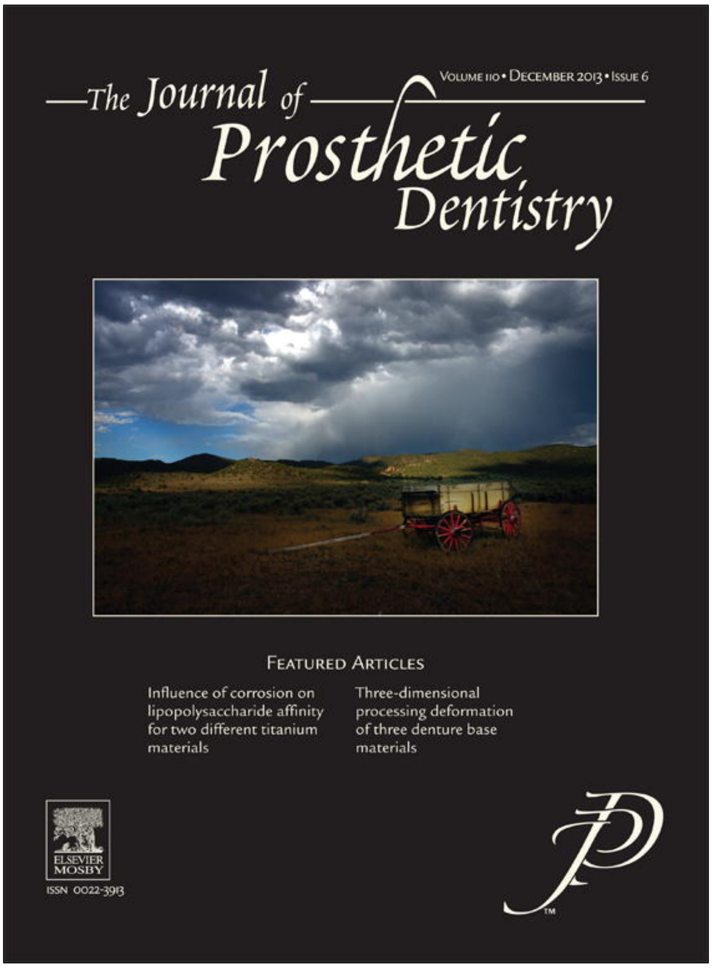
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Influence of coping design on the cervical color of ceramic crowns

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Statement of problem. The replication of natural teeth, especially with single-tooth restorations, represents a challenge. Similar to metal ceramic crowns, different designs of zirconia substructures have been suggested to improve the esthetic results of zirconia ceramic crowns.

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

Material and methods. The color, measured on the CIELAB color scale, of 3 different groups of restorations (n=10) fabricated with zirconia coping (Lava) and feldspathic porcelain (Noritake Super Porcelain) was analyzed with a spectrophotometer. Conventional zirconia crowns with zirconia facial margins were compared with ceramic crowns with porcelain facial margins and either a horizontal reduction of the zirconia coping (1.0 mm reduction) or an additional vertical reduction (1.0 mm additional reduction). The 3 groups, each with a different coping extension, were examined with a 1-way ANOVA and the Fisher exact test, and the differences of the groups were evaluated by applying ΔE thresholds (α=.05).

Results. The mean color difference among all the groups was not clinically significant ($\Delta E<3.7$). Reduced color differences were present between the 2 porcelain butt margin groups of crowns ($\Delta E=1.06$, between group H and V). Increased differences were present between the zirconia margin group and the porcelain butt margin group ($\Delta E=2.54$ between group C and H; $\Delta E=2.41$ between group C and V). Lab* values were examined in all the groups of crowns to determine the clinical implications.

Conclusions. Within the limitation of the study, no significant differences were present among the tested groups of crowns. Nevertheless, although some differences were present between the zirconia margin group and the porcelain butt margin group, reduced differences were present between the 2 different cutback designs. (J Prosthet Dent 2013;110:494-500)

Clinical Implications

If zirconia is selected to fabricate the supporting coping for a crown in the esthetic zone, a facial vertical cutback is not necessary. However, a horizontal reduction of the facial zirconia coping provides an improved esthetic result, even if no significant clinical differences are present with the conventional coping design.

