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Effect of Conventional and Electronic Cigarettes Smoking on the Color Stability and Translucency of Tooth Colored Restorative Materials: An In Vitro Analysis

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Abstract: This in vitro study compared the effects of conventional and electronic cigarettes on the aesthetics (color stability and translucency) of two types of composite resins: micro and nano-hybrid. **Methods:** A total of 120 specimens from two different composite materials Filtek Z250 XT (Nano-hybrid, 3M) and Filtek Z250 (Micro-hybrid, 3M) were divided into four groups (n = 30); shade A2 was used. The samples were exposed to conventional and electronic cigarette smoke via a custom made chamber device. The color values and measurements were recorded using a spectrophotometer before and after the exposure. The color and translucency were evaluated using the three-dimensional CIE Lab. **Results:** There was a significant change in the color (ΔE) and the translucency parameter (TP) in all of the specimens exposed to electronic cigarettes and conventional cigarettes. The results showed that the highest ΔE mean is for the nano-hybrid composite exposed to conventional cigarettes with 1.74 ΔE while the same material is 0.64 under the electronic cigarettes and the difference is significant with ($p < 0.05$). The micro-hybrid composite data showed less changes in color under both exposures with 0.85 ΔE mean under the conventional cigarette smoke and 0.48 under the electronic cigarette smoke with ($p < 0.004$). **Conclusions:** The conventional cigarette smoke has more effect on the color stability of the composite resins than electronic cigarettes. From a clinical point of view, the effect of smoke exposure on the tested specimens' color, for the time duration to which the specimens were exposed, were moderate ($\Delta E < 2$). The micro-hybrid composites showed better color stability as compared to the nano-hybrid composites.

Keywords: color; composite; smoking; conventional cigarette; resin; electronic cigarette

1. Introduction

The aesthetic demand from patients has increased in the past few decades. Composite resins are the preferred materials for direct restorations [1]; however, regardless of the outstanding improvement and development of the aesthetic and mechanical properties of resins, some deficiencies still exist [1–3]. Restorations that are exposed to some contents of the conventional cigarettes, such as carbon monoxide and ammonia, become yellow or even black and there is a great change in their color [4]. Nowadays, tooth-colored restorative materials have the ability to mimic the natural appearance of the tooth enamel and dentin, but unfortunately even the best restorations available are prone to staining and their optical behavior and color stability can be affected [5]. Many factors could cause extrinsic staining to the tooth-colored restorations such as tea, coffee, acidic beverages, and the nicotine in cigarettes [6]. Cigarette smoking changes the color and surface texture of

composite leading to increased staining. Polishing decreases superficial staining, but it may not return the composite to its original color [7].

The most common color parameters that help in choosing the dental ceramics from color/shade perspective and for the evaluation/comparison of color differences are the Delta E (ΔE) and Translucency [8,9]. ΔE , which is also termed as the total-color-difference, is obtained from calculation based on L^* , a^* , b^* values. The advantage of ΔE is that it quantifies the combined color/shade differences between the various esthetic materials with a numerical number, and makes the comparisons between these materials simple, convenient, and easy [9–11]. Further to ΔE , the dental ceramics translucency is also considered as important clinical parameter for classifying the esthetic materials into esthetic/non-esthetic and is obtained by calculating the difference between the $L^*a^*b^*$ values of the test materials over white/black background at a standardized thickness, termed as TP [12,13].

Electronic cigarettes (E-Cigarettes) known as vapes were first introduced to the market in the early 2000s and their use has been increasing since then due to the claims of their safety and their ability to help in smoking cessation [14–16]. Almost 750,000 E-Cigarettes were sold in 2010 reaching 3.5 million in 2012 and there is a strong expectation that the numbers of sales will continue to increase globally [17]. E-Cigarettes are battery-powered gadgets that try to mimic the act of conventional smoking and it allows the users to inhale nicotine aerosol without other cigarette content such as carbon monoxide, tar, ammonia, nickel, and cadmium [8]. One study showed an inquiry with the Food and Drug Administration (FDA) for nicotine amount and impurities quantitation in two E-Cigarette brands and results demonstrated low nicotine content [18]. Some other studies reported in aerosols presence of aldehydes and acroleins as a result of VG and PG heating, metals presence in fluids, and aerosol from “cartomizer—combination of atomizer and cartridge in new E-Cigarette model” fibrous pads and volatile organic compounds (VOCs) identification including xylene, benzene, styrene, and toluene presence after chemical analysis in both aerosol and liquids [10–12].

