ARAŞTIRMA/ORIGINAL ARTICLE

Gülhane Tıp Derg 2014;56: 199-205

doi: 10.5455/gulhane.152766

Assessment of thicknesses and color properties of opaque porcelain layers applied by different dental technicians

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SUMMARY

The aim of the present study was to evaluate the effect of individual manipulative variations on the thickness and color values of opaque porcelain layers applied by different dental technicians. A total of 11 dental technicians applied opaque porcelain onto prepared metal specimens (n=10). The thicknesses of these opaque porcelain layers were measured with an ultrasonic device, and color values were evaluated using a spectrophotometer. Obtained values were compared with those of the control group specimens (n=10), which were fabricated by a prosthodontist. Opaque porcelain thickness values of metal specimens applied by 10 dental technicians were significantly different than those of the control group. Color values of opaque porcelain layer applied by nine dental technicians were significantly different than those of the control group. It was concluded that the opaque porcelain layer thickness and color values may be affected by individual manipulative variations by the different dental operators according to results of present study.

Key Words: *Opaque porcelain layer, dental technician, manipulative variables.*

ÖZET

Farklı dental teknisyenler tarafından uygulanan opak porselen tabakasının kalınlık ve renk özelliklerinin incelenmesi

Bu çalışmanın amacı, kişisel uygulama farklılıklarının, farklı diş teknisyenleri tarafından tatbik edilen opak porselen tabakasının kalınlık ve renk değerlerine olan etkisinin değerlendirilmesidir. Çalışma için toplam 11 diş teknisyeni, önceden hazırlanmış metal örneklere (n=10) opak porselen uyguladılar. Opak porselen tabakası kalınlıkları bir ultrasonic ölçüm cihazı ile, renk değerleri ise spektrofotometre cihazı ile saptandı. Elde edilen değerler, bir prostodontist tarafından üretilen örneklerin oluşturduğu kontrol grubu değerleri ile karşılaştırıldı. 10 diş teknisyeni tarafından uygulanan opak porselen tabakası kalınlık değerleri control grubundan anlamlı bir şekilde farklı bulunmuştur. Dokuz diş teknisyenin uyguladığı opak porselen tabakası renk değerleri control grubundan anlamlı bir şekilde farklıdır. Bu çalışmanın sonuçlarına gore, opak porselen tabakası kalınlığı ve renk değerleri, kişisel uygulama faklılıklarından etkilenebilmektedir.

Anahtar Kelimeler: *Opak porselen tabakası, diş teknisyeni, uygulama farklılıkları.*

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Makalenin Geliş Tarihi: 20.01.2014 • **Kabul Tarihi:** 19.06.2014 • **Çevrim İçi Basım Tarihi:** 27.12.2014

Introduction

Despite the increasing popularity of all-ceramic systems, metal-ceramic restorations (MCRs) are still the leading treatment option for fixed restorations (1-3). The combination of aesthetic and mechanical strength with low cost is one of the most important reason underlying the great success of MCRs since they emerged in the 1950s (4,5). In fact, quite aesthetic MCRs may be produced by talented dental technicians, despite some optical disadvantages of their metal substructures (6). Clearly, accurate use of different materials and fabrication techniques is crucial for a successful MCR as all prosthetic applications.

An MCR is composed of at least three different layers of dental porcelain, each having different opacities, translucencies, shades, and thicknesses to provide a quite natural appearance (7,8). These layers are opaque porcelain (OP), body porcelain (BP), and incisal porcelain (IP), and applied in a set sequence to the metal substructure (7-9). To obtain completely masked metal substructure, application of OP are generally made in two stages (10,11). It has been reported that thickness of the layer should not exceed 0.1 mm for base metal alloys at the end of the OP application (11). On the other hand, a thicker OP layer may be required to mask the surface shade of some dental alloys that ensues from a darker oxide layer (11). Under the circumstances, an aesthetically pleasing appearance may become impossible because of overcontouring paradoxically caused by attempting a more aesthetic restoration (11). In fact, overcontouring results in increased ceramic layer thickness, and it is known that the thickness of different ceramic layers may influence the final shade of a MCR (8,12).

