



## INFLUENCE OF FRAMEWORK DESIGN ON THE CERVICAL COLOR OF METAL CERAMIC CROWNS

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**Statement of problem.** The replication of natural teeth, especially for single tooth restorations in patients with high esthetic needs, represents a challenge.

**Purpose.** The purpose of the study was to analyze the color of the cervical portion of single metal ceramic crowns fabricated with different metal framework designs.

**Material and methods.** The color, as measured on the CIELAB color scale, of 3 different groups of restorations (n=10) fabricated with a high noble metal alloy (V-Dentaloy) and feldspathic porcelain (Noritake Super Porcelain) was analyzed with a colorimeter. Conventional metal ceramic crowns with metal facial margins were compared to metal ceramic crowns with porcelain facial margins and a horizontal reduction of the metal framework (1.0 mm reduction) or an additional vertical reduction (1.0 mm reduction). In all specimens, the finish line was positioned at a subgingival or equigingival level. The 6 groups obtained by the combination of the levels of the 2 factors (framework extension and finish line location) were examined with an ANOVA Fisher's F-test and a post hoc Tukey's HSD test ( $\alpha=.05$ ).

**Results.** The mean color difference for all the groups was clinically acceptable ( $\Delta E < 3.7$ ). Conventional metal ceramic crowns showed higher differences in relation to finish line location ( $\Delta E = 2.34$ ), while a vertical reduction of the framework was related to lower values ( $\Delta E = 0.96$ ). Mean Lab\* values were reported for all the groups of crowns. Statistically significant differences were present for L\*, a\*, and b\* values when related to framework extension. Considering each value in relation to the interaction between framework extension and finish line location factors, significant differences were present only for L\* and a\* values.

**Conclusions.** No significant differences in base shade were present among the investigated crowns. Nevertheless metal ceramic crowns with vertical cut-back and porcelain facial margins presented more consistent results that tended to be closer to those of natural teeth. (J Prosthet Dent 2011;106:310-318)

### CLINICAL IMPLICATIONS

If metal ceramic is selected as the restorative material for a crown in the esthetic zone, a vertical cut-back of approximately 1 mm is recommended on the facial metal framework/porcelain facial margin to achieve an adequate esthetic result. If a conventional metal framework design is selected, deep subgingival margins might reduce the color impairment.

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The replication of natural teeth with single tooth restorations in patients with high esthetic needs and expectations represents a challenging task in restorative dentistry.<sup>1-4</sup> An important consideration is color reproduction in the cervical portion, where a thinner layer of restorative material must be used to prevent harm to the pulpal tissue or interference with the proper emergence profile.<sup>5-7</sup>

Different materials and techniques have been proposed to achieve an improved esthetic result. The metal ceramic crown is one of the most popular restorations since it combines good esthetics with adequate strength, accurate fit, and long-term survival.<sup>8</sup> Esthetic problems with this type of restoration are related to the opaque porcelain layer used to mask the dark color of the underlying metal framework. Acting as a barrier to light transmission, this opaque layer causes an impairment of color and translucency, which is more evident in the cervical portion, where the porcelain is thinner.<sup>2,9-11</sup> Furthermore, the presence of a facial, marginal metal collar thick enough to support the overlying layers of porcelain and resist metal deformation during porcelain firing<sup>12,13</sup> often becomes an esthetic issue.<sup>14</sup> To fulfill the esthetic requirements, collarless metal ceramic restorations have been suggested, limiting the extension of the metal framework to a certain distance from the margin of the preparation. Several techniques have been proposed to fabricate collarless metal ceramic restorations, including platinum foil techniques,<sup>14,15</sup> the direct-lift technique,<sup>16</sup> and the wax technique.<sup>17-20</sup> Research has confirmed adequate marginal adaptation<sup>21-24</sup> and fracture resistance<sup>25-31</sup> for this type of restoration. In particular, to achieve adequate strength, a deep chamfer preparation and no more than 1 mm of unsupported ceramic are recommended.<sup>27</sup>