The effect of conventional smoking on the color change of composite resins has been reported in several studies [19–22]. Additionally, conventional smoking affects the translucency of dental enamel and resin composites [23,24]. Translucency is the ability of a layer of a colored substance to allow an underlying background to show through. RBCs are optically translucent materials because of their structure, which is composed of a highly transparent matrix and small filler particles [25]. Translucency affects the depth of color in the restorations and influences the aesthetic harmonization with surrounding or adjacent teeth and restorations [23]. Since the use of E-Cigarettes substantially increased in past few years, currently, there is a lack of research on the effects of E-Cigarettes on the color stability and translucency of tooth-colored restorative materials. Therefore, the aim of this in vitro research study was to compare the effects of conventional and electronic cigarettes on the aesthetics (color stability and translucency) of two types of composite resins, i.e., micro and nano-hybrid. The null hypothesis was that there is no significant difference in the color and translucency of the two investigated composite materials after exposure to smoke of conventional and electronic cigarettes.

2. Materials and Methods

2.1. Study Design and Sample Size Calculation

In this in vitro study, a total of 120 specimens from two different commercially available composite materials were selected. Using sample size calculator software (SPSS, 2022, IBM, Chicago, IL, USA) with α (level of significance) set at 0.5, effect size of 0.35 and power of 0.9, the total sample size calculated was 120. A total of 60 Nano-hybrid Filtek Z250 XT (3M ESPE, Saint Paul, MN, USA) and 60 Micro-hybrid Filtek Z250 (3M ESPE, Saint Paul, MN, USA), (shade A2) were used (Table 1).

The samples were divided into four groups ($n = 30$) and randomly assigned according to the type of smoke that they were exposed to:

Group 1—Z250 XT composite that was exposed to conventional cigarettes.

Group 2—Filtek Z250 composite that was exposed to conventional cigarettes.

Group 3—Z250 XT composite that was exposed to electronic cigarettes' smoke.

Group 4—Filtek Z250 composite that was exposed to electronic cigarettes.

Table 1. Composition of the restorative materials used in the study.

Materials (Shade A2)	Composition
Nano-hybrid composite filtek (Z250 XT).	Bis-GMA, UDMA, TEGDMA, BIS-EMA, 55–57% of filler: Barium glass, ytterbium trifluoride, mixed oxides, and silica dioxide particles.
Micro-Hybrid composite feltek (Z250).	Bis-GMA, TEGDMA, UDMA, BisEMA, 60% of filler: zirconium/silica particles.

2.2. Specimen Preparation

A stainless-steel mold (10-mm in diameter and 2-mm in thickness) was used to prepare the specimens and a matrix strip (Mylar, Dupont, Wilmington, DE, USA) was placed over the mold and light pressure was applied on the matrix to remove any excess composite and to make the outer layer of the composite as smooth as possible then the specimens were placed on a glass slide after that they were light-cured with (3M Elipar™ Deep Cure-S LED, Saint Paul, MN, USA) for 40 s for each specimen at 2.5 cm distance from the specimens and power output of 1.470 mW/cm² (Figure 1). The specimens were stored in distilled water at room temperature 24 h before the exposure to cigarettes.

