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The Effect of Electronic Cigarettes on Color Stability of Different Denture Teeth

Elektronik sigaraların yapay dişlerin renkleşmesi üzerine etkisi

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Abstract

Aim: The aim of this in vitro study is to compare the coloration of different types of denture teeth with electronic cigarette smoke depending on thermal aging.

Methods: Denture teeth, consist of three different materials, are: microfiller reinforced polyacrylic resin (Vitapan, VITA Zahnfabrik), nanofilled composite resin (Sr Phoneres II, Ivoclar Vivadent AG), and feldspathic ceramic (Lumin Vacuum; VITA Zahnfabrik). The specimens were then randomly separated into groups (n=6), according to the material of the denture teeth, thermal aging, and the nicotine level of the electronic cigarette liquid. The color differences are determined by using a VITA Easyshade spectrophotometer.

Results: In groups where thermal aging is not applied, the color change resulting from the electronic cigarette creates a statistically significant difference between 3 different materials ($p < 0.05$). ΔE*ab value of Lumin vacuum is significantly lower than SR Phonares II; however, there is no significant difference in ΔE00 value. There is a statistically significant difference between 3 different materials in terms of ΔE*ab and ΔE00 values in all groups undergoing thermal aging ($p < 0.05$).

Conclusions: Denture teeth color was altered by ECIGs containing liquids with different nicotine contents.

Keywords: Color Science, Prosthodontics, Dental Materials

Öz

Amaç: Bu in vitro çalışmanın amacı, termal yaşlanmaya bağlı olarak elektronik sigara dumanı ile farklı içerikli yapay dişlerin renkleşmelerini incelemektir.

Gereç ve Yöntem: Üç farklı materyalden yapay dişler kullanılmıştır: mikrofiller ile güçlendirilmiş poliakrilik reçine (Vitapan, VITA Zahnfabrik), nano dolgulu kompozit reçine (Sr Phoneres II, Ivoclar Vivadent AG) ve feldspatik seramik (Lumin Vacuum; VITA Zahnfabrik). Örnekler daha sonra yapay dişlerin materyaline, termal yaşlanmaya ve elektronik sigara likitinin nikotin seviyesine göre rastgele gruplara (n=6) ayrılmıştır. Renk farklılıkları, VITA Easyshade spektrofotometresi kullanılarak belirlenmiştir.

Bulgular: Termal yaşlandırma uygulanmayan gruplarda; elektronik sigaranın neden olduğu renk değişimi 3 farklı malzeme arasında istatistiksel olarak anlamlı bir fark oluşturmaktadır ($p<0.05$). Lumin vakum'nun ΔE*ab değeri, SR Phonares II'den önemli ölçüde düşüktür; ancak ΔE00 değerinde anlamlı bir fark yoktur. Termal yaşlandırma uygulanan tüm gruplarda ΔE*ab ve ΔE00 değerleri açısından 3 farklı malzeme arasında istatistiksel olarak anlamlı fark bulunmaktadır ($p<0.05$).

Sonuçlar: Yapay diş rengi, farklı nikotin içerikli sıvılar içeren elektronik sigaralardan etkilenmektedir.

Anahtar Kelimeler: Renk Bilimi, Protez, Diş Malzemeleri

INTRODUCTION

Electronic Distribution Systems (ENDs), also known as electronic cigarettes (ECIGs), are rechargeable electronic devices designed to create an aerosol by heating the ECIGs' liquid content with various flavors and components such as nicotine (1). The use of ECIGs is increasing rapidly in global markets, including the United States and Europe (2). In the United States, ECIGs use is more than 15% of adults, and the majority are between the ages of 18 and 44 (3,4). Released as a safer alternative to traditional cigarettes, e-cigarettes are gaining popularity among traditional smokers (5). Reported e-cigarette use among traditional smokers ranges from 15.94% in the United States to 21.9% in the UK (6).

The working principle of ECIGs is as follows: a device called an atomizer heats a liquid mixture containing water, flavors, propylene glycol, glycerine, and different levels of nicotine. When activated by inhalation or push of a button, ECIGs concentrate on an aerosol inhaled by the person. This reaction is not a combustion reaction, so "vaping" produces fewer chemical compounds than conventional smoking (7).

Data examining the effect of ECIGs on oral health is scarce (3,8), and studies examining the effects on nat-

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ural teeth (7) or restorative dental materials (9) are scarce. Although many studies have been conducted to determine the effects of conventional cigarette smoke on the color stability of denture teeth (10,11), data on the staining effect of electronic cigarettes on denture teeth are not available in the literature.

