

RESEARCH AND EDUCATION

Effect of framework material on the color of implant-supported complete-arch fixed dental prostheses



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Implant-supported complete-arch fixed dental prostheses are a popular option for the rehabilitation of edentulous patients, with high cumulative survival rates.¹ To achieve a good outcome, an appropriate framework material, natural-looking emergence profile, optimal abutment type, and optimal prosthesis design need to be considered.²⁻⁴ Prosthetic framework material selection plays an important role in reducing biomechanical complications^{2,5,6} and improving the esthetics of the definitive restoration.²

Fixed implant frameworks can be fabricated using either computer-aided design and computer-aided manufacturing (CAD-CAM) or conventional lost-wax casting.^{5,7,8} The CAD-CAM technique has been shown to produce accurately fitting implant frameworks with less distortion and less susceptibility to human error than cast frameworks, with excellent durability.^{5,9,10} Titanium (Ti) and zirconia (Zir) are 2 widely used CAD-CAM materials for processing fixed prosthetic frameworks with good mechanical

ABSTRACT

Statement of problem. The effect of framework material on the color of implant-supported complete-arch fixed dental prostheses is unclear.

Purpose. The purpose of this in vitro study was to investigate the effect of different framework materials on the final color of implant-supported complete-arch fixed dental prostheses.

Material and methods. A master model was used to simulate an edentulous maxilla with 4 implants. A screw-retained complete-arch resin prototype with a 1.5-mm cut back on the facial surfaces of the teeth was fabricated. The master model and resin prototype were scanned and digitized with a laser scanner. A computer-aided design (CAD) model was constructed using software and used for milling titanium (Ti) and zirconia (Zir) frameworks. Four Zir frameworks were milled from solid presintered Zir blocks, and 4 Ti frameworks were milled from solid Ti blocks. The Zir frameworks were then sintered. To simulate gingiva on the Zir and Ti frameworks, feldspathic porcelain was layered on the facial aspects of the teeth (except for the molars) and glazed. Color coordinates (L^* , a^* , b^*) of anterior teeth and gingiva on both Zir and Ti frameworks were measured with a spectroradiometer, and color differences (CIEDE2000) were calculated between Zir and Ti frameworks using the CIEDE2000 formula. The color coordinates of the teeth and gingival porcelain on the frameworks were analyzed using an ANOVA ($\alpha=.05$).

Results. For the teeth, the 3-way ANOVA revealed a significant interaction for material, tooth, and coordinate ($P=.014$), material and coordinate ($P<.001$), and tooth and coordinate ($P<.001$). For the gingival porcelain, the 2-way ANOVA revealed a significant interaction between material and coordinate ($P<.001$). The L^* values of the teeth and gingival porcelain on Zir frameworks were statistically different from those on the teeth and gingival porcelain on the Ti frameworks ($P<.001$). The maxillary right central incisor on the Ti frameworks had a significantly higher a^* ($P=.013$) and b^* value ($P<.001$) than those on the Zir framework. The color differences (CIEDE2000) of teeth and gingival porcelain between Ti and Zir frameworks were 6.6 and 8.6, respectively.

Conclusions. Feldspathic porcelain layered for teeth and gingiva was lighter on Zir frameworks than on Ti frameworks. Porcelain on the facial aspects of teeth was redder and yellower on Ti compared with Zir. Gingival porcelain on Zir was yellower than that on Ti. The color of layering porcelain on the teeth and gingival areas was significantly different when different frameworks (Ti or Zir) were used. (*J Prosthet Dent* 2019;122:69-75)

properties, fit, and biocompatibility.^{6,8,11,12} Ti has been the most commonly used material for CAD-CAM implant frameworks and was used as an alternative to

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Clinical Implications

Clinicians should keep in mind that the color of layered porcelain for teeth and gingiva may differ significantly when porcelain is layered on a titanium framework compared with when a zirconia framework is used for a complete-arch implant prosthesis.

gold alloys for more than 20 years^{6,13} Zir has become popular as an esthetic abutment and framework material in implant-supported restorations.^{7,14,15}