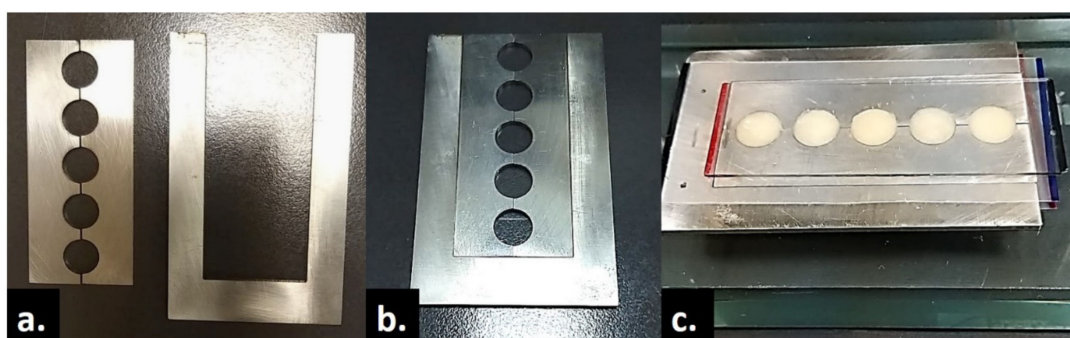


Figure 1. (a,b) Stainless-steel mold used for preparation of specimens; (c) composite specimens being prepared using the stainless-steel mold.

2.3. Exposure of Specimens to Smoking

Custom made chamber device was made consisting of a vacuum system that directed the smoke to a custom-made plastic box (Figures 2 and 3). The specimens were stabilized by polyvinyl siloxane putty index (manufacturer) which was placed inside the box at 8 cm distance from the smoke. The specimens were placed vertically on both sides of the customized chamber in order to mimic the intraoral scenario of restorations getting exposed to the smoking. Horizontal placement of the specimens was avoided intentionally to avoid unrealistic adherence of smoking dust to the specimens.

Conventional cigarettes (Marlboro, Philip Morris International Inc., New York, NY, USA) and electronic cigarette (Greensound LTD, GS Q80, Shenzhen, China) were used in the experiments. The specimens were exposed to cigarette smoke for 90 min (90 cigarettes). Then the specimens were gently washed with distilled water for 1 min, and the final color was measured with the spectrophotometer after 2 h. The E-Cigarettes batteries were fully charged and stored at room temperature. The vacuum flow rate to pull aerosol out of atomizer was 20 mL/min. This flow rate allowed aerosol capture in first trap without moving on to second trap and prior to aerosolization, none of the E-Cigarette non-aerosolized e-liquid was pulled out.

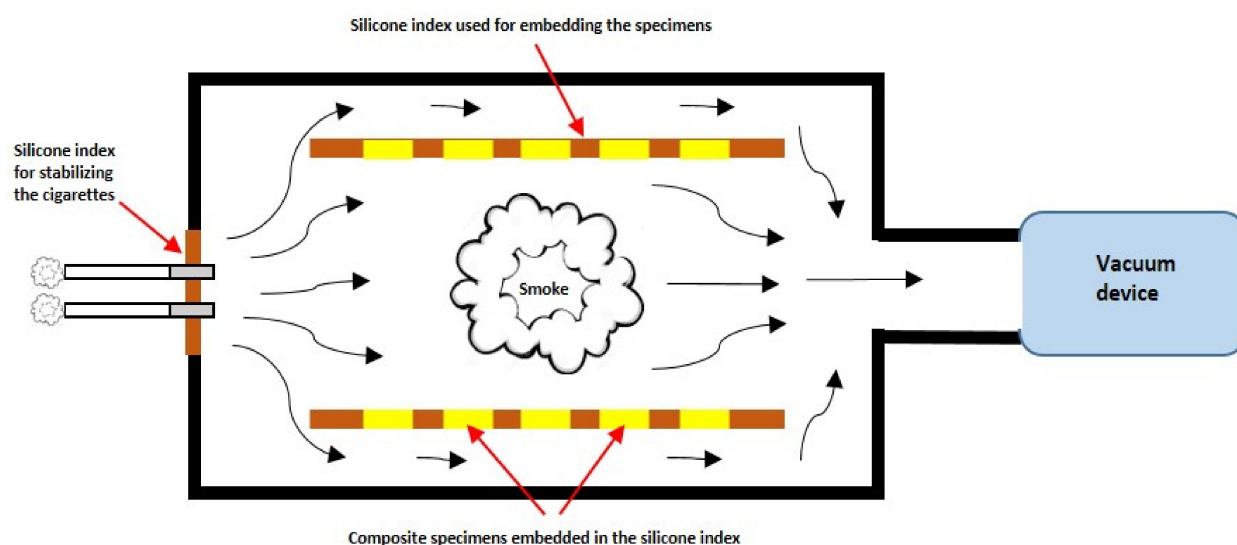


Figure 2. Schematic representation of the process of the experiment.



