Spectrophotometric evaluation of the optical influence of different metal alloys and porcelains in the metal-ceramic complex

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Statement of the problem. Color matching between natural teeth, shade guides, and metal-ceramic restorations is a common clinical problem. Difficulties related to color matching arise from structural differences that exist between metal-ceramic crowns and natural teeth, the limited range of available ceramic shades, inadequate shade guides, different types of metal alloys, and varying compositions of ceramic materials.

Purpose. The aim of this study was to investigate the influence of various metal alloys and 2 porcelains on the final color of metal-ceramic complex.

Material and methods. Four commercial alloys for metal-ceramic restorations, a Ni-Cr (Thermobond), a Co-Cr (Wirobond), a Pd-rich noble (Cerapal-2), and a high noble Au-alloy (V-Delta) were combined with 2 porcelains (Vita Omega and Ceramco Silver) in metal-ceramic specimens with a standardized thickness of layers. Five disc-shaped (10 × 1 mm) specimens were prepared for each alloy/porcelain combination. Only opaque and dentin layers were applied (shade A3). The specimens were analyzed with a spectrophotometer, and data were obtained in the CIE Lab color system. The recorded data were analyzed with a 2-way multiple analysis of variance , a pair-wise comparison of group means (Student's t test), and finally, a categorical regression analysis of variance (CATREG) (α=.01).

Results. The types of alloy substrate and overlying porcelain significantly affected the color (P<.01). Au and Co-Cr alloys were found to be brighter (higher L* values) than the Ni-Cr and the Pd alloys (P<.01, SE 0.239). Ceramco porcelain was found to be most red (higher a* values) of all tested alloys (P<.01). Gold and Pd alloys caused a yellow shift to the metal-ceramic color compared to the Ni-Cr and the Co-Cr alloys with both porcelains (P<.01, SE 0.165). The detected color differences were visually perceptible for some alloy-porcelain combinations.

Conclusions. The final color of metal ceramic specimens was influenced both from the type of alloy substructure and from the type of overlying porcelain. (J Prosthet Dent 2004;92:477-85.)

CLINICAL IMPLICATIONS

The type of metal alloy and porcelain used in metal ceramic restorations should be carefully considered in situations where accurate color matching is paramount.

Color is an important determinant in the esthetic appearance of metal-ceramic restorations. Problems related to color matching arise from structural differences that exist between metal-ceramic crowns and natural teeth, the limited range of available ceramic shades, inadequate shade guides, and different compositions of ceramic materials.[1,2] The primary difference between metal-ceramic restorations and natural teeth is due to the presence of the metal framework. The metal framework is an essential part of metal-ceramic restorations, as it provides necessary strength for clinical function. The presence of metal, however, detracts from the esthetic result. The contributing factors to the final color of metal-ceramic restorations include the type of ceramic,[3] the thickness of the ceramic layer, the number of firings,[4,5] the firing parameters and temperatures,[4] the applied stains, and the type of metal alloy.[6-11] An opaque porcelain thickness of 0.2 to 0.3 mm is adequate to mask the color of underlying oxidized metal, but the effective thickness of opaque varies among different shades and porcelains.[12,13] Color differences have also been demonstrated between fired porcelain and shade guides,[14] between shade guides,[15,16] and between porcelains from different batches.[17] Porcelain color changes have also been associated with specific metal ions, for example, Pd or Ni contained in the dental alloys used for metal-ceramic restorations.[18-20]

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Table I. Composition of metal alloys as purported by manufacturers and classification according to ADA

Alloys	Composition	ADA classification	Manufacturer
Thermobond	Ni 77%, Cr 13%, Mo 8%, Be 1,65%	Predominately base metal	Dedecon Co, Los Angeles, Calif
Wirobond	Co 61%, Cr 26%, Mo 6%, W 5%	Predominately base metal	Bego Co, Bremen, Germany
Cerapal-2	Pd 78,5%, Cu 6,9%, Ga 5,5%, In 4,5%, Sn 2%, Au 2%, Ru 0,5%	Noble metal	Metaux Precieux/ Metalor Co, Neuchatel, Switzerland
V-Delta	Au 51,5%, Pd 38,5%, In 8,5%, Ga 1,5%	High noble metal	Metaux Precieux/ Metalor Co, Neuchatel, Switzerland

Table II. Firing parameters for 2 porcelains tested according to manufacturers' instructions

