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Masking Colored Substrates Using Monolithic and Bilayer CAD-CAM Ceramic Structures

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Clinical Relevance

Bilayer ceramic systems are viable options for challenging clinical situations where discolored teeth or metal abutments need to be masked. Although the monolithic lithium disilicate seems to be able to mask a C4-shaded substrate, thinner bilayer structures showed similar results.

SUMMARY

Objective: To evaluate the masking ability and translucency of monolithic and bilayer CAD-CAM ceramic structures.

Methods: Discs of high translucency (HT) and low translucency (LT) lithium disilicate–based ceramic (IPS e.max CAD) with different thicknesses (0.7, 1, 1.5, and 2 mm) were evaluated as a monolithic structure or combined (bilayer) with a 0.5-mm-thick zirconia framework (IPS e.max ZirCAD). The masking ability and translucency were calculated based on CIE L*a*b* color coordinates measured with a spectrophotometer (SP60, X-Rite). The translucency parameter (TP) was calculated using color coordinates measured over standard white-and-black backgrounds. The masking ability was calculated by CIEDE2000 color difference metric (ΔE_{00}) for each specimen measured over a tooth-colored substrate (shade A2) compared to three darker backgrounds (shade C4 and two metal substrates). Confidence intervals (CI) for the means (95% CI) were calculated for TP and ΔE_{00}. The Pearson correlation between ΔE_{00} and TP was investigated for monolithic and bilayer structures over all backgrounds.

Results: The thinner the lithium disilicate layer, the greater the translucency and the higher the ΔE_{00} values. The effect of ceramic thickness on both translucency and masking

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ability was more pronounced for the monolithic structures. In addition, monolayers always presented a greater color variation than their bilayer counterparts. The metallic background produced greater ΔE_{00} than the C4-shaded substrate.

Conclusion: Monolithic veneers were able to mask C4-shaded background but did not mask metallic backgrounds. Bilayer structures showed greater shade masking ability than monolithic structures.

INTRODUCTION

Dental esthetics complaints are often related to discolored teeth or restorations.[1,2] Achieving natural tooth-like restoration is an important aspect influencing the treatment success.[1,2] Restorative procedures that involve full-coverage ceramic restorations are often associated with intraradicular retainers.[3] Although glass-fiber posts have been widely used,[3-5] there are still clinical cases demanding esthetic restorations over metallic post and cores.[3-5] Masking metallic cores and discolored tooth substrates with all-ceramic restorations is still one of the greatest challenges for restorative dentistry.

A diversity of all-ceramic systems is currently available, attempting to cover distinct clinical scenarios by combining strength and esthetics. Another important aspect that differentiates the various ceramic systems is their fabrication technique. Restorations placed after a chair-side single visit have an appealing advantage over the traditional multistep laboratory fabrication: reduced time to complete the treatment. Glass ceramics are often used in chair-side CAD-CAM dental treatments. The lithium disilicate–based ceramic (eg, IPS e.max CAD, Ivoclar Vivadent, Schaan, Liechtenstein) is the strongest glass ceramic yet shows superior esthetic qualities in its monolithic presentation.[6] On the other hand, the traditional multistep lab technique offers the possibility to achieve excellent individualization of the restoration and the use of zirconia infrastructure. Zirconia is the strongest and toughest of the dental ceramics,[7-10] and its opaque appearance yields high masking ability.[11,12] But zirconia is not esthetically pleasant; thus, most restorations demand a second fabrication step: veneering with an esthetic ceramic to obtain an optical appearance similar to natural teeth.[13,14]

Combining a machined glass veneer with a machined zirconia framework is a new trend in all-ceramic systems. The bonding of the two pieces can be achieved by a fused glass layer (CAD-on system, Ivoclar Vivadent) or bonding with a composite resin (VITA Rapid Layer Technology, Vita Zahnfabrik, Bad Sackingen, Germany). Reported benefits of these systems include the use of a veneer ceramic[6,15,16] with lower porosity because of the CAD-CAM fabrication technology.[17-22] Yet there is no report on the optical characteristics of all-ceramic restorations fabricated by milling both the veneer and the framework structures.

