Çukurova Üniversitesi Mühendislik Fakültesi Dergisi
Çukurova University Journal of the Faculty of Engineering
ISSN: 2757-9255 CİLT/VOLUME: 39 SAYI/ISSUE: 4 ARALIK/DECEMBER 2024

Design and Realization of a Novel Programmable Tobacco Smoking Simulator

Mustafa İSTANBULLU [1,a], A. Özgür POLAT [2,3,b], Koray SOYGUN [4,c], Deniz YUVA [5,d]

[1]*Cukurova University, Faculty of Engineering, Department of Biomedical Engineering, Adana, Türkiye*
[2]*Karamanoğlu Mehmetbey University, Faculty of Engineering, Department of Electrical and Electronics Engineering, Karaman, Türkiye*
[3]*Solvaytech Engineering, Adana, Türkiye*
[4]*Cukurova University, Faculty of Dentistry, Department of Prosthetic Dentistry, Adana, Türkiye*
[5]*Hatay Oral and Dental Health Center, Ministry of Health, Hatay, Türkiye*

[a]***ORCID**: 0000-0001-5414-7380;* [b]***ORCID**: 0000-0002-4922-6567;* [c]***ORCID**: 0000-0002-0145-3947;* [d]***ORCID**: 0000-0003-4868-4715*

Article Info
Received : 06.06.2024
Accepted : 23.12.2024
DOI: 10.21605/cukurovaumfd.1606041

Corresponding Author
Mustafa İSTANBULLU
mistanbullu@cu.edu.tr

Keywords
Smoking simulator
Effects of Smoke
Dental analysis
3D modelling
Microcontroller

***How to cite:** İSTANBULLU, M., POLAT, A.Ö., SOYGUN, K., YUVA, D., (2024). Design and Realization of a Novel Programmable Tobacco Smoking Simulator. Cukurova University, Journal of the Faculty of Engineering, 39(4), 961-968.*

ABSTRACT

Cigarette smoke significantly impacts teeth and dental composites, making smoking simulators vital for studying discoloration, staining, surface roughness, and topography. Conventional simulators face challenges such as incomplete process simulation, inadequate smoke exposure unit design, and improper specimen positioning. This study presents a novel, accurate, and automatic tobacco smoking simulator addressing these issues. The simulator includes a life-sized artificial mouth unit, 3D-printed jaw models for natural dental sample positioning, a vacuum system to simulate positive/negative pressure, and a reprogrammable microcontroller for customizable smoking profiles. Tested with 140 cigarettes over 14 days, the system effectively demonstrated color changes in dental materials. Adjustable parameters such as puff volume, inhalation/exhalation time, smoke density, and smoking speed allow replication of low, moderate, and high-intensity smoking profiles. Portable, low-cost, and versatile, the simulator provides a robust solution for research and education, enabling investigations into the effects of smoke on teeth and dental materials under realistic conditions.

Özgün Programlanabilir Bir Sigara İçme Simülatörünün Tasarımı ve Gerçeklemesi

Makale Bilgileri
Geliş : 06.06.2024
Kabul : 23.12.2024
DOI: 10.21605/cukurovaumfd.1606041

Sorumlu Yazar
Mustafa İSTANBULLU
mistanbullu@cu.edu.tr

Anahtar Kelimeler
Sigara içme simülatörü
Sigara dumanı etkileri
Dental analiz
3B modelleme
Mikrokontrolcü

***Atıf şekli:** İSTANBULLU, M., POLAT, A.Ö., SOYGUN, K., YUVA, D., (2024). Design and Realization of a Novel Programmable Tobacco Smoking Simulator. Cukurova University, Journal of the Faculty of Engineering, 39(4), 961-968.*