	Dry (min)	Preheat (min)	Low temp (°C)	High temp (°C)	Vacuum temp start-end (°C)	Heat rate (°C/min)
Vita						
Opaque, first layer	3	3	649	974	649-952	67
Opaque, second layer	3	3	649	954	649-952	67
Dentin, first layer	5	5	621	920	621-896	72
Dentin, second layer	5	5	621	915	621-891	72
Ceramco						
Opaque, first layer	2	2	600	970	600-970	124
Opaque, second layer	2	2	600	950	600-950	124
Dentin, first layer	6	6	600	930	600-930	55
Dentin, second layer	6	6	600	920	600-920	55

Brewer et al[6] used spectrophotometric analysis to compare the influence of 3 different alloy substrates on the resulting color of metal-ceramic restorations. Color changes were evaluated at each step in fabrication. The results indicated that although little color change occurred with the 3 alloys through the opaque stage, significant color changes occurred after firing the dentin layer, and the change was attributed to the alloy.

Jacobs et al[7] used spectrophotometric and visual assessment of hue, value, and chroma to study the effects of several variables (3 alloys, 3 porcelain shades, 3 layer thicknesses) on the resulting color of metal-ceramic restorations. With spectrophotemetric assessment, differences in color were found between the Ni-Cr and Pd alloys compared to the Au-Pt-Pd alloy. All detected differences were most obvious when thinner layers of dentin porcelain were used. Crispin et al[11] examined the influence of the alloy framework on the color of metal-ceramic crowns visually for differences in perceived value lightness. Ni-Cr and Au-Pd alloys were evaluated with 1 porcelain, and significant differences were noted.[11]

Although it appears that various alloys can affect the final color of a restoration, some disagreement exists among authors as to which combination of alloy and ceramic material produces the most clinically significant changes.[5,7,9,10] It remains unclear, however, which color change or chromatic shift is caused by each type of alloy on the different porcelains.

Furthermore, the Co-Cr alloys, which are used for metal-ceramic restorations, have not been investigated for possible color changes in the porcelain layer. The aim of the present study was to investigate the influence of 4 types of metal alloys and 2 porcelains on the final color of metal ceramic restorations. It was hypothesized that there would be no color differences among the color coordinate values of different metal ceramic combinations.

MATERIAL AND METHODS

Four commercial metal ceramic alloys, a Ni-Cr, a Co-Cr, a Pd-rich, and an Au-alloy were combined with 2 porcelains in metal-ceramic specimens with a standardized thickness of layers. The brand names, manufacturer information, compositions of the alloys as provided by the manufacturers, and the classifications according to the American Dental Association (ADA)[1] are shown in Table I. Forty disc-shaped metal specimens, 10 mm in diameter and 1 mm thick, were cast with the 4 dental alloys according to the manufacturer's recommendations. All alloys were Type IV (extra hard) according to ADA specification No. 5. [21] The cast metal specimens were adjusted with stones (Dura-Green Stones; Shofu Co, Kyoto, Japan), airborne-particle abraded with 50-μm aluminum oxide, cleaned with steam, and then oxidized according to the manufacturers' recommendations. The metal specimens were covered with 1 of 2 porcelains (Vita Omega; Vita Zahnfabrik, Bad Säckingen, Germany or Ceramco II Silver; Dentplsy Ceramco, Burlington, NJ). There were 5 specimens per group of each porcelain-alloy combination. The porcelains were fired following manufacturer's recommendations as

