

Variability in Colour Reproduction of Metal-Ceramic Crowns

LUMINITA OANCEA¹, ALEXANDRU PETRE¹, MIHAI BURLIBASA², EUGENIA EFTIMIE TOTU^{3*}, CORINA MARILENA CRISTACHE^{2*}

¹Carol Davila University of Medicine and Pharmacy, Faculty of Dental Medicine, Department of Occlusion and Fixed Prosthodontic, 17-23 Calea Plevnei, 010221, Bucharest, Romania

²Carol Davila University of Medicine and Pharmacy, Faculty of Midwifery and Medical Assisting (FMAM), Department of Dental Techniques, 8 Eroilor Sanitari Blvd, 050474, Bucharest, Romania

³University Politehnica of Bucharest, Faculty of Applied Chemistry and Material Science, 1-5 Polizu Str., 11061 Bucharest, Romania.

The aim of the present study was to objectively assess the variability in color reproduction of metal-ceramic (MC) single crowns fabricated by blending different color of opaque and body ceramic in order to point out which shade of the ceramic layers influences mostly the final color of the restorations. Eight nickel-chromium ceramic metal alloy copings were fabricated, on the same cast, following by blending the ceramic for the specific A3 color as follows: one reference ceramic (R) was blended, according to the producer's recommendation, and seven tests crowns have been build-up by considering as variables each one of the two uniform opaque layers, and dentin layer. Color of each manufactured crowns was measured after the three important steps of the technological workflow: the last opaque layer, enamel-dentin correction and final glaze firing using Vita Easyshade spectrophotometer. The best final color match (color difference of $\Delta E = 0.8$) was obtained for specimen no. 5, with a lighter opaque first layer (A1). Fabricated specimens of all groups, except for no.4, with a darker dentin layer (A 3.5), showed ΔE values between 0.8 and 2.8, in the limit of the threshold perception in the oral cavity, and were scored as good. Within the limits of the present study, we can conclude that the dentin-enamel layer mostly influences the final color of the MC crowns.

Keywords: metal-ceramic crowns, color reproduction, opaque, dentine-enamel

Metal-ceramic (MC) crowns have been used for more than 40 years and are still considered *gold standard* among indirect restorations [1], their qualities being certified in long term follow up studies [2]. Recent research papers assessing single MC crowns presented a 5-year survival rate ranging between 90 and 97.5%, and 10-year survival above 80% [1,3,4]. A 50 years follow up study by Olley and co-workers showed a mean survival of 47.53 years for MC crowns [5].

One of the most important issue in the esthetic appearance of MC restorations, resulting in a positive effect on a patient's self-esteem [6,7], is a successful shade match and shade reproduction [8,9].

Difficulties related to color matching in MC restoration could have many sources, one of them being the use of inadequate shade guides [9,10], made from very thick tabs (around 4 mm), without a metal substructure. The traditional color replication process for dental ceramic is visual selection, in the shade matching phase, and then, the use of corresponding ceramic to match the color, in the shade duplication phase. It has been shown, both by in vitro studies [12,13] and in clinical studies [14] that this process could be inaccurate.

Nowadays, the occurrence of new technology enhanced the predictability of achieving accurately matched restorations. Instrumental equipment, such as spectrophotometers and colorimeters, have been used as an attempt to overcome problems with visual matching, allowing quantitative and objective assessment of dental shades, not affected by human biases, vision deficiencies, or an unsteady light source [34] and, also, enabling a more precise and uniform communication.

Another possibility of final shade variation could retrieve in the technological workflow. For instance, the type of metal alloys [15-18], the thickness of the opaque layer [19], even different brands of opaque porcelain of the same shade [20] could significantly influence the color of the

final restoration. Factors also relevant, in influencing the final color of a MC crowns are the firing temperature of porcelain [19,21], glazing cycle [22], mixing ratio between powder and liquid [23], the condensation techniques [24], thickness of ceramic layers [25-28], and varying compositions of ceramic materials [16,29,30] employed. Fired porcelain of the same shade manufacturer, but of different batches, may also differ in color [31]. Furthermore, the same shade of porcelain from different manufacturers have visible differences in color [17,32].