Denture teeth, used to replace natural teeth lost for various reasons, play an essential role in complete dentures' aesthetic and functional success (10). Denture teeth are available in dental markets in different material contents (12). However, the first acrylic denture teeth are still used today. Several new types of resinous dentures have been introduced to increase the clinical success of acrylic resin teeth. For example, denture teeth based on cross-linked acrylic and micro-filled composite resin have been developed to improve clinical outcomes (13,14). Micro-filled composite and nanocomposite's high polishability as well as being resistant to stains and impacts have enabled them to be used as denture teeth (13).

There are some important physical properties that the teeth used in prosthesis should have. One of them is the ability to maintain color stability. Dental aesthetics can be achieved by choosing dental materials with excellent color stability, so it has become more and more important to increase the stain resistance of artificial denture teeth (10). Ceramic prosthetic teeth have also been used for abrasion resistance and to meet increasing aesthetic demands (15). However, ceramic has disadvantages such as brittleness, lack of bonding to the denture base, and difficulty polishing.

Previous studies have used various staining agents such as coffee, tea, or conventional cigarette smoke to determine the color stability of denture teeth (10,11). However, the authors are unaware that electronic cigarette smoke can affect the ability to preserve the color of denture teeth. Therefore, the purpose of this in vitro study is to compare the coloration of microfiller reinforced polyacrylic resin, nanofilled composite resin, and feldspathic ceramic denture teeth with electronic cigarette smoke, depending on thermal aging.

The null hypotheses were that electronic cigarette smoke with different nicotine levels would make no difference and be similar in discoloration of denture teeth with different material content exposed to thermal aging.

MATERIAL and METHODS

Denture teeth of three different materials were used: microfiller reinforced polyacrylic resin (Vitapan, VITA Zahnfabrik), nanofilled composite resin (Sr Phoneres II, Ivoclar Vivadent AG), and feldspathic ceramic (Lumin Vacuum; VITA Zahnfabrik). In addition, a maxillary right central incisor (shadow A1) was chosen for all denture teeth. Table 1 lists the origin and contents of the materials included in this study. The specimens were then randomly separated into eighteen groups (n = 6), according to the material of the denture teeth (microfilled, nanofilled and ceramic), thermal aging (yes or no), and the nicotine level of the electronic cigarette liquid (0 mg and 12 mg). All samples in the study were kept in distilled water at 370C for 24 hours.

Table 1: Materials used

Material	Type	Component	Manufacturer
SR Phonares II	Composite Resin Denture Teeth with Nanofillers (NCRT)	Urethane dimethacrylate matrix (TMX-UDMA),PMMA, silanized SiO2	Ivoclar Vivadent AG
Lumin Vacuum	Ceramic	Feldspathic	Vita Zahnfabrik
Vitapan	Composite Resin Denture Teeth (CRT)	PMMA with 14% inorganic fillers (highly dispersed silica)	Vita Zahnfabrik

After the first color measurements of all samples were made, half of the samples were aged with 5000 thermocycles (Buchi 461 Water Bath; Fisher Scientific). The cold water cabin is set at 5°C and the hot water cabin at 55°C. The waiting time inside the cabins was 30 seconds and the transfer time between the cabins was 10 seconds (16).

Samples were exposed to 20 cycles of aerosol using the ECIG device (EGO-CE5, CE FC RoHS). A smoking simulator was used for this procedure. A negative pressure vacuum device was used in the glass cabinet of the simulator device (the chamber in which the samples were placed) that simulates the inhalation of electronic cigarette smoke. The buccal surfaces of the samples were placed perpendicular to the entrance direction of the electronic cigarette smoke and at a distance of 1.5 cm. Colorless wax was used to fix it. The batteries of the electronic cigarette device were charged before each period, and the cartridges were completely filled with (1.6 mL) e-liquid (KF Brazil e-liquids, Brazil). It was connected to the top of the chamber by a vacuum system that applied negative pressure to expel the cigarette smoke that had entered the chamber. In this way, the smoke-free state in the period between breaths was simulated. A cycle of 3.6 minutes was created, consisting of 10 breaths,