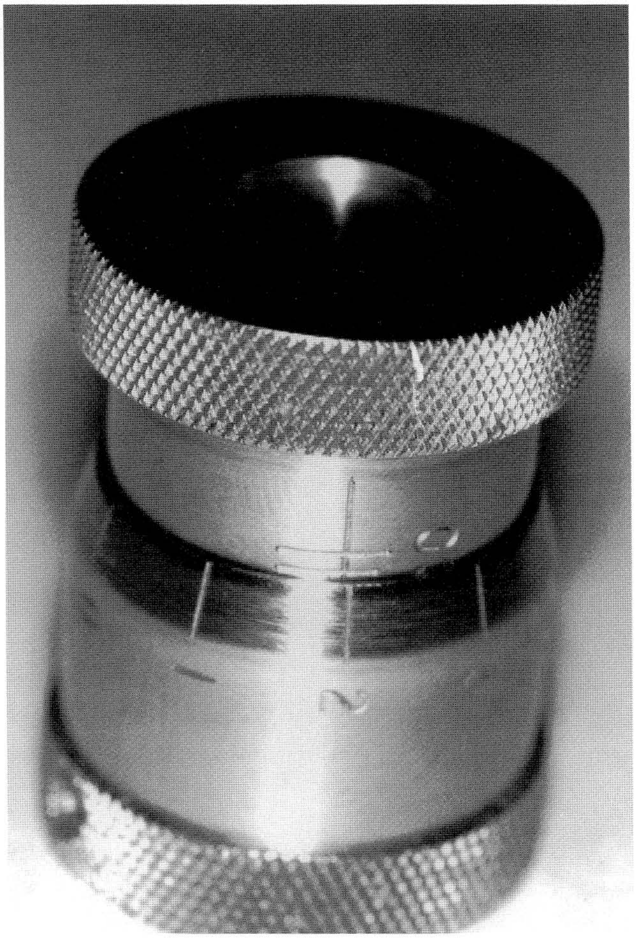

Fig. 1. Device used for fabrication of metal-ceramic specimens.

Table III. Descriptive statistics of L*, a*, and b* values for different porcelain-alloy combinations

Porcelain	Alloy	Values	Mean	SE	SD
Vita					
	Ni-Cr	L*	72.23	0.17	0.39
		a*	3.11	0.04	0.09
		b*	18.34	0.02	0.06
	Co-Cr	L*	75.86	0.11	0.24
		a*	2.01	0.09	0.20
		b*	18.45	0.12	0.28
	Pd	L*	71.59	0.15	0.34
		a*	2.58	0.05	0.12
		b*	18.72	0.11	0.26
	Au	L*	75.16	0.11	0.24
		a*	2.41	0.07	0.16
		b*	19.66	0.25	0.56
Ceramco					
	Ni-Cr	L*	70.22	0.18	0.39
		a*	3.57	0.17	0.39
		b*	18.31	0.25	0.57
	Co-Cr	L*	74.42	0.11	0.25
		a*	3.05	0.04	0.08
		b*	18.10	0.19	0.42
	Pd	L*	71.22	0.58	1.29
		a*	3.52	0.13	0.28
		b*	18.96	0.10	0.23
	Au	L*	74.59	0.06	0.14
		a*	3.11	0.03	0.07
		b*	18.49	0.13	0.29

shown in Table II. Each group of specimens (combination of ceramic and alloy) was fired separately, and the ceramic furnace was calibrated before each firing.

Porcelain addition was accomplished with a custom-made, cylindrical metal device. The metal specimen was inserted, and a uniform thickness layer of porcelain was applied. Using this device the overall thickness of metal specimen and opaque layer could be precisely adjusted (Fig. 1) and excess porcelain could be removed with a sharp instrument. Porcelain shade A3 was used for all opaque and dentin layers. For the addition of further opaque or dentin layers, the total allowed thickness was adjusted. For every specimen, 2 opaque layers and 2 dentin layers were applied. The thicknesses of the opaque layer and dentin layers were 0.2 mm ± 0.05 mm and 1 mm ± 0.05 mm, respectively. The total thickness of the ceramic layer was 1.2 mm. A caliper (Mitutoyo Co, Kawasaki, Japan) was used with an accuracy of 0.05 mm. The layer thickness was evaluated after each firing, and the necessary corrections were made by grinding with new stones (Dura-Green). Additional porcelain was added to compensate for the shrinkage

Table IV. Pairwise means comparisons (Student's *t* test) regardless of porcelain

Dependent variable	(I) Alloy	(J) Alloy	Mean difference (I-J)	Std. error	Sig.
L*	Ni-Cr	Co-Cr	−3.915	0.239	**
		Pd	−0.181	0.239	(NS)
		Au	−3.653	0.239	**
	Co-Cr	Pd	3.734	0.239	**
		Au	0.262	0.239	(NS)
	Pd	Au	−3.472	0.239	**
A*	Ni-Cr	Co-Cr	0.806	0.090	**
		Pd	0.289	0.090	**
		Au	0.577	0.090	**
	Co-Cr	Pd	−0.517	0.090	**
		Au	−0.229	0.090	*
	Pd	Au	0.288	0.090	**
B*	Ni-Cr	Co-Cr	4.700E-02	0.165	(NS)
		Pd	−0.516	0.165	**
		Au	−0.751	0.165	**
	Co-Cr	Pd	−0.563	0.165	**
		Au	−0.798	0.165	**
	Pd	Au	−0.235	0.165	(NS)

Based on estimated marginal means.
**Mean difference significant at .01 level ($P<.01$).
(NS) Mean difference is not statistically significant.