Zir frameworks commonly need to be veneered with more translucent porcelain to improve esthetics¹⁶⁻²² and can be veneered with poly(methyl methacrylate) or porcelain or designed for cemented ceramic crowns.¹¹ To obtain the color match of the veneering material, Ti frameworks require an opaque layer²³ because of the gray color of Ti,²⁰ whereas Zir frameworks require a liner or intrinsic characterization^{22,24,25} because of the white color and opacity of Zir.^{22,24,26,27}

Choosing an appropriate framework material is essential for successful esthetics.⁵ To achieve a natural appearance and fulfill esthetic expectations, the translucency and opacity, color, opalescence, light absorption, reflection, and transmission properties of the framework material are important.^{3,28-36} The optical property of the framework material is a controlling factor in the final shade of restoration.²⁵ The final color of the veneering porcelain could be influenced by the shade of the framework material.^{3,4}

Studies have reported the effect of implant abutment material on the final color of different porcelain layering materials.^{3,4} However, studies assessing the influence of different framework materials on the final color of complete-arch fixed dental prostheses are lacking. The purpose of this *in vitro* study was to evaluate the effect of framework material on the final color of implant-supported complete-arch fixed dental prostheses. The null hypothesis was that the type of framework material would not affect the final color of teeth and gingiva on implant-supported complete-arch fixed dental prostheses.

MATERIAL AND METHODS

A master model simulating an edentulous maxilla with 4 implants (NobelActive RP 4.3×13 mm; Nobel Biocare) resembling the tilted implant concept (Nobel Biocare Training Model; Nobel Biocare) was used. Based on denture tooth arrangement, a complete-arch resin prototype (Pattern Resin LS; GC) was fabricated with 4 copings (Multiunit Titanium Abutment Level; Nobel Biocare) for screw retention. A facial matrix was used to

Table 1. Materials used

Material	Code	Manufacturer
ICE Zirkon Translucent	Zir	Zirkonzahn
Titan 5	Ti	Zirkonzahn
GC Initial Zr FS	Zir FS	GC
GC Initial Ti	In Ti	GC
GC Initial Zr-FS Frame Modifier	Zir-FM	GC
GC Initial MC IN-44 Sand	MC-INS	GC
GC Initial MC IN-42 Terracotta	MC-INT	GC
GC Initial MC Fluo Dentin	MC-FD	GC
GC Initial MC Clear Fluorescence	MC-CF	GC
GC Initial Ti Bonder	TiB	GC

control a 1.5-mm even cut back on the facial aspect of all teeth. The master model and resin prototype were both digitized with a laser scanner (S600 ARTI; Zirkonzahn), and a CAD model was constructed using software (Zirkonzahn Software; Zirkonzahn). This CAD model was the basis for Ti and Zir frameworks to be milled. The expected sintering shrinkage (20%) was calculated using the software for Zir. Four Zir and Ti frameworks were milled from solid presintered Zir and solid Ti blocks (ICE Zirkon Translucent-95H16; Zirkonzahn, M1 Wet Heavy Metal Milling Unit; Zirkonzahn, respectively), with the aid of a 5-axis milling machine (Table 1). All Zir frameworks were then sintered for 9.5 hours to full density in a sintering furnace (Zirkonofen 700; Zirkonzahn) according to the manufacturer's recommended heating rate, holding temperature, and time parameters. A new set of milling burs was used after each framework milling procedure.