Analyzing the esthetic effect of metal ceramic restorations through transillumination and photography, Geller and Kwiatkowski<sup>32</sup> proposed a

metal framework reduction of 2 mm coronally from the buccocervical line angle. With this design, metal was not visible at the external crown surface, light transmission was increased, and the opaquing effect of metal and opaque porcelain was eliminated in the cervical region. Recent studies have confirmed that the metal framework should be cut back a minimum of 2 mm away from the shoulder to avoid a color mismatch.<sup>33</sup> However, others show similar esthetic results with less reduction of the metal framework, which also provides improved porcelain support.<sup>27</sup>

One of the objective methods for evaluating color in dentistry is through colorimetric or spectrophotometric analysis.<sup>34-40</sup> These instruments use the CIELAB color scale, which identifies tooth color through the black/white ( $L^*$  value), green/red ( $a^*$  value) and yellow/blue dimensions ( $b^*$  value).<sup>41</sup> In an analysis of the color of natural, maxillary central incisor teeth, Hasegawa et al<sup>42</sup> found significant variations in Lab\* values along the axis of the surface of the teeth:  $L^*$  was higher in the center;  $a^*$  was higher in the cervical region and significantly lower when approaching the incisal edge; and  $b^*$  was higher in the cervical area but with gradual and significant reduction toward the incisal area. Older subjects had darker and more yellowish color at the center of the natural tooth. Both reddish and yellowish colors of natural teeth tended to increase from the incisal to the cervical area, whereas translucency decreased. In an in vitro study, the distribution of color was identified for 3 regions with respective mean Lab\* values of 71.4, 0.9, and 12.8 for the incisal portion, 72.4, 1.2, and 16.2 for the middle portion, and 72.6, 1.5, and 18.4 for the gingival portion.<sup>43</sup>

The most commonly used method for evaluating color differences among specimens is through  $\Delta L^*$ ,  $\Delta a^*$ , and  $\Delta b^*$ . Their combination is described as color difference ( $\Delta E$ ), which is determined by the following equation:  $\Delta E = (\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2})^{1/2}$ .<sup>34</sup> The ul-

timate goal in achieving an accurate color match is to achieve the smallest possible  $\Delta E$  value.<sup>34</sup> The correlation between  $\Delta E$  and clinical observation was analyzed in an in vivo study of subjects treated with composite resin veneers. Within the limitation of the study, 3.7 was the average color difference among teeth rated as a match in the oral environment.<sup>44</sup> When analyzing metal ceramic crowns, different results were obtained. Thresholds for acceptability were reduced to  $\Delta E=1.7$ , while perceptibility was reduced to  $\Delta E=0.4$ . In addition, observers were more sensitive to and critical of crowns whose color differed in redness ( $\Delta a^*$ ) than crowns whose color differed to the same extent in yellowness ( $\Delta b^*$ ).<sup>45</sup> More recently, different thresholds for perceptibility ( $\Delta E < 2.6$ ) and acceptability ( $\Delta E < 5.5$ ) of shade mismatch have been described in a clinical setting and used in experimental research.<sup>46,47</sup>

The purpose of this study was to compare, through spectrophotometric digital technology, the color of the cervical portion of single metal ceramic crowns fabricated with different metal framework designs. Conventional metal ceramic crowns with metal margins (metal extended to the finish line) were compared with collarless metal ceramic crowns fabricated with different metal extensions. Subgingival and equigingival margin positions were evaluated. The null hypothesis was that there would be no color differences present in the cervical portion of single metal ceramic crowns fabricated with different metal framework design and tested with equigingival and subgingival margin placement.

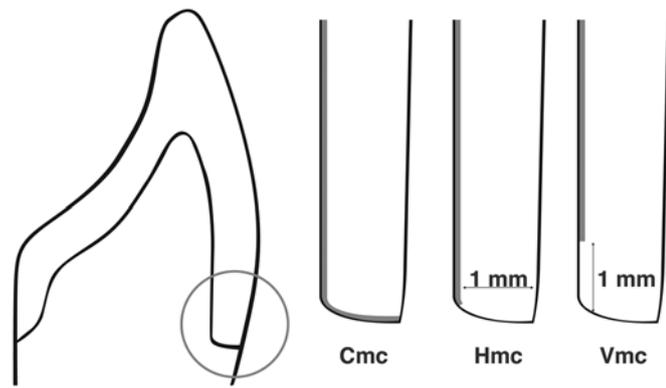
## MATERIAL AND METHODS

The color of 3 different margin design groups of restorations ( $n=10$ ) fabricated with high noble metal alloy (V-Deltaloy; Metalor Dental AG, Biel-Bienne, Switzerland) and feldspathic porcelain, (Noritake Super Porcelain; Noritake Dental Supply Co, Nagoya,