Beside the technical aspects exposed, the aesthetical result is very much influenced by the effective communication between clinician and laboratory technician, namely the human factor.

To overcome the deficiencies in color reproduction, inherent in porcelain systems, the dental technician must adjust porcelain color through the use of intrinsic and extrinsic colorants, modification of the opaque, and blending different shades of porcelain powders [33].

The aim of the present study was to objectively assess the variability in color reproduction of metal-ceramic single crowns fabricated by blending different color of opaque and body ceramic in order to point out which shade of the ceramic layers influences mostly the final color of MC restorations.

Experimental part

A standard preparation, for a full aesthetic metal-ceramic crown, was performed on the maxillary left first molar of a basic study model (KaVo Dental GmbH, Germany). An impression with condensation silicone (Speedex, Coltene/Whaledent AG, Switzerland) was made and poured using extra hard stone (Elite Stone class IV, Zhermack, Italy). A working cast with mobile abutment was produced, using Giroform system (AmannGirrbach AG, Austria). Eight nickel-chromium ceramo-metal alloy

* email: eugenia_totu@yahoo.com; corinacristache@gmail.com;

All authors have equally contributed to the manuscript and they should be regarded as main authors.

copings (Wiron 99; Bego, Germany) were fabricated, on the same cast, by one dental technician, for standardization (fig. 1). The metal copings were then processed to a standard thickness of 0.5 mm and air-abraded with 50 μ m alumina oxide particles.

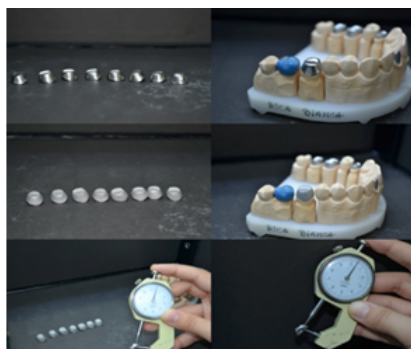


Fig.1 The eight standard metal copings manufactured on the same cast. Thickness measurement was performed with a precision thickness gauge

One reference ceramic crown (R) was blended, according to the producer's recommendation, for the specific A3 color and seven tests crowns have been build-up by a single experimented dental technician. Among the seven test samples (1-7), the color each one of the two uniform opaque layers, and dentin layer varied, as presented in table 1. For sample no.7, one non-uniform opaque layer was simulated and A3 dentin layer was added (table 1).

The porcelain material used to build-up each crown was IPS InLine (Ivoclar Vivadent AG, Principality of Liechtenstein) and the color specification to be matched was A3, according to Vitapan Classical shade guide. The two layers of opaque were coated on the metal copings, in a standardized 0.2 mm uniform final thickness (except for sample 7) and burned at 945° C for 16 min under vacuum conditions. The ceramic mass (80% dentine and 20% enamel) was prepared using the following protocol of firings: preheating for 5 min, first firing at 920°C for 17 min, corrections firing temperature of 910°C for 16 min. A standardized thickness of 1.2-1.5 mm after burning was obtained and the final glaze was applied at 850°C for 16 min.

The enamel layer applied to all manufactured crowns was Transpa Incisal TI2 and the finishing was System Glaze.

Table 1

CHARACTERISTICS OF THE REFERENCE (R) AND TEST SPECIMENS (1-7)

Specimens	Opaque first layer	Opaque second layer	Dentin layer
R	A3	A3	A3
1	A2	A2	A3
2	A3.5	A3.5	A3
3	A3	A3	A2
4	A3	A3	A3.5
5	A1	A3	A3
6	A4	A3	A3
7	A3 non-uniform layer		A3

A portable spectrophotometer (Easyshade VITA Zahnfabrik, H. Rauter GmbH, Germany) was used to evaluate the color reproduction.