Choosing a ceramic system for an esthetic restoration that demands masking ability is challenging. One may question whether a relatively easy-to-make monolithic glass-ceramic restoration is a suitable option or whether a thinner bilayer veneered zirconia restoration would present better masking ability, thus allowing the preservation of tooth structure. Therefore, the aim of this study was to evaluate the masking ability and translucency of CAD-CAM ceramic structures (monolayer and bilayer) with different thicknesses, testing the hypothesis that the masking ability is influenced by the thickness, translucency, and layering of the ceramic structure.

METHODS AND MATERIALS

Study Design

This *in vitro* study had a $2 \times 2 \times 4 \times 3$ factorial design (n=10), with the following factors under investigation: structural design (two levels: monolayer—CAD-CAM lithium disilicate; bilayer —CAD-CAM lithium disilicate veneer + zirconia framework), translucency of the veneer (two levels: high translucency [HT] and low translucency [LT]), thickness of the veneer layer (four levels: 0.7, 1.0, 1.5, and 2.0 mm), and background colored substrates (three levels: shade C4, coppery, and silvery). Figure 1 presents a diagram of the study design.

A lithium disilicate–based glass ceramic (IPS e.max CAD, Ivoclar Vivadent), clinically indicated for monolithic restorations or veneering material, and zirconia-based ceramic (IPS e.max ZirCAD, Ivoclar Vivadent), used as a framework material, were used in the present study. The response variables included the translucency parameter (TP) and the masking ability estimated by the CIEDE2000 color difference metric (ΔE_{00}) over a typical dental shade substrate (A2) and discolored backgrounds (shade C4, coppery, and silvery). The correlation between TP and ΔE_{00} was also investigated.