ÖZ

Sigara dumanının dişler ve dental kompozitler üzerindeki etkileri, renk değişimi, lekelenme, yüzey pürüzlülüğü ve topografya gibi konuların incelenmesinde önemli bir araştırma alanıdır. Ancak geleneksel sigara simülatörleri, sürecin eksik simülasyonu, uygun olmayan duman maruziyet birimi tasarımı ve dental örneklerin yanlış yerleştirilmesi gibi sorunlarla karşılaşmaktadır. Bu çalışma, bu eksiklikleri gidermeyi amaçlayan yenilikçi, doğru ve otomatik bir sigara simülatörü sunmaktadır. Simülatör, gerçek bir ağız hacmine sahip yapay bir ağız birimi, doğal diş yerleşimi için 3D yazıcıyla üretilmiş çene modelleri, pozitif/negatif basınç oluşturmak için bir vakum sistemi ve özelleştirilebilir sigara profilleri için yeniden programlanabilir bir mikrodenetleyici içermektedir. 14 gün boyunca 140 sigara ile test edilen sistem, dental materyallerdeki renk değişimlerini etkili bir şekilde göstermiştir. Ayarlanabilir parametreler (nefes hacmi, soluk alıp verme süresi, duman yoğunluğu, sigara içme hızı) düşük, orta ve yüksek yoğunluklu sigara profillerinin simülasyonunu sağlamaktadır. Taşınabilir, düşük maliyetli ve çok yönlü bu simülatör, araştırma ve eğitim için güçlü bir çözüm sunmaktadır.

1. INTRODUCTION

In recent years, the appearance of teeth has great importance for patients and dentists. The desire of patients to have whiter teeth has led dentists to meet expectations in terms of dental aesthetics. Discoloration of teeth is a common condition that almost everyone is exposed to. Watts and Addy [1] reported that tooth discoloration is classified as internal or external staining. Intrinsic stains are the result of the incorporation of pigmented materials into dental tissues. Localized discoloration may result from pulp necrosis and bleeding, infection of primary teeth, inadequate endodontic treatment, and amalgam staining as stated in the study of Hattab et al. [2]. Moreover, as given in [2,3], internal discoloration may also be caused by environmental or genetic factors affecting tooth structures, such as dental fluorosis, tetracycline therapy, childhood diseases, and hereditary disorders such as amelogenesis and dentinogenesis imperfecta. Another reason causing discoloration on the teeth could be due to habits that lead to external stains, using a substance that contains pigmented material or various chromogens. Addy and Moran [4] shown that, coffee, tea, red wine, orange juice, soft drinks, and food colorants are considered coloring agents that cause tooth discoloration. In addition, researchers [1,2,5] reported that occupational exposure to chemicals, tobacco smoking, chewing, mouthwashes, and frequent use of certain drugs are etiological factors that cause tooth discoloration.

In the literature, researchers investigate the effects of tobacco smoke on the color change, surface roughness, and surface topography of tooth samples. In these studies, using primitive smoking devices/simulators is the overall approximation for exposing dental samples to tobacco smoke. Patil et al. [6] placed 30 dental specimens in a plastic box including a hole to place the cigarette. Dental samples are exposed to tobacco smoke through a vacuum system. However, contrary to their natural placement in the mouth, tooth samples were placed on a circular teeth holder. The plastic box where the tooth samples are placed is much larger than the natural volume of a mouth. Thus, the large box volume makes an essential difference in the exposure of the teeth to tobacco smoke in terms of low smoke density. In the study of Roman et al. [5], only one dental sample is placed in the smoking device. The capsule where the tooth sample is placed is tiny compared to the natural volume of a mouth, unlike Patils's study. The tiny tooth capsule leads to high smoke density and over-smoke exposure. Furthermore, since the placement of the tooth sample in the capsule differs from the natural position of the tooth in the mouth, the experiment could not correctly simulate the smoke exposure process. Mathias et al. [7] designed a smoking device with two chambers to analyze the effects of tobacco smoke on composite tooth specimens. In the related device, dental samples are exposed to the smoke of ten cigarettes simultaneously. As in previous studies, the volume of the unit where the dental samples are placed differs considerably from the natural mouth volume. Similarly, the smoking device in the study of Wasilewski et al. [8] also has an inappropriate simulation environment in terms of both natural mouth volume and exposure process to tobacco smoke. The problems mentioned above are also observed in other studies in the literature [8-13] discussing the various effects of tobacco smoke on dental samples.

The literature studies summarized above indicate that, common problems arise in smoking simulator devices. Firstly, the smoking process has not been simulated correctly yet. In these studies, dental samples are only exposed to tobacco smoke for a particular time. However, the smoking process consists of three stages: inhaling the smoke, keeping it in the mouth for a specific time, and exhaling the smoke. Previous studies have not adequately examined the smoking process in a way that reflects natural smoking behaviors. This paper addresses this gap by presenting a novel simulator that more accurately mimics the natural smoking process, offering improvements over earlier designs and methodologies.

