Optical Efficacy of Titanium Nitride–Coated Abutment Material on Soft Tissue Discoloration: A Spectrophotometric In Vitro Analysis

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Purpose: The objective of this investigation was to assess the extent of mucosal discoloration caused by different CAD/CAM abutment materials and to determine the influence of mucosa thickness on the subsequent color, with a particular focus on titanium nitride. ***Materials and Methods:*** In a pig maxilla, a trapdoor-shaped mucosa flap was prepared unilaterally. Several CAD/CAM abutment materials were used to assess a number of clinical scenarios. Varying mucosa thicknesses were simulated by connective tissue grafts harvested at the contralateral side of the palate, resulting in layer thicknesses of 1.5, 2, and 3 mm. Titanium (Ti), zirconia (ZrO_2), and titanium nitride (TiN) served as test specimens with and without ceramic veneering. Color differences (ΔE) and deviations in brightness (L), chroma (C), and hue (H) were determined spectrophotometrically, comparing the measured value of the native tissue and the results obtained with different materials at varying mucosa thicknesses. ***Results:*** All tested specimens caused a mucosa discoloration in comparison to the native tissue, diminishing with increasing mucosa thickness. The use of TiN demonstrated the least mucosa discoloration in thin soft tissue of 1.5 mm, with a mean ΔE value of 1.93 ($P = .004$). While ZrO_2 revealed a comparable ΔE value of 2.13 ($P = .022$) at a tissue thickness of 1.5 mm, Ti showed the highest mucosa discoloration above the visibility threshold of ΔE = 3.1, with a mean ΔE value of 4.07 ($P = .002$). Ceramic veneering of the Ti samples led to a considerable reduction in soft tissue discoloration, with a resulting ΔE value of 2.2. The veneering of TiN and ZrO_2 samples with porcelain, on the other hand, had no noticeable effect on the mucosa color. ***Conclusion:*** CAD/CAM abutment materials cause an adverse soft tissue color shift that decreases with increasing mucosa thickness. In thin peri-implant mucosa, titanium nitride and zirconia lead to the least discoloration. Due to their positive optical properties and mechanical superiority compared with ceramic abutments, gold-hue titanium nitride–coated CAD/CAM abutments could be a clinical alternative in cases of thin peri-implant mucosa.
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Keywords: CAD/CAM abutment, gold hue, mucosa discoloration, peri-implant mucosa, spectrophotometer, titanium nitride

The longevity of dental implants depends on both osseointegration and the formation of a soft tissue barrier that protects the underlying bone by limiting bacterial invasion and mucosal and bone recession. Thus, health and stability of the peri-implant mucosa have a direct impact on the esthetic outcome of implant therapy.[1] Supply and selection of restorative materials in implant prosthodontics has increased in recent years.[2] Titanium as a material for implants and abutments has been successfully used in implant dentistry for several decades.[3,4] Titanium is characterized by its high stability and fracture resistance. However, a number of studies have shown that metallic abutment materials contribute to a grayish discoloration in thin peri-implant mucosa, thereby compromising the esthetic outcome of the restoration.[5–9] The peri-implant mucosa thickness is considered a critical factor in promoting light transmission and subsequent color change caused by the metallic implant shoulder and/or abutment.[6,7,10] It has been documented that this adverse color shift can be prevented by the use of ceramic abutments due to their toothlike color.[11–14] With the use of zirconia abutments, the challenge of mechanical abrasion at the interface between the metal and

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ceramic must be taken into account. In particular, high chewing loads lead to increased wear and abrasion (fretting) on the implant-abutment connection.[15] In addition to titanium stock abutments, encouraging results for titanium nitride–coated (TiN) CAD/CAM abutments have been reported in clinical trials.[6,16,17] The nitride coating is produced by a plasma layer method. In this process, titanium and nitrogen ions are combined with TiN and molecularly bound to the titanium substance of the abutment. Studies describe TiN as biocompatible and chemically inert with a low coefficient of friction.[18–20] A current review of the biologic impact of different abutment materials on peri-implant bone stability revealed no significant bone loss around TiN abutments over time.[21] TiN has good reflective properties, which are reflected in a spectrum similar to gold. Due to its golden hue, it achieves a warm, esthetically pleasing tone under the mucosa.[22] For gold-colored anodized abutments and CAD/CAM abutments coated with TiN, a lower degree of unfavorable color shift of the surrounding tissue was observed.[6–9]