Japan) was measured with a colorimeter (ShadeVision System; X-Rite, Inc, Grand Rapids, Mich). The sample size was arbitrary as no a priori power analysis was performed, and no reliable estimate of within-group standard deviation for the population could be obtained. The conventional metal ceramic crowns with metal margins (group C) were compared with metal ceramic crowns with 2 different designs of porcelain facial margin. One group had a horizontal reduction of the metal framework (group H: 1.0 mm reduction), and the second had an additional vertical reduction (group V: 1.0 mm vertical reduction) (Fig. 1).

One extracted, intact, human maxillary central incisor was prepared to receive the crowns. The facial reduction was 1.5 mm following the depth of a rounded shoulder finishing line. The margin was positioned at the level of the cement-enamel junction and 2.0 mm of incisal reduction was performed. Throughout the study, the tooth was stored in a 0.05 % thymol and distilled water solution. The prepared tooth was duplicated with a vinyl polysiloxane impression material (CapSil, Aquatrols Corporation of America, Paulsboro, NJ). Type IV dental stone (New Fuji-Rock, GC Corp, Tokyo, Japan) was used to fabricate the 30 dies, each corresponding to a single crown.

A standardized framework was cast for each die in a high noble metal alloy (V-Delta; Metalor Dental AG). After the heat treatment process, the intaglio surfaces were finished to a uniform facial and interproximal thickness of 0.3 mm. For the conventional margin design, group C, the metal framework remained extended to the preparation finish line (Fig. 1). For group H crowns, the cervical margin of the metal framework was reduced at the axiocervical line angle at a distance of 1.5 mm from the preparation finishing line; this reduction was made on the facial and interproximal margin, leaving 150 degrees of metal collar exposure on the



**1** Different designs of metal framework tested. Conventional metal ceramic crowns (Cmc), metal ceramic crowns with horizontal reduction of metal framework (Hmc), and metal ceramic crowns with additional vertical reduction of metal framework (Vmc).

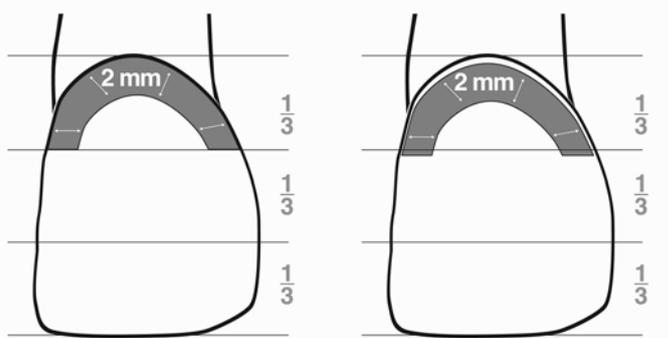
**TABLE I.** Type and thickness of materials used for crowns

Crown Layers	Materials (Manufacturer)	Cervical Thickness
Metal framework	High noble metal alloy (V-Delta Alloy, Metalor)	0.3 mm
Opaque layer	Porcelain opaque (POA1, Noritake Porcelain)	0.1 mm
Dentin porcelain	Feldspathic porcelain (A1B, Noritake Porcelain)	1.0 mm
Enamel porcelain	Feldspathic porcelain (A1B, Noritake Porcelain)	0.1 mm
Porcelain for butt margin	Feldspathic porcelain (MA1, Noritake Porcelain)	Minimal achievable
Cement medium	Translucent cement (Variolink II, trial-base, Ivoclar Vivadent AG)	Thin layer

lingual side of the crown. For group V crowns, an additional 1.0 mm was added to the vertical reduction of the metal framework.

