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Original Article

Effects of different surface treatments on the color stability of various dental porcelains[†]

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Abstract *Background/purpose:* There is a lack of information in the few studies reporting on the stainability of dental porcelain materials. However no studies have been found that investigated effects of polishing methods and staining agents on the color stability of dental porcelains. The purpose of this study was to evaluate the effects of different polishing techniques on the color stability of various dental porcelains.

Materials and methods: Fifty-five specimens were prepared for each of feldspathic (Vita VMK 95, Ceramco III), low-fusing porcelain (Matchmaker), and machinable feldspathic porcelain blocks (Vitablocs Mark II). The prepared specimens were divided into 11 groups ($n = 5$) representing different polishing techniques including a control (no surface treatment), glaze, and nine other groups which were finished and polished with a polishing disc (Sof-Lex), two porcelain polishing kits (NTI, Dialite II), a diamond polishing paste (Sparkle), a zirconium silicate-based cleaning and polishing prophy paste (Zircate), an aluminum oxide polishing paste (Prisma Gloss), and combinations of these. Specimens were stored for 48 hours at 37°C in a coffee solution. The color of all specimens was measured with a colorimeter before and after exposure, and color changes (ΔE) were calculated. Data were analyzed with a two-way analysis of variance, and mean values were compared by the Tukey's honest significant difference test ($\alpha = 0.05$).

Results: When comparing the four different porcelain materials, Ceramco III demonstrated the highest ΔE value. No significant difference was observed among the porcelain material groups of Mark II, Matchmaker MC, and VMK 95 ($P = 0.074$). When comparing the polishing techniques, the lowest ΔE values were observed in Group Gl for all porcelain materials tested. No significant difference was observed among Groups Sl, Di, and Pk, ($P = 0.883$), and these Groups demonstrated significantly higher ΔE values than Group Gl ($P < 0.05$).

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Conclusions: Within the limitations of this study, the results suggest that feldspathic and low-fusing porcelain specimens were found to be more color-stable for glazed specimens versus polished specimens regardless of whether they were stained with the coffee solution. Glazed and polished specimens with different polishing materials demonstrated that the ΔE values were at an acceptable level for all of the porcelain materials tested ($1 < \Delta E < 3.7$).

Introduction

Porcelain has became an important material in restorative dentistry because of its advantages of biocompatibility, longevity, durability, and excellent esthetic capabilities with long-term use.[1–4] The translucency, color, and intensity properties of porcelain materials resemble those of natural teeth.[1,4] Thus, healthy living restorations can be created with a glazed-porcelain surface texture which has the appearance of individual teeth.

On occasion, porcelain restorations require adjustment, so the glazed surface of the porcelain may be broken. An unglazed porcelain surface can cause gingival irritation,[5] plaque accumulation,[5,6] increased surface staining,[5] and excessive wear of the opposing dentition.[1,6–8] The roughened surface must be reglazed or polished.[4,6,8] Several studies on finishing and polishing dental ceramics were published, but there are lack of studies investigating the effectiveness of different polishing techniques for newer types of dental porcelains, such as Mark II porcelain blocks.

Since the final occlusal adjustment of a ceramic restoration must be made after cementation, there is always a need for careful intra-oral polishing of the surfaces. As a glazed surface is considered ideal, minor alterations to the porcelain surface can be corrected by polishing instead of reglazing in clinical situations.[1,4,5]

The resistance to staining is considered an important clinical criteria in evaluating a new porcelain.[9] A subjective method of evaluation was included in the American Dental Association (ADA) specification no. 69 for dental porcelains for all ceramic restorations.[10]

Color measurements using a colorimeter provide consistent color evaluations.[11] Colorimeters often report color using the Commission Internationale de'lEclairage (CIE) Lab Color System, which is a method developed in 1978 by the CIE for characterizing color based on human perception.[2,12,13] The CIE Lab color system introduces three attributes to the perception of color: L^*, $a*$, and $b*$. $L*$ refers to the lightness variable and is proportional to values in the Munsell Color System.[2,14,15] $a*$ and $b*$ are chromaticity coordinates, wherein 'a' corresponds to the red–green axis, whereas 'b' refers to the yellow–blue axis. Although they do not serve as direct correlates to hue and chroma, the respective numerals serve to determine numeric correlates for these attributes. A positive $a*$ value relates to the amount of redness whereas a negative $a*$ value relates to the amount of greenness of a particular color. Conversely, a positive $b*$ value corresponds to the yellowness of an object, whereas a negative $b*$ value corresponds to the amount of blueness.