The second problem for traditional smoking simulators is the inaccurate design in dimensions of the oral environment where the teeth are exposed to smoke. In the recent studies, the volume of the unit where the dental samples are exposed to tobacco smoke is usually much larger than the natural volume of the mouth. Thus, experiments in the literature fundamentally differ from the actual smoking process regarding smoke density.

The third problem with traditional smoking simulators is positioning dental specimens incorrectly in the smoke exposure unit. In the existing studies, tooth samples are exposed to tobacco smoke on single, circular, or linear tooth holders. However, dental specimens should have been positioned realistically as in a mouth during the experiment to achieve more accurate results.

Due to the deficiencies of the previous smoking simulator designs, a novel design is necessary to obtain and analyze the effects of cigarette smoke on dental specimens more accurately.

On the other hand, although commercially analytical smoking machines are available (Cerulean, Milton Keynes, UK), these devices mainly utilized for investigation of various chemicals in tobacco smoke, nicotine analysis, particulate matter determination, cigarette burning time, and combustion temperature. These devices are not designed to simulate different smoking profiles and do not provide tobacco smoke exposure to dental specimens similarly positioned in the mouth.

This paper addresses the critical gaps identified in the existing literature by presenting a novel, accurate, and automated smoking simulator designed specifically for dental research. Unlike previous devices, the simulator developed in this study replicates the entire smoking process ensuring a more realistic simulation of smoke exposure. Furthermore, the simulator incorporates a 3D-printed upper and lower jaw model to position dental specimens in a manner that mimics their natural placement in the mouth, which enhances the accuracy of exposure. The artificial mouth unit is designed to have a volume identical to that of an adult human, ensuring proper smoke density during the experiment. Additionally, the reprogrammable controller allows for the simulation of different smoking profiles (low, moderate, and high). These innovations make the presented simulator a valuable tool for accurately investigating the effects of cigarette smoke on dental materials, providing a solution to the limitations of previous designs.

2. MATERIALS AND METHODS

The presented novel reprogrammable smoking simulator system aims to simulate the complete smoking process of a low, moderate, or high-level smoker. Besides, users can define the smoking profile in terms of puff volume, inhalation/exhalation time, smoke density, and smoking speed. In the literature, it has not been designed that such a smoking simulator which uses the natural volume of the mouth, achieves the inhalation/exhalation process, and places the teeth in their original position inside the mouth. Since the presented simulator simulates the complete smoking process, the various effects of smoke on tooth samples can be observed as correctly as in real life.

In recent years, 3D printing and modeling techniques, as suggested in [14-17], are emerging to design and simulate the systems more realistically. Today many studies in various fields contain 3D modeling and printings. Hence, 3D models of the upper and lower human jaws, in the same dimensions with an adult man's, are printed in this work, as shown in Figure 1. Upper and lower 3D jaw models contain tooth knobs to mount the tooth samples in their natural positions in the mouth.

After placing the desired number of tooth samples (methyl methacrylate) on the jaw models, both jaws are fixed in an artificial mouth unit, as shown in Figure 2. Contrary to the systems in the literature, the artificial mouth unit of the presented simulator is designed according to an adult man average mouth dimensions (70.5ml) as stated in the study of Khare et al [18]. Besides, the artificial mouth unit is air-tight during the smoke exposure process.

Figure 1. 3D printings of upper and lower human jaws

The presented simulator has two step-motor systems operating synchronically. The first motor system inserts and removes the cigarette from the artificial mouth unit, while the second provides a vacuum according to a pre-defined smoking profile. The second motor system operates based on creating positive and negative pressure on the artificial mouth unit. The two motor systems run simultaneously until the cigarette is consumed. The presented simulator operates as many times as the number of cigarettes that will expose the tooth samples to the smoke. Finally, the remaining smoke is exhausted using two fans and a flue unit.

Figure 2. Natural placement of dental samples on the 3D printed jaw model

2.1. Software and Hardware of the Simulator

A 12V power supply provides the power of the smoking simulator. The presented smoking simulator is controlled by an ATMEGA328P microcontroller and application-specific software. The software contains two main parts. The first part controls the process of inhalation/exhalation of the cigarette, while the second controls the negative pressure that will be created in the artificial mouth. The flow chart of the presented smoking simulator is given in Figure 3.