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The replication of natural teeth with single restorations in patients with high esthetic demands represents a challenge for dentists.[1-3] The reproduction of the color of the cervical portion is more challenging because a thinner layer of material must be used to prevent harm to the pulpal tissue or interference with the proper emergence profile.[4,5] Shade is a crucial factor because the color of a restoration should be indistinguishable from that of the adjacent teeth.[6] The color of a restoration is determined by the core materials,[7-9] porcelain thickness, and fabrication process,[10-12] and by surface properties such as texture.[13] Furthermore, the shade is influenced by other factors, for example, the prepared tooth color,[14] thickness and color of the luting agent,[15] soft-tissue color,[16] lighting conditions,[17,18] and shade determination systems.[19,20]

One of the objective methods of evaluating color in dentistry is through colorimetric or spectrophotometric analysis.[21-27] These instruments use the CIELAB color scale, which determines tooth color in 3 dimensions: the black/white (L* value), green/red (a* value), and yellow/blue (b* value) dimensions.[28] In an in vitro study, the distribution of color was identified for the cervical portion of teeth with mean Lab* values of 72.6, 1.5, and 18.4, respectively.[29] The most commonly used method for evaluating color differences among different specimens is through ΔL*, Δa*, and Δb*. Their combination is described as the color difference (ΔE), which is determined by the following equation: $\Delta E=([\Delta L^*]^2+[\Delta a^*]^2+[\Delta b^*]^2)^{1/2}$. The final goal in achieving an accurate color match is to obtain the smallest possible ΔE value.[21] The correlation between ΔE and clinical observation was analyzed in an in vivo study of patients 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.[30] The analysis of metal ceramic crowns showed different results. Thresholds for acceptability were reduced to ΔE=1.7, and perceptibility was reduced to ΔE=0.4. In addition, observers were more sensitive to crowns whose color differed on the red scale (Δa*) rather than crowns whose color differed to the same extent on the yellow scale (Δb*).[31] More recently, different thresholds for perceptibility ($\Delta E<2.6$) and acceptability ($\Delta E<5.5$) were described in a clinical setting and used in experimental research.[32,33] All of these studies have been conducted in vitro with a colorimeter or a spectrophotometer and are commonly considered as references for dental researchers when measuring intraoral tooth color.[25,27,31-33]

The demand for improved dental esthetics with adequate biocompatibility has made ceramic crowns a popular type of restoration. Ceramic systems are chosen because they are better able to match the optical properties of the natural tooth.[34,35] Over the years, different ceramic systems have been developed with different materials and different fabrication techniques. Most ceramics are fabricated with translucent veneering ceramic and an opaque core ceramic, the color of which significantly influences the color of the definitive restoration.[14,36,37] Zirconia is often considered the material of choice because of its mechanical properties, but it has high opacity as a result of its density, elemental chemistry, and high crystallinity.[38] The esthetic properties of dental zirconia have been improved through infiltration, thinner coping thickness, different liner color, grain size, and veneering technique.[9,39-44]

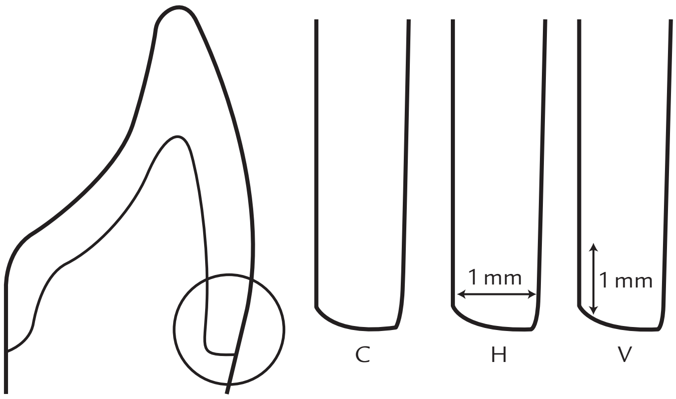
With metal ceramic crowns, a framework reduction from the finishing line increased the light transmission and eliminated the opaquing effect of the metal and opaque porcelain in the cervical region. Results of recent studies confirmed that the metal framework should be cut back a minimum of 2 mm from the shoulder to avoid a color mismatch.[45-47]

The purpose of this study was to compare, through spectrophotometric digital technology, the color of the cervical portion of single ceramic crowns fabricated with different zirconia coping designs. The conventional design with zirconia butt margins (extended until the finishing line) were compared with collarless ceramic crowns fabricated with different coping extensions. The null hypothesis for the study was that no difference would be observed in the color of the cervical portion of single ceramic crowns fabricated with different zirconia coping designs.

