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The Effect of Repeated Firings on the Color Change of Metal Based Ceramics Produced with Different Techniques

Tekrarlanan Fırınlamaların Farklı Tekniklerle Üretilen Metal-Seramik Restorasyonların Renk Değişimine Etkisi

Mehmet Gökberkkaan DEMİREL*[1]
kaandemirel@erbakan.edu.tr

Ali Rıza TUNÇDEMİR[1]
alirizatuncdemir@gmail.com

ABSTRACT

Aim: The purpose of this study was to compare the effects of repeated firings on the color change of metal-ceramic restorations with different porcelain thicknesses and metal coping fabrication methods.
Material and Methods: A total of 60 disc-shaped samples of 1 mm thickness and 13 mm diameter were produced using selective laser melting (SLM) and conventional casting (CC) methods. Feldspathic porcelain in thicknesses of 0.7, 1.2 and 1.7 mm were then applied to each group (n = 10). Each sample was subjected to five firing processes. After each repeated firing process, color measurement was performed using a spectrophotometer. One-way analysis of variance was used for the statistical analyses and Tukey's test was used for post-hoc analyses ($p = 0.05$).
Results: There were significant differences in color changes both groups ($p < 0.05$). The SLM samples underwent more color changes than the CC samples.
Conclusion: As a result of the study it was determined that repeated firings and an increase in the porcelain thickness enhanced color changes. Moreover, the color of SLM samples changed more than the CC samples.

Keywords: Color change, porcelain thickness, repeated firings, selective laser melting, spectrophotometer.

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ÖZ

Amaç: Bu çalışmanın amacı, farklı porselen kalınlıklarına ve metal altyapı oluşturma yöntemlerine sahip metal-seramik restorasyonların tekrarlayan pişirme işlemlerinin renk değişimleri üzerindeki etkilerini karşılaştırmaktır.
Gereç ve Yöntemler: Toplam 60 disk şeklindeki örnek, seçici lazer eritme (SLM) ve geleneksel döküm (CC) yöntemleri kulla-nılarak 1 mm kalınlığında ve 13 mm çapında üretildi. Her gruba (n = 10) sırasıyla 0,7, 1,2 ve 1,7 mm kalınlıklarında feldspatik porselen uygulandı. Her örnek beş pişirme işlemine tabi tutuldu. Her tekrarlayan pişirme işleminden sonra, bir spektrofoto-metre kullanılarak renk ölçümü yapıldı. İstatistiksel analizler için tek yönlü varyans analizi kullanıldı ve post-hoc analizler için Tukey testi kullanıldı ($p = 0.05$).
Bulgular: Her iki grup arasında renk değişikliklerinde önemli farklılıklar vardı ($p < 0.05$). SLM örnekleri CC örneklerine göre daha fazla renk değişikliği gösterdi.
Sonuç: Çalışmanın sonucunda, tekrarlanan fırınlamaların ve porselen kalınlığının artmasının renk değişimini de artırdığı be-lirlendi. Ayrıca, SLM örneklerinin rengi CC örneklerinden daha fazla değişti.

Anahtar Kelimeler: Porselen kalınlığı, renk değişimi, selektif lazer ergitme, spektrofotometre, tekrarlanan fırınlama.

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* Sorumlu Yazar/Corresponding Author
1. Necmettin Erbakan University, Faculty of Dentistry, Department of Prosthodontics, Konya/Turkey

INTRODUCTION

Smiling is one of the most important aspects of communication, and dental aesthetics is the leading component of a smile. Currently, even if their teeth are healthy, individuals demand an aesthetic appearance and a beautiful smile with all their teeth in harmony.[1] Therefore, aesthetic dentistry is rapidly gaining popularity and is becoming a science where dentists spend more time.[2]

Recreating the structure and color of a tooth using metal-based ceramics (MBC) is a challenging procedure.[3] MBCs are frequently used in clinics due to their excellent fracture resistance, and while the metal framework provides the necessary strength for clinical function, the restoration is made aesthetically pleasing with porcelain.[4] Several factors can affect the aesthetics of dental restoration, including tooth morphology, surface structure, light transmission and color of the material used. Moreover, it has been demonstrated that the biggest difficulty in providing the required standard is achieving a color match.[1,3] Factors such as the thickness of the ceramic layer, firing parameters and temperatures, and the number of firings affect the aesthetics, while another problem that hinders successful color matching is the difference between oral and in vitro conditions.[5] However, another problem arises from the structural differences between metal-ceramic restorations and natural teeth.[6] This structural difference leads to a difference in the absorption and reflection of optical wavelengths between teeth and restorative materials with high opacity.[7] In addition, the type of alloy used in the production of the infrastructure in metal-ceramic restorations [8] also affects the color of the restoration. However, there is no study in the literature that examines the effect of infrastructure production techniques on color matching of MBSs.