Dental porcelain (Noritake Super Porcelain; Noritake Dental Supply Co) was applied to all groups with a brush-on technique according to the manufacturer's recommendations and fired under vacuum in a porcelain furnace (Programat P300; Ivoclar Vivadent AG, Schaan, Liechtenstein). Three layers of opaque porcelain were applied to all of the metal frameworks. For groups V and H, 2

applications of margin porcelain were applied to achieve adequate marginal integrity. The thickness of the margin porcelain was reduced as much as possible. Two layers of dentin porcelain were applied to all 3 groups to achieve proper contour and reduced to a cervical thickness of 1.4 mm. Enamel porcelain was then applied over the dentin porcelain to achieve a proper final crown contour with a 1.5 mm thickness at the cervical area. All specimens were autoglazed according to the manufacturer's recommendations. A caliper (Iwanson Decimal



**2** Selected cervical portion in equigingival (left) and subgingival (right) groups of metal ceramic crowns. Note that subgingival crowns have margin positioned 0.5 mm apical to gingival level.

**TABLE II.** Groups analyzed. Variables included framework extension (3 groups of specimens) and finish line location (total 6 study groups)

Groups of Specimens (n=30)	Framework Extension (C, H, V)	Study Groups	Finish Line Location (S, E)
Cmc	Finish line	CST	Subgingival (0.5mm)
Hmc	1.5 mm horizontal reduction, (buccocervical line angle)	HST	
Vmc	1 mm additional vertical reduction	VST	
Cmc	Finish line	CET	Equigingival
Hmc	1.5 mm horizontal reduction, (buccocervical line angle)	HET	
Vmc	1 mm additional vertical reduction	VET	

Caliper; Asa Dental s.p.a., Lucca, Italy) with an accuracy of 0.05 mm was used to measure and adjust the final thicknesses, which are reported in Table I.

The color of the cervical region of the crowns, fitted on a prepared maxillary central incisor, was measured with a colorimeter (ShadeVision System; X-Rite, Inc). The measurements were made in a dental mannequin (KaVo Dental, Biberach/Riss, Germany) with the margin of the restoration positioned either 0.5 mm subgingivally (subgroup S) or at the gingival level (subgroup E) by moving the prepared tooth 0.5 mm more or less api-

cally (Fig. 2). To achieve repeatability of measurements, the position of the tooth and of the measuring instrument was standardized for all the measurements with custom-positioning indices. Each measurement was performed 5 times to reduce measurement error. Since natural teeth are usually observed in a wet environment, all measurements were made with the specimens in a slightly moist condition. All the crowns were measured with the application of transparent cement medium try-in paste (Variolink II; Ivoclar Vivadent AG). Tables I and II summarize the porcelain layer thicknesses and measurement

conditions for each of the experimental margins. Six experimental groups were evaluated in the study.

On the computer screen, the cervical portion of the teeth was selected by using a transparent custom-made plastic template, which was fabricated to fit the computer screen to better identify the different tooth portions. A 4 mm length was considered enough to represent the cervical portion since the initial length of the tooth before preparation was approximately 12 mm, and a standardized area, extending 2 mm from the gingival level, was selected in the cervical portion (Fig. 2). The measurements were recorded in CIELAB coordinates.

The color difference among the experimental groups was determined with the equation:  $\Delta E = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2}$ ,<sup>33,34</sup> calculated from the mean values of  $L^*$ ,  $a^*$ , and  $b^*$ . To determine clinical significance, the  $\Delta E$  values were related to those present in the literature, which range from 1.7 to 3.7.<sup>44,45</sup>

A 2-way ANOVA was calculated for each CIELAB coordinate ( $L^*$ ,  $a^*$ , and  $b^*$  values) to show which of the 2 factors (framework extension or finish line location) had a significant impact on the values of each coordinate. A post hoc Tukey's Honestly Significant Difference (HSD) test was performed to determine statistically significant differences among the group means.

