



# Economical and easy methods of smoke stain removal from maxillofacial prostheses

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## Abstract

**Aim:** Service life of a maxillofacial prosthesis is too short especially because of color instability. This study aimed to investigate the effects of hand soap and chlorhexidine gluconate mouthwash on the color of maxillofacial prosthesis after exposure of cigarette smoke.

**Materials and Methods:** Sixty specimens were fabricated from a maxillofacial silicone material. Two groups (n=20) were pigmented intrinsically mimicking dark and fair tone skin and one group was not pigmented for control. All the specimens were exposed to cigarette smoke in a closed apparatus designed for the study. Color measurements of the specimens were performed before and after smoke exposition by using a spectrophotometer. Half of all the specimens (n=30) consisting of dark, fair and non-pigmented ones was rubbed with liquid hand soap and the other half was immersed in chlorhexidine gluconate mouthwash (0.12% chlorhexidine digluconate). Color measurement was repeated after cleaning process. Color differences were calculated both CIELab ( $\Delta E^*ab$ ) and CIEDE2000 ( $\Delta E00$ ) color measurement formulas.

**Results:** Color groups had significantly different color change values in terms of  $\Delta E00$  and  $\Delta E^*ab$  after exposition to smoke and cleaning methods ( $p < 0.001$ ). The effect of soap and chlorhexidine on color change values did not differ from each other ( $p=0.284$  for  $\Delta E00$ ,  $p=0.312$  for  $\Delta E^*ab$ ). The interaction of color groups with cleaning methods was statistically insignificant ( $p=0.962$  for  $\Delta E00$ ,  $p=0.550$  for  $\Delta E^*ab$ ).  $\Delta E00$  and  $\Delta E^*ab$  values showing color alteration between initial color and after cleaning were significantly different in groups ( $p < 0.001$ ).

**Conclusion:** Cleaning process using hand soap and chlorhexidine gluconate mouthwash succeed to return the color of stained silicone to the initial color.



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## Introduction

Skin is the largest organ of the human body and its optical properties have drawn attention by various medical disciplines [1]. Maxillofacial prosthetics is a clinical specialty dealing with fabrication of prostheses to replace missing stomatognathic and craniofacial structures stemming from congenital, developmental or acquired malformations. Maxillofacial prosthesis is essential for restoring function and esthetics as well as surgical reconstruction. A natural maxillofacial prosthesis requires marginal adaptation, texture similar to natural skin, harmony with functional movements and accurate color match [2]. Service lifetime of a maxillofacial prosthesis is 1–2 years. Common reasons for re-fabrication of maxillofacial prosthesis are loss of retention, degradation of physical properties and

color instability [3, 4]. Color change is caused by ultraviolet light, temperature changes, humidity, air pollution, cleaning agents and body secretions [5-13].

The most widely used material for maxillofacial prostheses is silicone elastomer [4, 5, 8]. The silicone elastomer has a porous structure allowing the material to be infected by *Candida albicans* and other *Candida* species [14, 15]. Acquired malformations of craniofacial structures include traumatic defects and tumor resection. Maxillofacial prostheses are usually fabricated before healing of surgical sites to protect the remaining structures as well as to restore appearance [8]. Thus, cleaning of a maxillofacial prosthesis and surrounding tissue is important to reduce the risk of infection. Since mechanical cleaning gives damage to silicone elastomer, chemical soaking is the basic technique for disinfection of the prosthesis. Neutral soap and water, and 2-4% chlorhexidine digluconate solution are recommended and mostly used for cleaning maxillofacial prosthesis [16-

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19]. Essential-oil-containing mouth rinse, ethanol, hydrogen peroxide and isopropyl alcohol also have been effective in mixed species biofilms on silicone elastomer [20].

Studies on color change of silicone elastomer have been mostly about the effect of weather conditions [6, 9-13]. Our knowledge of the effect of smoking on the color of silicone and cleaning the smoke strain is based on very limited data. There seems to be only one research about this topic published in the literature which belongs to almost 40 years ago [21]. Considering the advances in materials and color measurement systems, there is still a need for further researches to assess cleaning methods of smoke stain on new elastomeric silicone materials. This study aimed to investigate the effect of cigarette smoke and the effect of hand soap and chlorhexidine gluconate mouthwash after exposure of cigarette smoke on the color stability of a maxillofacial elastomer. These two cleaning products were preferred because they are easy to access and economical.