The color of restorative materials is determined by using visual or instrumental methods. Spectrophotometers are one of the instruments used to investigate color change and convert spectral reflection data derived by a standard observer and illuminator (determined by CIE) into numerical color component codes, which are then converted to a corresponding scale to inform the physician.[9] The CIE Lab color system uses three axes to define the color and convert it to a numerical value. The L* axis is the vertical axis that describes the lightness-darkness value or the black-and-white character of the color. In this system, the L* value of absolute white is 100, while 0 is for absolute black. The coordinates a* and b* are positioned perpendicular to the L* axis on the vertical axis and perpendicular to each other on the horizontal axis. The a* coordinate gives the redness–greenness value of the color, and the b* coordinate gives the yellowness–blueness value.[10]

With the CIE Lab color system, colors can be standardised and variations between two color values can be calculated. The measurement of color change (ΔE) is accomplished using the following formula which is Δ represents the difference between the both of the same threshold values.[11]

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

Many studies have been conducted to interpret color values and variations, while detectable threshold values and tolerance values in color tone changes have been presented by different researchers. Johnston and Kao[10] stated that the detectable ΔE threshold value was 3.7 and the tolerance value was 6.8. In comparison, Douglas[12] reported that the ΔE threshold value was 2.6 and the tolerance value was 5.5, while O'Brien[4] reported that values above 3.5 were not clinically acceptable, which this is the evaluation criteria used in this study.

Optimising the color of MBS restorations presents another significant challenge because of the need to mask the color of the metal substructure. Although the Conventional casting (CC) technique has been used for more than 100 years for producing MBS restorations, computer aided design (CAD) and computer aided manufacturing (CAM) techniques have been integrated into the field of dentistry, in addition to developing technologies. This is due to CC's disadvantages, such as the necessity for technically precise production, the high risk of error and long periods of laboratory procedures. Selective Laser Melting (SLM) is another technique used in the production of substructures. This technique is based on producing selected areas on the build platform in layers by laser sintering. Although the SLM technique eliminates the disadvantages of CC method it has not become widespread in practice since it is a very costly system.

Glazing of porcelain dental restorations is a routine procedure applied to provide aesthetic and hygienic surfaces in the finished restoration.[13] Polished surfaces lead to less plaque accumulation. Furthermore, glazed porcelain can better mimic the appearance and properties of natural teeth. It reduces the exposure of the dental restoration in the oral cavity and provides the necessary smoothness.[14] In addition, sometimes an occlusal adjustment is needed when the fit of the restoration is not perfect. In such cases, the MBS restorations might employ repeated firings to correct any aesthetic deficiencies and for occlusal and morphological matching in the clinical stage. However, as highlighted in previous studies, exposing porcelain to repeated firings can affect the color.[15–17]

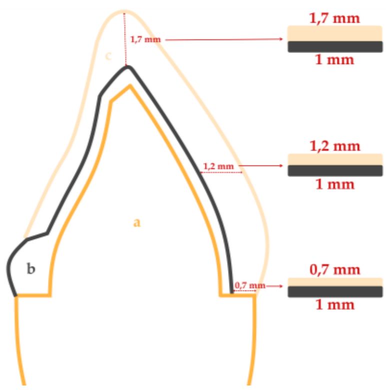
In this study, the effect of repeated firing on the color change of MBS restorations obtained by loading porcelain of different thicknesses on infrastructures obtained with different production techniques will be examined. The null hypothesis of the study is that the color changes of samples with different thickness porcelain superstructures and infrastructures obtained with different production techniques will be within clinically acceptable limits after repeated firing.

MATERIALS AND METHODS

To investigate the effect of repeated firings on the color change of restorations, a total of 60 disc-shaped substructure samples (1 mm thick and 13 mm diameter) were prepared, with 30 pieces to be produced by SLM and 30 by the CC technique. The produced discs were then divided into three groups (n = 10) to represent different parts of the tooth, and 0.7 mm thick porcelain was loaded on the substructure samples to represent the cervical third of the tooth. In addition, 1.2 mm thick porcelain was loaded into the substructure samples representing the middle third of the tooth, and 1.7 mm thick porcelain was loaded into the substructure samples representing the occlusal third (Figure 1). To ensure standardised production of the samples, a CAD file was created and 30 samples in 13 mm diameter and 1 mm thickness were designed by mounting with three supports (Dental System, 3Shape, Copenhagen, Denmark) (Figure 2).

