers with high-density alumina cores. *Int J Prosthodont* 2004; 17: 24-8.
 39. Sikri VK. Color: Implications in dentistry. *J Conserv Dent* 2010; 13: 249-55.
 40. Terry DA, Geller W, Tric O, Anderson MJ, Tourville M, Kobashigawa A. Anatomical form defines color; Function, form and aesthetics. *Pract Proced Aesthet Dent* 2002; 14:59–67.
 41. Naeimi Akbar H, Moharamzadeh K, Wood DJ, Van Noort R. Relationship between color and translucency of multishaded dental composite resins. *Int J Dent* 2012; 2012: 708032.
 42. Dozić A, Tsagkari M, Khashayar G, Aboushelib M. Color management of porcelain veneers: Influence of dentin and resin cement colors. *Quintessence Int* 2010; 41: 567-73.

43. Shokry TE, Shen C, Elhosary MM, Elkhodary AM. Effect of core and veneer thicknesses on the color parameters of two all-ceramic systems. *J Prosthet Dent* 2006; 95: 124-9.
44. Ozturk O, Uludag B, Usumez A, Sahin V, Celik G. The effect of ceramic thickness and number of firings on the color of two all-ceramic systems. *J Prosthet Dent* 2008; 100: 99-106.
45. Shono NN, Al Nahedh HNA. Contrast ratio and masking ability of three ceramic veneering materials. *Oper Dent* 2012; 37: 406-16.
46. Vichi A, Ferrari M, Davidson CL. Influence of ceramic and cement thickness on the masking of various types of opaque post. *J Prosthet Dent* 2000; 83: 412-7.