## Materials and Methods

Sixty disc-shaped specimens were prepared (13-mm diameter, 3-mm thick) using M511 maxillofacial silicone (Technovent Ltd., South Wales, United Kingdom). Wax patterns were invested in Type III dental stone (Alston, Ata Alçı Sanayi ve Ticaret AŞ, Ankara, Turkey) to fabricate molds. The silicone base and catalyst were mixed at a 10:1 ratio as recommended by the manufacturer. The mixture was poured into the molds under vibration and cured at 100°C for 1 hour in a dry heat oven (Mikrotek, Ankara, Turkey). Before molding, twenty of the specimens were intrinsically colored with light dapple (0.45% by weight), pink (0.74%), white (0.98%), cream (1.11%) and light grey (1.27%) pigment (QuickWeigh LSR, Spectromatch Ltd, Bath, United Kingdom) to represent fair skin tone. Other 20 of the specimens were intrinsically colored with olive (0.29%), white (0.67%), orange-brown (0.82%), dark dapple (0.91%) and ochre (1.85%) to represent dark skin tone. The rest of the specimens (n=20) were not pigmented for the control group. A total of three groups (n=20) were obtained. After curing, the specimens were removed from the molds and evaluated for porosity. Only the specimens without visible porosity were included in the study.

The qualities of color of all specimens were measured using a spectrophotometer (CM-2300d, Konika Minolta Inc., Osaka, Japan) on a white background. The device was set to D65 illumination, 8mm aperture, 10° observation angle and specular component included mode. This spectrophotometer uses a diffused illumination integrating sphere system with a d/8 mode (diffuse illumination, 8-degree viewing). Three measurements were made for each specimen and the means were recorded as the absolute values. CIELAB and CIEDE2000 systems developed by Commission Internationale de l'Éclairage (CIE) were used to calculate color differences. CIELAB system quantifies the color in three coordinate values; L\*, a\* and b\*. L\* corresponds to lightness, a\* corresponds to red or green chroma (+a\*=red, -a\*=green), b\* corresponds to yellow or blue chroma (+b\*=yellow, -b\*=blue). In CIELAB system, a numerical value “ΔE\*ab” indicates the size of the color difference [22]. ΔE\*ab was calculated by the following

equation:

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

In CIEDE2000 system, numerical value “ΔE00” indicates the size of the color difference. ΔE00 was calculated by the following equation:

$$\Delta E00 = \left\{ \left( \frac{\Delta L'}{K_L S_L} \right) + \left( \frac{\Delta C'}{K_C S_C} \right)^2 + \left( \frac{\Delta H'}{K_H S_H} \right)^2 + R_T \left( \frac{\Delta C'}{K_C S_C} \right) \left( \frac{\Delta H'}{K_H S_H} \right) \right\}^{1/2}$$

ΔL': lightness difference. ΔH': hue difference. ΔC': chroma difference. KL, KC, KH: correction factors related with observation environment. SL, SC, SH: lightness, chroma, and hue weighting factors. RT: rotation factor used to correct deflection in the blue region of the ellipse axis direction for visual perception [23].

All specimens were exposed to cigarette smoke after initial color measurement. Smoke exposition was carried out in an apparatus designed for this study. The apparatus consisted of a closed box with a cover attached to a platform to carry the specimens, an electrical fan to supply oxygen for burning cigarettes (Figure 1). The arms holding the platform was shorter than the height of the box to give space the cigarette which was placed at the bottom of the box (Figure 2). A total of 200 cigarettes were burned for 15 minutes per each. All the specimens were exposed to smoke of 200 cigarettes. Second color measurement was performed after smoke exposition.

Half of the specimens (n=30) was randomly selected from each group and liquid hand soap (Johnson's Pure Protect Hand Wash, Johnson and Johnson, New Jersey, USA) was rubbed on each of them with fingers for 30 seconds and washed with running tap water (Ingredient of the soap: aqua, cocamidopropyl betaine, PEG-80 sorbitan laurate, glycerin, PEG-150 pentaerythrityl tetrastearate, aspalathus linearis leaf/stalk extract, camellia sinensis leaf extract, nigella sativa seed oil, ethylhexylglycerin, mel, coconut acid, decyl glucoside, PPG-2 hydroxyethyl cocamide, sodium methyl cocoyl taurate, sodium chloride, citric acid, lactic acid, phenoxyethanol, potassium sorbate, sodium benzoate, parfum). Other half of the specimens (n=30) was immersed in chlorhexidine gluconate mouthwash (Andorex; Pharmactive İlaç Sanayi ve Tic AŞ. İstanbul, Turkey) for 10 minutes and washed with running tap water (Ingredient of the mouthwash: 0.12% chlorhexidine digluconate, 0.15% benzydamine hydrochloride, mint flavor, sorbitol, patent blue V, glycerol, polysorbate 20, tartrazine, ethanol, distilled water). Cleaning with soap and chlorhexidine was performed twice a day for 15 days. After cleaning process, last color measurements were done using the spectrophotometer.

