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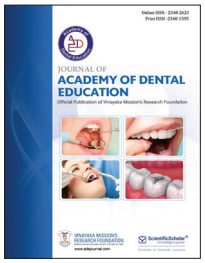

Original Article

An *in vitro* estimation of pH of mainstream smoke from smoked tobacco products using a custom fabricated smoking device – A pilot study

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Received: 04 September 2023
Accepted: 05 October 2024
Published: 22 November 2024

DOI
10.25259/JADE_76_2023

Quick Response Code:

ABSTRACT

Objectives: External factors, namely, nutrition, microorganisms, temperature, and cigarette use, have an impact on the oral pH. This influence is counteracted by saliva, which maintains the pH within the range of 6.2–7.6. One aspect contributing to this balance is tobacco preferences, which are influenced by delivery methods and popularity, ultimately leading to pH alterations. The aim of this study was to determine and compare the pH levels of the mainstream smoke emitted from three smoked tobacco products; beedis, filtered cigarettes, and unfiltered cigarettes.

Material and Methods: The study comprises of three groups of 25 samples each: unfiltered and filtered cigarettes and beedis. A custom-fabricated apparatus was developed to estimate the mainstream smoke pH. The device consists of a disposable plastic container with two holes on top for flexible plastic tubing. One tubing end goes into distilled water while the other attaches to the heated tobacco product (HTP), directing smoke into the water. A 5 mL disposable syringe simulates inhalation, creating negative pressure in the water. The pH of the collected smoke was measured with a digital pH meter. The mainstream smoke was standardized using the international organization for standardization and federal trade commission cigarette filter test method smoking regimens, with one puff per minute, 35 mL volume over 2 s, to a defined butt length.

Results: The study revealed that filtered and unfiltered cigarettes had lower pH levels than beedis, with acidic pH for cigarettes (unfiltered – 6.286, filtered – 6.057) and alkaline pH for beedis (7.253).

Conclusion: According to the study, the pH of mainstream smoke from HTPs deviates from the physiological range of the oral cavity. Continuous exposure of saliva to this smoke not only interacts synergistically with carcinogens in these products but it is also one of the techniques employed by manufacturers for increasing absorption into the bloodstream.

Keywords: Mainstream smoke, Smoke pH, Smoking machine

INTRODUCTION

The oral cavity is exposed to various external factors, including dietary habits, microorganisms, temperature fluctuations, and tobacco among individuals with the habit. Saliva's buffering capacity maintains a neutral pH, counteracting these effects and balances acidity and alkalinity, keeping the pH within a range of 6.2–7.6, with an average of 6.7.[1] Tobacco consumption is increasing and available in diverse forms, determined by stimulating constituents' delivery.[2] Preferences

for specific forms are based on their delivery mode and stimulation rate. These harmful habits, stemming from long-term tobacco use, alter oral cavity pH, rendering the oral mucosa susceptible to various oral and dental diseases.[3]

The study utilized a custom-fabricated device to determine the pH of mainstream smoke from three heated tobacco products (HTPs); filtered and unfiltered cigarettes and beedi.

MATERIAL AND METHODS

The study was approved by the Institutional Ethics Committee, April 27, 2023, Ethical approval number 296 (IEC/Approval No.296). All procedures performed in the study were conducted in accordance with the ethical standards given in the 1964 Declaration of Helsinki, as revised in 2013**.**

Study design

The present study was an *in vitro* study and the sampling method utilized in the study was stratified sampling.

Study setting

The study was conducted in the Department of Oral Pathology and Maxillofacial Pathology and Oral Microbiology.