**RESULTS**

The mean  $L^*$ ,  $a^*$ , and  $b^*$  values are presented in Table III. When considering  $L^*$  values through the analysis of variance (2-way ANOVA), there were significant differences ( $P=.012$ ) among the different groups of crowns, with framework extension having the main effect (Table IV). The mean  $L^*$  value for the Vmc group (78.8) was significantly lower ( $P=.027$ ) than the mean value for the Cmc group (79.4) and also significantly lower ( $P=.023$ ) than the value for the Hmc group (79.4) (Fig. 3). Considering  $L^*$  values in relation to framework ex-

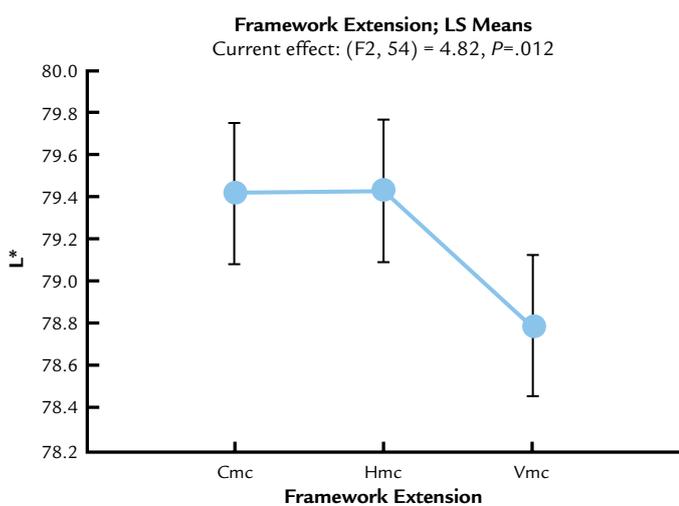


**TABLE III.** Mean L\* values, a\* values, and b\* values for each single group of crowns (n=6)

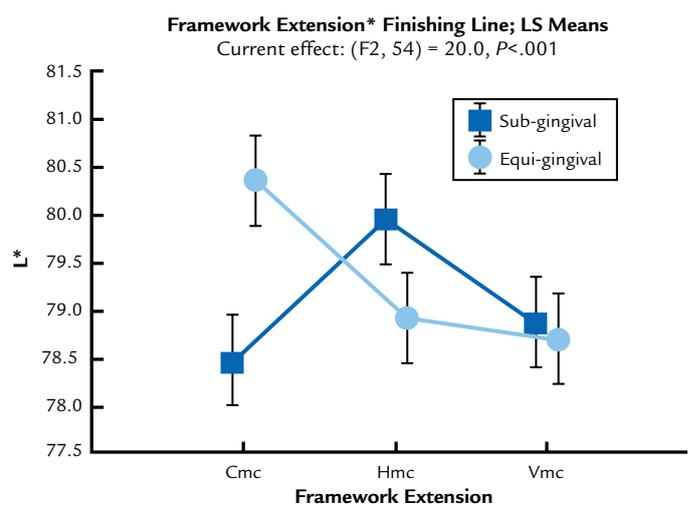
Group	L*		a*		b*	
	Mean Values	SD	Mean Values	SD	Mean Values	SD
CST	78.48	0.93	3.77	0.34	12.26	0.65
HST	79.96	0.81	3.06	0.47	11.87	1.00
VST	78.89	0.55	3.64	0.07	13.33	0.60
CET	80.37	0.84	2.53	0.27	11.65	0.58
HET	78.92	0.68	2.31	0.23	11.78	1.15
VET	78.71	0.57	2.69	0.25	13.30	0.82

**TABLE IV.** Two-way ANOVA table for L\* value (main effects and interaction term)

Source	Sum of Squares	df	Mean Square	F	P
Framework extension	5.39	2	2.69	4.81	.12
Finish line location	0.74	1	0.74	1.33	.25
Framework extension × Finish line location	22.5	2	11.25	20.07	<.001
Error	30.3	54	0.56		



**3** L\* values in relation to framework extension factor.



**4** L\* values in relation to framework extension and finishing line location factors.

tension and finish line location factors, significant differences ( $P<.001$ ) were present (Table IV). The post hoc Tukey test revealed no significant differences ( $P=.95$ ) between subgingival (78.9) and equigingival (78.7) measurements within the Vmc group. However, significant differences were present within the Cmc ( $P<.001$ ) and Hmc ( $P=.035$ ) groups. Conventional metal ceramic crowns had an  $L^*$  value of 78.4 when measured subgingivally and 80.4 when measured equigingivally. Specimens from the Hmc group had a mean  $L^*$  value of 80 when measured subgingivally and 78.9 when measured equigingivally (Fig. 4).