## Statistical Analyses

Sample size was determined according to similar studies (6, 8, 17, 18). No power analysis was conducted. All statistical analyses were provided by SPSS software (Statistical Package for Social Sciences for Windows, Version 23.0, Armonk, NY, IBM Corp.). Normal distribution examination of the data was analyzed by Shapiro-Wilk test when n < 50 and by Kolmogorov-Smirnov test when n > 50.



**Figure 1.** Apparatus used for smoke exposition.

In addition to these tests, conformity to normal distribution was also evaluated according to the statistics of "skewness coefficient/standard error of skewness coefficient" and "kurtosis coefficient/standard error of kurtosis coefficient". In comparisons of more than two independent groups, the homogeneity of variances was examined by Levene's test. Comparisons of more than two independent groups were made using Welch ANOVA, since the variances were not homogenous. In the existence of difference, the groups that made the difference were investigated by using the Games-Howell multiple comparison test. The comparisons of more than two groups with two factors were made by two-way ANOVA. In case of difference in two-way ANOVA results, Bonferroni multiple comparison test was used to search the groups that made the difference.  $p < 0.05$  was taken as the statistical significance level.

## Results

The effect of smoke on color change is presented in Table 1. There was statistically significant difference between the color groups in terms of  $\Delta E_{00}$  and  $\Delta E^*_{ab}$  color change values ( $p < 0.001$ ) after exposition to smoke.

Table 2 and Table 3 show  $\Delta E_{00}$  and  $\Delta E^*_{ab}$  values, re-



**Figure 2.** Cigarette in apparatus.

spectively, after cleaning process. There was no statistically significant difference between the cleaning methods in terms of  $\Delta E_{00}$  and  $\Delta E^*_{ab}$  ( $p=0.284$  for  $\Delta E_{00}$ ,  $p=0.312$  for  $\Delta E^*_{ab}$ ). Cleaning methods affected the color groups statistically different in terms of both  $\Delta E_{00}$  and  $\Delta E^*_{ab}$  ( $p < 0.001$ ). The interaction of color groups with cleaning methods was statistically insignificant in terms of  $\Delta E_{00}$  and  $\Delta E^*_{ab}$  ( $p=0.962$  for  $\Delta E_{00}$ ,  $p=0.550$  for  $\Delta E^*_{ab}$ ).

$\Delta E_{00}$  and  $\Delta E^*_{ab}$  values demonstrating the color change of groups before exposition to smoke and after cleaning is presented in Table 4 and Table 5 respectively. There was no statistically significant difference in  $\Delta E_{00}$  and  $\Delta E^*_{ab}$  between the cleaning methods ( $p=0.709$  for  $\Delta E_{00}$ ,  $p=0.103$  for  $\Delta E^*_{ab}$ ). Bonferroni multiple comparison test showed significant difference in all color groups in terms of  $\Delta E_{00}$  and  $\Delta E^*_{ab}$  ( $p < 0.001$ ). The interaction of color groups with cleaning methods was statistically insignificant in terms of  $\Delta E_{00}$  and  $\Delta E^*_{ab}$  ( $p=0.809$  for  $\Delta E_{00}$ ,  $p=0.119$  for  $\Delta E^*_{ab}$ ).

## Discussion

Color instability is a common problem with maxillofacial silicones. There are several factors in deterioration of color [5-13]. However, there is still need for data about the effect of cigarette smoke on color of silicone. In this study, the color change of silicone after exposition to smoke and after cleaning with hand soap and chlorhexidine gluconate mouthwash was investigated.

Color differences can be measured using either  $\Delta E^*_{ab}$  or

**Table 1.** Comparison of color change based on smoke.

Baseline Smoke	Color Groups			Total	p value
	Dark	Light	Control		
	M ± SD	M ± SD	M ± SD	M ± SD	
ΔE00	6.06±0.69	14.94±1.71	31.12±1.20	17.37±10.54	< 0.001 <sup>a</sup>
E*ab	6.31±0.81	20.51±1.51	46.04±2.51	24.29±16.67	< 0.001 <sup>b</sup>

a Games-Howell multiple comparison test after Welch ANOVA  
 Dark-Light (p < 0.001); Dark-Control (p < 0.001); Light-Control (p < 0.001)  
 b Games-Howell multiple comparison test after Welch ANOVA  
 Dark-Light (p < 0.001); Dark-Control (p < 0.001); Light-Control (p < 0.001)