Measurement protocol

Color of each manufactured crowns was measured after the three important steps of the technological workflow: the last opaque layer, enamel-dentin correction and final glaze firing. The instrumental measurements were performed three times in the middle third of the labial surface [35]. All factors considered to influence the results, such as: place, light, moment of the day, have been standardized. All measurements have been performed by a same investigator. After each set of measurements the device was turn off, restarted and recalibrated [36].

Vita Easyshade provides measurements in CIE L*a*b* units (Commission International de l'Eclairage color system), the international standard for color measurements [37]. The CIE L* coordinate, ranging from 0 to 100, represents the luminosity, the a* coordinate represents greenness (positive a*), and redness (negative a*), and the b* coordinate represents yellowness (positive b*) and blueness (negative b*). Differences between colors were calculated in the CIE L*a*b* system using the color distance between the coordinates of two stimuli with the following Euclidean formula [38]:

$$\Delta E = \sqrt{\Delta L^2 + \Delta a^2 + \Delta b^2} \quad (1)$$

After the initiation of the measurement procedure, the measurement tip was kept stable until the long beep appear and following parameters were recorded (fig. 2):

- ΔL =differences in Value (lightness) between specimen and A3,
- ΔC =differences in Chroma between specimen and A3,
- ΔH =differences in Hue between specimen and A3,
- ΔE = color difference between specimen and A3 calculated as Euclidean distance between the two points (colors) in the three dimensional space,
- ΔE_{LC} = ΔE calculated excluding H,
- Colour matching with A3, with the following scores: Good, Fair, or Adjust, where *Good* meaning that little or no difference between the restoration and the target shade could be seen; *Fair* meaning that a noticeable but acceptable difference between the restoration and the target shade could be observed, and *Adjust* meaning that the difference between the restoration and the target shade is obvious, and the restoration should be adjusted to be an acceptable shade match.

- Colour shade. The spectrophotometer Easyshade displays the nearest classical Vita shade of the measured sample, and sometimes, one or two alternate.



Fig 2 Spectrophotometric analyses of the final MC crowns

Statistical analyses were performed using SAS statistical software version 9.1.3 (SAS Institute, USA). One-way analysis of variance (ANOVA) and the Tukey's range test for multiple comparisons was run to evaluate the color differences of the reference specimen (R) as related to A3 shade (Classical Vitapan). Student t test was used to determine the differences in colour of each specimen related to R. A p-value <0.05 was considered statistically significant. Descriptive analyze of all evaluated colour parameters in the three phases of measurements were also performed.

Results and discussions

The small aperture of the portable spectrophotometer Vita Easyshade used in our evaluations, could be considered as an advantage in the MC crown specimens color registration, allowing the assessment of a distinct area of the crown (middle or incisal third). A wider aperture provides an average area color, which may not represent the color array [39] for MC crowns, where light is lost through translucency, consequently, the resultant color measurement is affected.

Reference (R) compared to A3

The color evaluation of the reference (R) MC crown, manufactured according to the producer's recommendations was performed by comparing it to A3 Classical Vitapan (fig. 3). Measurement were made after firing the final opaque layer, dentin - enamel layer and final glaze.