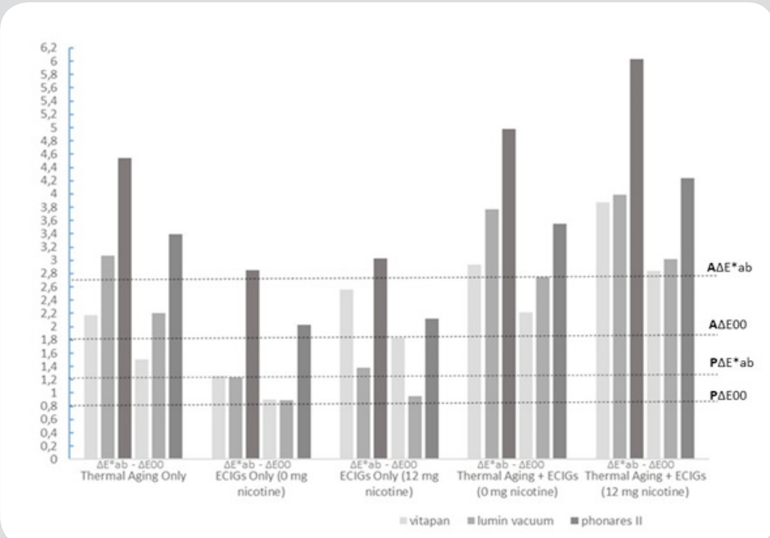

Figure 1. Graphic illustration of ΔE from CIELab and CIED2000 formulae, considering thermal aging, e-cigarette, and nicotine levels. Dotted lines represent the thresholds for perceptible (P) and acceptable (A) values.

with a breathing time of 4 seconds and a 20 seconds interval between each breath. After 10 cycles, the cartridges were refilled with e-liquid to prevent overheating. After 20 cycles were completed, the samples were washed with non-pressure distilled water, and color measurements were made (7).

A spectrophotometer (Vita Easyshade, VITA Zahnfabrik, Germany) was used to measure the color of each sample before and after exposure to the e-cigarette aerosol. A single researcher made all color measurements. Samples were placed in colorless acrylic molds with a 6 mm diameter circular hole in the center to make a standard color measurement. The central hole corresponds to the buccal middle third of each specimen. The measuring tip of the spectrophotometer was directed over the hole, and the position was kept constant in the first and last measurements. Results were expressed using the formulas CIELab (ΔEab) and CIED2000.

The formula for CIELab color difference (ΔE*ab) is (17):

ΔE*ab = [(ΔL*)2 +(Δa*)2 +(Δb*)2]1/2

The formula for CIED2000 color difference (ΔE00) is (18,19):

ΔE00 = [(ΔL/KL.SL)2 + (ΔC/KC.SC)2 + (ΔH/KH.SH)2 + RT. (ΔC/ KC.SC) X (ΔH/KH.SH)]0.5

The 50:50% detectability threshold (PT) was set to ΔEab=1.2 and ΔE00=0.8,

while the 50%:50% acceptability threshold (AT) was set to

ΔEab=2.7 and ΔE00=1.8 (20) (Figure 1).

All data were recorded in the SPSS (statistical package for social sciences) for Windows 22 program on the computer and analyzed. In analyzing the data, firstly, the assumptions must be met to decide which tests (parametric/nonparametric) to apply are tested. To decide the normality of the distribution, Shapiro-Wilk, kurtosis and skewness values, which are other assumptions of the normal distribution, and the histogram plot were used. One-way analysis of variance was used to compare two or more unrelated groups, and the Tukey test, one of the post hoc tests, was used to determine the source of the difference. In order to determine the homogeneity of the variance, Levene statistics were examined and it was found that the variances were homogeneous. The significance level of 0.05 was used as the criterion in interpreting whether the values obtained were meaningful or not.

RESULTS

In groups in which thermal aging is not applied, the color change caused by the electronic cigarette creates a statistically significant difference between 3 different materials ($p < 0.05$). According to the Tukey multiple

Table 2: Colorations calculated with CIELab (ΔE * ab).

	Vitapan [a]	Lumin vacuum [b]	Phonares [c]	F	p	Difference
No TA + No smoke [1]	1.23±0.53	1.05±1.38	1.71±0.48	0.71	0.51	
No TA + 0 mg nicotine [2]	1.26±1.28	1.23±1.01	2.85±0.81	3.9	0.5	
No TA + 12 mg nicotine [3]	2.56±0.97	1.38±0.46	3.03±0.96	5.19	0.02*	b<c
TA + No smoke [4]	2.17±0.74	3.07±0.28	4.54±0.98	13.59	0.01*	a<b,c
TA + 0 mg nicotine [5]	2.93±1.29	3.77±1.18	4.98±0.62	4.64	0.03*	a<c
Termal + 12 mg nicotine [6]	3.87±1.23	3.99±1.02	6.03±1.02	6.18	0.01*	a,b<c
Statical Test	F:4,72, p:0.01	F:9,59, p:0.01	F:18,32, p:0.01			
Difference	1,4<6	1<4,5,6 2,3<5,6	1,2,3<4,5,6			

TA: Thermal Aging

*p<0.05

Table 3: Colorations calculated with CIED2000 (ΔE00).