**Table 2.** ΔE00 values after cleaning.

Cleaningmethod	Color groups			Total	p value		
	Dark	Light	Control		Color	Method	Color*Method
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD			
Soap	2.54±0.37	3.85±0.40	4.15±1.27	3.51±1.05	< 0.001a	0.284	0.962
CHXb	2.37±0.38	3.60±0.33	4.01±0.74	3.33±0.87			
Total	2.45±0.37	3.73±0.38	4.08±1.01				

**Table 3.** ΔE\*ab values after cleaning.

Cleaningmethod	Color groups			Total	p value		
	Dark	Light	Control		Color	Method	Color*Method
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD			
Soap	3.08±0.37	4.86±0.37	5.39±1.82	4.44±1.46	< 0.001 <sup>a</sup>	0.312	0.550
CHXb	3.14±0.32	4.92±0.35	6.04±1.39	4.70±1.46			
Total	3.11±0.34	4.89±0.35	5.71±1.61				

a Bonferroni multiple comparison test after two-way ANOVA  
 Dark-Light (p < 0.001); Dark-Control (p < 0.001); Light-Control (p < 0.001)  
 b CHX: Chlorhexidine.

**Table 4.** E00 color change between initial color and after cleaning.

Cleaning method	Color groups			Total	p value		
	Dark	Light	Control		Color	Method	Color*Method
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD			
Soap	8.35±0.56	17.39±1.87	32.61±1.23	19.45±10.27	< 0.001 <sup>a</sup>	0.709	0.809
CHXb	8.36±0.71	17.40±1.65	32.97±1.21	19.57±10.41			
Total	8.35±0.62	17.39±1.72	32.79±1.20				

a Bonferroni multiple comparison test after two-way ANOVA  
 Dark-Light (p < 0.001); Dark-Control (p < 0.001); Light-Control (p < 0.001)  
 bCHX: Chlorhexidine.

**Table 5.** ΔE\*ab color change between initial color and after cleaning.

Cleaning method	Color groups			Total	p value		
	Dark	Light	Control		Color	Method	Color*Method
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD			
Soap	8.63±0.65	21.33±1.57	45.63±3.10	25.20±15.74	< 0.001a	0.103	0.119
CHXb	8.68±0.79	21.12±1.47	43.54±1.80	24.45±14.73			
Total	8.65±0.70	21.22±1.49	44.59±2.69				

a Bonferroni multiple comparison test after two-way ANOVA  
 Dark-Light (p < 0.001); Dark-Control (p < 0.001); Light-Control (p < 0.001)  
 b CHX: Chlorhexidine.

**Table 6.** Summary of color changes of all groups after smoke exposition and cleaning processes.

	$\Delta E_{00}/\Delta E^{*ab}$		
	Dark	Light	Control
Baseline-smoke	6.06/6.31	14.94/20.51	31.12/46.04
Smoke-cleaning	2.45/3.11	3.73/4.89	4.08/5.71
Baseline-cleaning	8.35/8.65	17.39/21.22	32.79/44.59

recently introduced  $\Delta E_{00}$  [24]. Both formulas were used in the study to compare the quantification of color change reported in the literature. Multiple studies report variations in clinical perceptible and acceptable range of  $\Delta E^{*ab}$  and  $\Delta E_{00}$ . Paravina et al. determined the perceptible  $\Delta E^{*ab}/\Delta E_{00}$  value for light and dark tones as 1.1/0.7 and 1.6/1.2, respectively, and the acceptable value as 3.0/2.1 and 4.4/3.1, respectively [25]. Leow determined perceptible  $\Delta E^{*ab}$  as 0.8 and acceptable as 1.8 for light tones, perceptible 1.3 and acceptable 2.6 for dark tones [26]. In the present study, cigarette smoke altered color of all specimens over acceptable  $\Delta E^{*ab}$  and  $\Delta E_{00}$  threshold values mentioned above. The dark tone group had the least color change and the control group had the highest change after smoke exposure. Dark pigments seem less affected by smoke. The effect of pigment color on color stability of maxillofacial silicone have been reported by Kiat-Amnuay et al. Kiat-Amnuay et al. reported different levels of change in  $\Delta E^{*ab}$  values due to pigment color [27, 28]. Although different combinations of colors were used in this study, ochre is the common color in both studies. Kiat-Amnuay et al reported that ochre increased  $\Delta E^{*ab}$  values significantly [27, 28]. Despite higher percentage of ochre in dark specimens used in the present study, dark group had the least  $\Delta E^{*ab}$  value after smoke exposition. The effects of pigments on color change of silicone have been also reported by Farah. Farah reported color alterations due to pigments as; Indian yellow ( $\Delta E$ : 5.20), Logwood maron ( $\Delta E < 1$ ) and non-pigmented ( $\Delta E$ : 4.86) [29]. The difference in color changes of the groups is probably due to the pigments used.