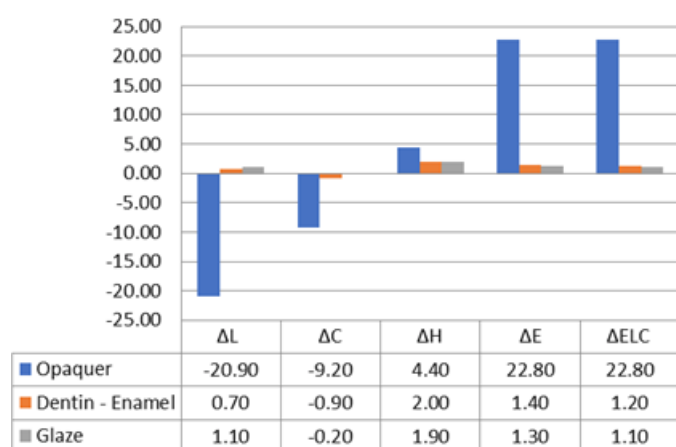


Fig. 3 Analysis of R compared to A3 Vitapan Classical shade

After the final opaque layer, an important negative difference in value (ΔL) and chroma (ΔC) were observed (fig. 3). The overall evaluation was *Adjust*, meaning that a noticeable color difference could be distinguished between the restoration and the target shade. The color shade detected by the spectrophotometer was C4. The measurements, made after dentin-enamel body application and firing revealed an increased luminosity of the specimen, still a negative saturation of the colour with a decreased yellow tendency. The spectrophotometric evaluation was *good* and detected shade was A3. After final glaze, the reference specimen had an increased luminosity and a yellowish tendency related to A3 Classical Vitapan, but the colour saturation decreased. The reference specimen was evaluated as *good* but the colour shade registration was between A3 and A3.5.

However, this result was perceived as clinically acceptable (ΔE =1.3) as long as the limit of the threshold perception in the oral cavity is between 3.3 and 3.7 [40].

Mean of the seven test specimens compared to R

The mean of the seven test specimens, measured after each of the three important steps of the technological workflow (provided in tables 2, 3 and 4), were compared to the reference (R).

After comparing the mean of the seven test specimens to R the following results have been obtained for the first phase of measurements: the means ΔLo and ΔCo for the test specimens were significant lower compared to R, p=0.021, respectively p=0.049; mean ΔHo was not significant modified (p=0.071), while means ΔEo and ΔELCo values were significant higher in samples 1 to 7 comparing to R, p=0.022, respectively p=0.023.

In the second stage of measurements (table 3), none of the parameters was significantly modified related to the reference (mean ΔLde, p=0.868; mean ΔCde, p=0.878; mean ΔHde, p=0.797; mean ΔEde, p=0.185; mean ΔELCde, p=0.162).

Similar results have been obtained for the final stage (table 4) measurements (mean ΔLg, p=0.882; mean ΔCg, p=0.236; mean ΔHg, p=0.627; mean ΔEg, p=0.119, mean ΔELCg, p=0.627).

After comparing the mean of the seven test specimens to R, statistical significant differences have been found only in the first measurement, performed after opaquer layers firing, results different to those obtained by O'Brien [31], where the variation for the opaque shades (mean ΔE was 0.46) was generally lower than that of the body/opaque combinations (mean E was 0.86).

Table 2

MEAN VALUES AND STANDARD DEVIATION OF COLOUR PARAMETERS AFTER THE FINAL OPAQUE LAYER FOR THE 7 TEST SPECIMENS

1to7 specimens	ΔLo	ΔCo	ΔHo	ΔEo	ΔELCo
Mean	-22.53	-8.86	3.43	24.24	24.21
Standard deviation	±1.38	±0.37	±1.17	±1.25	±1.23

Table 3

MEAN VALUES AND STANDARD DEVIATION OF COLOR PARAMETERS AFTER THE DENTIN-ENAMEL LAYER FOR THE 7 TEST SPECIMENS

1to7 specimens	ΔLde	ΔCde	ΔHde	ΔEde	ΔELCde
Mean	0.60	-0.96	1.79	1.97	1.77
Standard deviation	±1.52	±0.94	±2.11	±1.01	±0.95

Table 4

MEAN VALUES AND STANDARD DEVIATION OF COLOR PARAMETERS AFTER THE GLAZE LAYER FOR THE 7 TEST SPECIMENS

1to7 specimens	ΔLg	ΔCg	ΔHg	ΔEg	ΔELCg
Mean	1.20	-0.51	2.36	2.14	1.80
Standard deviation	±1.71	±0.63	±2.36	±1.23	±1.28

Comparison specimens to reference	ΔL	ΔC	ΔH	ΔE	ΔE_{LC}
1/R	0.82	0.75	0.45	0.05	0.04*
2/R	0.28	0.84	0.16	0.44	0.44
3/R	0.56	0.12	0.04*	0.80	0.67
4/R	0.75	0.61	0.20	0.01*	0.01*
5/R	0.33	0.46	0.11	0.63	0.63
6/R	0.53	0.75	0.12	0.30	0.27
7/R	0.04*	0.39	0.11	0.06	0.30

Each of the seven specimens compared to R

Each specimen was individually compared to reference, using student t test, in the three measurement steps (second opaquer layer, enamel-dentin layer and glaze) (table 5).