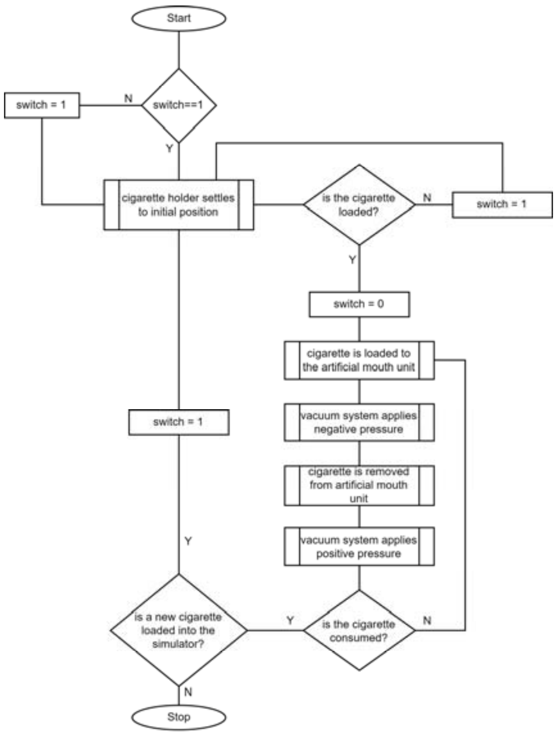


Figure 3. The flow chart of the smoking simulator

Inserting and removing the cigarette from the artificial mouth unit is done by the first part of the simulator. The related part consists of a cigarette holder, an artificial mouth unit, a 3D-printed upper/lower jaw, the motor that provides the linear movement of the cigarette in two axes, a rack, and various connection equipment. The second part of the presented simulator performs the inhalation and exhalation of the smoke to the artificial mouth unit. This part consists of an injection cylinder, a holder, a motor that provides the linear movement of the injection piston in two axes, a shaft, and various connection equipment. Figure 4(a) shows the technical drawing of the complete system in a 1/5 ratio, while the 3D model of the simulator is given in Figure 4(b).

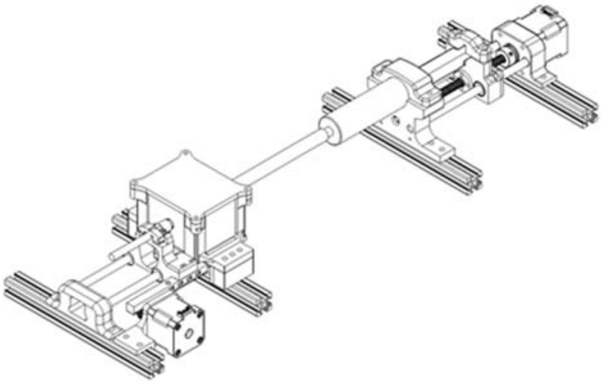
Before operating the presented smoking simulator, a cigarette should be placed in the cigarette holder, and tooth samples should be placed on the 3D jaw model in natural positions. When the simulator starts, the cigarette holder and injection piston come to their starting positions. Hence, the two parts of the system mentioned above start to run simultaneously. At first, the cigarette is placed in the artificial mouth via motor and rack in the first part, and then, the piston in the second part moves to the new position by creating negative pressure (inhalation process). This new position of the piston can be defined by using the following equation:

$$\Delta V = K\eta\lambda \tag{1}$$

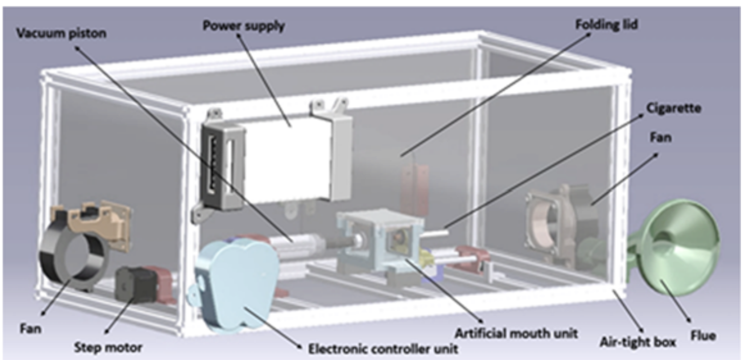
where, ΔV is the inhalation volume of the tobacco smoke, η is the circular tour number, λ is the pitch range of the shaft, and K is the volume transformation coefficient in ml/m.