Table V. Means comparison (Student's *t* test) of different porcelains for type of alloy

Dependent variable	Porcelain	Alloys			
		Ni-Cr	Co-Cr	Pd	Au
L*	Ceramco	70.216	74.416	71.22	74.594
	Vita	72.228	75.858	71.586	75.156
	Mean dif.	−2.012**	−1.442**	−0.366(NS)	−0.5628**
a*	Ceramco	3.566	3.052	3.522	3.11
	Vita	3.11	2.012	2.576	2.412
	Mean dif.	0.456(NS)	1.04**	0.946**	0.698**
b*	Ceramco	18.31	18.104	18.958	18.512
	Vita	18.338	18.45	18.722	19.658
	Mean dif.	−0.028(NS)	−0.346**	0.236(NS)	−1.146**

**Mean difference is significant at .01 level.
(NS) Mean difference is not statistically significant.

Table VI. Tests of between-subjects effects (MANOVA)

Source	Dependent variable	*df*	F	Sig.
Model	L*	8	94128.266	**
	A*	8	1074.508	**
	B*	8	12729.948	**
Porcelain	L*	1	42.182	**
	A*	1	150.740	**
	B*	1	7.792	**
Alloy	L*	3	160.423	**
	A*	3	29.940	**
	B*	3	11.251	**
Porcelain *	L*	3	5.204	**
Alloy	A*	3	4.215	NS
	B*	3	6.786	**
Error	L*	32		
	A*	32		
	B*	32		
Total	L*	40		
	A*	40		
	B*	40		

df, Degrees of freedom.
**Significant at .01 level (*P*<.01).
(NS) Mean difference is not statistically significant.

Table VII. Type of porcelain and type of alloy as predictors of L*- value fluctuations. **A,** Categorical regression analysis. **B,** ANOVA

A.	Categorical regression analysis (dependent variable: L*)	Predictors: Porcelain	Alloy
Standard coefficients	Beta	−0.282	0.667
	SE	0.117	0.117
df		2	2
F		5.845	32.763
Exact significance		**	**
Correlations	Zero order	−0.282	0.667
	Partial	−0.378	0.695
	Part	0.282	0.667
Predictor's importance (%)		15.1	84.9

B.	Regression	Residual	Total
Sum of squares	20.980	19.020	40.000
df	4	35	39
Mean square	5.245	0.543	
F	9.652		
Significance	**		

df, Degrees of freedom.
**Significant difference at .01 level (*P*<.01).

of the first firing. All specimens were subjected to 4 firings. Neither opaque dentin nor enamel ceramic was used, and the specimens were not glazed. All specimens were finished to a uniform gloss using waterproof abrasive paper (Riken Corundum Carbosand waterproof paper cc180; Riken Co, Tokyo, Japan).

The color coordinates of each specimen were measured with a spectrophotometer (Datacolor Spectrophotometer, Spectraflash 600 with integrated sphere; Datacolor AG, Lawrenceville, NJ) set to the standard illumination source D65 with a 2-degree observation angle according to the 1931 CIE recommendation.[22] The data were displayed in L*, a*, and b* values according to the CIE Lab system. In the CIE Lab color system each color is defined by 3 coordinates in the color space.[23] These coordinates are expressed as values L* (Lightness), a* (red-green axis), and b* (yellow-blue). Each set of recorded data represented the mean value of 3 measurements. The device was calibrated before measurement of each specimen.