When comparing each specimen to reference, a statistically significant color difference was observed for no. 4. All the other specimens registered similar characteristics to R, except for specimens no. 1, no. 3 and no.7. Specimen no.1 registering statistically significant higher ΔE_{LC} specimen no. 3, a significant negative ΔH , with a final reddish/blueish tint and specimen no.7 had a reduce luminosity comparing to R, probably due to the non-uniform opaque layer, and (table 5).

Color matching to A3 and color shade

Each specimen has been individually compared to A3 in all the three important steps of the technological workflow, analysing the following parameters: ΔL , ΔC , ΔH , ΔE , ΔE_{LC} and the result are presented in figure 4 to figure 8.

A reduced luminosity (negative value - ΔL_o) can be observed in all specimens after second opaquer layer firing. However, after the next technological steps (dentin-enamel and glaze application), all the specimens are close to the standard of the requested colour (A3). Specimens 2 and 7 have still negative ΔL_g , meaning reduced luminosity after the final glaze. As it can be observed in figure 4, specimen 5 is the only sample with diminish luminosity after glaze firing. The closest to the ideal characteristics regarding luminosity are observed, as could be expected, for R specimen. The greater luminosity is noticed at sample 4 (fig. 4).

Chroma values increased, during the manufacturing workflow, for all specimens. However, after glaze firing, specimen no.1, registered a lower ΔC_g comparing to ΔC_{de} ,

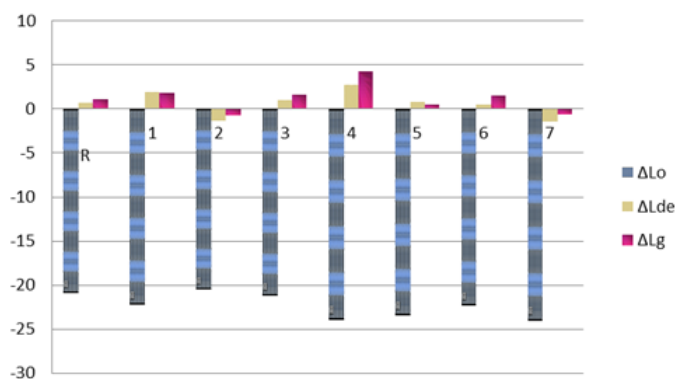


Fig. 4 Analysis of specimen's ΔL color parameter, in each of the three important steps of the technological workflow

Table 5
STATISTIC ANALYSIS OF ΔL , ΔC , ΔH , ΔE AND ΔE_{LC} DIFFERENCES BETWEEN SPECIMENS AND R IN EACH OF THE THREE IMPORTANT STEPS OF THE TECHNOLOGICAL WORKFLOW (*STATISTICAL SIGNIFICANCE, $p < 0.05$)

and specimen no. 2 had no variance in ΔC with the final glaze - $\Delta C_g = \Delta C_{de}$, (fig.5).

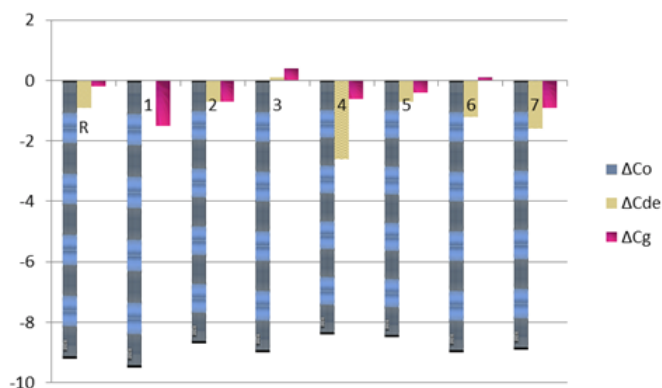


Fig. 5 Analysis of specimen's ΔC color parameter, for each of the three important steps of the technological workflow

The closest hue value to the required characteristics has been obtained for specimens 5 and 6. Specimen 3 has a very good trend after enamel-dentine layers firing but the final colour tends to red/blue after glaze application, in opposition to sample 4 with a good trend after glaze firing. Specimen 7 has the worse chroma reproductibility compared to all other samples (fig. 6).