The CIE Lab system for measuring chromacity was chosen for the present study to record color differences, as it is well suited for determining small color differences.[11]

The quantitative evaluation of color differences (ΔE) with a colorimeter has advantages such as repeatability, sensitivity, and objectivitiy, despite some limitations.[2,11] In principle, if a material is completely color-stable or unstained by colorations, no color difference will be detected after its exposure to the test environment ($\Delta E = 0$). Various studies reported different thresholds of color difference values above which the color change is perceptible and acceptable to the human eye.[2,16,17] A ΔE value of ≤ 3.7 is considered visually imperceptible and clinically acceptable.[16,17]

Most existing studies on the color of porcelain materials were concerned with the effects of repeated firings, aging, and the thickness of opaque and dentin porcelains.[3,18–20] Effects of staining agents on color stability were investigated with an excess of composite resin materials.[21] There is a lack of information in the few studies reporting on the stainability of dental porcelain materials. However no studies have been found that the investigated effects of different polishing methods and a staining agent on the color of dental porcelains.

The purpose of this *in vitro* study was to evaluate the stainability of feldspathic and low-fusing porcelain materials, to which were applied glaze and different polishing techniques and their combinations on exposure to coffee. The hypothesis for this study was that the stainability of different porcelain materials is related to the application of different polishing techniques.

Materials and methods

In the present study, four commonly used and commercially available specimen types of dental porcelains were investigated. The porcelains and polishing materials used in this study are described in Table 1. Fifty-five cylindrical specimens (15 × 2 mm) were prepared for each feldspathic and low-fusing dental porcelains by a single investigator who condensed the porcelains into a polyvinyl siloxane mold in a standardized manner.[22] After each specimen was mixed using the same amount of porcelain and liquid, placed into the mold, and compressed with a plastic plunger, the excess moisture was absorbed using a tissue (Selpak, Eczacıbaşı Group, Kocaeli, Turkey). After removal from the mold, specimens were fired in a furnace (Programat P80, Ivoclar-Vivadent, Schaan, Liechtenstein) according to the manufacturer's directions (approximately 920–960°C).

Fifty-five specimens of machinable feldspathic porcelain blocks (12 × 14 × 18 mm) were cut into slices with a thickness of 2 mm (2 × 12 × 14 mm) with a low-speed saw (Isomet Low Speed Saw, Buehler Ltd., Lake. Bluff, IL, USA). All ceramic discs were wet-ground with 600-grit silicon

Table 1 Materials used in this study.

Material type	Product	Manufacturer
Feldspathic porcelain	VMK 95	Vita Zahnfabrik, Bad Sackingen, Germany
Feldspathic porcelain	Ceramco III	Degudent GmbH, USA
Low-fusing porcelain	Matchmaker MC	Schottlander, UK
Feldspathic porcelain blocks	Vitablocs Mark II	Vita Zahnfabrik, Germany
Finishing and polishing disc	Sof- Lex	3M ESPE, St. Paul, MN, USA
Porcelain polishing kit	NTI CeraGlaze	NTI- Kahla GmbH, Kahla, Germany
Porcelain polishing kit	Dialite II	Brasseler USA, Savannah, GA
Diamond polishing paste	Sparkle	Pulpdent Corporation, Watertown, MA, USA
Zirconium silicate cleaning- polishing prophy paste	Zircate	Dentsply Int. Inc., DE, USA
Aluminum oxide polishing paste	Prisma Gloss	Dentsply Int. Inc., DE, USA

carbide sandpaper for 10 seconds on a 300-rpm grinding machine (Buehler Metaserv, Buehler, Germany).