Feldspathic porcelain (Table 1) was used to layer the facial aspects of teeth (except for the molars) on Zir (GC Initial Zr-FS Frame Modifier; GC) and Ti (GC Initial Ti; GC) frameworks. Veneering and firing procedures for all frameworks were performed by 1 experienced dental technician according to the manufacturer's instructions. For Zir frameworks, a modifier (GC Initial Zr-FS Frame Modifier; GC) was initially applied for layering. Then, a primary dentin (GC Initial MC IN-44 Sand and GC Initial MC IN-42 Terracotta; GC) material was applied on the cervical and proximal surfaces. Another thin dentin layer (GC Initial MC Fluo Dentin FD-93; GC) was applied on both the incisal and labial surfaces. The entire dentin layer was covered with a thin layer of clear fluorescence porcelain (GC Initial MC CL-F; GC). An enamel layer was applied over the CL-F layer to finalize the shape. For Ti frameworks, a Ti bonding agent (GC Initial Ti Bonder; GC) was initially applied for layering, and then, 2 opaque porcelain layers were applied. The sequence used for Zir specimens was followed for layering the remaining layers of Ti frameworks. Then, all Ti and Zir frameworks were glazed. The thickness of porcelain was controlled using polyvinyl

siloxane guides and a digital micrometer (Electronic micrometer; Mitutoyo).

The spectral radiance (SR) of 48 teeth (maxillary anterior teeth, canine to canine) on Zir and 4 Ti frameworks was measured 3 times using a noncontact spectroradiometer (SpectraScan PR 705; Photo Research) measuring system,³⁷⁻³⁹ and the average of these measurements was calculated with a total number of 114 observations. SR ($W/sr/m^2$) measurements were obtained in the visible spectrum from 380 nm to 780 nm with a 2-nm interval on a smooth and homogenous white tile with known spectral reflectance using software (SpectraWin v2.0; Photo Research).³⁸⁻⁴⁰ The calculation of reflectance of each specimen was conducted according to the procedure described by Kurklu et al⁴¹ and using the following formula:

$$\text{Reflectance}_{\text{Specimen}} = \left(\frac{\text{Radiance}_{\text{Specimen}}}{\text{Radiance}_{\text{Standard}}} \right) \times \text{Reflectance}$$

SR measurements were converted to Commission Internationale de l'Eclairage (CIE) 2-degree standard human observation and D65 CIE Illumination values. The color difference was calculated from the CIEDE2000 (ΔE_{00}) color difference formula.⁴² The accuracy and precision of colors resulting from this overall method has been previously described⁴³, and this method is considered highly accurate and precise.

The master model was attached on the optical table (Mecom Inc; Risingsun) during measurements to ensure every tooth was measured at the center and perpendicular to the color sensor's line of observation in the spectroradiometer at the same distance. Gingival colors were measured 3 times 2-mm apical to the cervical margin of all anterior teeth.

The data were analyzed with statistical software (SAS Proprietary Software 9.3; SAS Institute). L^* , a^* , b^* , and the color differences (ΔE) of different teeth on both Zir and Ti frameworks were analyzed using an ANOVA, with the main effects being material, tooth, and coordinate and with the 3-way interactions using the restricted maximum likelihood estimation method and Satterthwaite degrees of freedom methods. L^* , a^* , b^* , and the color differences (ΔE) of the gingival colors of Zir and Ti frameworks were analyzed using an ANOVA, with the main effects being material and coordinate and with the 2-way interactions using the restricted maximum likelihood estimation method and Satterthwaite degrees of freedom methods. CIEDE2000 (ΔE_{00}) values were evaluated using the CIEDE2000 50% perceptibility ($0.8 \Delta E_{00}^*$) and acceptability ($1.8 \Delta E_{00}^*$) thresholds.⁴⁴ For both analyses, any significant interaction was resolved for clinically important comparisons using t tests with Bonferroni corrections ($\alpha=.05$ for all tests).

Table 2. Summary of ANOVA data on color coordinates of teeth on different frameworks

Effect	Df	F Ratio	P
Material	1	4.08	.051
Tooth	5	7.99	<.001
Coordinate	2	23049.6	<.001
Material×tooth	5	0.44	.816
Material×coordinate	2	129.33	<.001
Tooth×coordinate	10	4.53	<.001
Material×tooth×coordinate	10	2.45	.014

Df = numerator degrees of freedom; denominator degrees of freedom=72.