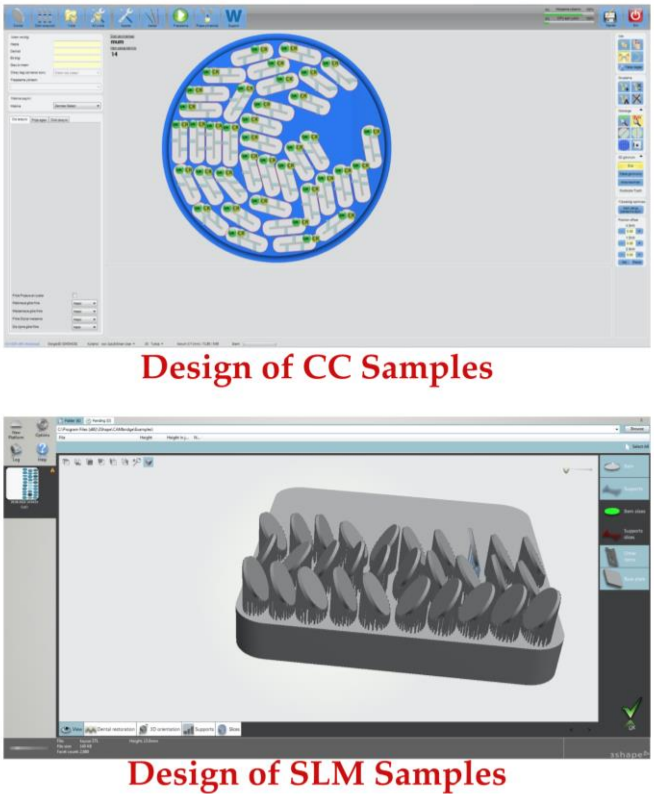
Disc shaped wax samples produced for the preparation of CC samples were then transferred to a flask by revetment (Bellavest SH, Bego Dental, Bremen, Germany). The flask was placed in the pre-heating furnace (MFX-1025, Mikrotek Dental, Ankara, Turkey), after which it was maintained at room temperature. The waxing process was carried out using a 900 °C pre-heating furnace (shock heat). The 100% pure alloy cores (Wirobond C, Bego Dental, Bremen, Germany) to be used for casting were deposited into a ceramic crucible, and the waxed revetment was transferred into a centrifugal induction furnace using tongs (Fornax T, Bego Dental, Bremen, Germany). After complete melting of the alloy cores at a temperature of 1400 ° C and a 10 s additional heating, the casting process was carried out by the effect of centrifugal force generated by centrifugation for 20 s. Subsequently, the mould was removed from the furnace and allowed to cool at room temperature. After the revetment cooled, the metal part was removed from the revetment and the supporting pieces were carefully cut with the aid of a carbon separator (Econo Cutters, Keystone Industries, Gibbstown, NJ, USA). The flashes on the discs were removed by a tungsten carbide drill (MX Tungsten Carbide Cutters, Meisinger, Neuss, Dusseldorf, Germany) and the revetment powder was cleaned by blasting in a sand blasting machine (Sand S24R, Zhermack, Badia Polesine, Italy) with 50 µm Al_2O_3 particles under low pressure. All stages were performed in accordance with relevant company data.

Figure 1: Sample Scheme with thickness of abutment (a), substructure (b) and porcelain (c).



The STL (Figure 2) format-converted file designed for the preparation of SLM samples was transferred to the CAM unit (Mlab cusing R, Concept Laser GmbH, Lichtenfels, Germany). Then, metal powders (Remanium Star CL, Dentaurum GmbH & Co., KG, Ispringen, Germany) were poured into the powder chamber in the desired quantity and any excess was removed with a brush.

Figure 2: Design of Samples.



After processing the appropriate parameters, the run command was issued and disk-shaped samples were obtained. Following the successful completion of the production of discs, the development of mechanical properties of the material was provided by heat treatment under inert nitrogen for 210 min at 1150 °C. The structure was then cut from the platform with the cutter (Econo Cutters, Keystone Industries, Gibbstown, NJ, USA) and the final dressing of the separated discs was performed with tungsten carbide drills (MX Tungsten Carbide Cutters, Meisinger, Neuss, Dusseldorf, Germany). Finally, the discs were blasted with 50 µm Al_2O_3 particles in a sand blasting machine (Sand S24R, Zhermack, Badia Polesine, Italy) under low pressure and excessive particles were cleaned from the surface. All stages were performed in accordance with the company's data.