Besides the thicknesses of the different porcelain layers, countless variables such as the type of dental alloy, application method, slurry preparation method, powder/likit ratio of the porcelain slurry, condensation technique, and number of firings may affect the physical properties or the final color of MCRs (1,5,8,13-16). The influences of various application techniques or materials types on the color properties of MCRs have been extensively investigated. However, considering the whole complex fabrication process, it seems clear that the mechanical and aesthetic success of an MCR could be affected by not only technique or material selection but also uncontrolled variables arising from disparities in dental technicians' experience or skill (12). Unfortunately, there is very sparse data regarding emerging changes on the specific properties of MCRs caused by interpersonal differences among technicians.

The most challenging issue in prosthetic dentistry is to ensure the initially predicted shade in the final restoration. That could create troubles for even a skilled, experienced technician. However, no published study assessing the effect of dental technician differences on the final shades of OP, BP, and IP layers in MCRs exists in the literature.

The aim of the present study was to determine whether or not the applications executed by different dental technicians affect OP layer thickness and color properties. The null hypothesis was that individual variables among dental technicians may cause differences in OP layer thickness and color values, even if the same materials and laboratory conditions are used.

Materials and Methods

This study was approved by the Ethic Committee of Gülhane Military Medical Academy in Ankara, Turkey (October 2012), and executed in accordance with the Helsinki Declaration (1975), as revised in 2008.

A total of 11volunteer dental technicians participated in this study. All participants gave written informed consent. Participation criteria were as follows:

- Absence of color-vision deficiency or any serious visual impairment
- Absence of any neuromuscular disorders
- Having at least 5 years' dental technician experience
- Aged between 30 and 55

The methodology was designed in five stages as follows:

- Production of a stainless steel mold and use of that mold to fabricate disc-shaped metal substructures (MSs)
- OP application on MSs by different dental technicians
- Measurement of the thickness of OP layers from the surface of MSs
- Spectrophotometric analysis of OP layers
- Statistical analyses of obtained data

Mold Production and Disc-Shaped MSs Fabrication

A total of 120 disc-shaped MSs with a diameter of 12.5 mm and thickness of 2.75 mm were fabricated. A stainless steel mold was created to obtain standard wax patterns, which were used to cast the MSs. For this purpose, two stainless steel plates (length; 260 mm, width; 60 mm, thickness; 2.85 mm) were used. A total of 10 equidistant (4.5 mm) circles (Ø; 12.5 mm) were concentrically drawn onto one of the metal plates via computer-aided design (BricsCAD® V12, Bricsys, Ghent, Belgium). These circles were subjected to laser cutting technology (Amada, CA, USA) so that 10 circular holes were cut in the body of the plate, and the plate was then cut in a straight line from the first hole to the last hole through the exact center of each. The laser cutting was continued with a single zigzag at each sides of the plate to construct a lock system. Finally, the laser cutting was completed linearly with zigzag slits to the end of the plate on each side. After the laser cutting process, two identical parts comprising a lock system for integrating separate parts remained. The cut plate, which now consisted of two pieces, was placed onto the first plate, which was still in one piece. While both plates were superimposed, four screw holes, two on the left and two on the right side of the plates, were drilled and all of the screws driven into their respective holes. Each piece of the mold was cleaned for 10 minutes in an ultrasonic bath (Bandelin Sonorex Super RK 514/H, Bandelin Electronic, Berlin, Germany) with distilled water. Then, all of the parts were immersed in 80% ethyl alcohol for 10 minutes, and ultrasonic cleaning was repeated for an additional 10 minutes. Finally, all pieces were dried and assembled ready for use.