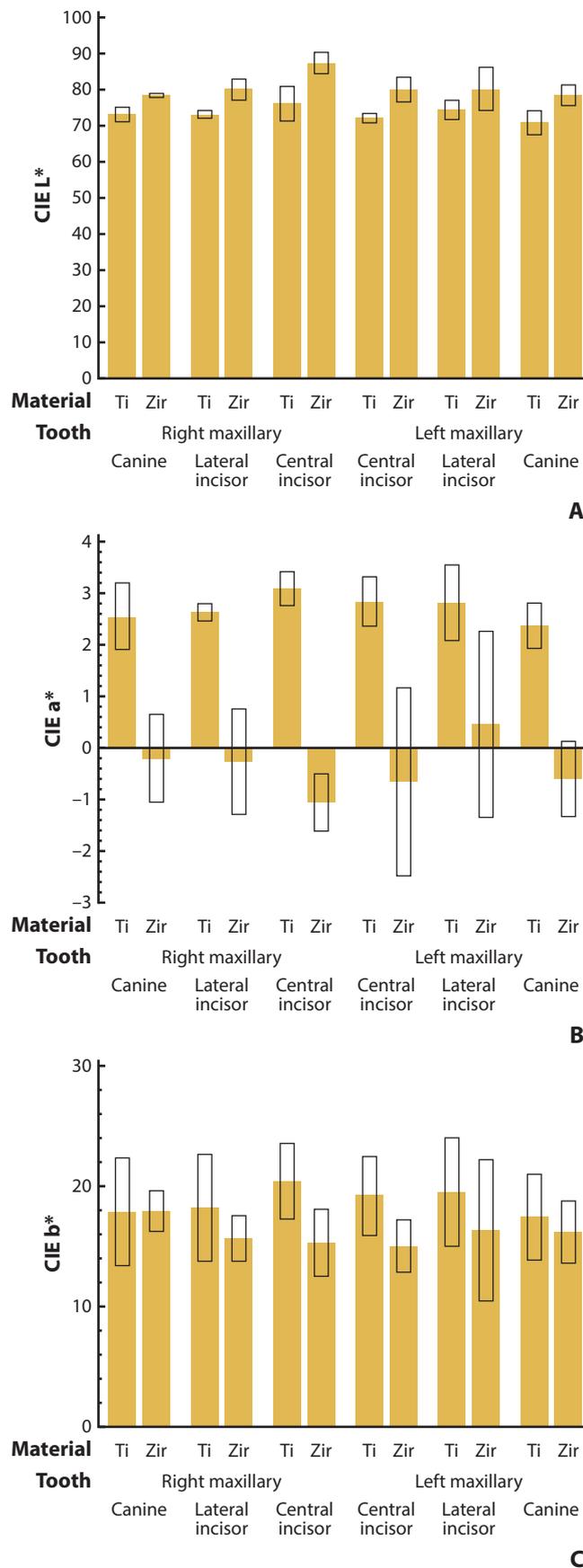
RESULTS

The 3-way ANOVA (Table 2) of differences in the color coordinates of layering porcelain on teeth on different frameworks revealed a significant interaction between material and coordinate ($P<.001$), tooth and coordinate ($P<.001$), and material, tooth, and coordinate ($P=.014$). The L^* , a^* , b^* values of teeth on Zir and Ti frameworks are presented in Figure 1. The color differences (ΔE) between porcelain on Zir and Ti are presented in Figure 2. L^* values of all teeth on the Zir frameworks were in the same direction and statistically significantly higher than the same teeth on the Ti frameworks ($P<.001$) (Fig. 1A). The a^* value of porcelain on the maxillary right central incisor (MRCe) of the Zir framework was statistically significantly different from the a^* value of the MRCe on the Ti framework ($P=.013$) (Fig. 1B). The b^* values of teeth on both the Zir and Ti frameworks were in the same direction (Fig. 1C). The b^* values of the central incisors (MRCe, maxillary left central incisor [MLCe]) on the Ti framework were statistically significantly higher than the b^* values of the central incisors (MRCe, MLCe) on the Zir framework ($P<.001$, $P=.013$, respectively). The mean color difference (CIEDE2000) between teeth on the Ti and Zir frameworks was 6.6.