The prepared specimens were randomly divided into 11 Groups of 5 specimens in each group for the different polishing techniques. The polishing procedure was carried out by a single single investigator, and the different polishing groups are described in Table 2. Group C specimens with no polishing procedure applied served as the control group. Group Gl specimens were glazed using a specific glaze medium for each one. Group Sl specimens were polished with a series of 12.7-mm-diameter polishing discs (Sof-Lex, 3M ESPE, St. Paul, MN, USA) on an electric handpiece at a speed of 10,000 rpm for 10 seconds with coarse and medium discs and at a speed of 30,000 rpm for 10 seconds with fine and superfine discs according to the manufacturer's directions. Group Pk specimens were polished with an NTI CeraGlaze polishing kit (NTI- Kahla GmbH, Kahla, Germany) on an electric handpiece at 15,000 rpm for 10 seconds with a pre-polishing wheel, at 10,000 rpm for 10 seconds with a refined finishing wheel, and at 5000 rpm for 10 seconds with a high-shine polishing wheel according to manufacturer's directions. Group Di specimens were polished with a Dialite II porcelain polishing kit (Brasseler USA, Savannah, GA) including pre-, fine-, and high-shine wheels on an electric handpiece at 10,000 rpm for 10 seconds according to the manufacturer's directions. In Group Sp specimens, Sparkle diamond polishing paste (Pulpdent Corporation, Watertown, MA, USA) was applied with a prophylactic cup (Kenda Polishers, Kenda AG, Schaan, Liechtenstein) on an electric handpiece at 15,000 rpm for 10 seconds. In Group Zr specimens, Zircate zirconium silicate cleaning-prophy paste (Dentsply Int. Inc., DE, USA) was applied with a prophylactic cup (Kenda Polishers, Kenda AG) on an electric handpiece at 15,000 rpm for 10 seconds. In Group Pg specimens, Prisma Gloss aluminum oxide polishing paste (Dentsply Int. Inc., DE, USA) was applied with a prophylactic cup (Kenda Polishers, Kenda AG) on an electric handpiece at 15,000 rpm for 10 seconds. Group SlSp specimens were polished as in Group Sl, and diamond polishing paste was applied as described for Group Sp. Group SlZr specimens were polished as in Group Sl, and zirconium silicate cleaning-prophy paste was applied as described for Group Zr. Group SlPg specimens were polished as in Group Sl, and aluminum oxide polishing paste was applied as described for Group Pg. The specimens were then ultrasonically cleaned (Eurosonic Energy, Euronda, Italy) with deionized water for 10 minutes and dried.

Table 2 Polishing methods.

Group	Polishing techniques
Group- C	Control (no surface treatment)
Group- Gl	Glaze
Group- Sl	Sof- Lex
Group- Pk	NTI CeraGlaze Polishing kit
Group- Di	Dialite II
Group- Sp	Sparkle
Group- Zr	Zircate
Group- Pg	Prisma Gloss
Group- SlSp	Sof- Lex+ Sparkle
Group- SlZr	Sof- Lex+ Zircate
Group- SlPg	Sof- Lex+ Prisma Gloss

Colorimetric measurements

Before exposure to the staining agent (coffee), baseline color measurements of all specimens were recorded with a colorimeter (Minolta CR-300, Minolta, Osaka, Japan) using CIE[11,12,16] L∗, a∗, and b∗ values relative to a standard illuminant A against a white background. L∗ refers to the lightness coordinate with values ranging from 0 (black) to 100 (white). Values of a∗ and b∗ are chromaticity coordinates in the red—green and the yellow—blue axes, respectively. Positive a∗ values indicate a shift to red, and negative values indicate a shift to green. Similarly, positive b∗ values indicate a yellow color range, and negative values indicate a blue color range. The colorimeter has a measuring head that uses a 45° illumination and 0° viewing angle geometry for color measurements of glossy surfaces, with light provided by a pulsed xenon arc lamp over a measuring area of 8 mm. To position the tip of the colorimeter in the same location on each specimen, a polytetrafluoroethylene mold was prepared. The colorimeter was calibrated according to the manufacturer's instructions, before each measurement period. Measurements were repeated 3 times for each specimen, and the mean values of L∗, a∗, and b∗ data were calculated. After baseline color measurements were made, specimens were stored in 100 ml of coffee (Nescafe Classic; Nestlé Suisse SA, Vevey, Switzerland) for 48 hours at 37°C [21]. The coffee

(3.6 g) was dissolved in 300 ml of boiling distilled water according to the manufacturer's suggested concentration. After 10 minutes of stirring, the solution was filtered through filter paper.