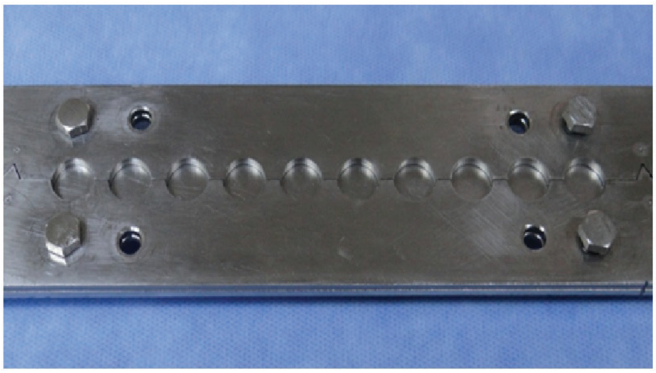

Figure 1. Stainless steel mold

The use of occlusal wax (Aroma Occlusal Wax, Bego, Bremen, Germany) was preferred in the fabrication of the disc-shaped wax patterns to avoid distortion during the sprueing and investing procedures. Occlusal wax was melted and dropped into the holes of the mold, and the upper surfaces of the wax patterns were cleaned with ethyl alcohol after cooling to provide completely smooth OP-bearing surfaces without any scratches. Later, the wax patterns were retrieved from their holes and carefully inspected by two prosthodontists with regards to smoothness, finish, and contours. Wax patterns that had deformed contours and finishes or uneven surfaces were excluded from the study and refabricated.

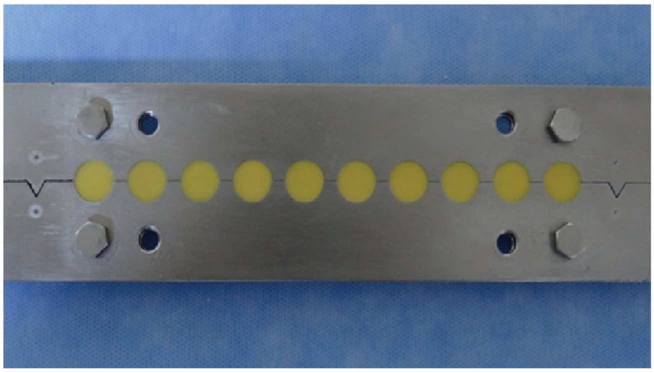

Figure 2. Wax patterns obtained with occlusal wax dropping.

All of 120 wax patterns were sprued and given a phosphate-bonded investment (Castorit Super C, Dentaurum, Ispringen, Germany). After the investment set, a base metal alloy (Remanium CSe, Dentaurum, Ispringen, Germany) was cast in the cavities of wax patterns obtained via the lost wax technique. The alloy was melted with a high-frequency induction heating system, and cast with a centrifugal machine (Bego Fornax GEU, Bremen, Germany). After divesting, the sprues were cut off, and ultrasonic cleaning was performed to remove small investment particles from the surfaces of the metal specimens.

Casting burrs were eliminated with sintered diamond burrs, and the OP-bearing surfaces of the metal discs were ground with 400- and 600-grit silicone carbide abrasive paper. The diameters and thicknesses of all specimens were controlled by two prosthodontists from six reference (three for thickness, three for diameter) points using a digital caliber (TL2610 Digital Caliber, Tarot RC, San Diego, CA, USA), and any specimens that were out of order were excluded from the study and refabricated. All metal discs were exposed to ultrasonic cleaning for 10 minutes and dried. Afterwards, the OP-bearing surfaces of the metal discs were sandblasted with 50 µm aluminum oxide particles (Korox 50, Bego, Bremen, Germany) and steam cleaned. Initial oxidation treatments were performed after sandblasting.

Finally, 120 metal structures (MSs) were randomly assigned to 12 experimental groups (n=10). A total of 110 MSs were randomly distributed to 11 dental technicians, 10 each. The first letters of the technicians' names were marked onto the backside of each MS. The remaining 10 MSs were kept as a control group (CG), and the first letter of the group name was written onto the backs of these. All of the MSs were numbered from 1 to 120.