The substructures were divided into two groups according to material type to prevent mixing of the obtained metal discs. Both SLM and CC discs were subjected to the same steps, as they suggested similar instruction manual. Samples were washed under running water for 1 min and allowed to dry. After drying, surface modification was carried out with Al_2O_3 particles of medium size grains (125 µm) under 2 bar pressure in the sandblasting machine (Sand S24R, Zhermack, Badia Polesine, Italy). The surface was then recleaned with dry steam and was oxidised for 5 min at 920 °C. After the oxidation process, the re-cleaned substructures were transferred into a clean container.

Opaque porcelain application was carried out in two steps. First, opaque powder (Powder Opaquer, IPS Classic, Ivoclar Vivadent AG, Schaan, Liechtenstein) mixed with opaque liquid (Powder Opaquer Liquid, IPS Classic, Ivoclar Vivadent AG, Schaan, Liechtenstein), then it was applied to the disc surface with a single brush stroke in a very thin layer. After ensuring that the layer was homogeneous as possible, discs were placed in the furnace (ProgramatP310, Ivoclar Vivadent AG, Schaan, Liechtenstein) and the first opaque application was performed.

For the second opaque application, a powder–liquid mixture was applied as a homogeneous and thicker layer that was as opaque as possible (to cover all surfaces) and the firing process was carried out again in the same way. The next step was initiated by avoiding the contamination of opaque surfaces.

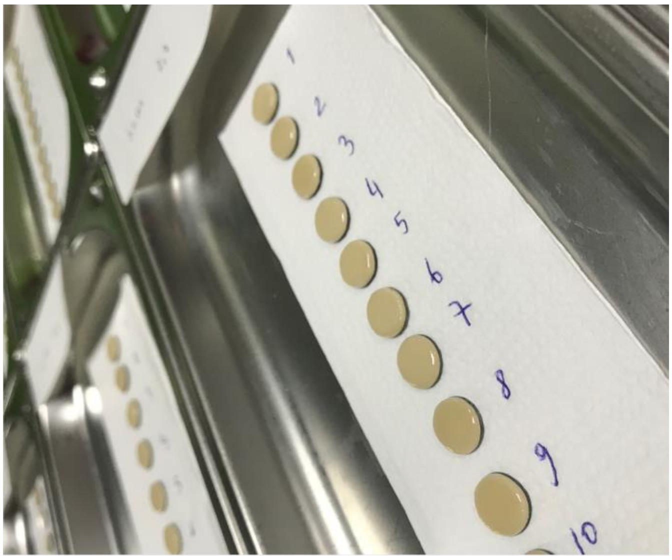
After dividing the disks into two groups, they were randomly divided into three subgroups of 10 discs. The desired consistency was obtained by mixing the dentine porcelain powder (Dentin Body A3.5, IPS Classic, Ivoclar Vivadent AG, Schaan, Liechtenstein) with liquid (Build-Up Liquid, IPS Classic, Ivoclar Vivadent AG, Schaan, Liechtenstein). Thickness control was conducted using a digital calliper. For application in this study, each group of predetermined-sized porcelain discs was stacked in two stages.

The first firing (1.F) process was performed to simulate the glaze step. For glaze application, glaze material (Glazing Paste, IPS Classic, Ivoclar Vivadent AG, Schaan, Liechtenstein), was diluted with a small amount of liquid (Glazing/Staining Liquid, IPS Classic, Ivoclar Vivadent AG, Schaan, Liechtenstein) and was applied to the porcelain surface without any stratification using a brush. In the second, third and fourth firing (4.F) processes, the discs were subjected to repeated firing without any application of their surface. At these stages, care was taken not to cause contamination on the disc surface and all stages were performed in accordance with the company's data. In the fifth and final firing (5.F) processes, glaze material was again applied to the surfaces of the samples as a thin and homogeneous layer before being fired again with the same process in the appropriate program.

The same porcelain furnace, the same glaze material and the same heating plates were used to provide standardisation in all repeated firing cycles and all operations were performed by the same experienced clinician.