After 48 hours in the coffee solution, specimens were rinsed with distilled water for 5 minutes and blotted-dry with tissue paper before the color measurement.[21] At this point, color readings were made using the colorimeter in the same manner described for the baseline readings. Calculation of the color variation, ΔE, between the two color measurements (baseline and after 48 hours of storage) in the three-dimensional (3D) $L* a* b*$ color space was as follows:[12,14]

$$\Delta E = \left[(L_1^* - L_0^*)^2 + (a_1^* - a_0^*)^2 + (b_1^* - b_0^*)^2 \right]^{1/2}.$$

A standard two-way analysis of variance (ANOVA) method using statistical software (SPSS for Windows, vers. 12.0.1, Chicago, IL, USA) was used to evaluate the effect of material type and surface polishing procedure on the color change, including the possibility of interactions between the two factors. Mean values were then compared by Tukey's honest significant difference (HSD) test ($\alpha = 0.05$).

Results

According to the ANOVA results, porcelain materials, surface polishing procedures, and their interactions were statistically significant ($P < 0.05$) (Table 3). Mean values and standard deviations (SDs) of color changes and group differences (ΔE) of the feldspathic porcelain materials (Vita VMK 95, Ceramco III), low-fusing porcelain material (Matchmaker MC), and feldspathic porcelain blocs (Vitablocs Mark II) are respectively given in Tables 4–7.

For the VMK 95 feldspathic porcelain material groups, the lowest color difference (ΔE) value was observed in Group Gl (0.916) which significantly differed from the other groups ($P = 1.000$). The highest ΔE values in the VMK 95 porcelain material groups were observed in Groups SlZr (1.924), Sp (1.986), Pg (2.024), SlSp (2.024), SlPg (2.030), and Zr (2.094), which did not significantly differ from each other ($P = 0.155$). Differences among the VMK 95 feldspathic porcelain material groups are given in Table 4.

For the Ceramco III feldspathic porcelain material groups, the lowest color difference (ΔE) value was observed in Group Gl (1.022) which significantly differed from the other groups ($P = 1.000$). The highest ΔE values for the Ceramco III feldspathic porcelain material groups were observed in Groups SlSp (2.004), SlZr (2.038), SlPg (2.050), Pg (2.112), Sp (2.128), and Zr (2.142), which did not significantly differ from each other ($P = 0.202$). Differences among Ceramco III feldspathic porcelain material groups are given in Table 5.

For the low-fusing porcelain material groups (Matchmaker MC), the lowest color difference (ΔE) value was observed in Group Gl (0.972) which significantly differed from the other groups ($P = 1.000$). The highest ΔE values in the Matchmaker MC porcelain material groups were observed in Groups SlPg (2.088), SlSp (2.102), Zr (2.102), and SlZr (2.182), which did not significantly differ from each other ($P = 0.982$). Differences among Matchmaker MC porcelain material groups are given in Table 6.

For the feldspathic porcelain block groups (Mark II), the lowest color difference (ΔE) value was observed in Group Gl (0.912) which significantly differed from the other groups ($P = 1.000$). The highest ΔE values in the Mark II porcelain material groups were observed in Groups C (1.880), Zr (1.976), SlSp (1.982), SlPg (1.988), Pg (2.006), and SlZr (2.094), which did not significantly differ from each other ($P = 0.098$). Differences among Mark II porcelain material groups are given in Table 7.

Table 3 Two-way ANOVA for porcelain materials and different polishing techniques.

Variable (source)	df	Sum of squares	Mean squares	F	P
Polishing technique	10	20.741	2.074	194.793	0.000*
Porcelain	3	0.484	0.161	15.150	0.000*
Interaction	30	1.060	0.035	3.318	0.000*
Error	176	1.874	0.011		

* Significant difference at $P < 0.05$.

Table 4 Mean (SD) of color changes (ΔE) and differences between groups for Vita VMK 95.

Group	ΔE	Difference*
C	1.848 (0.08)	b, c, d
Gl	0.916 (0.08)	a
Sl	1.682 (0.11)	b
Pk	1.792 (0.60)	b, c
Di	1.666 (0.07)	b
Sp	1.986 (0.10)	c, d, e
Zr	2.094 (0.05)	e
Pg	2.024 (0.11)	d, e
SlSp	2.024 (0.10)	d, e
SlZr	1.924 (0.12)	c, d, e
SlPg	2.030 (0.11)	d, e

* Different letters indicate significantly different groups ($P < 0.05$).

Table 5 Mean (SD) of color changes (ΔE) and differences between groups for Ceramco III.