In recent years, a series of in vivo and in vitro studies have been conducted to investigate the color-changing effects of different abutment materials on the peri-implant mucosa.[4–14] The aim of these studies was to identify objectifiable criteria that would predict an unintended color shift of the peri-implant mucosa. In vivo studies are by definition more difficult to standardize than in vitro studies. Furthermore, the aforementioned investigations also differ in their inclusion and exclusion criteria, eg, the localization of the examined regions.[6,9,10] Bleeding indices and the status of dentition vary between the individual reports. Exclusion criteria such as smoking, heart disease, coagulation or blood disorders, metabolic disorders, and previous radiation with possibly negative effects on oral hygiene, immune compromise, and drug or alcohol abuse are not uniformly comprehensible. Gil et al have shown that the microcirculation of the mucosa has a decisive influence on its color.[23] Thus, the aforementioned medical criteria most likely have an impact on the outcome as well as a nonuniform study design in terms of ambient light, angle of admission, or treatment-dependent recording. Differences in color, on the other hand, can be assessed objectively using calibrated instruments such as spectrophotometers.[24] It has been documented that spectrophotometers achieve high reproducibility and recognize smaller color differences compared with the human eye.[25] Their photo-optical measurement enables the quantification of colors with the CIE (Commission Internationale de l'Eclairage) L*a*b* coordinates (L = lightness; a = chroma along red-green axis; b = chroma along yellow-blue axis). The data on mucosa and tooth color obtained by means of computer-aided spectrophotometry enable a mathematically objectifiable calculation of color differences.[14] The measure for the color change between two given objects is summarized by their ΔE value. The higher the ΔE value, the greater the deviation of the compared hues. Although existing in vitro studies, if standardized, are more comparable, the individual study designs diverge in some respects, so a clinically meaningful summary is not possible.[7,8,11] Different processing of the tested materials, varying classification between thick and thin mucosa, and an incomprehensible large spread between the defined thresholds for a visible color shift (ΔE) are the most obvious differences. While some authors have set the critical threshold at ΔE = 1, in one clinical study, it was adjusted significantly higher (ΔE = 8.74).[9] On the basis of an early study that examined the color perception on teeth, a value of ΔE 3.7 has been frequently used as the threshold for detecting color differences with the bare eye.[26] In a more recent study, a combined total threshold for the capture of gingival color alterations was defined as ΔE = 3.1.[27] Since this last survey examined color differences of the soft tissue, this threshold could be considered more appropriate for the assessment of soft tissue discoloration around implants.

Although there have been numerous attempts at conducting clinical trials to define a threshold above which a mucosal color shift is visible to humans, there are only few standardized studies on the reproducibility of the results for the established CAD/CAM abutment materials. Since practitioners in the clinical setting tend to be more indulgent toward color deviations,[14] a screening performed in a supervised laboratory environment may be more precise. Standardized in vitro studies on TiN are not available. For this reason, the present in vitro investigation was carried out. The null hypothesis was that TiN-coated abutment material does not cause mucosal discoloration in thick (3 mm) and thin (≤ 2 mm) peri-implant soft tissue exceeding the visibility threshold of ΔE = 3.1.

MATERIALS AND METHODS

In the present in vitro study, a porcine maxilla was used since its palatal mucosa approximates the human keratinized mucosa in terms of color and texture. The pig was bred and sacrificed for food production according to the German veterinary standards for animal care. Hence, this investigation was not considered an animal study, and the regulatory ethics committee had no concerns with regard to the procedure. The jaw was kept airtight, humid, and cool from the time the pig was dissected until the study was carried out. In the disto-palatal area of the second molar at the right side of the maxilla, a trapdoor-shaped flap with a thickness of 0.5 mm and a dimension of 5 × 5 mm (width × length) was prepared (Figs 1a to 1c). A number of connective tissue grafts (CTG) with a