The direct comparison of L*, a*, and b* values was preferred rather than a comparison of Color Difference (ΔE), as has been used in other publications.[9,13,16,22] The Color Difference is calculated by a formula[22] from differences in L*, a*, and b* values (ΔL*, Δa*, Δb*) using the equation: $\Delta E = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2}$, and it does not allow for the evaluation of the chromatic shift in every tested combination. However, mean color differences between alloy-porcelain combinations were calculated to verify if the color differences noted would have clinical significance (less than or equal to 3.7 units

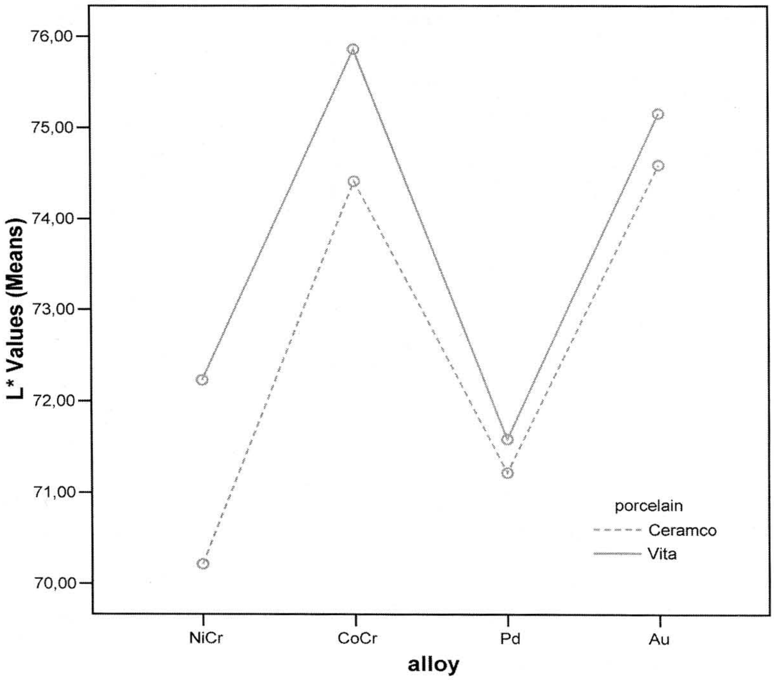

Fig. 2. Means of L* for different porcelains and alloys.

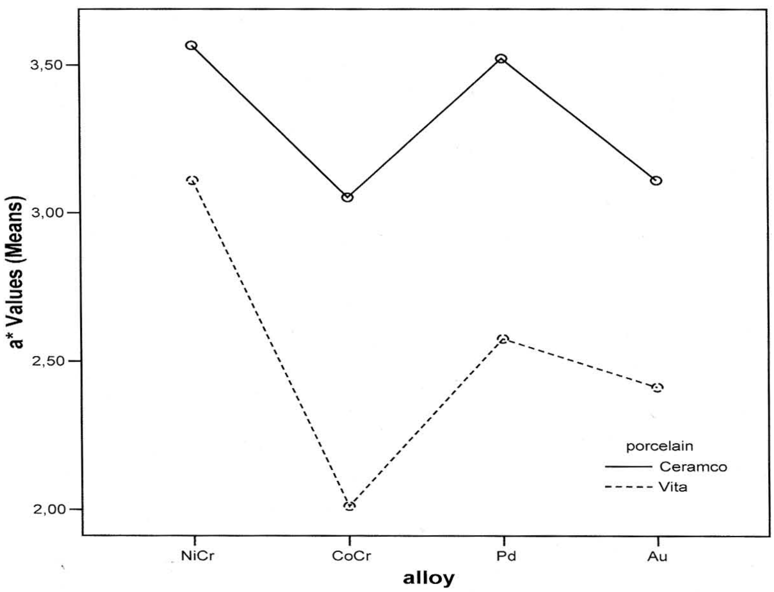

Fig. 3. Means of a* for different porcelains and alloys.

indicates visually perceivable, but acceptable, color difference, according to Johnston and Kao[24]). The recorded data (color coordinates L*, a*, and b*) were analyzed with a 2-way multiple analysis of variance (MANOVA), a pairwise comparison of group means (Student's t test), and, finally, a categorical regression analysis of variance (CATREG) (α=.01). Categorical regression analysis of variance reveals the contribution of each predictor (alloy, porcelain) to the dependent variables (color coordinates).