Application of the OP Layer

A 0.1 mm thick OP layer was applied to the MSs of the CG. The OP application of was performed by the same prosthodontists, in two stages. B1 shade OP paste (IPS Inline Opaquer, Ivoclar, Vivadent, Schaan, Liechtenstein) and opaque liquid (IPS Inline Opaque Liquid, Ivoclar, Vivadent, Schaan, Liechtenstein) were used to prepare OP slurry.At first, the OP paste material was diluted with its liquid, and the relevant surfaces of the MSs were wetted with the first layer of OP, using special opaque porcelain brushes (B-260, BK-Medent Co., Ltd, Bukgu Daegu, South Korea), and then fired under vacuum (Ivoclar Programat P20, Ivoclar, Vivadent, Schaan, Liechtenstein) as recommended by the manufacturer. In the second stage, precise masking of the MSswas performed witha more viscous OP, and firing was repeated. After the OP application to the MSs of the CG was complete, the OP thicknesses were measured with an ultrasonic measurement device (UMD). MSs with OP-layer thickness values of 0.1 ± 0.01 mm were excluded from the study and refabricated.

Afterwards, each dental technician applied OP material onto the surface of 10 MSs under the same laboratory, equipment, and materials conditions as the CG. The technicians worked without any counseling about their materials or techniques. After the OP applications were finished, the OP thicknesses were again measured.

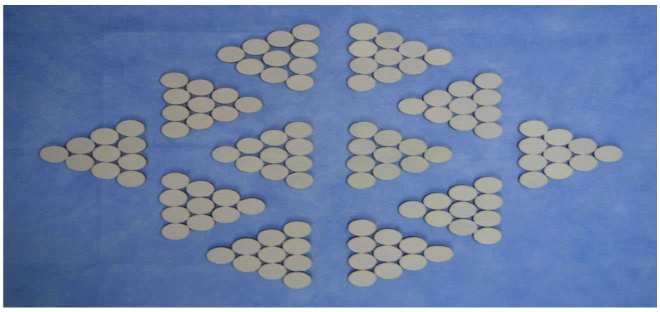

Figure 3. Opaque porcelain applied metal specimens

Thickness Measurement of OP Layers

An ultrasonic measurement device (UMD) (Elcometer, Elcometer Inc, MI, USA) with 0.01 mm precision was used to measure the thickness es of the OP layers. The UMD was calibrated using the 120 µm thick calibration foil (Figure 4). After the calibration, UDM was positioned at the center of each MS, and three measurements were performed consecutively by the same practitioner and the results registered.

Figure 4. Calibration of the UMD before OP layer thickness measurement

OPL Spectrophotometric Measurements.

The ColorFlex EZ (HunterLab, Hunter Associates Laboratory, Inc., VA, USA) spectrophotometer was used for spectrophotometric measurements of the MSs. All measurements considered CIEL*a*b* color space (in which the brightness is shown with L*, red-green chromacy with a*, and yellow-blue chromacy with b*) in the present study. Before measurements, the spectrophotometer was calibrated according to the manufacturer's instructions with ceramic tiles. All mesurements were performed under a D65-type illuminant with 10º observation angle conditions. The measurement geometry of the spectrophotometer was 45/0. After calibration, specimens were placed into negative cavities located in the optical cavity of the spectrophotometer. The spectrophotometer was covered with its cap, and initial measurements were performed.