The L^* , a^* , b^* values of gingival porcelain on Zir and Ti frameworks are shown in Figure 3. The 2-way ANOVA (Table 3) for the differences in color coordinates of gingival porcelain on different frameworks revealed a significant interaction between material and coordinate ($P<.001$). The L^* , a^* , and b^* values for gingival porcelain on Zir and Ti frameworks were in the same direction, and the L^* value of gingival porcelain on the Zir framework had a statistically significantly higher L^* value than the gingival porcelain on the Ti framework ($P<.001$) (Fig. 3). The mean color difference (CIEDE2000) between the gingival porcelain on the Ti and Zir frameworks was 8.6.

DISCUSSION

The null hypothesis was rejected because the type of framework material affected the final color of the teeth ($P=.05$) and gingiva ($P<.001$) of implant-supported



complete-arch fixed dental prostheses. When a^* values were evaluated, the majority of a^* values for teeth on both Zir and Ti frameworks were in different directions (all “+” values for means for Ti, but “-” values for Zir, except for the maxillary left lateral incisor (MLLa) having “+” mean, but also “-” readings). Teeth on the Ti framework exhibited a higher tendency to redness (high a^* value). The color of the Ti alloy⁴ and the oxides released during firing procedures may explain the redness of porcelain on Ti alloy. Parallel with this, Ozcelik et al²⁹ evaluated the color alterations in different types of metal alloys (3 base metal, 3 noble, and 1 high noble) during the fabrication stages of metal-ceramic restorations and reported that all tested alloys exhibited increased redness after casting (higher a^*) and that some of the alloys exhibited increased redness (higher a^*) after oxidation and opaque porcelain application. In contrast with the present study, Abualsaud et al²⁵ compared the color of the cervical region of 5 commercially available crown systems and reported that tested Zir restorations (white and shaded) were more reddish (higher a^*) and had a higher tendency to lightness (higher L^*) than metallic systems (high-noble gold alloy, high-noble gold alloy treated with gold paste material, precious reinforced alloy). The difference between the present study and this study might be due primarily to the different metal alloys and layering porcelain tested.

When b^* values were evaluated, the central incisors (MRCE, MLCE) on the Ti frameworks had a significantly higher tendency to yellowness than those on the Zir framework (higher b^*) ($P < .001$ and $P = .013$, respectively). Consistent with the results of the present study, Al-Wazzan and Al Hussaini³⁰ reported that the Ti alloy specimens were darker and more yellow than the gold controls. The different L^* , a^* , and b^* values obtained in different teeth on the same framework material may be attributed to the vertical reduction of the design and the surface curvature of the different regions of the framework.

The chromatic coordinates (a^* , b^*) of the gingival colors of Zir and Ti frameworks were in the same direction. The gingiva colors of the Zir framework were more yellow (higher b^*) and had a higher tendency to redness (higher a^*) than the gingival colors of the Ti frameworks, but the difference was not statistically significant. The color differences (CIEDE2000) of both teeth

Figure 1. Mean and 95% confidence limits of CIE Lab values for zirconia and titanium frameworks. A, CIE L^* values. The mean L^* value was significantly lower ($P < .001$) on titanium framework for all teeth. B, CIE a^* values. The difference in a^* values between zirconia and titanium frameworks was significant for right maxillary central incisor ($P = .013$). C, CIE b^* values. The difference in b^* values between zirconia and titanium frameworks was significant for each of maxillary right ($P < .001$) and left ($P = .013$) central incisors. Ti, titanium; Zir, zirconia.