When considering  $a^*$  values, there were significant differences ( $P<.001$ ) among the different groups of crowns,

with framework extension having the main effect (Table V). Hmc crowns showed lower  $a^*$  values (2.69) than Cmc crowns (3.17) and Vmc crowns (3.17) (Fig. 5). Considering  $a^*$  values in relation to framework extension and finish line location factors, significant differences ( $P=.043$ ) were present (Table V). The post hoc Tukey's test showed that, for all of the groups of crowns, mean values were significantly higher when measured subgingivally. Cmc crowns ( $P<.001$ ) showed a value of 3.78 when measured subgingivally and 2.54 when measured equigingivally. Hmc crowns ( $P<.001$ ) showed a value of 3.06 when measured subgingivally and 2.31 when measured equigingivally. Vmc crowns ( $P<.001$ ) showed a value of 3.65 when

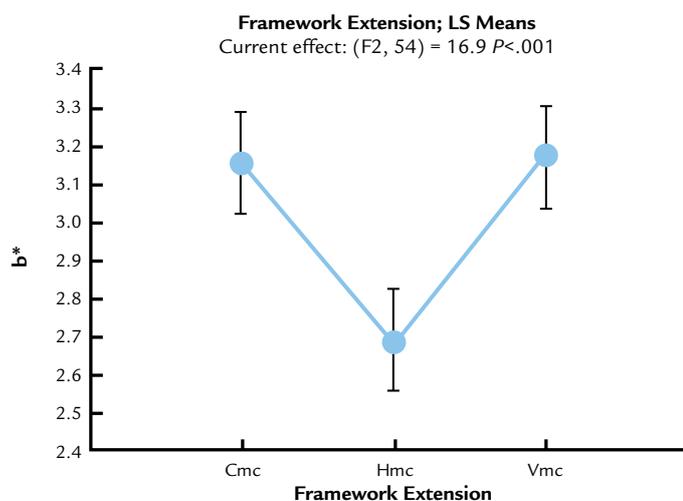
measured subgingivally and 2.7 when measured equigingivally (Fig. 6).

When considering  $b^*$  values, there were significant differences ( $P<.001$ ) among the different groups of crowns, with framework extension having the main effect (Table VI). Vmc crowns show higher values (13.3) than Cmc (12,  $P<.001$ ) and Hmc (11.9,  $P<.001$ ) crowns (Fig. 7). Considering  $b^*$  values in relation to framework extension and finish line location factors, no significant differences ( $P=.488$ ) were present (Table VI and Fig. 8).

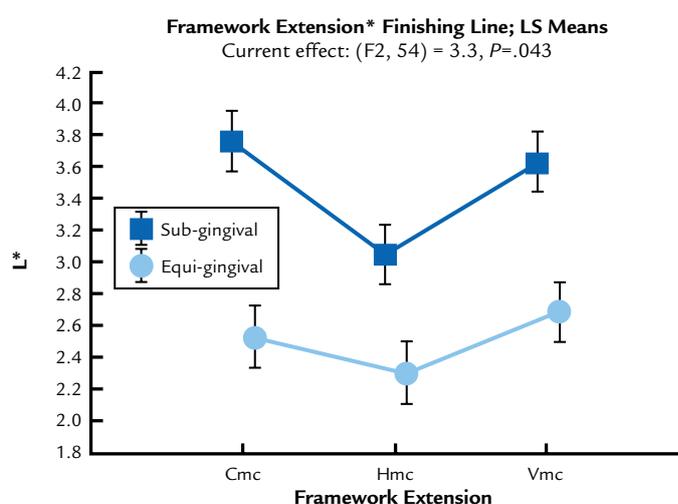
The  $\Delta E$  values among the groups of crowns are represented in Table VII. Evaluating subgingival groups of crowns, the base shade comparison between Cmc crowns (CST) and Vmc crowns (VST) showed  $\Delta E=1.15$ . The

**TABLE V.** Two-way ANOVA table for  $a^*$  value (main effects and interaction term)

Source	Sum of Squares	df	Mean Square	F	P
Framework extension	3.03	2	1.51	16.85	<.001
Finish line location	14.4	1	14.4	159.4	<.001
Framework extension x Finish line location	0.60	2	0.30	3.34	.04
Error	4.86	54	0.09		