Spectrophotometric measurements were performed in two stages. Initial spectrophotometric measurements were taken from the relevant surfaces of the MSs, before OP applications. The spectrophotomer was set to perform three measurements for each specimen and average values were recorded. After completion of the initial measurements, average L*, average a*, and average b* values of all 120 MSs were calculated. Afterwards, L*a*b* values of each MS were compared with theaverage L*a*b* value of all of the MSs, and ΔE values were calculated. MSs with ΔE values lower than 0.2 were excluded from the study to ensure color standardization before final spectrophotometric measurements. For the calculation of ΔE values, the following formula was used:

$$\Delta E=[(L^*1-L^*2)^2+(a^*1-a^*2)^2+(b^*1-b^*2)^2]^{1/2}$$

Final spectrophotometric measurements were performed after OP application to the MSs surfaces. The calibration was re-adjusted before the measuring each groups. As before, the spectrophotomer was set to perform three measurements for each specimen, and average values were recorded. The L*a*b* values of the 11 experimental groups were compared with those of the CG, and ΔE values were calculated.

The obtained ΔE values have been quantified by National Bureau of Standards (NBS) units to match color differences for the clinical conditions (NBS units: clinically acceptable level < 3.0) (17). The NBS units were calculated by the following formula:

$$\text{NBS Units} = \Delta E^* \times 0.92$$

Statistical Analyses

The Statistical Package for Social Sciences software program (SPSS 15.0) was used for statistical analyses. Obtained data were subjected to descriptive analysis, and ANOVA analysis was performed to compare the groups. Dunnett's test was used for multiple comparisons. The effect of OP thickness on OP-layer color was evaluated with the Pearson correlation test.

Results

Average L*a*b* values (avegare L*, 9.499; average a*, 0.462; average b*, 0.276) of all 120 MSs were calculated after the initial spectrophotometric evaluation. All 120 ΔE values obtained from comparing the average L*a*b* value with each MSs are presented in Tables 1 and 2.

Table I. ΔE values obtained by comparing average L*a*b* values and L*a*b* values of MSs for groups CG, T1, T2, T3, T4, and T5.

CG	ΔE	T1	ΔE	T2	ΔE	T3	ΔE	T4	ΔE	T5	ΔE
1	0,048	11	0,068	21	0,061	31	0,060	41	0,095	51	0,073
2	0,078	12	0,070	22	0,063	32	0,013	42	0,067	52	0,047
3	0,140	13	0,081	23	0,025	33	0,106	43	0,106	53	0,109
4	0,106	14	0,097	24	0,060	34	0,012	44	0,099	54	0,042
5	0,128	15	0,119	25	0,036	35	0,078	45	0,051	55	0,112
6	0,051	16	0,063	26	0,112	36	0,065	46	0,059	56	0,081
7	0,043	17	0,049	27	0,039	37	0,102	47	0,034	57	0,046
8	0,092	18	0,078	28	0,048	38	0,089	48	0,037	58	0,032
9	0,089	19	0,051	29	0,100	39	0,055	49	0,035	59	0,114
10	0,122	20	0,044	30	0,132	40	0,058	50	0,042	60	0,063

Table II. ΔE values obtained by comparing average L*a*b* values and L*a*b* values of metal specimens for groups T6, T7, T8, T9, T10, and T11.

T6	ΔE	T7	ΔE	T8	ΔE	T9	ΔE	T10	ΔE	T11	ΔE
61	0,062	71	0,120	81	0,080	91	0,054	101	0,079	111	0,074
62	0,054	72	0,119	82	0,062	92	0,115	102	0,137	112	0,126
63	0,056	73	0,082	83	0,079	93	0,091	103	0,060	113	0,054
64	0,084	74	0,071	84	0,082	94	0,061	104	0,043	114	0,096
65	0,050	75	0,070	85	0,064	95	0,121	105	0,028	115	0,006
66	0,152	76	0,062	86	0,034	96	0,077	106	0,056	116	0,095
67	0,120	77	0,024	87	0,086	97	0,084	107	0,072	117	0,067
68	0,122	78	0,053	88	0,092	98	0,033	108	0,076	118	0,031
69	0,088	79	0,063	89	0,065	99	0,063	109	0,080	119	0,094
70	0,077	80	0,031	90	0,088	100	0,028	110	0,081	120	0,039

Geometric averages of each group's ΔE value were calculated, and the results subjected to descriptive analyses as described in Table 3.