	Vitapan (a)	Lumin Vacuum (b)	Phonares(c)	F	p	Difference
No TA + No smoke (1)	0.84±0.29	0.76±0.91	1.29±0.28	1.03	0.32	
No TA + 0 mg nicotine (2)	0.90±0.85	0.89±0.71	2.03±0.59	4.06	0.04*	
No TA + 12 mg nicotine (3)	1.83±0.70	0.95±0.30	2.12±0.68	5.29	0.02*	b<c
TA + No smoke (4)	1.51±0.49	2.20±0.19	3.39±0.64	19.7	0.01*	a,b<c
TA + 0 mg nicotine (5)	2.21±0.78	2.75±0.87	3.55±0.39	4.48	0.04*	a<c
TA + 12 mg nicotine (6)	2.84±0.94	3.02±0.82	4.24±0.73	4.17	0.04*	
Statical Test	F:5,89, p:0.01	F:10,75, p:0.01	F:19,18, p:0.01			
Difference	1,4<6	1<4,5,6 2,3<5,6	1,2,3<4,5,6			

TA: Thermal Aging

*p<0.05

comparison tests conducted to understand which materials the difference is, ΔE*ab value of Lumin vacuum is significantly lower than Phonares II (Table 2); however, there is no significant difference in ΔE00 value (Table 3).

There is a statistically significant difference between 3 different materials in terms of ΔE*ab and ΔE00 values in all groups undergoing thermal aging (p <0.05). According to Tukey, multiple comparison tests were conducted to understand which groups the difference is; Vitapan's ΔE*ab value is significantly lower than Lumin vacuum and Phonares II in groups that do not apply electronic cigarettes. The ΔE00 values of Vitapan and Lumin vacuum are significantly lower than Phonares II. Both ΔE*ab and ΔE00 values of Vitapan in 0 mg nicotine e-cigarette groups were significantly lower than Phonares II. ΔE*ab values of Vitapan and Lumin vacuum are significantly lower than Phonares II in groups administered 12 mg nicotine e-cigarette. There was no significant difference between the groups in the value of ΔE00 in the 12 mg nicotine electronic cigarette groups.

ΔE*ab and ΔE00 values of Vitapan show a statistically significant difference between all groups. (p <0.05) According to the Tukey multiple comparison test conducted to understand which groups the difference is, the ΔE00 and ΔE*ab values of all groups without e-cigarettes were significantly lower than the group exposed to thermal aging and exposed to 12 mg nicotine e-cigarettes.

ΔE*ab and ΔE00 values of Lumin vacuum show a statistically significant difference between all groups (p <0.05). According to the Tukey multiple comparison test conducted to understand which groups the difference is, the ΔE00 and ΔE*ab values of the group that did not undergo thermal aging and did not apply electronic cigarettes were significantly lower than all groups that applied thermal aging. In addition, those who did not undergo thermal aging in the groups treated with 0 mg or 12 mg nicotine e-cigarettes show significantly lower ΔE*ab and ΔE00 values than those who underwent thermal aging.

ΔE*ab and ΔE00 values of Phonares II show a statistically significant difference between all groups ($p < 0.05$). According to the Tukey multiple comparison test conducted to understand which groups the difference is, all groups that underwent thermal aging show significantly higher ΔE*ab and ΔE00 values than all groups that did not undergo thermal aging.

DISCUSSION

Discoloration in denture teeth can be caused by internal and external factors (21). Internal discoloration occurs due to the aging of the material resulting from thermal changes and engages in physical and chemical interactions involving moisture. The reason for color changes due to external factors is absorption and adsorption (22).

Although some authors have evaluated discoloration of denture teeth from exposure to oral fluids and coloring agents such as tea and coffee (11,23), there are no studies in the literature testing the ability to maintain color of denture teeth affected by electronic cigarettes. Besides, studies on discoloration in denture teeth, including thermal cycling, are scarce in the literature (24). Current studies examining the behavior of denture teeth against staining agents also state that the effect of aging should be examined (12). In a study examining the color change of acrylic resin-based prosthetic teeth of different brands, acrylic prosthetic teeth subjected to thermal aging yielded higher E values, and ΔE of ≤3.3 was considered clinically acceptable (24). In this study, ΔE values were found to be highest in nanohybrid (3.39 and 4.54) and lowest in microfilled (1.51 and 2.17) and ceramic (2.26 and 3.07) in the groups that underwent thermal aging only.