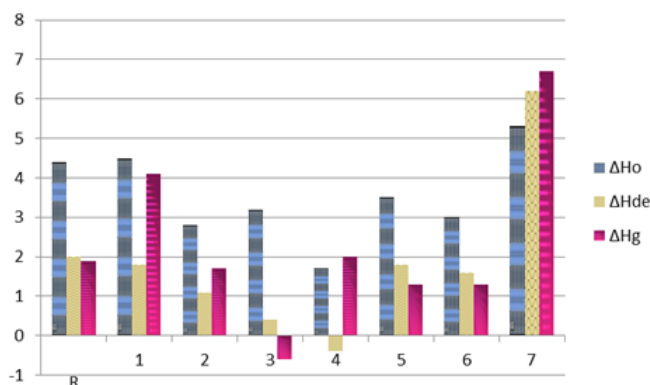


Fig. 6. Analysis of specimen's ΔH color parameter, for each of the three important steps of the technological workflow

ΔE values smaller than 1 ($\Delta E < 1$) are reported as unperceivable by the human eye [12], whereas a ΔE score of less than 3.3 - 3.7 are considered clinically acceptable [40]. Therefore, in this study, $\Delta E = 0.8$ in specimen 5 was accepted as visually undetectable. All the other specimens scored between 1.2 and 2.8, considered to be clinically acceptable, except for specimen 4 with $\Delta E = 4.4$, considered clinically unacceptable (fig. 7).

When evaluating of ΔE_{LC} , color difference between specimen and A3 without considering hue, similar results

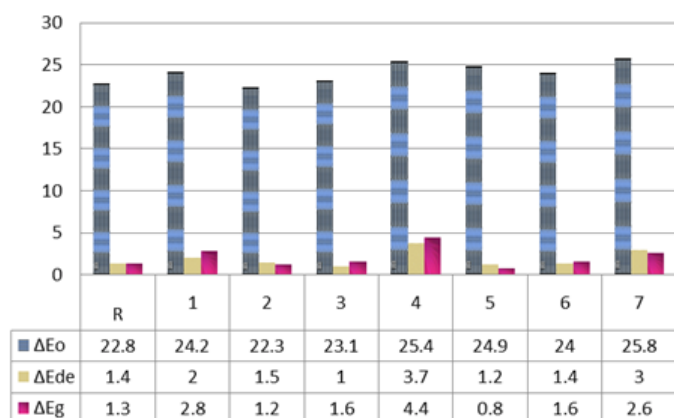


Fig. 7. Analysis of specimen's ΔE color parameter, in each of the three important steps of the technological workflow.

to ΔE are observed. The best colour matching at the final evaluation is observed in specimen 5. All the specimens are acceptable, except for no. 4 (A3.5 dentin layer) (fig. 8).

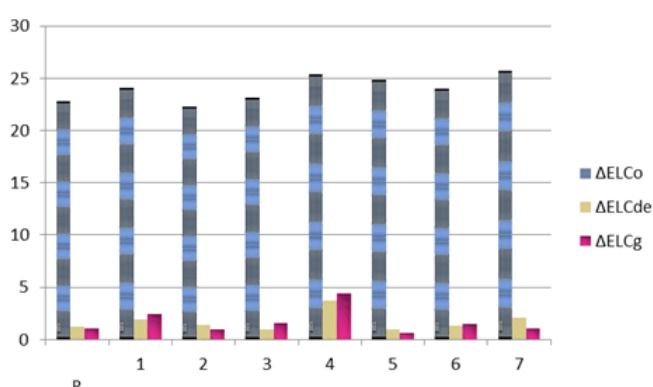


Fig. 8. Analysis of specimen's ΔELC color parameter, in each of the three important steps of the technological workflow

Color evaluation was performed in two different ways for all specimens and in each of the three important steps of the technological workflow. The obtained results are displayed in table 7.