For the purpose of the study, it was very important to prevent mixing the order of samples. Accordingly, six separate cuvettes were prepared to prevent any possible mistakes and samples in the same group were arranged in each cuvette. Only one group was processed at a time and the processing of the other group was not started until the measurements of the processed group were completed. After completing the color measurement process, all samples were placed in the cuvettes in the same order (Figure 3).

Figure 3: All samples placed in the cuvettes.



A spectrophotometer was used for the color measurements (Spectrophotometer PCA - CSM 7, PCA Technical Instruments Marketing Trade Co. Ltd., Istanbul, Turkey), which were performed with the device always on the same flat and fixed position by the same experienced clinician. White background calibration of the instrument was performed before each measurement.

The results of this study were obtained using IBM SPSS V21.0 program (IBM Statistics, IBM, New York, US) and a one-way analysis of variance (ANOVA) was used to examine the differences between groups. To compare the difference of determined groups, Tukey's test was applied among the post hoc tests, and the significance level was accepted as p = 0.05.

RESULTS

Figure 4 shows the average color change values of each thickness and material after repeated firings. Considering both SLM and CC materials in terms of all thickness values, the 4.F–5.F group had the smallest ΔE value, while the 1.F–5.F group exhibited the highest color change. The color of the SLM samples changed more than the CC samples, as shown in Table 1. However, it was found that none of the color changes were within the limit that could be detected visually for any sample (Table 1).

Figure 4: Mean ΔE values.

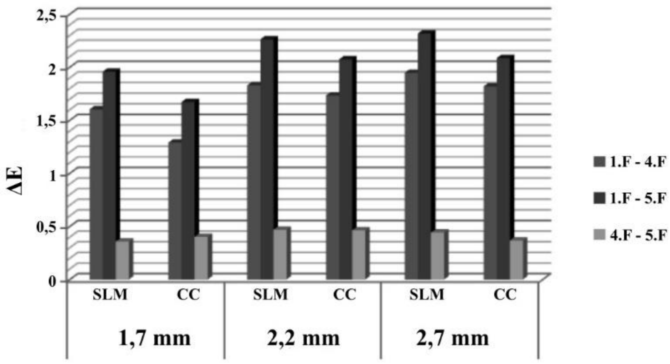


Table 1: ΔE values according to thickness and materials.

Firings	Thickness	n	SLM		CC	
			Mean ± SD	p	Mean ± SD	p
ΔE(1-4)	1.7mm #	10	1,63 ± 0,14 ^{Aa}	0,002*	1,29 ± 0,12 ^{Cc}	0,000*
	2.2mm	10	1,83 ± 0,19 ^{A}		1,73 ± 0,23 ^{C}	
	2,7mm	10	1,95 ± 0,2 ^{a}		1,82 ± 0,28 ^{c}	
ΔE(1-5)	1.7mm #	10	1,96 ± 0,21 ^{Bb}	0,002*	1,67 ± 0,21 ^{Dd}	0,004*
	2.2mm #	10	2,26 ± 0,21 ^{B}		2,07 ± 0,1 ^{D}	
	2,7mm	10	2,32 ± 0,23 ^{b}		2,09 ± 0,43 ^{d}	
ΔE(4-5)	1.7mm	10	0,36 ± 0,08	0,344	0,4 ± 0,13	0,799
	2.2mm	10	0,47 ± 0,24		0,46 ± 0,45	
	2,7mm	10	0,44 ± 0,15		0,37 ± 0,29	

p = 0,05; n: Number of samples; SLM: Selective Laser Melting Groups; CC: Conventional Casting Groups; Mean: Mean values; SD: Standard deviation; *: p<0,05; #: Statistical difference between different production technique in the same line; Different superscript letters show the statistical difference between thickness groups for same production technique in the same column.

DISCUSSION

The null hypothesis was accepted as a result of this study because although the color change increased as the number of firings and porcelain thickness increases, this change was within clinically acceptable limits.

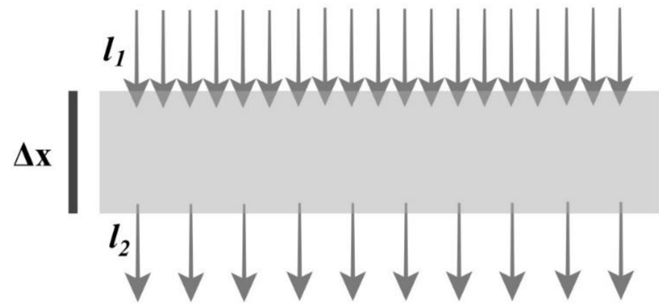
In previous studies, although different ceramic systems were compared with each other [15–18], different casting alloys produced by conventional lost-wax casting methods with each other [7,19–23] or among themselves [24], although color changes in substructures produced by the laser melting technique were not examined. In this study, porcelain of different thicknesses was applied to copings produced with different metal substructure production techniques and apart from standard production processes, the color changes of the samples were examined by firing five times.