When the injection piston comes to its new position, the tobacco smoke is propagated in the artificial mouth unit in ΔV volume.

In the next step, the cigarette holder comes to the previous position, and the cigarette is removed from the artificial mouth. After that, to exhaust the cigarette smoke from the artificial mouth unit, the injection piston creates positive pressure and comes to its previous position. Hence, the inhalation/exhalation process is performed. This cycle continues until the cigarette is consumed. Commercially available short-length cigarettes were tested on the simulator. The cigarette length and puff volume were kept constant. The amount of cigarette burned during each puff was measured, and through trial and error, it was determined that the cigarette is completely consumed after 37 cycles. Therefore, when a cigarette is lighted up on the simulator, the simulator operates for 37 cycles for short-length cigarettes before automatically stopping. The presented smoking simulator is placed in an air-tight box, and the remaining smoke is continuously exhausted via two fans and a flue system.



a) Technical drawing of the mechanical system in a 1/5 ratio



b) Details of the equipment

Figure 4. Design of the smoking simulator

3. RESULTS AND DISCUSSION

Discoloration, stain, surface roughness, and surface topography are common adverse effects of cigarette smoke on teeth or dental composite specimens. Unfortunately, many researchers focusing on these topics study with primitive simulators. Traditional smoking simulators generally suffer from three main issues: absence of inhalation/exhalation process of smoking, high/low smoke exposure densities of dental specimens, and incorrect positioning of tooth samples during the experiments. These major unsolved problems of traditional smoking simulators cause insufficient and inaccurate data during the analysis. In this work, the complete process of smoking is modelled and simulated by the presented novel simulator.

The presented simulator is designed to simulate cigarette smoking in a manner that closely mimics real-life conditions, allowing for controlled exposure of dental samples to cigarette smoke. Based on a comprehensive literature review, it was determined that the average human oral cavity volume is 178.75 cm^3, the average puff volume is 43 ml, the average puff duration is 1.8 seconds, and the average number of cigarettes smoked per day is 10. A rectangular prism-shaped artificial mouth unit with dimensions of 6.5 x 5 x 5.5 cm has been designed for the simulator. This artificial mouth unit features a 0.5 cm diameter hole to insert a cigarette. Integrated into the artificial mouth unit is a vacuum system that draws cigarette smoke in and expels it. The planned smoking cycles for testing the presented simulator are as follows: A cigarette is automatically inserted into the artificial mouth unit, and by creating negative pressure, a total of 43 ml of cigarette smoke is drawn in over 1.8 seconds. Following this, a mechanism removes the cigarette from the artificial mouth unit. Next, positive pressure is generated within the artificial mouth unit to expel the smoke at the same rate and volume. These processes complete one cycle. After the first cycle, the cigarette is reinserted into the artificial mouth unit, and the cycles continue until the cigarette is wholly consumed.

In order to test the presented smoking simulator, dental samples mounted on 3D printed jaw model given in Figure 2 are used as a control group. Related samples are exposed smoke of 140 cigarettes (10 cigarettes per day) in 14-day duration. Dental samples exposed to cigarette smoke were brushed twice daily with toothpaste for 2 minutes. As a experiment group, Figure 5 shows the discoloration of samples after testing the system. The presented simulator offers a controlled, reprogrammable and accurate smoking simulation. The photograph of the presented smoking simulator is given in Figure 6.

Figure 5. Dental samples after 140 cigarette smoke exposure

Table 1 provides a detailed comparison between this study's simulator and other advanced models in the literature, highlighting several significant improvements. The presented simulator distinguishes itself by uniquely positioning dental specimens in a natural mouth placement, enabling realistic smoke exposure on samples—a feature absent in prior designs. By replicating the natural orientation of dental samples within a mouth structure, this simulator more accurately mimics actual conditions encountered during smoking, thereby enhancing the validity of the measurements. Furthermore, unlike previous simulators, this device incorporates inhalation and exhalation processes, a critical factor that adds dynamic flow to the simulation, which more closely resembles real-life smoking patterns.