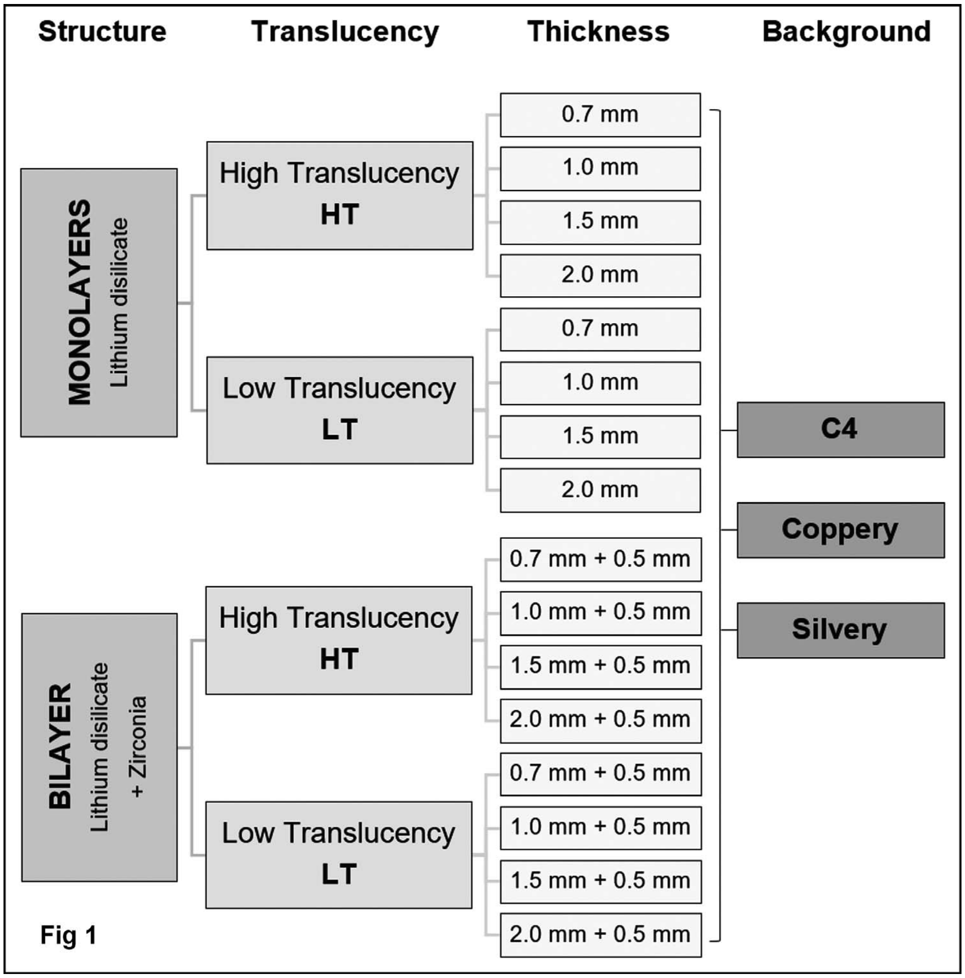

Figure 1. *Diagram of the experimental design.*

Preparation of Ceramic Structures

Discs (diameter 10 mm) from A1 shade of HT and LT IPS e.max CAD blocks were cut with thicknesses of 0.7, 1.0, 1.5, and 2.0 mm, simulating monolayer restorations. Additionally, 0.5-mm-thick zirconia discs were produced from IPS e.max ZirCAD blocks to simulate the framework of bilayer restorations. All discs had both sides polished to 1200-grit SiC paper under running water. For the bilayer structures, a drop of glycerin was placed between the glass-ceramic and the zirconia discs. Glycerin was also used between the ceramic structures and the background substrate. A liquid coupling medium, such as glycerin, is necessary to avoid undesirable effects of air on optical properties, thus minimizing light scattering due to different refractive indices (ie, air and ceramic).[23]

Preparation of Background Substrates

Tooth substrate was simulated with 2-mm-thick porcelain specimens (Vita VM7, dentin, Vita Zahnfabrik). Shades A2 (positive control) and C4 (dark substrate) were used as tooth-like substrates. Additionally, discs were fabricated from two metal alloys, with coppery (Pd-Cu, 79% Pd, Spartan Plus, Ivoclar Vivadent) and silvery (Ag-Pd, 80% Ag, Pratalloy, Dentsply Caulk, Milford, DE, USA) appearance. Fabrication procedures were carried out according to the manufacturers' recommendations. The background specimens were flattened with 600-grit SiC abrasive papers, and the top surface was polished to 1200-grit SiC abrasive papers, always under running water.

Measuring the Color Coordinates

The CIE L*a*b* color coordinates of monolithic and bilayer specimens were measured with a spectrophotometer (SP60, X-Rite, Grand Rapids, MI, USA). The spectrophotometer was plugged into a voltage stabilizer to avoid changes in light source intensity. The equipment was calibrated on the standard tiles provided by the manufacturer. The specimens were

Table 1: *Mean (95% confidence interval) Values for the Translucency Parameter (TP) of Monolayer (Lithium Disilicate–Based Ceramic) and Bilayer (Lithium Disilicate–Based Ceramic + 0.5-mm-Thick Zirconia Framework) Ceramic Structures.*

Veneer Ceramic[a]	TP Monolayer[b]	TP Bilayer[b]
HT0.7	44.9 (44.2-45.6) A	13.8 (13.5-14.1) A
HT1.0	37.3 (36.8-37.8) B	12.1 (11.8-12.4) C
HT1.5	29.4 (28.8-30.0) D	10.2 (9.9-10.5) E
HT2.0	22.9 (22.6-23.2) F	8.3 (7.9-8.7) F
LT0.7	34.4 (33.9-34.9) C	13.1 (12.8-13.4) B
LT1.0	27.3 (26.7-27.9) E	11.1 (10.7-11.5) D
LT1.5	22.2 (21.7-22.7) F	9.0 (8.7-9.3) F
LT2.0	15.5 (15.2-15.8) G	6.6 (6.4-6.8) G