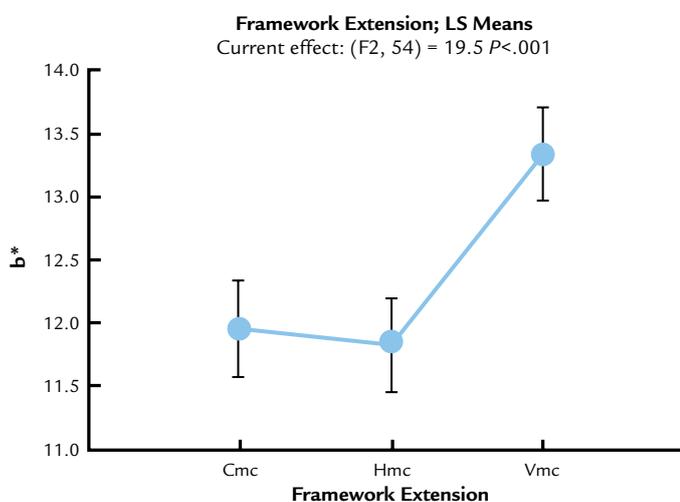
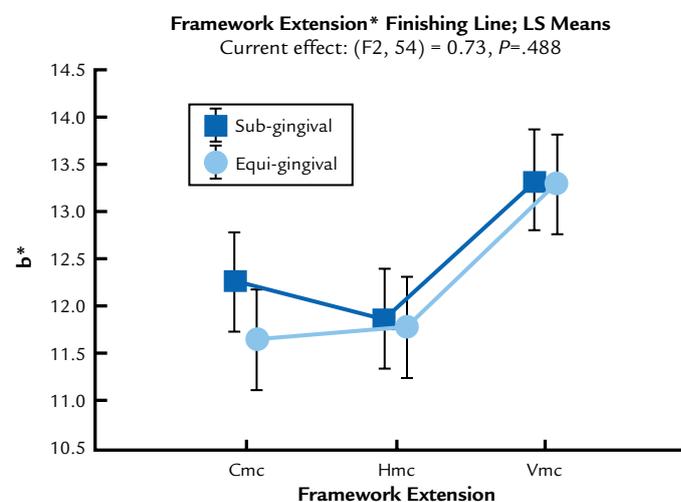
**5**  $a^*$  values in relation to framework extension factor.



**6**  $a^*$  values in relation to framework extension and finishing line location factors.

**TABLE VI.** Two-way ANOVA for  $b^*$  value (main effects and interaction term)

Source	Sum of Squares	df	Mean Square	F	P
Framework extension	27.1	2	13.6	19.53	<.001
Finish line location	0.89	1	0.89	1.28	.26
Framework extension × Finish line location	1.01	2	0.50	0.72	.48
Error	37.5	54	0.69		

**7**  $b^*$  values in relation to framework extension factor.**8**  $b^*$  values in relation to framework extension and finishing line location factors.**TABLE VII.**  $\Delta E$  values among different groups of crowns

---	CST	HST	VST	CET	HET	VET
CST	---	1.68	1.15	2.34	1.59	1.51
HST	1.68	---	1.90	0.70	1.28	1.93
VST	1.15	1.90	---	2.49	2.04	0.96
CET	2.34	0.70	2.49	---	1.47	2.34
HET	1.59	1.28	2.04	1.47	---	1.58
VET	1.51	1.93	0.96	2.34	1.58	---

same comparison performed equigingivally (CET vs. VET), found higher mean values ( $\Delta E=2.34$ ). Considering the color of each specific group of specimens, Vmc crowns showed  $\Delta E=0.96$  when comparing equigingival and subgingival groups, Hmc crowns showed  $\Delta E=1.28$ , and Cmc crowns showed  $\Delta E=2.34$  (Table VII).

## DISCUSSION

This study was designed to achieve a standardized evaluation of 3 different metal framework designs for the color of the cervical area of metal ceramic restorations. The goal was to understand whether the technical challenges of fabricating and managing a collarless metal ceramic restoration<sup>19, 21-24, 26-32</sup> were justified to achieve an improved esthetic result. The data support rejecting the null hypothesis that no color differences would be present in the cervical portion of single metal ceramic crowns fabricated with different metal framework designs.