Table 1. Comparison of the presented study with the other state of art studies

Ref.	Natural placement of samples	Simulation environment volume	Inhalation/exhalation processes	Different smoking profiles
[5]	No	<10 ml (high exposure)	No	No
[6]	No	>1500 ml (low exposure)	No	No
[7]	No	>1000 ml (low exposure)	No	No
[8]	No	>750 ml (low exposure)	No	No
Prop. Study	**Yes**	**≈ 70.5 ml (proper exposure)**	**Yes**	**Yes**

A key design feature of the presented simulator is its simulation chamber, which approximates the volume of an adult male mouth (70.5 ml). This carefully controlled environment avoids the high or low smoke exposure levels seen in previous systems, where larger chambers (750–1500 ml) often diluted exposure. By achieving a balanced exposure intensity, this device offers a more consistent simulation that can enhance the reliability of results, particularly when studying material degradation or surface alterations in dental specimens. Additionally, the simulator's adaptability allows it to run three smoking profiles—low, moderate, and high exposure settings—reflecting variations in individual smoking habits. This feature makes it possible to examine the differing impacts of smoking intensity on dental materials and soft tissues, expanding its range of potential applications.

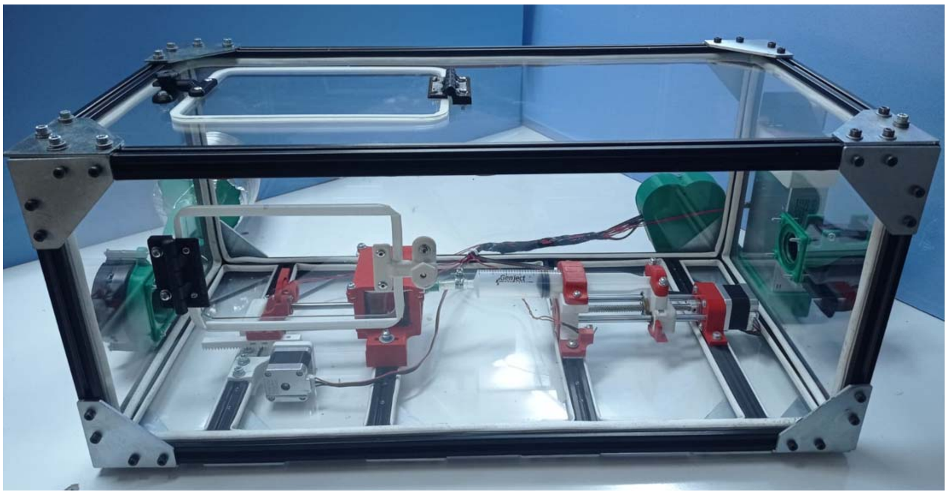


Figure 6. The photograph of the presented smoking simulator

In overcoming these major limitations of earlier devices, the simulator's microcontroller-based control mechanism ensures high flexibility and programmability, making it a versatile and accessible research tool. This low-cost, user-friendly, fully automated platform supports not only whole-cigarette exposure simulations but also an array of experimental needs. Planned future studies include investigating cigarette smoke's impact on osseointegration in intraosseous applications, specifically between bone and dental implants, to better understand how smoke affects implant stability. Additional experiments will assess the effects of cigarette smoke on the color and surface properties of dental application materials, such as restorative resins and composites, providing insight into long-term aesthetic outcomes.

Furthermore, animal studies using the simulator could explore the effects of smoke on soft tissue healing in periodontal applications, yielding valuable information on how smoke exposure influences recovery and tissue regeneration. Beyond its research utility, the simulator is envisioned as an educational tool, capable of demonstrating to patients and dental students the detrimental effects of smoking on teeth and dental materials, thereby promoting greater awareness of smoking's risks.

4. ACKNOWLEDGMENTS

This work is supported by Scientific Research Projects Unit of Çukurova University, in project TDH-2021-14095. The simulator designed and implemented in this study has been patented, named a "Programlanabilir Sigara İçme Simülatörü" (Patent No: TR 2022 018975B), and protected by the Turkish Patent and Trademark Office.