[a] *HT, high translucency; LT, low translucency. The number represents the thickness of specimens.*
[b] *Different letters following the values in the same column indicate statistically significant differences.*

evaluated over white (L^*=93.1, a^*=1.3, b^*=5.3) and black (L^*=27.9, a^*=0.0, b^*=0.0) backgrounds as well as over simulated tooth substrates: shades A2 (L^*=88.1, a^*=4.9, b^*=16.3) and C4 (L^*=79.0, a^*=5.3, b^*=12.9). Simulated metal abutments were also used as background substrates: coppery (L^*=57.5, a^*=6.5, b^*=18.4) and silvery (L^*=57.1, a^*=1.7, b^*=5.0).

Evaluation of TP

TP was estimated by the difference between color coordinates measured over a white background (L^*_W, a^*_W, and b^*_W) and a black background (L^*_B, a^*_B, and b^*_B) using the following equation:[24]

$$TP = [(L*_W - L*_B)^2 + (a*_W - a*_B)^2 + (b*_W - b*_B)^2]^{1/2}$$

Evaluation of Masking Ability

The masking ability was estimated by calculating the CIEDE2000 color variation (ΔE_{00}) between each ceramic structure over a light tooth-colored substrate (A2) and over the dark backgrounds (C4, coppery, and silvery), according to the following equation:[24,25]

$$\Delta E_{00} = [(\Delta L'/K_L S_L)^2 + (\Delta C'/K_C S_C)^2 + (\Delta H'/K_H S_H)^2 + R_T(\Delta C'/K_C S_C)(\Delta H'/K_H S_H)]^{1/2}$$

where $\Delta L'$, $\Delta C'$, and $\Delta H'$ are the differences in lightness, chroma, and hue between two sets of color coordinates; R_T is the rotation function that accounts for the interaction between chroma and hue differences in the blue region; S_L, S_C, and S_H are the weighting functions used to adjust the total color difference for variation in perceived magnitude with variation in the location of the color coordinate difference between two color readings; and K_L, K_C, and K_H are the correction terms for the experimental conditions.

Clinical thresholds described by Paravina and others[26] were considered. The perceptibility and acceptability thresholds were set at $\Delta E_{00} = 0.8$ and $\Delta E_{00} = 1.8$, respectively.

Statistical Analysis

Confidence intervals (CI) for the means (95% CI) were calculated for TP and ΔE_{00}. Groups were considered significantly different when the 95% CI bounds did not overlap. A *post hoc* power analysis was carried out with TP and ΔE_{00} data. The Pearson test was used to investigate the correlation between ΔE_{00} and TP for monolithic and bilayer structures over all backgrounds, reporting the linear regression coefficients (R^2) and their respective p-values.

RESULTS

TP

Table 1 presents the TP values for all groups, showing that the presence of a 0.5-mm zirconia framework (bilayer) significantly increased the opacity compared to the monolayer counterparts. Even the thinner bilayers (0.7 mm veneer + 0.5 mm zirconia) were more opaque than the thicker monolayers (2 mm). Within HT and LT groups, a reduction in thickness resulted in an increase in translucency for monolayer and bilayer structures. The HT groups showed higher translucency values than LT structures with the same thickness regardless of the structural design (monolayer or bilayer). The power analysis indicated a beta = 1 (power = 100%) for TP data.

Masking Ability

Figure 2 presents the results of ΔE_{00} for the masking ability of discolored substrates. The color variation over metallic backgrounds was always significantly higher than over the C4 simulated tooth substrate. For all substrates, within the same translucency and veneer thickness, monolayer groups presented a lower masking ability than bilayer groups. Over C4 simulated tooth substrate, thinner bilayers (0.7 mm veneer + 0.5 mm zirconia) presented masking ability similar to that of thicker monolayers (2 mm).