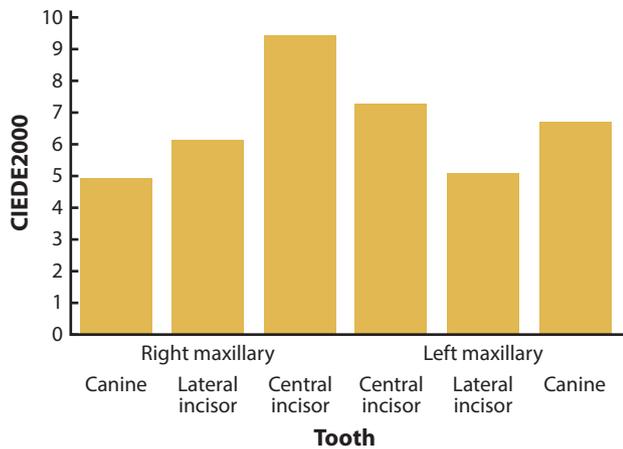


Figure 2. Color difference (CIEDE2000) values between different teeth on zirconia and titanium frameworks. Ti, titanium; Zir, zirconia.

(mean of 6.6) and gingiva (mean of 8.6) on Ti and Zir frameworks were above the clinically acceptability threshold reported by Paravina et al⁴⁴ ($1.8 \Delta E^*_{00}$). The a^* , b^* values of teeth on Ti frameworks indicated higher redness and yellowness than those on Zir frameworks, whereas the gingival colors of Zir framework exhibited higher redness and yellowness. This difference may be due to the different layering porcelain used on 2 different surfaces. A1 shade porcelain was applied for teeth, whereas pink porcelain was applied for gingiva. Consistent with this, different types of porcelain affected the final color of restorations differently.³²

In the present study, a modifier was applied on Zir frameworks, whereas a Ti bonding agent and 2 opaque porcelain layers were applied on Ti frameworks to conceal the metal.³³ Opaque porcelain has been reported to affect the final color of a restoration depending on the opaque porcelain thickness²⁹ and the color and grain size of the opacifiers.³⁵ In addition to opaque porcelain, oxidation is also one of the essential stages in the fabrication of a metal-porcelain restoration.²⁹ Although opaque porcelain is used for masking the dark metal oxide, different alloy groups have been reported to affect the resulting color of metal-porcelain restorations because different metal alloys may produce different types of metal oxides that may influence the final color.^{29,31} The lack of color stability of certain metal oxides and their reaction with adjacent porcelain have been associated with discoloration.³⁶ Ozcelik et al²⁹ also reported that the chromatic behavior of different alloys differed after oxidation and opaque porcelain application and that L^* values decreased after oxidation. Therefore, the difference in the a^* , b^* values of Zir and Ti frameworks obtained in this study may also be attributed to the different layers applied to mask the background framework color and discoloration due to oxidation.

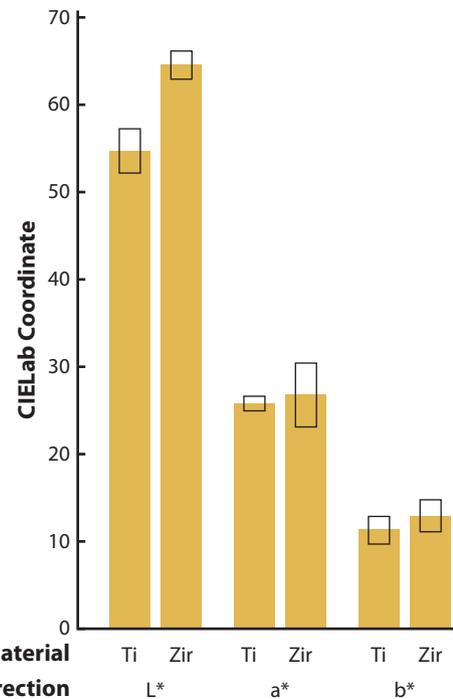


Figure 3. Mean and 95% confidence limits for CIELab coordinates of gingival colors with zirconia and titanium frameworks. Gingival porcelain on Zir framework had significantly higher L^* value than that on Ti framework ($P < .001$). Ti, titanium; Zir, zirconia.