Yu et al [21] investigated the effect of cigarette smoke on color of maxillofacial silicone and cleaning effect of trichlorethane on stained silicone almost 40 years ago. The results of color change values cannot be compared due to the differences in the color measurement systems used in the two studies. Yu et al. calculated the color change according to CIE 1931 Chromaticity Diagram which comprises of luminous reflectance, dominant wavelength and excitation purity as color parameters [21]. However, they reported large color changes after smoke and trichlorethane was effective to remove cigarette stain similar to our results.

The effects of liquid hand soap and chlorhexidine mouthwash on color change of the stained specimens were similar to each other. There have been no interactions between cleaning methods and color groups. This may be due to similar contents of the soap and the mouthwash used in the study. Ethanol, sorbate and chloride are common items in both products. Ethanol may be liable for color change

because color change can be attributed to surface characteristics of the polymers along with the extraction of some compounds from the polymer matrix to disinfection solutions or water [30]. However, this similar effect of soap and chlorhexidine cannot be fully explained by this structural change, considering the pigment effect mentioned above.

After cleaning process, dark group had the lowest  $\Delta E^{*ab}$  and  $\Delta E_{00}$  values followed by light and control group. Several authors reported the effect of various cleaning methods on color change of silicone. Since no staining procedure has been carried out in these researches,  $\Delta E^{*ab}$  and  $\Delta E_{00}$  values cannot be compared accurately. Kurt et al. [18] investigated effects of 5 disinfection methods on color change of maxillofacial silicone. They reported  $\Delta E_{00}$  as 1.205 after chlorhexidine whereas  $\Delta E_{00}$  values in this study were 2.45 for dark, 3.73 for light and 4.08 for control group. This difference is probably due to method of experiment used in their study. They did not make any process potentially changing color before disinfection and also used one pigment for the specimens. Mehta [10] reported acceptable  $\Delta E^{*ab}$  values ( $\Delta E^{*ab} < 3$ ) after immersion of silicone in neutral soap for 30 hours. In the present study, effect of soap was  $\Delta E^{*ab}$  ( $\Delta E^{*ab}$  values: 3.08 for dark, 4.86 for light and 5.39 for control). Griniari [12] immersed silicone specimens in soap for 1 week and found acceptable  $\Delta E^{*ab}$  values. Eleni [13] reported that color change values exceeded acceptable threshold after immersion in soap for 30 hours ( $\Delta E^{*ab}$ : 3.64 and 5.92 for two different types of silicone). Among these results, Eleni's are the only one similar to our results. The fact that our results differ from the results of other studies leads to the thought that soap may cause more color change on the stained silicone than unstained silicone.

According to the  $\Delta E^{*ab}$  and  $\Delta E_{00}$  values demonstrating the color difference between initial color and after cleaning process, the dark group had the least color change and the control group had the highest change. No interaction was found between the cleaning methods and the color groups. Both soap and chlorhexidine were sufficient to change the colors of the specimens close to the initial ones. Table 6 is a summary of color changes of all groups after smoke exposition and cleaning processes. Considering the dark group with the least color change after both exposure to smoke and cleaning, it can be concluded that the dark pigments are less affected by smoking and cleaning. In other words, the maxillofacial prostheses of light-skinned patients seem to be more prone to smoking-related discoloration than the prostheses of dark-skinned patients.

This research was limited with cigarette smoke as a color changing factor. Other factors like weather conditions, type of silicone and pigments were not included. Also, this work was limited with only two cleaning methods. In fact, disinfection is used to destroy the biofilm formed on the surface of the prosthesis. Biofilm was also not included in the study. These cleaning methods may have different effects on the color in the presence of this biofilm. Although chlorhexidine digluconate having concentration of 2-4% is recommended, the current concentration in commercially available chlorhexidine mouthwash was preferred because accessibility and affordability were targeted. This low concentration makes the antimicrobial effect of chlorhexidine

digluconate on the maxillofacial prosthesis questionable.

Within the limitations of this research, soap and chlorhexidine which are economical and easily accessible seems to be sufficient to decrease smoke stain on maxillofacial silicone. Applying soap or chlorhexidine mouthwash on a daily basis would improve both hygiene and color of smoke stained maxillofacial prosthesis.

## Conclusions

This research showed that cigarette smoke changes the color of maxillofacial silicone and also both hand soap and chlorhexidine gluconate mouthwash proved to be a satisfying cleaning method to remove the smoke stain.

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