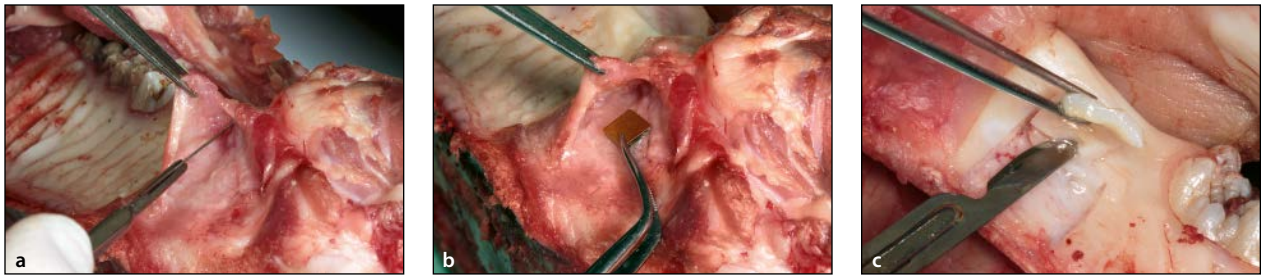

Fig 1 Palatal view of pig maxilla. *(a)* Trapdoor flap with thickness of 0.5 mm. *(b)* Placement of abutment material underneath. *(c)* Harvesting of connective tissue graft (CTG) of 0.5 mm at contralateral aspect.

thickness of 0.5 mm were harvested on the contralateral side of the palate to simulate different mucosal thicknesses (Figs 1a to 1c). To obtain grafts of consistent thickness, a mucotome device (GB270, Aesculap) was employed for the harvesting procedure as described by Jung et al.[10] Thicker mucosa layers were prepared by placing the different grafts underneath the palatal mucosal flap. This resulted in soft tissue samples with thicknesses of 1.5, 2.0, and 3.0 mm. By means of a spectrophotometer, opto-electronic measurements were taken of the native tissue in the mucosal area without a test sample (control). CAD/CAM-generated material specimens were then subsequently positioned below the mucosa, and spectrophotometric measurements of the same area were repeated. Various abutment and crown materials were tested to evaluate a number of clinical scenarios (Fig 2). The following test disks were produced in a size of 5 × 5 mm and a material thickness of 1.0 mm for non-veneered samples and up to 2.0 mm for veneered samples: titanium (Ti; Ti alloy, Dentsply Sirona Implants), titanium with veneering ceramic (color A3; Ti-v; GC Initial Ti), titanium nitride (TiN; GoldHue, Dentsply Sirona Implants), titanium nitride with veneering ceramic (color A3; TiN-v, GC Initial Ti), zirconia (ZrO_2; Zirlux, Henry Schein Dental), and zirconia with veneering ceramic (color A3; ZrO_2-v, GC Initial Zr-FS). Spectrophotometric readings were carried out with a ShadePilot (Dentsply Degudent) three times in succession (Figs 3a to 3c). This device is identical in construction to the

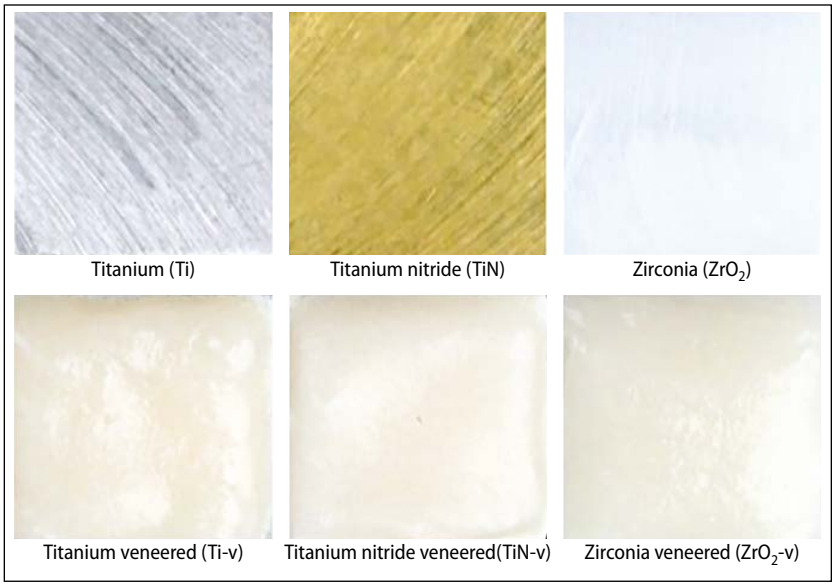

Fig 2 Test specimens 5 × 5 mm.