Table III. Descriptive statistics of ΔE values

Group	n	Mean	Minimum	Maximum	St. Dev.
CG	10	0,0897	0,04	0,14	0,034
T1	10	0,0720	0,04	0,12	0,023
T2	10	0,0676	0,03	0,13	0,035
T3	10	0,0638	0,01	0,11	0,032
T4	10	0,0625	0,03	0,11	0,028
T5	10	0,0719	0,03	0,11	0,031
T6	10	0,0865	0,05	0,15	0,034
T7	10	0,0695	0,02	0,12	0,031
T8	10	0,0732	0,03	0,09	0,017
T9	10	0,0727	0,03	0,12	0,031
T10	10	0,0712	0,03	0,14	0,029
T11	10	0,0682	0,01	0,13	0,036
Total	120	0,0724	0,01	0,15	0,030

OP-layer thickness values of the CG and 11 experimental groups are depicted in Tables 4 and 5.

Table IV. OP-layer thickness values of groups CG, T1, T2, T3, T4, and T5.

CG	μ	T1	μ	T2	μ	T3	μ	T4	μ	T5	μ
1	100	11	140	21	100	31	200	41	160	51	200
2	100	12	190	22	100	32	130	42	160	52	140
3	100	13	160	23	140	33	160	43	200	53	140
4	100	14	150	24	150	34	190	44	170	54	140
5	100	15	110	25	110	35	220	45	170	55	130
6	100	16	110	26	140	36	160	46	150	56	190
7	100	17	160	27	130	37	180	47	160	57	120
8	100	18	150	28	120	38	220	48	190	58	130
9	100	19	150	29	110	39	220	49	130	59	150
10	100	20	110	30	180	40	170	50	170	60	170

Table V. OP-layer thickness values of groups T6, T7, T8, T9, T10, and T11.

Table V. OP-layer thickness values of groups T6, T7, T8, T9, T10, and T11.

T6	μ	T7	μ	T8	μ	T9	μ	T10	μ	T11	μ
61	210	71	290	81	170	91	160	101	160	111	170
62	140	72	240	82	150	92	170	102	150	112	160
63	180	73	190	83	120	93	180	103	160	113	160
64	170	74	230	84	160	94	170	104	170	114	170
65	170	75	210	85	130	95	140	105	200	115	160
66	170	76	220	86	150	96	180	106	140	116	180
67	130	77	240	87	150	97	150	107	160	117	180
68	200	78	250	88	150	98	190	108	140	118	160
69	120	79	190	89	160	99	190	109	210	119	180
70	190	80	230	90	140	100	150	110	180	120	160

Descriptive statistics obtained from the geometric averages of each group are given in Table 6.

Table VI. Descriptive statistics of experimental groups.

Group	n	Mean	Minimum	Maximum	St. Dev.
CG	10	100	100	100	100
T1	10	143	110	190	26,26
T2	10	128	100	180	25,29
T3	10	185	130	220	30,64
T4	10	166	130	200	19,55
T5	10	151	120	200	26,85
T6	10	168	120	210	29,73
T7	10	229	190	290	29,60
T8	10	148	120	170	14,75
T9	10	168	140	190	17,51
T10	10	167	140	210	23,59
T11	10	168	160	180	9,18
Total	120	160	100	290	37,20

After the L*a*b* values of each specimen were obtained via final spectrophotometric evaluation of the OP surfaces, the L*a*b* values of each CG specien were compared one by one with the other 119, and ΔE values obtained. Geometric averages of these ΔE values for each experimental group were calculated and the data subjected to descriptive analysis. Results are presented in Table 7.