It is known that traditional cigarette smoking can affect the discoloration of denture teeth and various dental materials. Moreover, these color changes cause dissatisfaction with the aesthetic expectation of the person (7). However, information on the effects of smoke produced by any ECIG device on the color of natural teeth (7) and dental materials (9) is rarely found in the literature. Moreover, there is no information about its effect on prosthetic teeth.

More than half of the review studies examining perceptibility and acceptability thresholds for color differences in dentistry use the perceptibility threshold ΔE*=1, and one-third of the studies indicated ΔE*=3.7 as the acceptable threshold for color difference in half of the observers (25-27). In a study examining the visual perception of color differences by different observers, the perceptibility and acceptability thresholds for ΔE*ab were 1.2 and 2.7, respectively, while the thresholds for ΔE00 were 0.8 and 1.8, respectively (28). In our study, ΔE*ab values vary between 1.23 and 6.03, while ΔE00 values vary between 0.89 and 4.24. Therefore, based on predetermined thresholds for color difference detection, we may believe that ECIGs (regardless of nicotine content and thermal aging) cause perceptible discoloration on denture teeth.

The CIEDE2000 and CIELAB formulas are also used in studies on color measurement in dentistry; however, it has been reported in the literature that the CIEDE2000 performs better. The CIEDE2000 formula balances the differences between colors in L*, a* and b* and removes inequality (26).

Considering the individual differences in human perception, since it is complex and challenging to measure the color difference, different systems have been developed to strengthen the relationship between color measurements and visual perception. However, it is impossible to convert these values to each other because the color variations calculated by different systems depend on the chosen color coordinate pair (27).

Various studies (26,27) examined the correlation between systems evaluating color differences, and they concluded that color coordinates are important and necessary for color perception and claimed that the CIEDE2000 formula makes more successful adjustments in evaluating color differences. However, it continues to be used extensively in calculations related to ΔE, both in the literature and clinical applications (28).

While Karen et al. examined the ECIG effect on tooth enamel discoloration, they showed that the increase in nicotine content increased the color difference (7). Our study found the staining effect of ECIG without nicotine to be lower. Besides, the ΔE*ab values in the results of this in-vitro study were higher than those reported by Karen et al. (1.90-4.60). In studies using conventional cigarettes, ΔE*ab values are much higher. This can be attributed to the dark components of the fumes produced in the combustion reaction (10).

On the other hand, unlike conventional cigarettes, ECIG devices do not have a burning reaction; A vaporized aerosol is mentioned. Therefore, ECIG aerosol does not contain the carbon monoxide found in conventional cigarette smoke. However, in the cartridges where e-liquid is stored, liquid absorbent fibers and heating elements containing heavy metals are in contact (29).

Although ECIGs do not contain most of the toxic substances associated with the burning reaction in conventional cigarettes, the size of the particles sent by ECIGs is much smaller than that of conventional cigarettes (3). The ultrafine particles of ECIGs (modes, ≈100-200 nm) may be the reason for their lower ΔE*ab values compared to conventional cigarettes (7).

One of the limitations of our study is that the use of ECIG in vitro studies (number of cycles, inhalation and exhalation time, resting time, EC fluid amount) is different from traditional cigarettes, and the application protocol supported in the literature is not standard. Another limitation is that ECIG devices of different brands and models may differ in terms of charging time, battery life, nicotine distribution, aerosol evaporation, and heating temperature; all of these can affect results (3,30,31). The last limitation is that this study did not evaluate other factors that may affect discoloration, such as tooth brushing and other oral hygiene controls.

It is important to develop standardized test methods to evaluate the effects of ECIGs on the discoloration of dental materials, especially in Dentistry. Despite some limitations, this study is the first to evaluate the discoloration of denture teeth in different materials exposed to ECIG aerosols in vitro.

CONCLUSION

In light of the findings of this in vitro study, these conclusions can be assumed:

- Denture teeth color changes with ECIGs containing e-liquids with different nicotine percentages.
- The high nicotine levels of e-liquids caused more discoloration.
- The thermal cycle adversely affected the color stability of denture teeth.
- The color change of nanohybrid denture teeth due to ECIGs was more than microfilled and ceramic denture teeth.

Conflict of Interest:

The authors declare that there is no conflict of interest.

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