SpectroShade Micro (MHT Optic Research). The colorimetrical analyses were obtained using the spectral measurement method. When the measuring process is triggered, light is emitted in the wavelength range of 410 to 680 nm. The light source consists of two optical fibers that illuminate the object, polarized, monochromatic, telecentric, and at an angle of 45 degrees. The light reflected from the test object is registered in the range of visible light from 400 to 720 nm by a sensor in steps of 10 nm. The sensor is a CCD black and white sensor that measures the acquired data spectrometrically and with a digital resolution of 640 × 480 pixels. The reading surface is approximately 18 mm × 14 mm. The optical resolution is approximately 0.03 mm × 0.03 mm for each pixel. Before each recording, the device was calibrated on panels supplied by the manufacturer. The ShadePilot analyzed the lightness (L), chroma (C), and color (H) and expressed them in numerical values. These individual values resulted in an overall value that made the color deviation of different readings mathematically representable. The measurements were converted into L*a*b* values, and the differences between two values were recorded as ΔE. According to Sailer et al, a value of ΔE = 3.1 was set as the visibility threshold for mucosa color deviations with the bare eye.[27] For the present in vitro investigation, each specimen was recorded three times per tissue thickness, resulting in a total of 6 × 3 × 3 = 54 recordings (six specimens, three tissue thicknesses, and three recordings). In the analysis of the obtained data, a distinction was made between interval-scaled, rank-scaled, and nominal-scaled variables. The one-sample *t* test for a dependent reference value 0 (ΔE

Fig 3 *(a)* Placement of 0.5-mm CTG above test specimen. *(b)* Spectrophotometer and example for color deviation L*a*b* values measured for zirconia test specimen. *(c)* Spectrophotometric measurement.

Table 1 Mean ΔE Values Depending on Material and Mucosa Thickness Including Statistical Significance (*P*) of Comparison Between Mucosa Color With and Without Test Specimen

Mucosa thickness (mm)	Titanium (Ti)	Titanium veneered (Ti-v)	Titanium nitride (TiN)	Titanium nitride veneered (TiN-v)	Zirconia (ZrO_2)	Zirconia veneered (ZrO_2-v)
1.5 mm	4.1 (*P* = .002)	2.4 (*P* < .001)	1.9 (*P* = .004)	2.1 (*P* = .001)	2.1 (*P* = .022)	2.2 (*P* = .002)
2 mm	2.6 (*P* = .005)	2.2 (*P* = .005)	2.0 (*P* = .002)	2.2 (*P* < .001)	1.9 (*P* = .002)	1.8 (*P* = .004)
3 mm	1.5 (*P* = .002)	1.0 (*P* = .042)	1.4 (*P* < .001)	1.9 (*P* = .004)	1.9 (*P* = .021)	1.3 (*P* = .013)

All values were statistically highly significant (**P < .01).

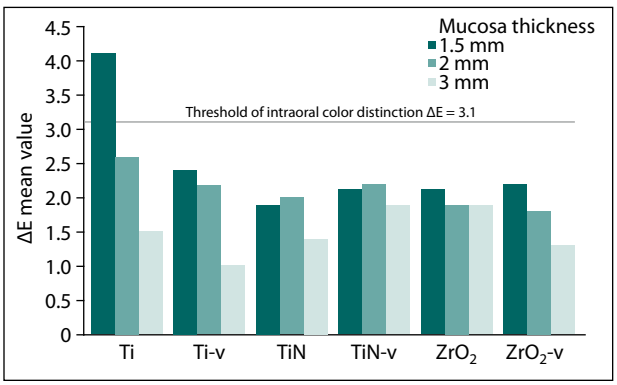

Fig 4 Mean ΔE value as a function of material (Ti, TiN, ZrO_2, ZrO_2-v) and mucosa thickness.

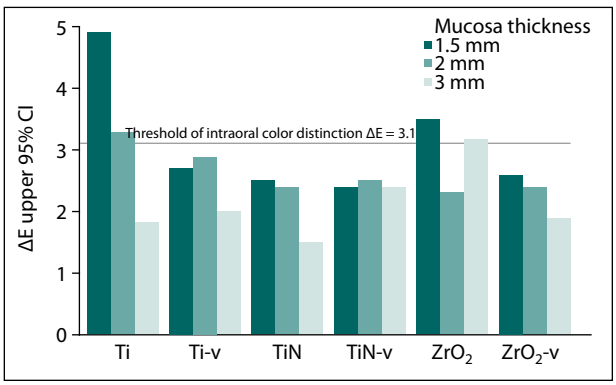

Fig 5 ΔE upper 95% confidence interval (CI) as a function of material (Ti, TiN, ZrO_2, ZrO_2-v) and mucosa thickness.

without specimen) was performed. The significance level was set at .05.