RESULTS

The descriptive statistics are summarized in Table III. The means, standard deviations (SD), and standard errors (SE) are reported for each group and for each color

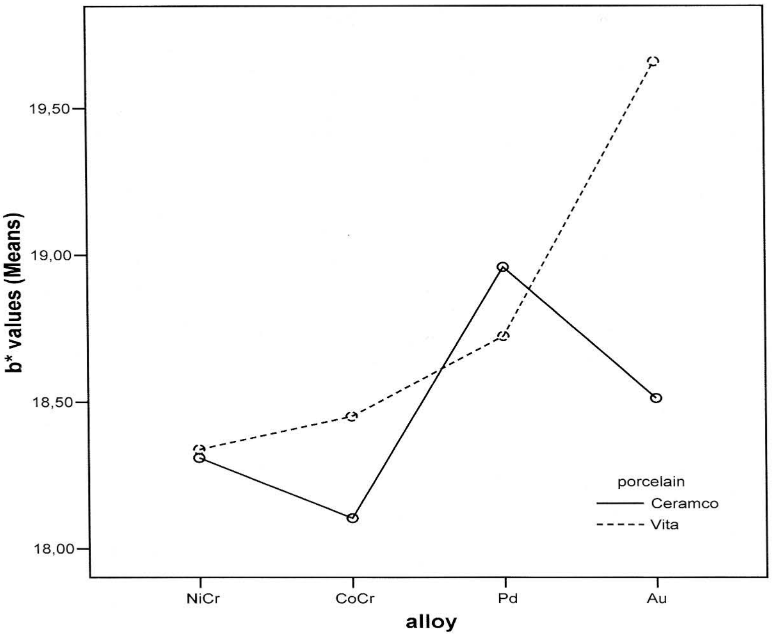

Fig. 4. Means of b* for different porcelains and alloys.

Table VIII. Type of porcelain and type of alloy as predictors of a*-value fluctuations. **A,** Categorical regression analysis. **B,** ANOVA

A.	Categorical regression analysis (dependent variable: a*)	Predictors Porcelain	Alloy
Standard coefficients	Beta	0.736	−0.408
	SE	0.090	0.090
df		2	1
F		66.815	20.491
Exact significance		**	**
Correlations	Zero order	0.736	−0.408
	Partial	0.806	−0.602
	Part	0.736	−0.408
Predictor's importance (%)		76.5	23.5

B.	Regression	Residual	Total
Sum of squares	28.322	11.678	40.000
df	3	36	39
Mean square	9.441	0.324	
F	29.102		
Significance	**		

df, Degrees of freedom.
**Significant difference at .01 level ($P<.01$).

Table IX. Type of porcelain and type of alloy as predictors of b*-value fluctuations. **A,** Categorical regression analysis. **B,** ANOVA

A.	Categorical regression analysis (dependent variable b*)	Predictors Porcelain	Alloy
Standard coefficients	Beta	−0.223	0.628
	SE	0.126	0.126
df		2	2
F		3.137	24.800
Exact significance		NS	**
Correlations	Zero order	−0.223	0.628
	Partial	−0.287	0.644
	Part	−0.223	0.628
Predictor's importance (%)		11.2	88.8

B.	Regression	Residual	Total
Sum of squares	17.755	22.245	40.000
df	4	35	39
Mean square	4.439	0.636	
F	6.984		
Sig.	**		

df, Degrees of freedom.
**Significant difference at .01 level ($P<.01$).
NS: Not significant difference.

coordinate (L*, a*, b*). In Table IV, pairwise means comparison (Student's *t* test) results are shown for different alloys regardless of porcelain. Statistically significant differences were noted among most tested combinations. In Table V, Means Comparisons (Student's *t* test) are shown for L*, a*, and b* values of the 2 tested porcelains combined with various alloys .

The MANOVA revealed significant differences in the main effect of porcelain or alloy (examined separately) and for the interaction between the alloy/porcelain combination. The Wilks' Lamda values (a statistical test ranging from 0 to 1 which shows discrimination between groups) were 0.78 (F = 117.674, $P<.01$) for the porcelain, 0.14 (F = 38.872, $P<.01$) for the alloy,

Table X. Mean color differences (ΔE) for various alloy-porcelain combinations

	Vita	Ceramco
Ni-Cr Vs Co-Cr	3.79	4.24
Co-Cr Vs Pd	4.32	3.34
Pd Vs Au	3.7	3.43
Ni-Cr Vs Pd	0.92	1.20
Co-Cr Vs Au	1.45	0.45
Ni-Cr Vs Au	3.29	4.41

and 0.246 ($F = 6.343$, $P < .01$) for the alloy-porcelain combination. Both factors (porcelain-alloy) showed significant influence on the dependent variable (color coordinates). The combination (interaction) also revealed significant influence on the color. The MANOVA showed significant differences among all factors at the .01 level, except for the porcelain-alloy combination with respect to the a* value (Table VI).