As it can be noticed from table 6, all the specimens, except for no. 4 (with the dentin layer A 3.5), scored *good* at the last two evaluations. After the glaze firing, considered the last step of the technical workflow, none of the 8 specimens (including R, strictly manufactured, following producer's recommendations) was clearly A3, according

to the spectrophotometer's evaluations. However, specimens no. 1 and 4 were evaluated as A3.5 with no other alternate.

The use of different opaque color (A2 vs. A3.5), in specimens no. 1 and 2, showed a tendency of the specimen no. 2 (with darker opaque) to a lower brightness, increased color intensity, and increased spectrum to yellow. Although, at the last two color evaluations the specimens no. 1 and 2 received a *good* grade for A3 color, the actual determination is A3.5 (no. 1) and an average between A3.5 and A4 (no. 2). Therefore, the difference in opaque color influenced the final color within acceptable limits, in accordance to Seggi and co-workers observations [20].

After applying and firing the enamel/dentin layer, the difference between the specimens (A2 vs A3.5) led to significant changes for the specimen no.4 (table 6), with darker dentin layer. The color obtained for specimen no.4 was far from the A3, and was scored as *fair*. The mismatch remained till the final step of the technological workflow and the registered color difference was $\Delta E = 4.4$ (fig. 7). The lighter dentine/enamel specimen (no.3), obtained a *good* score and a color determination between A3 and A2. These observations lead to the assumption that the different color of the enamel/dentine layers influences the final color, especially when the selected shade is darker.

When a single layer of opaque (with varying thickness) is applied, through which the metal color transpires, specimen no.7, color can be compensated by the subsequent layers, indicating that the final shade turns to yellow and the final color evaluation scored *good*. This result is in accordance to Burak and co-workers findings who tested different alloys, emphasizing that subsequent porcelain firings significantly affected the color of a 0.1-mm-thick layer of opaque porcelain for all alloys tested [19].

A balance between aesthetics and mechanical strength is always follow up when obtaining restored teeth. The optical and mechanical properties of applied ceramic are governed by the ratio of the present crystalline and glassy phase. In the considered cases under study, the opaque layer consists of a vitreous leucite based ceramic. It is known that a higher content of the glassy phase would lead to a good translucency, while a good strength suppose an important amount of crystalline phase. Leucite, $K[AlSi_2O_6]$, presents a crystal content between 35 to 45%

Table 6
COLOR EVALUATION OF THE SPECIMENS USING THE SPECTROPHOTOMETER EASYSHADE,
IN EACH OF THE THREE IMPORTANT STEPS OF THE TECHNOLOGICAL WORKFLOW. THE FIRST DISPLAYED
COLOR IS MARKED WITH BOLD FONTS

Specimens	Opaque		Enamel-dentin		Glaze	
	Color matching A3	Color determination	Color matching A3	Color determination	Color matching A3	Color determination
R	Adjust	C4	Good	A3	Good	A3, A3.5
1	Adjust	C4	Good	A3, A2	Good	A3.5
2	Adjust	C4	Good	A3.5, A3	Good	A3.5, A4
3	Adjust	C4	Good	A3, C2, D3	Good	A3, A2
4	Adjust	C4	Fair	A2, A3	Fair	A3.5
5	Adjust	C4	Good	A3, A3.5	Good	A3.5, A3
6	Adjust	C4	Good	A3	Good	A3, A3.5
7	Adjust	C4	Good	B4, A3, D3	Good	B4, A3, B3