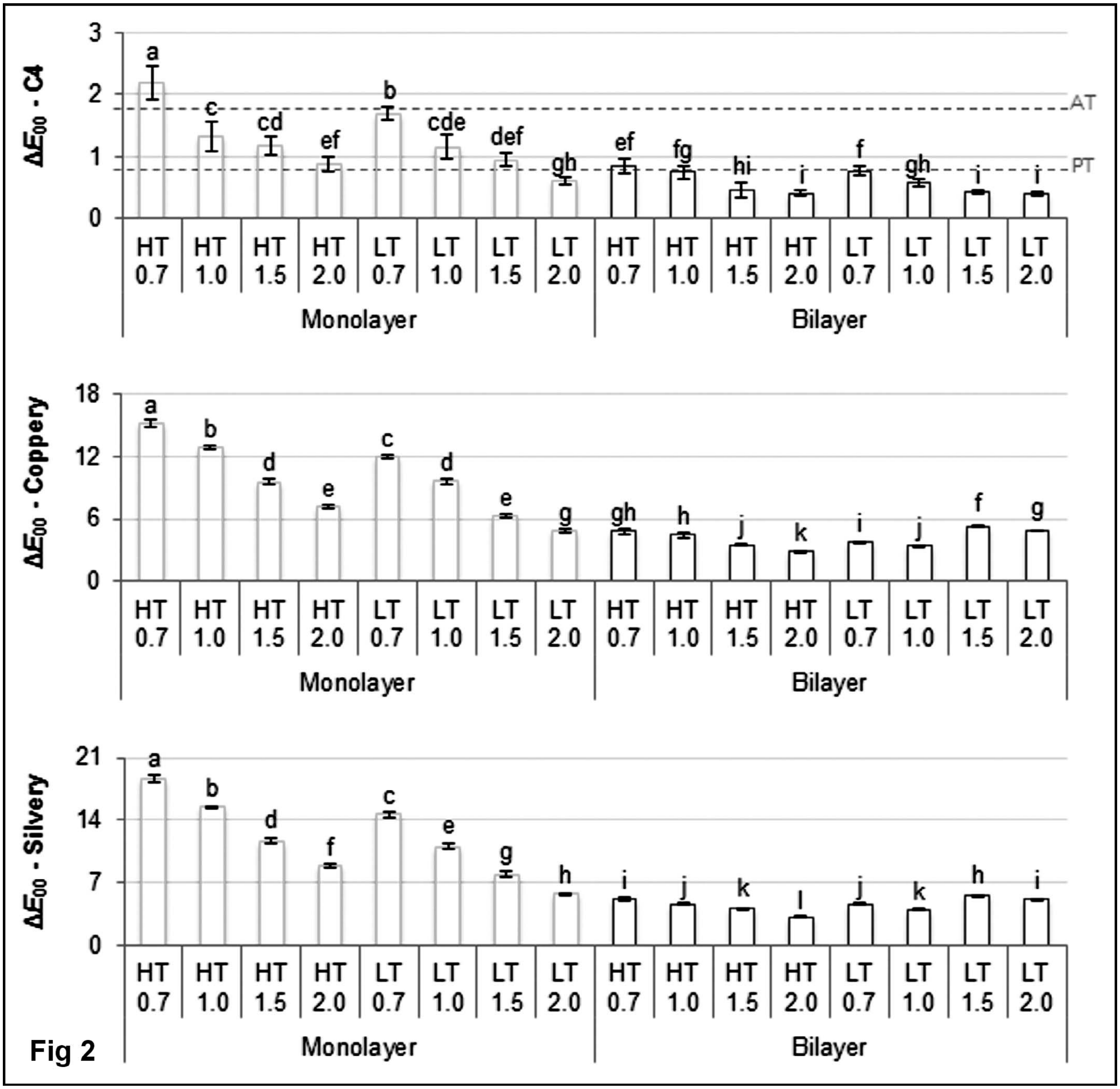

Figure 2. *Bar graph showing the mean and 95% confidence interval of color variations (ΔE_{00}) estimating the masking ability of monolayer and bilayer structures over discolored substrates (C4, coppery and silvery). The dashed lines seen in the C4 graph represent visual thresholds for 50%:50% perceptibility ($\Delta E_{00} = 0.8$) and acceptability ($\Delta E_{00} = 1.8$) of the color difference between two shades.[26] Those lines are not shown in the coppery and silvery charts because all groups had ΔE_{00} values above these thresholds. Different letters above columns in each graph indicate significance difference between groups.*

Nonetheless, over metallic backgrounds, thinner bilayers presented superior masking ability than thicker monolayers. For monolayers, regardless of the substrate, thinner ceramic structures produced lower masking ability. This effect was less evident for bilayers, especially when LT structures were used. For monolayer structures with the same thickness, HT ceramic most often showed a poorer masking ability than LT ceramic. On the other hand, the masking ability of bilayer structures of the same thickness was less sensitive to differences in ceramic translucency (HT or LT). The best masking ability