The gold alloy and the Co-Cr alloy specimens showed higher L* values with both porcelains. The Ni-Cr and the Pd alloy specimens showed lower L* values that were significantly different from the Au and Co-Cr alloys with both porcelains. The Vita porcelain showed increased L* values with all alloys compared to Ceramco specimens, with the exception of the Pd alloy, where the difference was not statistically significant (Table V and Fig. 2).

The a* values of all Ceramco specimens were higher than the Vita a* values for all alloys. With both porcelains, the Ni-Cr and the Pd alloys showed higher a* values compared to gold and Co-Cr alloys (Fig. 3). There were significant differences in all tested combinations. The b* values of the Au and Pd alloys were higher than the values of Ni-Cr and Co-Cr alloys, with significant differences. The Au alloy with Vita porcelain showed the highest b* value, which was significant compared to the value of the same alloy with Ceramco porcelain. Similar findings were noted for the Co-Cr alloy. The Pd alloy showed higher b* values compared to Ni-Cr and Co-Cr alloys; these values were significantly different. The Pd alloy revealed significant differences in b* values when tested with both porcelains (Fig. 4).

The CATREG showed that alloy was a predominant factor in the fluctuation of L* (84.9% influence compared to 15.1% influence attributed to porcelain) and b* value (88.8% influence compared to 11.2% influence attributed to porcelain). The a* value fluctuation was influenced mainly by the porcelain (76.5% influence compared to 23.5% influence caused by the alloy). The results of the CATREG analysis are presented in Tables VII through IX. The Mean Color Differences (ΔE) of various alloy-porcelain combinations are presented in Table X. According to Johnston and Kao,[24] ΔE values higher than 3.7 units indicate visually perceivable color differences which are clinically unacceptable.

DISCUSSION

According to the research hypothesis, no significant differences should be found between various alloy-porcelain combinations since the opaque should completely mask the color of the underlying metal substrate and the porcelains are considered to have the same color shade. The results of the present study indicate a strong influence of the alloy on the color of the metal-ceramic complex. The final color was also significantly affected by the type of porcelain used, and thus the research hypothesis was rejected.

The problems associated with the final color of metal ceramic restorations have been discussed extensively in the literature.[1-3,5-7] However, differences in materials and techniques make it difficult to compare results and draw clinically relevant conclusions. In the present study gold and cobalt-chrome alloys were found to develop brighter metal-ceramic combinations (higher L*values) than the Ni-Cr and the Pd alloys. Ceramco porcelain was found to be more red (higher a*values) with all tested alloys. Gold and Pd alloys caused a yellow shift to the metal-ceramic color compared to the Ni-Cr and the Co-Cr alloys with both porcelains. High-gold alloys are the alloys of choice for color replication of metal-ceramic restorations[18,20,21] because noble alloys are easier to mask with an opaque layer than Ni-Cr alloys.[13] Crispin et al[10] reported that Au-Pd alloys showed no significant difference compared to high-gold alloys. In the same study, however, the Pd alloys and the Ni-Cr alloys caused the greater color changes compared to the high-gold alloy, and a silver-palladium alloy was also included. Brewer et al[6] found significant color differences in porcelain combined with 3 alloys. The color values of the porcelain fired on the silver-palladium alloy differed significantly from those of the porcelain fired onto both the high-gold and the Ni-Cr alloy, which were very similar. In the present study, however, significant differences were noted between Au and Ni-Cr alloys with both porcelains used.

Jacobs et al[7] investigated the effect of various parameters on the color of metal ceramic restorations. In this study, 3 alloys (Au-Pt-Pd, Ni-Cr, and Pd) and 3 porcelain shades were tested in 3 different thicknesses. The spectrophotometric assessment indicated that for certain shades, the Ni-Cr and the high-Pd alloys resulted in significantly different hue values than the Au-Pt-Pd alloy group. Visual assessments of these differences, however, indicated that the Ni-Cr alloy group was significantly different than both the high-Pd and the Au-Pt-Pd alloy groups. In the present study the color differences were more intense between the Au/Co-Cr and Ni-Cr/Pd alloy groups. Color differences between a Ni-Cr and an Au-Pd alloy were noted by Crispin et al[11] visually on metal ceramic crowns. Differences in the color coordinates of the same alloy categories were detected in the present study and were large enough to be considered beyond acceptability ($\Delta E > 3.7$) according to the standards proposed by Johnston and Kao[24] (Table X).