RESULTS

All test specimens led to a mucosa discoloration in comparison to the mucosa region with no test specimen (control), diminishing with increasing mucosa thickness (Tables 1 and 2). In the case of thin tissue that was 1.5 mm thick, the use of TiN abutment material showed the least discoloration of the mucosa, with a mean ΔE value of 1.93 (*P* = .004). While zirconia (ZrO_2) revealed a comparable ΔE value of 2.13 (*P* = .022) at a tissue thickness of 1.5 mm, titanium alloy (Ti) showed the highest mucosa discoloration above the visibility threshold of ΔE = 3.1, with a mean ΔE value of 4.07 (*P* = .002; Figs 4 and 5). In contrast, a ceramic veneering of the Ti samples led to a considerable reduction in soft tissue discoloration, with a resulting ΔE value of 2.2. The veneering of TiN and ZrO_2 samples with porcelain, on the other hand, had no noticeable effect on the mucosa color.

DISCUSSION

The esthetic appearance of an implant rehabilitation in the anterior region is a decisive criterion for ultimate success. In addition to a functional and natural-looking superstructure, the appropriate contour, volume, and color of the surrounding mucosa are of crucial importance. A peri-implant mucosa thickness of ≤ 2 mm is considered the critical threshold for increased light transmission and subsequent tissue discoloration caused by the metallic implant shoulder and/or abutment.[7,10] The mere visual determination of color has a highly subjective nature.

Table 2 Mean Values of Lightness (L), Chroma (C), and Color (H) at Different Mucosa Thickness Including Statistical Significance (P) of the Deviation from the Control Recording (No Test Specimen)

Value/mucosa thickness	Titanium (Ti)	Titanium veneered (Ti-v)	Titanium nitride (TiN)	Titanium nitride veneered (TiN-v)	Zirconia (ZrO_2)	Zirconia veneered (ZrO_2-v)
L						
1.5 mm	0.967 (*P* = .082)	−0.800 (*P* = .195)	1.167 (*P* = .015*)	1.267 (*P* = .001**)	0.300 (*P* = 1.000)	0.134 (*P* = .456)
2.0 mm	−1.367 (*P* = .011*)	0.134 (*P* = .784)	−0.034 (*P* = .874)	−0.267 (*P* = .066)	1.000 (*P* = .102)	0.367 (*P* = .616)
3.0 mm	−0.034 (*P* = .967)	−0.100 (*P* = .729)	1.534 (*P* = .024*)	.034 (*P* = .742)	0.700 (*P* = .561)	−0.300 (*P* = .429*)
C						
1.5 mm	−2.467 (*P* = .001**)	−0.400 (*P* = .367)	0.300 (*P* = .644)	0.800 (*P* = .005**)	1.634 (*P* = .015*)	0.734 (*P* = .058)
2.0 mm	−0.067 (*P* = .635)	−0.834 (*P* = .074)	1.167 (*P* = .003**)	0.667 (*P* = .585)	0.534 (*P* = 0.446)	1.333 (*P* = .012*)
3.0 mm	1.800 (*P* = .007**)	2.500 (*P* = .010**)	0.900 (*P* = .095)	1.800 (*P* = .009**)	1.000 (*P* = .109)	1.067 (*P* = .001**)
H						
1.5 mm	3.067 (*P* = .013*)	2.300 (*P* = .013*)	0.434 (*P* = .253)	1.900 (*P* = .003**)	1.334 (*P* = .012*)	0.600 (*P* = .140)
2.0 mm	1.334 (*P* = .010**)	1.667 (*P* = .005**)	0.634 (*P* = .011*)	1.000 (*P* = .064)	1.600 (*P* = .009**)	0.700 (*P* = .007**)
3.0 mm	0.534 (*P* = .047*)	1.267 (*P* = .019*)	0.633 (*P* = .034*)	1.100 (*P* = .048*)	1,.233 (*P* = .018*)	0.367 (*P* = .212*)

*$P < .05$; **$P < .01$.