Table VII. Descriptive statistics of ΔE values after OP application

Group	n	Mean	Minimum	Maximum	St. Dev.
CG	10	0,2680	0,22	0,36	0,0518
T1	10	0,7662	0,55	0,84	0,0569
T2	10	0,5115	0,28	0,78	0,1941
T3	10	0,7965	0,67	0,99	0,1230
T4	10	1,2558	1,06	1,59	0,1714
T5	10	1,2509	0,93	1,63	0,2758
T6	10	1,1253	0,87	1,40	0,1904
T7	10	0,4856	0,36	0,61	0,0884
T8	10	0,5310	0,47	0,62	0,0432
T9	10	1,2761	0,94	1,62	0,2627
T10	10	0,7236	0,68	0,76	0,0228
T11	10	0,5595	0,38	0,79	0,1570
Total	120	0,7958	0,22	1,63	0,3689

After this, the data were evaluated using analysis of variance (ANOVA) as shown in Table 8. The confidence level was set at 95% (p<0.05).

Table VIII. ANOVA results of analyzed data.

	p*
ΔE values of MSs	0,747
Thicknesses of OP Layers	0,000
ΔE values of OP Layers	0,000

No statistical significance was found among L*a*b*values obtained from color measurements performed on MSs surfaces before OP application.After OP application, significant differences were found in the color and thickness values of the specimens. These were assessed with a Dunnett's test. Results are listed in Table 9.

Table IX. OP thickness comparisons between groups (significance level: p< 0.05)

	CG	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
T1	0,04										
T2	0,484	1,000									
T3	0,000	0,005	0,000								
T4	0,000	1,000	0,022	1,000							
T5	0,000	1,000	1,000	0,081	1,000						
T6	0,000	1,000	0,011	1,000	1,000	1,000					
T7	0,000	0,000	0,000	0,003	0,000	0,000	0,000				
T8	0,001	1,000	1,000	0,031	1,000	1,000	1,000	1,000			
T9	0,000	1,000	0,011	1,000	1,000	1,000	1,000	0,000	1,000		
T10	0,000	1,000	0,015	1,000	1,000	1,000	1,000	1,000	1,000	1,000	
T11	0,000	1,000	0,011	1,000	1,000	1,000	1,000	0,000	1,000	1,000	1,000

Differences among experimental group data obtained with OP-layer color measurements were also evaluated with the Dunnett's test (Table 10).

Table X. Comparison of OP-layer color differences among groups (significance level; p< 0.05)

	CG	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
T1	0,000										
T2	0,059	0,035									
T3	0,000	1,000	0,008								
T4	0,000	0,000	0,000	0,000							
T5	0,000	0,000	0,000	0,000	1,000						
T6	0,000	0,000	0,000	0,001	1,000	1,000					
T7	0,188	0,010	1,000	0,002	0,000	0,000	0,000				
T8	0,023	0,086	1,000	0,020	0,000	0,000	0,000	1,000			
T9	0,000	0,000	0,000	0,000	1,000	1,000	1,000	0,000	0,000		
T10	0,000	1,000	0,237	1,000	0,000	0,000	0,000	0,075	0,525	0,000	
T11	0,005	0,297	1,000	0,079	0,000	0,000	0,000	1,000	1,000	0,000	1,000

The effect of OP thicknesses on OP-layer color values of was evaluated with a Pearson correlation test, but no correlation was found (r; 0.165).

Discussion

According to the results of the present study, significant differences were found in the thicknesses and color values of OP layers applied by different dental technicians, so the null hypothesis was accepted.

Despite numerous studies in the literature evaluating the effects of different materials and fabrication techniques on the success of prosthetic restorations (5,18-21), the number of studies investigating the effect of individual manipulation variations among laboratory personnel on the prosthetic fabrication process is very limited.

The brush-on and spray techniques are the two main OP application methods used in a dental laboratory. In previous, similar studies, the OP layer application was generally per formed with the brush-on technique (9,14,15). In the present study, the brush-on technique was again used for OP layer application because dental technicians included in the present study were used to applying this technique in their professional lives.