In analyzing tooth color, the primary concern was to obtain clinically relevant results, and for this reason, the data obtained through the colorimetric measurement were related to the values reported in the literature. A natural tooth was not selected as a standard since previously completed *in vitro* research clearly showed significant color differences when comparing tooth structure to a metal ceramic restoration.<sup>33</sup> According to Johnston and Kao,<sup>44</sup> a  $\Delta E > 3.7$  indicates visually perceivable color differences which are clinically unacceptable. By using this threshold and comparing the groups with the most clinical relevance, no clinical differences were noted (Table VII). A similar comparison can be made to other recent clinical references.<sup>47</sup> Even if Johnston and Kao<sup>44</sup> is often cited in the literature, other values were considered for this *in vitro* study. According to Douglas and Brewer,<sup>45</sup> the threshold for acceptability is  $\Delta E=1.7$  and for perceptibility, 0.4. Several comparisons demon-

strated  $\Delta E$  to be lower than 1.7 (Table VII). Evaluating subgingival groups of crowns, excluding the first 0.5 mm coronal to the finish line (Fig. 2), the base shade comparison between Cmc crowns (CST) and Vmc crowns (VST) showed clinically acceptable results ( $\Delta E=1.15$ ). The same comparison performed equigingivally, including the most apical 0.5 mm (CET vs VET), found mean values above the limit of acceptability ( $\Delta E=2.34$ ). This result suggests that, when the shade of conventional metal ceramic crowns is analyzed, there is significant color impairment in the most apical 0.5 mm of the restoration. Furthermore, the color of the cervical portion of Vmc crowns is most consistent between the equigingival and subgingival groups ( $\Delta E=0.96$ ), while that of the Hmc crowns is moderate ( $\Delta E=1.28$ ), and that of the Cmc crowns is the worst ( $\Delta E=2.34$ ) (Table VII). The possible positive esthetic implication of the use of an additional millimeter of metal framework reduction was not tested in this study because of the increased fracture risk present with this type of restoration.<sup>25,27,28</sup>

Through the analysis of Lab\* values, a deeper understanding of the color differences and of influencing factors can be drawn (Figs. 3-8). Considering L\* values, Cmc crowns showed the highest value when equigingival (CET), the lowest when subgingival (CST), and the highest difference of values between equigingival and subgingival specimens (Figs. 3, 4). As discussed in the  $\Delta E$  analysis, this confirmed that significant color impairment occurs in the most apical 0.5 mm of the ceramic of metal ceramic crowns. In contrast, when analyzing Vmc crowns, the results were more consistent and the color also closer to that of natural teeth.<sup>43</sup>

Considering a\* values, consistent differences were present between equigingival (E) and subgingival (S) crowns. In general, equigingival crowns demonstrated lower values (Figs. 5 and 6). Among the different types of design, horizontal cutback

crowns (Hmc) showed lower values, indicating a color closer to that of natural teeth.<sup>43</sup>

Considering b\* values, equigingival and subgingival crowns showed similar b\* values, except for the analysis of Cmc crowns, which showed lower values when equigingival (Figs. 7, 8). In general, vertical cut-back crowns (Vmc) showed higher values, indicating a color closer to that of natural teeth.<sup>43</sup>

The use of a dental mannequin with a plastic gingival substitute allowed exclusion of portions of the crowns, creating 2 different groups of specimens, subgingival (S) and equigingival (E). However, the plastic gingiva did not replicate a clinical situation since it eliminated the impact of the crown on the soft tissue, whose color influences the final esthetic outcome. Similarly, this study did not consider the possibility of short-term or long-term tissue recession. The use of a different gingival substitute could help overcome these shortcomings in possible future research. Furthermore, considering the development of ceramic restorations, a similar study design could be used to evaluate core ceramic restorations.

## CONCLUSION

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

1. No significant differences in base shade were present among the investigated crowns.
2. Vertical cut-back crowns (Vmc) had a cervical shade which was more consistent and appeared to be more similar to that of a natural tooth.
3. Conventional metal ceramic crowns (Cmc) were characterized by significant color impairment in the most apical 0.5 mm of the ceramic.
4. Vertical cut-back crowns (Vmc) tended to have mean L\* and b\* values closer to those of natural teeth, while horizontal cut-back crowns (Hmc) tended to have closer mean a\* values.

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