Study size

The study comprised three groups of 25 samples each: unfiltered and filtered cigarettes, and beedis. For all groups, only one brand of the commercially available filtered cigarette and beedi was utilized. For unfiltered cigarettes, the filter was sliced and the cigarette rod carrying the tobacco was utilized. A custom-fabricated apparatus was developed for estimating the pH of mainstream smoke. The design was a modified version of the device used by Gellner *et al.*[3,4] The device comprised a disposable plastic container with a lid filled with 20 mL of distilled water (immediately after distillation). Two holes were cut on the lid to insert two flexible plastic tubings (one long and one short) that were used to carry the smoke from and away the HTP. One end of the long tubing was placed into the distilled water (below the surface), while the other short tubing was above the surface of the distilled water. The tobacco product was carefully attached to the other end of the long tubing that carried the mainstream smoke into the distilled water. A 5 mL disposable syringe was attached to the free end of the short tubing to simulate an individual's inhaled breath by creating a negative pressure in the distilled water and forcing the mainstream smoke through the water. After collecting mainstream smoke from the cigarette or beedi, the pH was measured with a digital pH meter. The schematic design and the actual apparatus are shown in Figure 1. For standardization of mainstream smoke, the international organization for standardization (ISO) and federal trade commission cigarette filter test (FTC CFT) method smoking regimens recommendation of one puff per minute with a 35 mL volume over 2 s to a defined butt length was followed.[4]

Statistical analysis

After obtaining pH readings from each of the three groups, the data were documented in an Microsoft Excel spreadsheet and statistical analysis was performed using the Statistical Package for the Social Sciences (SPSS) Version 19.0 software (IBM SPSS, US). Two statistical evaluations were done, the Kolmogorov–Smirnov Test, employed to assess normality, and analysis of variance (ANOVA), and utilized to compare the weight and pH variations of the mainstream smoke among the three study groups with $P = 0.05$ level of significance.

RESULTS

The mean pH of mainstream smoke in the three study groups was 6.532, with a standard deviation of 0.621. The pH of unfiltered and filtered cigarette mainstream smoke was 6.286 and 6.057, respectively, while the pH of beedi mainstream smoke was 7.253. Using one-way ANOVA, a statistical difference with $P = 0.001$ was observed between the pH of the mainstream smoke of three study groups, as shown in Table 1 and Figure 2.

The mean weights of the unfiltered and filtered cigarette and beedi were 0.507, 0.665, and 0.321, respectively. The mean

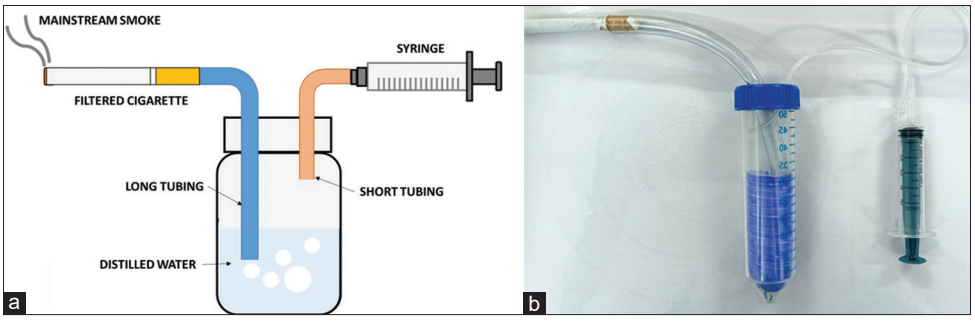

Figure 1: (a) The schematic design and (b) the custom fabricated device.

Table 1: pH of the mainstream smoke of study groups: Unfiltered and filtered cigarette and beedi.

Tobacco product	*n*	Mean	SD	SE	ANOVA	*P*
pH of the mainstream smoke						
Unfiltered cigarettes	25	6.286	0.082	0.016	86.61	0.001*
Filtered cigarette	25	6.057	0.506	0.101		
Beedi	25	7.253	0.293	0.059		
Total	75	6.532	0.621	0.072		

n: Number of samples, SD: Standard deviation, SE: Standard error, *P*: *P* value, *Significant at 5%, *Highly significant at 1%, ANOVA: Analysis of variance