Color measurement can be performed by visual methods or with the aid of devices. However, acquiring clear and standardised results with visual color measurement methods that depend on color scales, the measuring observer, the environment or natural tooth color is a difficult method. The superiority of color measurements conducted with devices instead of visual measurements has been demonstrated in many studies.[9,25,26] For color measurements made with the help of devices, colorimeters and spectrophotometers are generally employed. Moreover, studies have revealed that spectrophotometers are more reliable than both visual color measurement methods [27–29] and colorimeters.[30,31] In this study, color measurements were made using a spectrophotometer.

In previous studies on the effect of repeated firing processes on color change, the authors argued that a larger number of firings increases color change [8,15–17,21,22,32–34], which is supported by the results of this study. The reasons why repeated firings increase color changes could be that as the porcelain is exposed to the firing process, the color pigments inside may be discolored, causing discoloration. Another view suggests that the color stabilisation of metal oxides deteriorates during the firing process. This condition, which is referred to as mass transfer, affects color stabilisation by moving the ions of metals or oxides released during the firing into the voids in the porcelain from the metal-porcelain interface. However, the accumulation of released steam at the porcelain interface could also be a reason for the discoloration.[7]

Authors examining the effect of porcelain thickness on color change could not reach a consensus on this issue. Moreover, differences such as materials used, superstructure production techniques, the thickness of the condensed porcelain, and environmental conditions make it difficult to standardise the results. However, most authors have reported that increasing porcelain thickness also increases color change.[15–18,23] Hasssija et al.[19] could not correlate porcelain thickness with color change and did not provide an explanation. The reason why porcelain thickness affects color change can be explained by the Lambert–Beer law, which describes the amount of liquid and gaseous materials absorbing the transmitted light, and can also be applied to solids. The Lambert–Beer law for solids (Figure 5) states that the loss of radiation intensity (*ΔI*) for a parallel monochromatic radiation beam passing through a material is proportional to the path (Δ*x*) through which the beam passes through the material and the initial brightness intensity (*I*). In other words, considering that the same material and the same light source are used, it is possible to assume that light travelling on a longer path will be absorbed by the material and reflected less.

Figure 5: The Lambert-Beer Law for Solids.



The reason why SLM samples change color more than CC samples could be due to elemental penetration. In their study on the metal-porcelain bonding strength of samples produced by the selective laser melting method, Wu et al.[35] identified an area of elemental penetration at the interface between the SLM substructure and the porcelain. Furthermore, they reported that this interface increases the metal porcelain connection. Beside that, metal ions that diffuse into microporous cavities in the porcelain during elemental penetration can cause color changes in the porcelain superstructure after repeated firings. Moreover, metal ions can penetrate cavities between layers during the production process and exhibit better fusion with porcelain. However, porcelain moving into these cavities can also cause greater color changes.[36]

In terms of the limitations of this study, there is a need for more comparisons with more samples. In addition, measurements were made with a single measuring device. Therefore, measurements with different devices and a comparison of these measurements could provide more accurate results. In future studies, the color changes of the metal substructures produced with the selective laser melting technique and restorations with full ceramic substructures could be compared.

CONCLUSION

Within the limitations of this study, regardless of the substructure production technique and superstructure thickness of the restoration, when the number of firings increases, color changes also increased for all samples produced by the SLM and CC methods. In addition, as the thickness increased, color changes also increased for both groups subjected to repeated firings. The color change in restorations produced with the SLM technique was found to be higher than for restorations produced with the CC technique after three or more firings. In addition to these results, color changes of porcelain supported by both substructure materials were found to be within clinically acceptable limits (based on O'Brien). From this viewpoint, it can be concluded that no situation prevents the aesthetic and clinical use of substructures produced by selective laser melting and they can be used safely.

Ethical Committee Approval: Since no sources obtained from humans or animals were used in this study, ethical committee approval was not obtained.

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Author Contributions: Design: ART, Data collection or processing: MGD, Analysis or interpretation: ART, MGD, Literature review: MGD, Writing: MGD.

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