Figure 3. Customized chamber with suction device.

2.4. Color Measurements

The color measurements were taken by CIELab color system and (ΔE) was calculated before and after the experiment via the spectrophotometer (Hunterlab, Labscan XE, Reston, VA, USA) with automated Variable Sample Illumination and target mask opening of 44 mm. There are two chromatic axes, a^* (red-green parameter difference) and b^* (yellow-blue parameter difference), which are at right angles to one another, representing the saturation level and hue dimensions. The third axis, L^* , perpendicular to the chromatic planes represents the value or lightness. The CIELab color difference (ΔE) was calculated as follows [9]:

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

To measure the translucency, the color of all the specimens was measured using black and white backgrounds before and after the experiment and the translucency parameter TP to detect the differences was calculated according to this formula:

$$TP = [(L^*B - L^*W)^2 + (a^*B - a^*W)^2 + (b^*B - b^*W)^2]^{1/2} \quad (2)$$

where W is against the white background and B is against the black background [9].

2.5. Statistical Analysis

All the data were tabulated and analyzed by Statistical package for social sciences (SPSS; Version 23; SPSS Inc., Chicago, IL, USA). Descriptive stats for mean $L^*a^*b^*$ values, calculation of ΔE and TP from the $L^*a^*b^*$ values were recorded and tabulated for the test composite materials. The data were found to be normally distributed according to Kolmogorov–Smirnov test. The formal analysis was carried out, comparing the mean values of ΔE and TP (95% CIs) of all the five groups using Paired Samples t test at probability of $\alpha < 0.05$.

3. Results

It was verified that all four groups presented a significant change in color ΔE under exposure to both the electronic and conventional cigarettes and they became darker in color. Table 2 presents the results of paired samples t test with the mean ΔE for each test group. The results showed that the highest ΔE mean is for the nano-hybrid composite exposed to conventional cigarettes with 1.74 ΔE while the same material is 0.64 under the electronic cigarettes and the difference is significant with ($p < 0.05$). The micro-hybrid composite data show less changes in color under both exposures with 0.85 ΔE mean under the conventional cigarette smoke and 0.48 under the electronic cigarette smoke with ($p = 0.004$). These data revealed that the conventional cigarettes have more effect on the color change of composite materials than electronic cigarettes.

Table 2. Comparing smoking within each type of composite.

Composite	Smoking	N	Mean	Std. Deviation	<i>p</i> -Value
Nano	Conventional	30	1.714	1.166	0.000
	Electronic	30	0.646	0.301	
Micro	Conventional	30	0.8512	0.589	0.004
	Electronic	30	0.487	0.262	

Table 3 shows that micro-composite group specimens had more color stability than the nano-composite ($p < 0.05$) under conventional smoking and less significant change under electronic smoking with ($p = 0.033$). Furthermore, the results revealed that the electronic cigarettes affected both tested materials to similar levels while conventional cigarettes affected the color and caused more staining for the nano-composites as compared to the micro composites.

Table 3. Comparing the type of composite with each type of smoking.

Smoking	Composite	N	Mean	Std. Deviation	<i>p</i> -Value
Conventional	Nano	30	1.714	1.166	0.001
	Micro	30	0.646	0.301	
Electronic	Nano	30	0.8512	0.589	0.033
	Micro	30	0.487	0.262	

With respect to the three-dimensional CIE Lab system, the value of L^* axis which represents the lightness decreased in all groups. The nano-composite became greener and more bluish while the micro-composite became more reddish and yellowish (Table 4).