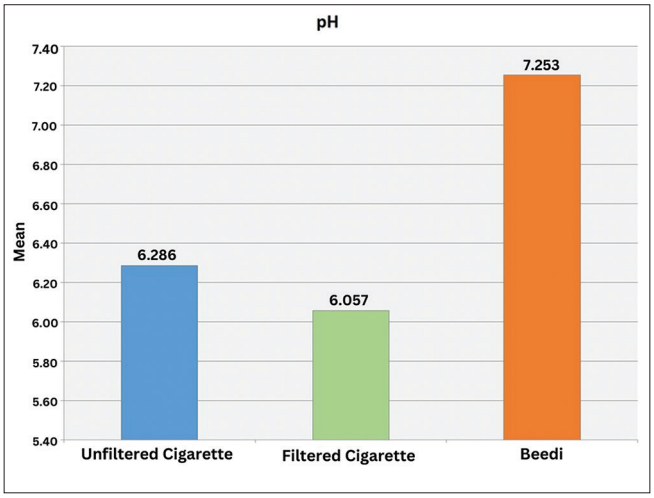

Figure 2: Graphical representation of pH of the mainstream smoke of study groups: Unfiltered and filtered cigarette and beedi.

weights of the remaining unfiltered and filtered cigarette and beedi were 0.309, 0.272, and 0.069. The mean weights of the ash from the filtered, unfiltered cigarette and beedi after collecting the mainstream were 0.073, 0.048 and 0.037, respectively. A high statistical difference with $P < 0.001$ was observed between the weights of tobacco products before and after being lit. A statistical difference was also observed between the ash of tobacco products with $P = 0.031$, as shown in Table 2.

DISCUSSION

Tobacco products are detrimental recreational consumables that have gained appeal despite their adverse impact on the human body. These products are commercially available in a variety of forms and designs, each evolved to individual preferences. Notably, a recent modification to this form is the HTP, a derivative of the smoked format that is assumed to have a lower negative impact on the lungs and related organs. Regardless of design, the composition of these tobacco products remains generally same, differing primarily in the method of delivery that allows customers to get maximal stimulation. One of these factors by which the delivery and absorption of the toxic ingredients is facilitated is by altering the pH of the tobacco products.[4-6]

Saliva is the first biological fluid to be exposed to mainstream smoke from HTPs, and it is the fluid that not only maintains the oral cavity's neutral pH but also buffers the acidic and alkaline substances to which the oral cavity is exposed. Any significant changes in the pH of the oral cavity can result in a variety of diseases affecting the hard and soft tissues of the oral cavity. Therefore, the present study considers distilled water with a neutral pH of 7 to accurately estimate the tobacco product's pH.

Several research studies have assessed smokers' saliva pH. When a cigarette is lit, it releases two primary types of smoke: "Side stream smoke" from the combustion end and "mainstream smoke" from the end of an individual's inhale. Some studies have estimated the pH of smoked tobacco products using "smoking machines" that replicate smoking behavior. The advantage of such studies is that they eliminate the need for contaminated saliva or other habits that can alter pH, allowing for standardized assessments.[3,5] The present study adopted a custom-fabricated apparatus to determine the pH of mainstream smoke from three commercially utilized tobacco products; unfiltered and filtered tobacco products and beedi. The design of the device was a modified version of the device used by Gellner *et al.* with a basic principle of a smoking machine.[3,4] Among the various standardizations available to collect mainstream smoke, the ISO and FTC CFT method smoking regimens recommendation was used.[7,8]

The pH levels of mainstream smoke from unfiltered and filtered cigarettes exhibited acidity, while the smoke from beedis had an alkaline pH. In comparison to unfiltered cigarettes, the mainstream smoke of filtered cigarettes demonstrated a higher level of acidity. These findings suggest that the inclusion of a filter led to elevated acidity levels. As a result, filtered cigarettes displayed an acidic nature, while both unfiltered cigarettes and beedis retained their alkaline pH. These results imply that by utilizing of filter limits the passage of specific tobacco constituents yet concurrently contributing to the heightened acidity in the inhaled mainstream smoke.[9-11] The higher acidity in the mainstream smoke of filtered cigarettes, compared to unfiltered cigarettes, can be attributed to the filter's ability to trap basic compounds, leaving acidic substances in greater

Table 2: Weights of the tobacco product (before and after lighting) and ash of study groups.