Variables such as external illumination conditions, experience, specialization of the assessor, and fatigue of the human eye lead to deviations.[24] Computer-aided spectrophotometry, on the other hand, is considered highly reproducible in detecting color differences.[25] As part of their daily routine, practitioners have to decide which abutment material is best suited for a particular clinical situation. Titanium and zirconia CAD/CAM abutment materials are frequently used for cemented or screw-retained reconstructions.[14,21] Gold-hue CAD/CAM abutments coated with titanium nitride are among the novel innovations with first clinical studies[16,17] and initial in vitro results on the integrity of their coating.[28] The results of the present spectrophotometric in vitro study showed that the abutment materials tested had an influence on the appearance of the soft tissue color. Titanium alloy specimens in combination with thin soft tissues of 1.5 mm caused significant ΔE deviations (ΔE = 4.07/*P* = .002) above the reference threshold of visibility of ΔE = 3.1. It can therefore be assumed that titanium as an abutment material under a peri-implant mucosa of 1.5 mm or less leads to a soft tissue discoloration visible to the bare eye. This was mainly induced by changes of the variables chroma (C −2.467/*P* = .001) and hue (H 3.067/*P* = .013; Table 2). Lightness (L 0.967/*P* = .082) did not appear to have a significant influence on the mucosa discoloration under the described circumstances. Although the ceramic veneering of the titanium alloy samples resulted in a considerable reduction in soft tissue discoloration with a resulting ΔE value of 2.2, this is no longer considered a routine laboratory procedure. There has been concern as to whether the procedures used to bake porcelain on the abutment shoulder might alter the precision of the implant-abutment connection.[29] The development of various materials for customized CAD/CAM abutments have replaced this early attempt to achieve improved esthetics.

Every other combination of material and mucosa thickness also showed statistically significant color deviations but remained below the visible threshold of ΔE = 3.1. A 95% confidence interval was related to this threshold and confirmed the findings (Fig 5). In summary, titanium nitride (TiN) and zirconium oxide (ZrO_2), whether veneered with ceramic or not, do not cause visible color changes in thin mucosa of 1.5 mm or less. The present results confirm numerous findings that an adverse color shift of peri-implant mucosa can be prevented by the use of ceramic abutments due to their tooth-like color.[11–14] To the best of the authors' knowledge, however, this is the first study under standardized in vitro conditions that shows that CAD/CAM abutment material coated with titanium nitride has properties comparable to zirconia. Therefore, the null hypothesis stating that TiN-coated abutment material does not cause mucosal discoloration in thick (3 mm) and thin (≤ 2 mm) peri-implant soft tissue could not be rejected. In contrast to the mean values, the upper limits of the confidence interval in the case of titanium at 2 mm and zirconia at 1.5 and 3 mm exceed the relevant threshold value. Since such an influence on color changes of the peri-implant mucosa cannot be spontaneously expounded, it can be assumed that in this case, there could be a greater dispersion of parameters. Further investigations performed under controlled and standardized conditions with a higher number of test samples are necessary to supplement these in vitro results with clinical data.

Esthetic concerns in implant restorative dentistry have led to an increasing use of all-ceramic abutments. However, it must be borne in mind that the material properties of zirconia ceramic differ from those of titanium in terms of fracture toughness. Compared with titanium, zirconia is more brittle and therefore less resistant to bending forces and the perpetration of cracks.[30]

Consequently, titanium can compensate for stress peaks by plastic deformation, while zirconia breaks as it approaches its elastic limit.[31] Due to their positive optical properties and mechanical superiority compared with ceramic abutments, titanium nitride–coated CAD/CAM abutments could therefore be a clinical alternative for thin peri-implant mucosa in the anterior region.

CONCLUSIONS

Within the limitations of this spectrophotometric in vitro study, the following conclusions can be drawn:

- All restorative materials tested (with and without ceramic veneering) caused a color change of the soft tissue, which decreased with increasing mucosa thickness.
- With a mucosa thickness of 3 mm overlying the tested materials, the differences in ΔE readings were negligible.
- In thin soft tissue of 1.5 mm, both zirconia and titanium nitride materials did not cause any color changes that were visible to the bare eye.
- A gold-hue titanium nitride coating as a modification of custom abutments leads to promising optical results in cases of thin peri-implant mucosa.

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