Regarding the translucency, there was a significant change in the values of the translucency parameter before and after the experiment. Table 5 shows the results of the t paired test with a significant level of ($\alpha = 0.05$). The mean of the TP reduced after the experiment in all groups. The first group of the nano-hybrid composite that was exposed to conventional cigarettes reduced from 10.4 TP before the exposure and 7.4 after the exposure with ($p = 0.006$). Additionally, the second group of micro composites exposed to conventional smoking reduced from 9.9 TP before the exposure and 6.9 after it with ($p = 0.031$), so the nano-hybrid were more affected than the micro-hybrid. The groups exposed to electronic

cigarettes also experienced a significant decrease in the TP values but it was less than the gropes exposed to conventional cigarettes, thus the null hypothesis is rejected and we observed significant change in translucency and color after exposure to E-Cigarettes in restorative materials used.

Table 4. CIE LAB System values.

		Mean of L, a and b Axis before and after					
Smoking	Composite	L* before	a* before	b* before	L* after	a* after	B* after
Conventional	Nano	58.67	−1.66	5.03	57.88	−2.23	4.75
	Micro	54.72	−2.45	3.543	54.11	−2.25	3.79
Electronic	Nano	57.4	−1.83	4.16	57.07	−2.013	4.01
	Micro	54.53	−2.44933	3.371	54.49	−2.268	3.53

Table 5. The effect of the smoke on translucency.

Smoking	Material	Translucency Parameter (TP)	N	Mean	p-Value
Conventional smoking	Nano-hybrid Composite	Before	30	10.408	0.006
		After	30	7.468	
	Micro-hybrid Composite	Before	30	9.921	0.031
		After	30	6.907	
Electronic smoking	Nano-hybrid Composite	Before	30	10.518	0.129
		After	30	7.418	
	Micro-hybrid Composite	Before	30	9.791	0.174
		After	30	6.528	

4. Discussion

The present study evaluated and compared the effects of conventional and electronic cigarettes on the color stability and translucency of micro and nano-hybrid composites. A unique method of exposing the specimens to the smoke of cigarettes in a custom designed smoking chamber was employed in the study. The results of the study revealed significant change in translucency and color of the tested restorative materials after exposure to the cigarettes, thus rejecting the null hypothesis.

In the present study specimens were fabricated from two resin composites Nano-hybrid Filtek Z250 XT (3M ESPE, Saint Paul, MN, USA) and Micro-hybrid Filtek Z250 (3M ESPE, Saint Paul, MN, USA) as per manufacturer's instructions to examine the effect of conventional and electronic cigarettes use on their color stability and translucency. Both composites were selected due to developed reputation in restoration stabilization in oral environment due to their high quality [26]. Nano-hybrid Filtek Z250 XT restorative composites are found beneficial in attaining longevity of restorations as they show similar "mean flexural modulus (17.44 GPa)" to "dentin flexural modulus (19 GPa)" [27–29] the other used restorative resin composite is Micro-hybrid Filtek Z250 (3M ESPE, Saint Paul, MN, USA) claimed to decrease polymerization shrinkage and improve resin efficacy in class I restorations due to use of monomers i.e., mixture of TEGDMA and Bis-GMA in addition to Bis-EMA or UDMA.

Nowadays the younger generation/youth are very careful and possessive about the appearance and the whiteness of their teeth. There is also an increase in the rate of consumption and use of the products that cause extrinsic staining such as coffee, acidic beverages, and smoking [10]. Smoking is responsible for so many health consequences and most of them do not show until late adulthood [30]. Smoking affects the oral health too. A study found out that smoking is associated with the increase of both severity and the prevalence of the periodontal disease; another study in the United States found out that 41% of people with periodontitis are current smokers and 10% are previous smokers [14,31]. Electronic cigarettes were found to be helping people in smoking cessation and people

who smoked them for more than 2 years had a higher chance in smoking cessation than those who used them for a short period of time. Additionally, the electronic cigarettes help in reducing the number of conventional cigarette smoked per day [14–16]. However, the current data showed that the use of electronic cigarettes posed a different type of effect on the color of restorations compared to conventional cigarettes. Some people use both electronic cigarettes and conventional cigarettes at the same time and this increases the rates of morbidity and mortality [13].