The results of the present study confirm results of previous studies[6,7,13] and differences were found both between metal alloys and porcelains. The color deviations were more intense for the Ni-Cr and the Pd alloy. In the present study color differences that could be detected with visual examination were found between Ni-Cr and Co-Cr alloys, between Co-Cr and Pd alloys, and between Pd and Au alloys, when tested with Vita porcelain. For Ceramco porcelain the visually detectable color differences were noted between Ni-Cr and Co-Cr alloys and between Ni-Cr and Au alloys.

In another study, with visual comparison of color changes, the Ni-Cr alloy caused significant color changes compared to the Pd alloy.[7] It must be emphasized, however, that a direct comparison of the results is not possible due to differences in the tested metal-ceramic combinations and in the structure, geometry, or surface texture of the specimens.

In various studies different colorimetric devices have been used for the evaluation of color differences.[6,7,9,13] Colorimetric devices are also subject to "edge loss effects," which may result in differences due to variation in the absorption and scattering of the specimens incorrectly appearing to be due to color variation.[22] On translucent specimens light escapes through the periphery of the specimen and does not return to the sensor. This loss of light cannot be factored into the sensor's determination of the color resulting in inaccuracies. The use of spectroradiometers can offer more accurate results because the specimen is illuminated from the front and the periphery, therefore not allowing light to escape. Although a high degree of correlation can exist between color difference measurements regardless of the design of the instrument-measuring geometry,[22] a direct comparison of results is not possible within the limitations of this study. Comparisons between porcelains may result in inaccurate conclusions since different scattering coefficients may affect the "edge loss" effect in a different way. However, comparison of the metal alloy's effect on the color of the ceramometal complex may be more accurate, as the porcelain system and the scattering variability remain constant between specimens.

The Pd-Ag alloys have been reported to cause a yellow or yellow-green discoloration of the porcelain.[18,21] This type of discoloration has not been attributed to Pd-rich alloys without silver. The Ni-Cr and the Pd alloys are widely used.[18,21] The data indicate that these alloy types can result in significant color changes compared to other groups of alloys. The Ni-ions are colorants that have been shown to produce a neutral gray color in sodium silicate glasses and are probably associated with color changes in porcelain.[19] A direct correlation, however, cannot be drawn from the existing results. Although other visual and instrumental studies have reported the existence of such color changes, conclusions based on the clinical significance of these findings have varied.[6,7,9]

The purpose of this study was to investigate the possible influence of the metal alloy substrate and the porcelain on the final color of the metal ceramic restoration. Comparison of color differences between various specimens and the intended color of a shade tab may determine the importance of metal selection in the final color, allowing more clinically relevant conclusions. A direct comparison, however, between specimens and tabs from a commercial shade guide is not possible due to differences of structure and applied ceramic layers. Within the limitations of the present study differences in color were noted among various metal-ceramic combinations, although the final color should be identical according to the research hypothesis. Nevertheless, as previously mentioned, alloys with a high gold content have been considered as a reference point for color reproduction.[18,20,21] Comparison with such specimens may indicate a relative clinical relevance. For situations where accurate color matching and color reproduction is necessary, the use of individually fabricated all-ceramic or metal-ceramic shade guides should be considered, especially when depth of color and preparation thickness is limited.

Further research is needed to investigate the magnitude of color changes in terms of clinical detectability. Other questions include whether all brands of porcelains and shades are affected to the same extent by Ni-Cr and Pd alloys and whether all alloys of the same type cause similar color changes.

CONCLUSIONS

Within the limitations of this study, the final color of metal ceramic specimens was influenced by the type of alloy substructure and by the type of overlying porcelain. Au and Co-Cr alloys were found to be significantly brighter (higher L^*-values) than the Ni-Cr and the Pd alloys ($P<.01$). Ceramco porcelain was found to be more red (higher a^* values, $P<.01$) with all tested alloys. Gold and Pd alloys caused a significant yellow shift (higher b^* values) to the metal-ceramic color compared to the Ni-Cr and the Co-Cr alloys with both porcelains tested ($P<.01$).

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