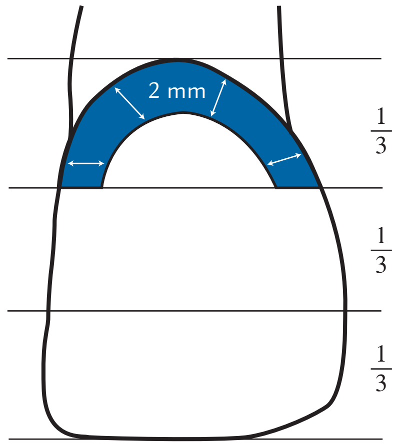
MATERIAL AND METHODS

The color of 3 different groups of restorations (n=10) fabricated with a different design of zirconia coping (Lava; 3M ESPE) and feldspathic porcelain, (Cerabien ZR, Noritake Dental Ceramic; Noritake Co) was measured with a spectrophotometer (Spectroshade Micro Device; MHT S.p.A., Medical High Technologies). The sample size was selected according to previously published studies.[36] The conventional ceramic crowns with a thin zirconia margin (group C) were compared with ceramic crowns with 2 different coping designs of feldspathic porcelain facial margin. The first group had a horizontal reduction of the zirconia coping (group H, 1.0-mm horizontal reduction), and the second had an additional vertical reduction (group V, 1.0-mm vertical reduction) (Fig. 1).

The method used was similar to that described in previous research by the authors regarding the color of the cervical portion of metal ceramic crowns.[47] One extracted, human, intact maxillary central incisor was prepared for all of the crowns. The facial reduction was approximately 1.5 mm and followed the depth of a rounded shoulder finishing line of the same depth. The margin was positioned at the cement-enamel junction, and 2.0 mm of incisal reduction was performed. Throughout the study, the tooth was



1 Different designs of zirconia coping tested. Conventional zirconia-ceramic (C), zirconia-ceramic crowns with horizontal facial reduction of the zirconia coping (H), zirconia-ceramic crowns with additional vertical facial reduction of zirconia coping (V).



2 Selected cervical region of crowns measured with spectrophotometer.

kept in a solution of 0.05% thymol and distilled water. The prepared tooth was duplicated with a polyvinyl siloxane impression material (Capsil; Aquatrols Corp of America). Type IV dental stone (New Fuji-Rock; GC Corp) was used to fabricate the 30 dies, each corresponded to a single crown. Digital technology was used to fabricate each single coping with an even thickness of 0.3 mm (Lava Scan ST Design System; 3M ESPE). For the conventional margin design, C, the zirconia coping remained extended to the preparation finish line (Fig. 1). For the crowns in group H, the cervical margin of the zirconia coping was reduced at the axiocervical line angle at a distance of approximately 1 mm from the finishing line; this reduction was made on the facial and interproximal margin, which left 150 degrees of coping exposure on the lingual side of the crown. For group V crowns, an additional 1.0 mm was added to the vertical reduction of the coping.

Dental porcelain (Cerabien ZR, Noritake Dental Ceramic; Noritake 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). One layer of shade base stain was applied to the entire coping. For groups V and H, 2 applications of margin porcelain were placed to achieve adequate marginal integrity. The thickness of the feldspathic porcelain for the butt margin was reduced to the minimum possible and then 2 layers of dentin porcelain were applied to all of the groups to achieve proper contour and were thinned to a cervical thickness of 1.4 mm. Enamel porcelain was finally applied over the dentin porcelain to achieve a proper definitive crown contour with a 1.5-mm thickness at the cervical area. All the specimens were autoglazed according to the manufacturer's recommendations. A caliper (Iwanson Decimal Caliper; Asa Dental spa) with an accuracy of 0.05 mm was used to measure and adjust the final thicknesses, which are reported in Table I. One technician performed all of the laboratory procedures.