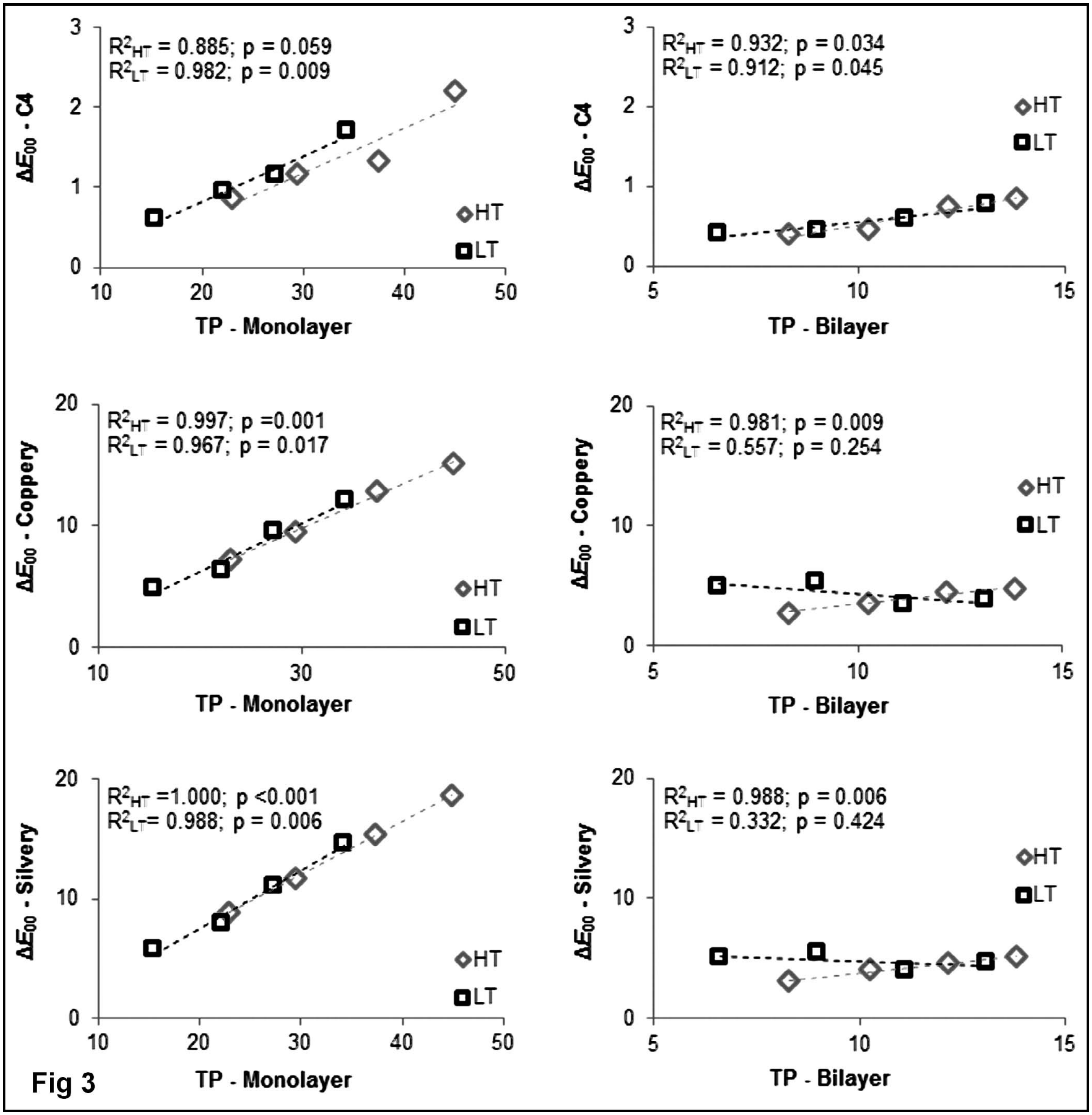

Figure 3. *Correlations between* ΔE_{00} *and TP for the monolayer and bilayer groups over the different backgrounds. Linear regression coefficients* (R^2) *and their respective* p*-values are shown for each correlation.*

for monolayers was achieved with LT2.0 (C4 ΔE_{00}=0.6, coppery ΔE_{00}=4.88, silvery ΔE_{00}=5.69). For the bilayers, HT2.0 showed the best masking ability (C4 ΔE_{00}=0.41, coppery ΔE_{00}=2.82, silvery ΔE_{00}=3.13), which was not statistically different from groups LT1.5 and LT2.0 over the C4 substrate. The power analysis indicated a beta = 1 (power =100%) for ΔE_{00} data.

Correlation Between TP and ΔE_{00}

Figure 3 shows the correlation between TP and ΔE_{00} for all groups evaluated over the three discolored substrates (C4, coppery, and silvery). For all monolithic ceramic structures, the correlations were strong and positive for both ceramic translucencies (HT and LT) regardless of the color background (C4, coppery, or silvery). Similar correlations were also found for the bilayer structures over the C4 background. The bilayer structures placed over metallic substrates (coppery and silvery) showed similar correlations. For monolayer structures over metallic substrates, correlations were strong and positive for both HT and LT veneers. For bilayer structures over metallic substrates, strong and positive correlations were observed only when HT veneers were used. LT veneers resulted in no significant correlation between TP and ΔE_{00}.

DISCUSSION

The present study evaluated the masking ability and translucency of the CAD-CAM ceramic structures used as either a monolayer (lithium disilicate–based glass-ceramic) or a bilayer (lithium disilicate veneer with zirconia framework), confirming the hypothesis that the masking ability is influenced by the thickness, translucency, and layering of the ceramic structure. A ceramic veneer layer with lower translucency (LT material and/or greater thickness) and the presence of the zirconia framework greatly favored the masking of the discolored substrates. The ability of ceramic restorations to mask discolored backgrounds and their final esthetic appearance result from a complex balance of factors that are not restricted to those evaluated in this study and mentioned above.[11,27-29]

Concerning translucency, the present study showed that thinner ceramic specimens had higher TP values, which is in line with previous studies.[30,31] In addition, greater TP values were found for the thinnest HT glass-ceramic specimens (0.7 mm) of both monolayer and bilayer ceramic structures. Previous studies have shown that the color of restorations is significantly affected by ceramic thickness and substrate shade.[27,29-33] Therefore, the indication of translucent and thinner ceramic restorations should be restricted to substrates closely matching the desired final color of the restorations.