Group	ΔE	Difference*
C	1.810 (0.07)	b
Gl	1.022 (0.11)	a
Sl	1.866 (0.99)	b, c
Pk	1.960 (0.09)	b, c, d, e
Di	1.882 (0.06)	b, c, d
Sp	2.128 (0.04)	e, f
Zr	2.142 (0.04)	f
Pg	2.112 (0.10)	e, f
SlSp	2.004 (0.04)	c, d, e, f
SlZr	2.038 (0.80)	d, e,f
SlPg	2.050 (0.09)	d, e, f

* Different letters indicate significantly different groups ($P < 0.05$).

Table 6 Mean (SD) of color changes (ΔE) and differences between groups for Matchmaker MC.

Group	ΔE	Difference*
C	1.908 (0.03)	c, d
Gl	0.972 (0.09)	a
Sl	1.702 (0.13)	b, c
Pk	1.626 (0.17)	b
Di	1.714 (0.03)	b, c
Sp	1.878 (0.09)	b, c, d
Zr	2.102 (0.04)	d, e
Pg	2.112 (0.10)	b, c, d
SlSp	1.860 (0.09)	d, e
SlZr	2.182 (0.29)	e
SlPg	2.088 (0.11)	d, e

* Different letters indicate significantly different groups ($P < 0.05$).

When comparing the four different porcelain materials, the Ceramco III (1.910) feldspathic porcelain material group demonstrated the highest ΔE value, which significantly differed from the other groups ($P < 0.05$). No significant differences were observed among the porcelain material groups of Mark II (1.782), Matchmaker MC (1.830), and VMK 95 (1.817), ($P = 0.074$); these groups also demonstrated the lowest ΔE values.

When comparing the polishing techniques, the lowest ΔE value was observed in Group Gl (0.956). No significant difference was observed among Groups Sl (1.702), Di (1.750), and Pk (1.753), ($P = 0.883$), and these groups demonstrated significantly higher ΔE values than Group Gl ($P < 0.05$). Otherwise, groups Zr (2.079), SlSp (2.028), SlZr (2.060), and SlPg (2.039) demonstrated the highest ΔE values of all porcelain groups, and there were no statistically significant differences among them ($P = 0.379$).

Discussion

On the basis of these data, the hypothesis stated as the premise of this study was accepted. The stainability of porcelain materials was related to the porcelain type, firing temperature, manufacturing technique, glazing, surface roughness, and type of staining agent[1,23]. The considerations relative to these statements are presented below. However, visual color matching is still the primary method for evaluating the color of teeth and restorations and may create results.[24] Instrumental color analyses offer potential advantages over visual determinations. Instrument readings are objective, can be quantified, and are more rapidly obtained.[17,24] Color can be measured in dentistry using a tristimulus color analyzer that measures reflective surface colors.[25] It was shown that a photometric tristimulus colorimeter had the best overall performance for determining color on porcelain surfaces.[11] The CIE Lab system for measuring chromacity was chosen for the present study to record color differences, as it is well suited to determine small color differences.[11]

Table 7 Mean (SD) of color changes (ΔE) and differences between groups for Mark II.

Group	ΔE	Difference*
C	1.880 (0.02)	d, e, f
Gl	0.912 (0.09)	a
Sl	1.556 (0.14)	b
Pk	1.636 (0.19)	b, c
Di	1.736 (0.09)	b, c, d
Sp	1.840 (0.08)	c, d, e
Zr	1.976 (0.06)	e, f
Pg	2.006 (0.08)	e, f
SlSp	1.982 (0.14)	e, f
SlZr	2.094 (0.14)	f
SlPg	1.988 (0.04)	e, f

* Different letters indicate significantly different groups ($P < 0.05$).

When measuring reflective surfaces, the measured color depends on both the actual colors of the surface, and the lighting conditions under which the surface is measured. In the present study, a standard illuminant (A) against a white background was used. Since color differences were being tested, the choice of the illuminant was not important. The thickness and smoothness of the specimen surface also affect the color.[26] In the present study, the thickness of the porcelain material specimens was uniformly prepared at 2 mm. However, calculations of color variations, ΔE, between two color positions (at the baseline and after 48 hours of storage) in the 3D Lab color space were investigated, and the specimen thickness was not important. The repeatability of the experimental design was not evaluated.