The color of the cervical region of the crowns, which were positioned on a prepared maxillary central incisor, was measured with a spectrophotometer with a reading area of 18×14 mm (Spectroshade Micro Device; MHT S.p.A.). All of the measurements were performed in a dental mannequin (KaVo) with the margin of the restoration positioned at the gingival level, as performed in a previous study[36] (Fig. 2). To achieve the repeatability of the measurements, the position of the tooth and the measuring instrument were standardized with a custom-positioning

TABLE I. Type and thickness of materials used for crowns

Crown Layer	Materials (manufacturer)	Cervical Thickness (mm)
Coping	Zirconia (Lava, 3M ESPE)	0.3
Base	Shade Base Stain (SSA1, Noritake Cerabien ZR)	0.1
Dentin porcelain	Feldspathic porcelain (A1B, Noritake Cerabien ZR)	1.0
Enamel porcelain	Feldspathic porcelain (E2, Noritake Cerabien ZR)	0.1
Porcelain for butt margin	Feldspathic porcelain (MA1, Noritake Cerabien ZR)	Minimal achievable
Cement medium	Translucent cement (Variolink II, trial-base, Ivoclar Vivadent AG)	Thin layer

device. Each measurement was performed 5 times to reduce measurement error. Because natural teeth are usually in a wet environment, all measurements were made with moist specimens. All of the crowns were measured after the application of transparent cement medium try-in paste (Variolink II, trial-base; Ivoclar Vivadent AG). Porcelain layer thicknesses and measurement conditions for each of the experimental margins are summarized in Tables I and II. Three experimental groups were evaluated in the study.

On the computer screen, the selected cervical portion of the teeth was outlined by using a transparent custom-made plastic template, which was fabricated to identify the different tooth portions. A 4-mm length was considered to represent the cervical portion because the initial length of the tooth before preparation was approximately 12 mm, and a standardized area of approximately 2 mm from the gingival level was selected in the cervical portion (Fig. 2). The measurements were recorded in CIELAB coordinates. The color difference between each combination of experimental groups was determined with the following equation: $\Delta E = ([\Delta L^*]^2 + [\Delta a^*]^2 + [\Delta b^*]^2)^{½}$,[35,37] calculated from the mean values of L*, a*, and b*. The ΔE values were related to those reported in the literature.[9,44]

One-way ANOVA was calculated for each CIELAB coordinate (L*, a*, and b* values) to show if the framework extension factor had a significant impact on the values of each coordinate. The 3 groups, each with a different coping extension, were examined with 1-way ANOVA and the Fisher exact test. The differences among the groups were evaluated by applying ΔE thresholds (α=.05).

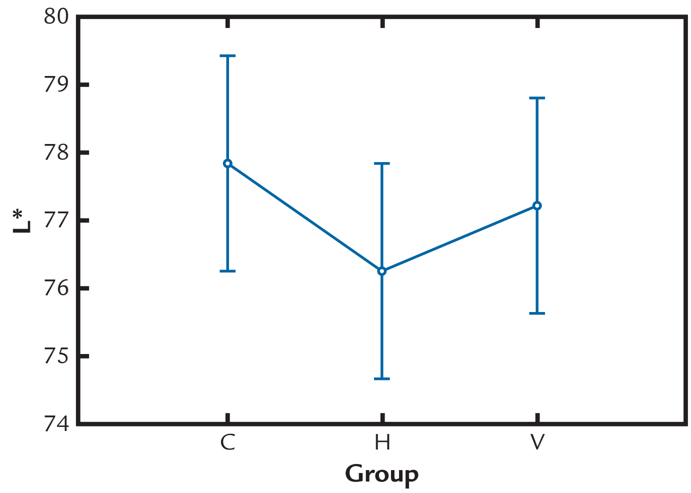
Table II. Groups analyzed in relation to coping extension (3 groups of specimens, n=30)

Specimen Group	Coping Extension
C	Finish line
H	1-mm horizontal reduction, (axiocervical line angle)
V	1-mm additional vertical reduction

Table III. Groups analyzed in relation to coping extension (3 groups of specimens)

	L*		a*		b*	
Group	Mean Values	SD	Mean Values	SD	Mean Values	SD
C	77.84	0.72	2.24	0.29	15.32	0.28
H	76.23	9.93	2.54	0.16	17.26	0.43
V	77.23	0.76	2.66	0.12	17.62	0.56
All groups	77.10	5.76	2.48	0.27	16.73	1.10

L*, black/white; a*, green/red; b*, yellow/blue; SD, standard deviation.