The preferred OP layer thickness was reported in the literature as between 0.1 and 0.3 mm (10,11). However, general agreement is that the optimal OP-layer thickness is about 100 microns in order to mask the metal substructure and provide an essential color for the restoration (11,22,23). Because of this the control group's specimens had OP layers 100 microns thick. Ensuring a standard OP layer in MCRs is crucial to have sufficient spacing for the aesthetic veneering materialand meet aesthetic requirements. OP thicknesses exceeding 100 microns may generate problems in establishing a BP-layer thickness of 0.8–1.0 mm and in creating optical properties required for a natural appearance. Establishing an initial bond between the BP and MS layers and providing bonding strength to the restoration are other important functions of the OP layer's substructure (5,9). It has been reported that firing temperature and OP-layer thicknesses may affect an MCR's bonding strength (24,25). The present study indicated that OP layers formed by different dental technicians may result in statistically significant differences; thus, the average OP-layer thickness values among the 10 experimental groups showed statistically significant differences compared to the CG, except Group T2.The comparison among these experimental groups also revealed significant thickness differences.

The appearance and color properties of a ceramic restoration may be affected by a variety of factors that may arise because of material or method differences. Thickness differences in the porcelain layers, surface finishing procedures, the number of firings, and surface staining were the most frequently investigated ones (26-32). Moreover, there are studies in the literature reporting that different metal substructures may affect the final shade of restorations (33,34). In the present study, the ability of color differences in the metal substructures to affect OP-layer color were evaluated, while the base metal alloy type and the fabrication technique were kept constant. Data obtained from spectrophotometric measurements of the MSs revealed no significant difference among the 120 metal specimens. Probable color differences in the OP layers originating from MSs were minimized. The OP-layer application by different dental technicians on metal specimens with equalized color characteristics was possible only after realizing such a standardization. The results of the present study showed that the color properties of OP layers applied by different dental technicians were significantly variable.Nine experimental groups displayed significant color differences compared to the control group, except groups T2 and T7. Significant differences were observed among the experimental groups; however, these were under the critical ΔE value of 2.6, the lower limit of human visual perceptibility. Additionally, no correlation between color differences and OP-layer thicknesses of was found.

On the other hand, the color characteristics of an object are highly dependent on its surface properties. There are some studies emphasizing that the changes in surface texture of restorative materials may significantly affect their optical and color properties (21,35-37). Regarding the present study, color differences in OP layers may originate from surface variations. Indeed, while the OP-layer thickness of group T7 was significantly higher than that of the control group, group T7 was one of the two experimental groups (T7 and T2) which did not show significant color differences compared to the CG. We do not have any data about the surface characteristics of OP layers to confirm this though. The amount of additional liquid used in preparing the OP material may also have an effect on color values. Unfortunately, no information is available in the English literature regarding the potential effects of excessive liquid on the color value of an OP layer. For whatever reason, however, color differences among these OP layers are statistically significant. Thus, the influence of OP color on the final color of BP and IP layers should be evaluated in future studies.

There are important limitations for the present study. One of these is that only one application technique was considered. It would be more informative to evaluate the operator differences with different forms of OP application such as powders, liquids, or sprays. The second limitation is that there is nothing in the literature evaluating the effect of manipulative variations of different dental operators on dental restorations. This fact not only affected the initial planning of the materials and methods of this study but also complicated the discussion of obtained results. Finally, the tests in the present study were performed on flat metal surfaces, but an MCR rarely displays smooth surfaces. Thus, OP-layer thicknesses applied onto curved metal substructures may lead to differences. However, the findings of the present study could shed light in evaluating the effects of individual dental technicians' manipulations on dental restorations.

Within the limitations of the present study, the following items were observed:

1. Significant OP layer thickness differences were found among the experimental groups.

2. Significant but not visually perceptible OP layer color differences were found among the experimental groups.

3. No correlation existed between OP layer thickness differences and color differences.

Finally, increased OP layer thickness may result in insufficient space for BP and IP layers, and this may cause unacceptable clinical appearance of completed restorations. But how the different thicknesses in OP layer effect the appearance of the restoration should be invetsigated with further studies.

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