When comparing the polishing techniques, the lowest ΔE values were observed in Group Gl (0.956) among all the porcelain materials tested. The highest ΔE values were observed in Group Zr (2.094) of VMK 95 porcelain specimens, Group Zr (2.142) of Ceramco III porcelain specimens, Group SlZr (2.094) of Mark II porcelain specimens, and Group SlZr (2.182) of Matchmaker MC porcelain specimens. Although the polishing techniques significantly affected color differences, in the present study, it was concluded that all of the specimens demonstrated ΔE values that were in an acceptable range for all of the porcelain materials tested ($1 < \Delta E < 3.7$).

According to the results of a previous study,[27] the machinable feldspathic porcelain block group (Mark II) demonstrated significantly lower Ra values than the other porcelain materials examined. No significant difference was observed between the VMK 95 and Ceramco III porcelains, which exhibited the highest Ra values. This was thought to have been due to the extreme hardness of the Mark II feldspathic blocks. Color stability is affected by the surface texture of the material. The reason that the highest ΔE value was observed for Ceramco III porcelains might be related to surface irregularities.

The type of immersion solution can affect the degree of color change. In the present solution, a coffee solution was used as the staining agent. Since there is a lack of studies on porcelain materials, in various studies on resin-based materials, coffee and tea often contributed to the most significant staining.[21,25,28] Furthermore, Odioso et al.[29] reported that after adjusting for all other explanatory variables, coffee/tea consumption is one of the factors that significantly affects b∗ and L∗ values. Individuals who consumed coffee or tea daily averaged a 1.2-unit increase in b∗ and a 1.5-unit decrease in L∗. Storage for 48 hours was selected as a standard time. However, the coffee manufacturer that the average time for consumption of one cup is 15 minutes, and among coffee drinkers, the average consumption of coffee is 3.2 cups per day. Therefore, 48 hours of storage time simulated the consumption of this beverage for 2 months.[30]

Saraç et al.[31] investigated the effects of porcelain polishing systems on the color and surface texture of feldspathic porcelain, and found significant differences among polishing techniques in terms of color differences, and ΔE values ranged 1.03–3.36. The authors furthermore reported that the use of an adjustment kit alone or preceding polishing paste or polishing stick application was found to be superior to other polishing techniques evaluated in decreasing the surface roughness and color change.

Corresponding to the present study, Yılmaz et al.[32] investigated the color stability of glazed and polished dental porcelains, and they reported that polished porcelain surfaces of low-fusing and ultra-low-fusing porcelain materials had statistically significant color deviations compared to the glazed surface in the same group after immersion in methylene blue. Based on the results of the present study, it was concluded that glazed specimens showed better color stability. On the other hand, staining observed with polished specimens was not clinically notable in this study.

The present study had the following limitations. The specimen surfaces were flat, whereas, clinically, porcelain restorations have irregular shapes with convex and concave surfaces. Specimens used for extraoral evaluations are usually monochromatic, uniformly translucent, un-textured, and viewed under ideal light conditions. Teeth, on the other hand, are polychromatic, non-uniformly translucent, textured, and viewed under ambient lighting conditions intraorally. Teeth are also clinically framed adjacent to other teeth with varying degrees of polychromaticity and translucency. Furthermore, the application of polishing procedures tested in this study may be difficult to perform clinically. Other factors that could influence the degree of total color change include thermal cycling and abrasion. These should be considered in future studies.

Therefore, there is a lack of information about the efficacy of different polishing systems and techniques on the color stability of porcelain materials. Further investigations are necessary to evaluate color changes of newer types of dental porcelains.

Conclusions

The stainability of four porcelain materials was evaluated after 48 hours of storage in a coffee solution. Within the limitations of this study, the following conclusions were drawn.

Significant differences were found in the color change of feldspathic and low-fusing porcelain materials subjected to the different polishing techniques evaluated ($P < 0.05$). The Mark II, Matchmaker MC, and VMK 95 porcelain materials tested were found to be more color-stable than the Ceramco III porcelain. The largest color difference was observed with the Ceramco III porcelain material. These differences were found to be significant ($P < 0.05$). Glazed specimens demonstrated less color change than polished specimens for all porcelain materials tested. Glazed and polished specimens with different polishing materials demonstrated that ΔE values were at an acceptable level for all of the porcelain materials tested ($1 < \Delta E < 3.7$).

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