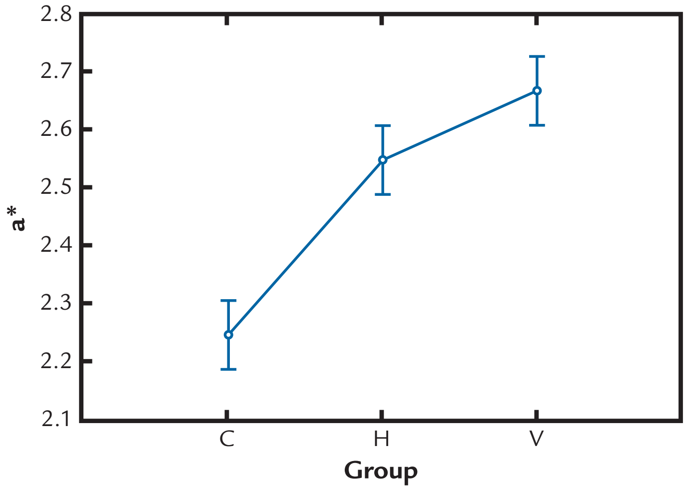
3 L* values among tested group of crowns. Current effect: F(2, 147)=0.99, *P* =.37.

RESULTS

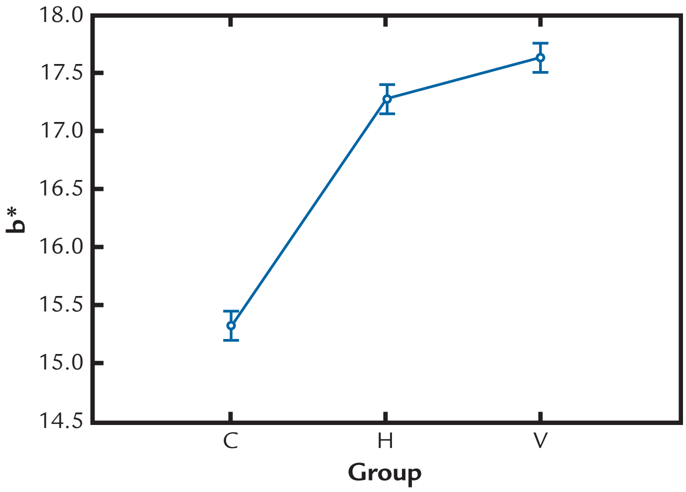
The mean L*, a*, and b* values are presented in Table III. The 1-way ANOVA showed no significant differences (P=.372; $d.f._N$=2, $d.f._D$=147) in L* values among the different groups of crowns. The mean L* value for group C (77.84) was similar to the mean value for group H (76.23) and group V (77.23) (Fig. 3).

Significant differences in a* values (P<.001; $d.f._N$=2; $d.f._D$=147) were noted among the different groups of crowns. Crowns in group C showed lower a* values (2.24) than crowns in group H (2.54) or crowns in group V (2.66). The post hoc Bonferroni test revealed significant differences between group C and group H (P<.001), between group C and group V (P<.001), and between group H and group V (P=.015) (Fig. 4).

Significant differences (P<.001; $d.f._N$=2; $d.f._D$=147) in b* values were noted among the different groups of crowns. Crowns in group C showed lower b* values (15.53) than crowns in group H (17.26) and crowns in group V (17.62). The post hoc Bonferroni test revealed significant differences between group C and group H (P<.001),



4 a* values among tested groups of crowns. Current effect: F(2, 147)=54.35, $P \leq .001$.



5 b* values among tested groups of crowns. Current effect: F(2, 147)=386.09, $P < .001$.

TABLE IV. ΔE values among different groups of crowns

Group	Group C	Group H	Group V
C		2.54	2.41
H	2.54		1.06
V	2.41	1.06	

between group C and group V ($P<.001$), and between group H and group V ($P<.001$) (Fig. 5).