which would impart a certain translucency ensuring, in the mean time, a certain mechanical strength. Considering that the opaque porcelain layer should fulfill three main actions: to ensure the bond between metal and ceramic, to mask the dark shade of metal and to promote the development of the ceramic shade, the leucite based ceramic structure becomes significant. The opaque material consisting in fact of various oxides mixture: $K_2O-Al_2O_3-SiO_2$ with different supplements of: Na_2S , SnO_2 , TiO_2 , ZrO_2 , CeO_2 , BaO and ZnO presents a tetragonal crystal system and dipyramidal crystal class. The structure of leucite, $K[AlSi_2O_6]$, could be included into the poly(sialate-siloxo) type, being similar to the analcime - $NaAlSi_2O_6 \cdot H_2O$ - and pollucite - $CsAlSi_2O_6 \cdot xH_2O$. It should be mentioned that the leucite structure is based on the frame formed by: $Si-O-Al-O-Si-O$, which are further connected forming rings of 4 and 6 units. In present study, as substructure has been used non-precious alloy components, Ni-Cr based. As in the preparation procedure a firing stage was involved it is very likely for an oxide layer to be formed over the metallic base. In such situation, at the boundary between metal and ceramic an oxide monolayer could appear, belonging both to metal and ceramic material. The formation of such oxide monolayer is able to assure a chemical bonding between the metallic base and opaque ceramic - as suggested in figure 9.

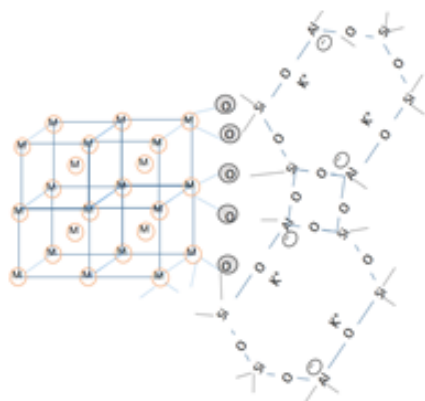


Fig. 9. Suggested chemical bonding of metal to leucite ceramic

Following the previous considerations, it could be affirmed that the final color of metal-ceramic specimens is also influenced by the type of alloy substructure and the overlaying porcelain [41]. Data from literature indicates that the Ni-Cr alloy, used in our study, can determine significant color changes due to Ni ions, having shown to produce a neutral gray color in sodium silicate glasses, associated with some color changes in porcelain [41]. The primary difference between metal-ceramic restorations and natural teeth is due to the presence of metal framework, used to compensate for the low fracture resistance of the porcelain. The metal framework acts as a barrier to the transmission of light, giving the prosthetic dental restoration an unaesthetic opaque aspect, with the presence of a darkening region, which is more evident in the cervical portion, where the porcelain layer is thinner [42].

In order to better mask the influence of metal framework, the aim of our study was to determine which shade of the ceramic layers influences mostly the final color of MC restorations. The obtained results showed that when porcelain was fused to a ceramic alloy, colour differences were smallest for the opaque layer and increased substantially when body porcelain was applied, similar to other studies findings [20].

In the present study, the reference specimen (R) strictly manufactured according to the producers recommendations was evaluated as *good* and the color

difference was perceived as clinically acceptable ($\Delta E = 1.3$), similar to the others specimens, except for no. 4

However, one should consider that there are some study limits. The spectrophotometric devices used measured a curved tooth surface instead of flat surface and its small aperture could yield edge-loss effect which can cause a deviation of color interpretation and must be considered a potential source of error.

The ability to fabricate ceramic prostheses using a machine-readable technology, design (CAD) [43] and manufacturing (CAM) and the proved qualities of zirconia ceramics, such as biocompatibility, esthetic appearance, high mechanical properties and chemical stability will probably lead, in the next future, to the gradually replacement of MC crowns and bridges.

Conclusions

Fabricated specimens of all groups, except for no.4, showed ΔE values between 0.8 and 2.8, in the limit of the threshold perception in the oral cavity, considered between 3.3 and 3.7 [40]. Specimen no. 4, with a darker dentin layer (A 3.5), scored a perceivable color difference ($\Delta E = 4.4$), evaluated clinically unacceptable.

Within the limits of the present study, we can conclude that the dentin-enamel layer mostly influences the final color of the MC crowns.

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