Metal and Zir have dissimilar optical properties because of the differences in their structure.⁴ Zir is a semitranslucent ceramic material with a natural tooth-like appearance and color and enables slight light transmission,²⁶ whereas Ti has a grayish metal color and decreases the transmission of light due to the shine-through effect; this can be a disadvantage under translucent layering porcelain and results in an unnatural appearance.^{3,4} The significant ($P = .05$) color difference results between teeth on Zir and Ti frameworks may be due to differences in L^* values. The significant interaction between material and coordinate of teeth ($P < .001$) and gingival colors ($P < .001$) of Ti and Zir frameworks may also be attributed to differences in L^* values. The higher L^* values of the teeth and gingival colors of Zir frameworks may be explained by the semitranslucent nature of the Zir materials.²⁶ This may also be explained by the fact that more light is absorbed by a grayish metal framework and less is reflected⁴; lower L^* values are, thus, recorded in Ti frameworks.³⁴ Increased porcelain thickness may also help to mask the grayish color of the Ti framework.⁴ According to the results of the present study, a more opaque porcelain system or increased porcelain thickness may be advised to increase the esthetic outcome of Ti frameworks. Consistent with the results of the present study, Capa et al¹⁹ reported that the Ti layer increased the L^* value, which means that Ti had a darker appearance and dark metallic structures reflected

Table 3. Summary of ANOVA data on color coordinates of gingiva colors from different frameworks

Effect	Df	F Ratio	P
Material	1	66.67	<.001
Coordinate	2	2275.43	<.001
Material×coordinate	2	22.96	<.001

Df = numerator degrees of freedom; denominator degrees of freedom=12.

incident light.^{19,23} Consistent with the present study, in some studies, metal abutments were reported to provide a darker appearance because of decreasing scattering of incident light, whereas for nonmetallic materials, light scattering was reported to occur from the refraction and transmission of light both at the interface and inside the material.^{4,24}

A background material may manifest color properties of Zir restorations and may affect the final color.²³ In some studies, a different Zir core and veneer thickness was found to mask background color depending on the background material.^{23,24} Porcelain thickness and type is also important in masking metallic color and discolored backgrounds.³ Different porcelain thickness has been reported to mask the underlying metallic color of Ti abutments and collars.^{3,31} Although in some previous studies, disk- or plate-shaped specimens were used that did not simulate the clinical conditions,^{3,4} in the present study, an attempt was made to simulate implant-supported complete-arch fixed dental prostheses clinically with the framework design and veneering procedures. A 1.5-mm porcelain thickness was selected to veneer the buccal surfaces of anatomically contoured frameworks.¹⁹ One porcelain thickness was used for veneering, but it should be kept in mind that different veneer porcelain thicknesses may yield different results on the final color.^{3,20,23}

In the present study, a spectroradiometer was used for color measurements to minimize the edge-loss phenomenon.^{40,41} A color space was used in which the L* color coordinate represents lightness or darkness, the a* chromaticity coordinate corresponds to the red-green axis (+a* is the redness, and -a* is the greenness), and the b* chromaticity coordinate represents the yellow-blue axis (+b* is the yellowness, and -b* is the blueness).^{3,30,31}

The conclusions of the present study are limited to the materials tested and the sample size used. Complete-contour Zir may lead to different results in the final color. One of the limitations of this study is the use of only 1 shade and thickness of veneering porcelain and 1 technician being involved in porcelain layering. Further studies are needed to evaluate the effects of different porcelain thicknesses on the final color of implant-supported complete-arch fixed dental prostheses with different framework materials.

CONCLUSIONS

Within the limitations of this in vitro study, the following conclusions were drawn:

1. Layering porcelain on teeth on a Ti framework had a tendency to higher redness and yellowness than on teeth on a Zir framework.
2. Gingival porcelain on a Zir framework had a tendency to higher redness and yellowness than gingival porcelain on a Ti framework.
3. Color differences of both teeth and gingival porcelain on Ti and Zir frameworks were significantly different.
4. Layering porcelain on teeth and gingiva on a Zir framework presented higher lightness than layering porcelain on a Ti framework.

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