Furthermore, the findings of the present study showed that the bilayer structure (CAD/CAM fabricated zirconia-based ceramic framework veneered with a lithium disilicate–based glass ceramic) has a lower TP than the counterpart monolayer ceramic structure (monolithic CAD/CAM lithium disilicate–based glass ceramic). Even the thinner bilayer (0.7 mm veneer + 0.5 mm zirconia) was more opaque than the thicker monolayer (2 mm). This observation can be explained by the following: 1) the opacity of the dense zirconia framework, which hinders light transmittance through the bilayer restoration, and 2) the refractive index mismatch between glass ceramic and zirconia—the light beam is scattered while traveling across media with different refractive indexes.[23] Considering this rationale, it can be suggested that a bilayer structure allows the preservation of tooth structure by using a thinner restoration yet offers a better esthetic appearance than a monolithic ceramic structure to mask dark substrates.

All evaluated ceramic structures (except for the monolithic HT0.7) showed acceptable (AT) values for masking a simulated tooth-discolored C4 substrate. The best C4 substrate masking ability was obtained with LT2.0 monolayers and all bilayers, which stayed under the perceptibility threshold. With regard to color and appearance of dental restorations, thresholds for perceptible/acceptable color mismatch are constantly being revised in the literature.[26,34-36] Some color difference formulas using weighting factors, including CIEDE2000 (K_L:K_C:K_H), were developed to predict color differences.[37] The present study used the parametric factors $K_L = 1$, $K_C = 1$ and $K_H = 1$, which are used for the CIEDE2000 (1:1:1) color difference metric. Yet studies on visual judgments performed on the acceptability of dental ceramics[38] and the comparison of visual and instrumental shade matching in dentistry[37] showed that using CIEDE2000 (2:1:1), where $K_L = 2$, resulted in color differences that better correlated to visual observations from average observers. In addition, a recent worldwide multicenter study[26] reported that 50% of the observers perceive a color difference[24] that reaches $\Delta E_{00} >$ 0.8 (PT), yet they will consider the color difference unacceptable only when it reaches values of $\Delta E_{00} >$ 1.8 (AT). Such findings were considered for the ISO/DTR 28642 standard[39] and adopted in the present study.

Regarding the masking of simulated metal abutments (coppery and silvery backgrounds), none of the evaluated ceramic structures were able to yield $\Delta E_{00} < 1.8$,[26] which would correspond to a clinically acceptable color difference (AT) in comparison to the control, observed over the A2 simulated dental substrate. This observation held true regardless of the structural thickness or the presence of the zirconia framework, in agreement with other studies.[40,41]

The present study provided additional scientific support to overcome the clinical challenge of esthetically masking dark substrates, such as metal abutments, using all-ceramic restorations. Yet there still is a need for further investigation on whether increasing the thickness of the zirconia framework as well as the use of opaque cements and/or opaque pigments could offer acceptable masking of metal abutments. The use of glycerin as a coupling agent between the glass-ceramic and the zirconia discs may not replicate the optical effects of the fusing layer (glass or composite resin) and is a limitation of the present study. Nonetheless, it eliminates light scattering between the two ceramic layers.[23] Further investigation is needed to understand the optical effects of various fusing materials used to bond machined glass veneer to the machined zirconia framework.

CONCLUSIONS

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

- Monolithic CAD-CAM lithium disilicate was able to mask a discolored tooth background but did not succeed in masking metallic substrates;
- Bilayer ceramic structures, associating a CAD-CAM zirconia framework with a CAD-CAM lithium disilicate veneer, improved masking over all evaluated substrates.

Conflict of Interest

The authors of this article certify that they have no proprietary, financial, or other personal interest of any nature or kind in any product, service, and/or company that is presented in this article.

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