The ΔE values among the groups of crowns are represented in Table IV. Reduced clinically significant color differences were present between the 2 porcelain butt margin groups of crowns (ΔE=1.06 between groups H and V). Increased differences were present between the zirconia margin and porcelain butt margin groups (ΔE=2.54 between groups C and H; ΔE=2.41 between groups C and V) (Table IV).

DISCUSSION

This study was designed to achieve a standardized evaluation of 3 different zirconia coping designs for the color of the cervical area of ceramic restorations. The aim of the study was to understand whether the technical challenges of fabricating and managing collarless zirconia ceramic restorations were justified by an improved esthetic result.[1,45] Analysis of the data supports rejecting the null hypothesis that no color differences would be present in the cervical portion of single ceramic crowns fabricated with different zirconia coping designs.

The primary concern was to obtain clinically relevant results, and, for this reason, the data obtained through the spectrophotometric measurement were related to the values previously reported in the literature. A natural tooth was not selected as a standard because in vitro research clearly showed significant color differences when teeth were compared with ceramic.[46] According to Johnston and Kao,[30] a ΔE>3.7 indicates visually perceivable color differences that are clinically unacceptable. According to this threshold, no clinical differences were noted among the 3 groups (Table IV). Even if the research by Johnston and Kao[30] is often cited in the literature, it was not designed to determine thresholds. According to Douglas and Brewer,[31] the threshold for acceptability is ΔE=1.7.

Color differences below this threshold were present between the 2 porcelain butt margin groups of crowns (ΔE=1.06 between groups H and V). Therefore, an additional 1 mm of vertical cutback of the zirconia coping does not appear necessary. However, increased differences, with values higher than the thresholds for acceptability, were present between the zirconia margin and the porcelain butt margin groups (ΔE=2.54 between groups C and H; ΔE=2.41 between groups C and V). Reducing the facial zirconia coping to have a porcelain butt margin appears to be clinically significant, but an additional vertical reduction is not necessary because these 2 designs appear very similar. Because these thresholds have been concluded from an in vitro study, some limitations should be considered, For example, if the lighting is not perfect, then, most probably, different thresholds can be expected.

For this reason, the thresholds presented by Douglas et al[33] in 2007 should be considered as the most relevant in a clinical setting. According to their article, the threshold for perceptibility was $\Delta E<2.6$ and, for acceptability, was $\Delta E<5.5$. By using this article as a reference, no obvious mismatch was present among the crowns, and also, at the threshold for perceptibility of 2.6, all types of crowns tested in the present study appeared to be similar, with reduced ΔE values. Nevertheless, the correlation between the 2 porcelain butt margin groups of crowns (groups H and V) and the conventional group of crowns (group C) was much closer to the threshold for perceptibility.

When analyzing the L*a*b* values, some understanding of the color differences can be had (Table III) even if limitation are present. The L* values of crowns in group H showed the highest value, which appeared to be closer to the reported values of natural teeth.[29] The a* values of crowns in group C showed lower values, which indicated a color that appeared to be closer to that of natural teeth.[29] The b* values of crowns in group V and group H showed higher values, which indicated a color closer to that of natural teeth.[29] Nevertheless, these differences were not statistically different and, therefore, may not be clinically significant. In addition, the coordinates of the color of natural teeth have been determined from different studies and with different instruments, and so clinically acceptable conclusions cannot be drawn. In future studies, a comparison to a target tooth or restoration should be made.

In addition, the use of a dental mannequin with plastic gingiva did not replicate an actual clinical situation because it eliminated the effect of the crown on the soft-tissue color. Similarly, this study did not consider the possibility of short-term or long-term tissue recession. The use of a different gingival substitute could overcome these shortcomings in possible future research.

The shade of the coping before porcelain application was considered as standardized for all the groups. Nevertheless, because it was not verified through spectrophotometer evaluation, this aspect can be considered as a possible source of confounding variability. In addition, with the development of ceramic restorations, a similar study design could be used for lithium disilicate restorations or other newly developed types of 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 margin design groups.

2. Reduced clinical differences in the cervical base shade were present between the porcelain butt margin groups of crowns (H and V), and the zirconia margin group of crowns (C) presented higher differences from the other 2 groups.

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