Ideally the differences in the composition of the aesthetic restorative composites available in the market should behave similarly to any extrinsic staining and exhibit no difference in their color to these stains [32]. The results of this study revealed significant changes in the color of the investigated composite materials with regards to the changes observed in the ΔE and the translucency values. The total color difference or ΔE is considered as a standardized tool for evaluation and comparison of color changes in color science. According to the color changes in aesthetic restorations the $\Delta E < 1$ cannot be detected by the naked human eye and if $1 < \Delta E < 3.3$ can be detected only by an experienced dentist and finally $\Delta E > 3.3$ can be detected easily by anyone and it is unacceptable clinically [9,10]. While it is true that all values of ΔE in this study increased it is also true that all of them were < 3.3 which makes them clinically acceptable. One of the reasons for this was the small distance of 2.5 cm used. On the other hand, in a previous study done on Nano-hybrid composite Filtek (Z250 XT) exposed to conventional cigarettes, the mean value after the exposure was 24 ΔE which is much higher than this study's value of 1.7 ΔE . They claimed that their high values are due to using cigarettes with dark components, and the distance that was between the samples and the exposure was 1 cm, which might play a big role in that high value, if we compare it with this study's distance (8 cm) [4]. Another study done on a bovine enamel exposed to electronic cigarettes showed a mean value of 3.3 ΔE and it is more than this study's values 0.64 ΔE for the nano-hybrid [1]. The study used an exposure time of 70 min which is 20 min less than the time used in this study, so it can be observed that if we increase the exposure time it will produce more similar results [1]. A study exposed the nano-hybrid composite Filtek (Z250 XT) to conventional smoke and the mean value was 9.7 ΔE . This study also used a 1 cm difference between the exposure and the specimens which led to higher ΔE value. The same study measured the translucency of the same material and it was 10 TP compared to 7.4 TP in our study [13].

The translucency of teeth differs from tooth to tooth and from area to area at the same tooth, for example, the translucency of the central upper incisor is 15 TP at the incisal area, and it decreases to 5 at the cervical area [19]. The mean TP of 1 mm thickness human tooth was 16.4 and another study suggests that there are some differences and variations in the TP values of sectioned human dentin with thicknesses ranging from 0.5 to 2.0 mm [20]. The values of TP in this study reduced significantly under the exposure of the conventional smoking from 10.409 to 7.469 for the nano-hybrid and from 9.922 to 6.907 for the micro-hybrid composite. Additionally, the electronic cigarettes smoking affected the translucency: it decreased from 9.791 to 6.528 for the micro-hybrid composite and from 10.518 to 7.418 for the nano-hybrid composite. This significant change in the TP values shows that both methods affect the translucency negatively, but the conventional cigarettes have more effect on the translucency than the electronic cigarettes and the micro-hybrid seemed to be the least affected by both methods. The distance between the smoke entrance and the exposed specimens was 8 cm and it affected the results.

The present study had some limitations because of the in vitro design. In addition, it did not examine multiple brands, concentrations, and flavors of nicotine to further evaluate impact on dental restorative materials or absence of brushing simulation during the exposure of specimens to the smoke. Future studies are recommended on larger sample sizes along with use of different nicotine brands and concentrations. In addition, standardization of number and duration of puffs for all the test groups will be helpful in further validating the results and overcoming some of the limitations of the present study.

5. Conclusions

Within the limitations of this study, we conclude that both conventional cigarettes and electronic cigarettes affect the color and the translucency of composite resins negatively, and they make them appear darker. However, conventional cigarette smoke has more effect on the color stability of the composite resins as compared to electronic cigarettes. From a clinical point of view, the effect of smoke exposure on the tested specimens' color for the time duration to which the specimens were exposed were moderate ($\Delta E < 2$). The micro-hybrid composites showed better color stability as compared to the nano-hybrid composites.

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