5. REFERENCES

1. Watts, A., Addy, M., 2001. Tooth discolouration and staining: a review of the literature. British Dental Journal, 190(6), 309-316.
2. Hattab, F.N., Qudemiat, M.A., Al-Rimawi, H.S., 2013. Dental discoloration: an overview. Journal of Esthetic and Restorative Dentistry, 11(6), 291-310.
3. Nathoo, S.A., 1997. The chemistry and mechanism of extrinsic and intrinsic discoloration. J. Am. Dent. Assoc., 128, 6-10.
4. Addy, M., Moran, J., 1985. Extrinsic tooth discoloration by metals and chlorhexidine. II. Clinical staining produced by chlorhexidine, iron and tea. British Dental Journal. 159(10), 331-334.
5. Alandia-Roman, C.C., Cruvinel, D.R., Sousa, A.B.S., Pires-de-Souza, F.C.P., Panzeri, P., 2019. Effect of cigarette smoke on color stability and surface roughness of dental composites. Journal of Dentistry, 41(3), 1-5.
6. Patil, S.S., Dhakshaini, M.R., Gujjari, A.K., 2013. Effect of cigarette smoke on acrylic resin teeth. Journal of Clinical and Diagnostic Research, 7(9), 2056-9.
7. Mathias, P., Costa, L., Saravia, L.O., Rossi, T.A., Cavalcanti, A.N., Nogueira-Filho, G.R., 2010. Morphologic texture characterization allied to cigarette smoke increase pigmentation in composite resin restorations. Journal of Esthetic and Restorative Dentistry, 22(4), 252-259.
8. Takeuchi, C.Y.G., Correa-Afonso, A.M., Pedrazzi, H., Dinelli, W., Palma-Dibb, R.G., 2011. Deposition of lead and cadmium released by cigarette smoke in dental structures and resin composite. Microscopy Research and Technique, 74(3), 287-291.
9. Bazzi, J.Z., Bindo, M.J.F., Rached, R.N., Mazur, R.F., Vieira, S., Souza, E.M., 2012. The effect of at-home bleaching and toothbrushing on removal of coffee and cigarette smoke stains and color stability of enamel. Journal of the American Dental Association, 143(5), e1-e7.
10. DeMarini, D.M., Gudi, R., Szkudlinska, A., Rao, M., Recio, L., Kehl, M., Kirby, P.E., Polzin, G., Richter, P., 2008. Genotoxicity of 10 cigarette smoke condensates in four testsystems: comparisons between assays and condensates. Mutation Research/Genetic Toxicology and Environmental Mutagenesis, 650(1), 15-29.
11. Mahross, H.Z., Mohamed, M.D., Hassan, A.M., Baroudi, K., 2015. Effect of cigarette smoke on surface roughness of different denture base materials. Journal of Clinical and Diagnostic Research, 9(9), ZC39-ZC42.
12. Vitoria, L.A., Aguiar, T.R., Santos, P.R.B., Cavalcanti, A.N., Mathias, P., 2013. Changes in water sorption and solubility of dental adhesive systems after cigarette smoke. ISRN Dentistry, 605847, 1-5.
13. Zanetti, F., Zhao, X., Pan, J., Peitsch, M.C., Hoeng, J. Ren, Y., 2019. Effect of cigarette smoke and tobacco heating aerosol on color stability of dental enamel, dentin, and composite resin restorations. Quintessence International, 50(2), 156-166.
14. Kumar, P., Vaid, D., Singh, S., Kumar, J., Kumar, A. Dwari, S., 2021. Design of 3D printed multi-wavelength DRA. IETE Technical Review, 38(6), 662-671.
15. Dawood, A., Marti, B., Sauret-Jackson, V., 2015. 3D printing in dentistry. British Dental Journal, 219(11), 521-529.
16. Mishra, S., 2016. Application of 3D printing in medicine. Indian Heart Journal, 68(1), 108-109.
17. Segaran, N., Saini, G., Mayer, J.L., Naidu, S., Patel, I., Alzubaidi, S., Oklu, R., 2021. Application of 3D printing in preoperative planning. Journal of Clinical Medicine, 10(5), 917.
18. Khare, N., Patil, S.B., Kale, S.M., Sumeet, J., Sonali, I., Sumeet, B., 2012. Normal mouth opening in an adult Indian population. Journal of Maxillofacial and Oral Surgery, 11(3), 309-313.