Weights	Tobacco product	N	Mean	SD	SE	ANOVA	*P*
Weight of the tobacco product (grams)	Unfiltered cigarettes	25	0.507	0.095	0.019	60.93	0.001**
	Filtered cigarettes	25	0.665	0.149	0.030		
	Beedi	25	0.321	0.071	0.014		
	Total	75	0.498	0.178	0.021		
Weight of the remaining tobacco product (grams)	Unfiltered cigarettes	25	0.309	0.114	0.023	26.82	0.001**
	Filtered cigarettes	25	0.272	0.181	0.036		
	Beedi	25	0.069	0.029	0.006		
	Total	75	0.217	0.162	0.019		
Weight of the ash (grams)	Unfiltered cigarettes	25	0.073	0.079	0.016	3.65	0.031*
	Filtered cigarettes	25	0.048	0.020	0.004		
	Beedi	25	0.037	0.015	0.003		
	Total	75	0.053	0.050	0.006		

N: Number of samples, SD: Standard deviation, SE: Standard error, ANOVA: Analysis of variance, *P*: *P* value, *Significant at 5%; **Highly significant at 1%

concentration. This was due to its presence in the mainstream smoke inhaled by the consumer. This change in smoke composition lowers the pH of saliva, creating an acidic oral environment conducive to the activation of tobacco-specific carcinogens, such as nitrosamines, which are more harmful in acidic conditions. The acidic environment also impairs the protective function of salivary enzymes, which would otherwise neutralize harmful substances. Consequently, the use of filters, while reducing certain harmful constituents, contributes to conditions that promote carcinogenesis by enhancing the activation of carcinogens and weakening natural defenses.[12,13]

Another notable aspect involved the measurement of tobacco product weights both before and after ignition, as well as the weight of the resulting ash post-ignition. Research on dimensions of smoked tobacco products has shown no statistical significance in the exposure of constituents. Interestingly, the presence of filters led to an increase in the cigarette's weight, simultaneously causing a reduction in the length of the tobacco portion after ignition. This suggests that the act of inhaling the smoke would likely lead to a more substantial consumption of the tobacco product. In contrast, an unobstructed inflow of inhaled air allowed for relatively lower consumption per breath when compared to filtered cigarettes.[14,15] Similar trends were evident in the case of beedis. The absence of a filtering mechanism allows more air to flow through the beedi while smoking, causing it to burn more quickly and resulting in a shorter beedi length. This unrestricted airflow can increase the rate at which the beedi is consumed, comparable to the manner by which filters in cigarettes influence smoking dynamics by affecting burn rate and consumption patterns. The same findings can be applied to the weights of the ash collected before and after being lit. The findings of the present study indicate that the filter of cigarette had not only reduced the pH of the mainstream smoke but also causes increased consumption of the cigarette, thus annulling the purpose of the filter mechanism. Research findings suggest that the presence of filters in smoking products can lead to a deceptive sense of reduced health risk among smokers. These studies indicate that smokers might perceive filtered cigarettes as being safer or less harmful due to the perception that the filter is effectively removing or reducing the harmful components of the smoke. However, this perception can be misleading, as filters may not significantly alter the overall health risks associated with smoking. As a result, individuals who use filtered cigarettes could potentially underestimate the potential health consequences of their smoking habit. In addition, another observation is that employing filters could lead to an escalation in the number of cigarettes consumed by each individual, which serves as a method utilized by manufacturers to drive sales growth.[16,17]

Limitation

The limitations of the present study include the reduced sample size and consideration of only pH in mainstream smoke, which is just one of the many factors that can influence the health effects of smoking.

CONCLUSION

The pH values of HTP mainstream smoke deviate from the normal pH range of the oral cavity, according to the research findings. Extended exposure with this smoke not only associates with the carcinogens in these products but it is also a strategy utilized by manufacturers to enhance bloodstream absorption. Another significant finding is that leveraging filters may contribute to an increase in the number of cigarettes smoked per person, which manufacturers employ in favor of sales growth.

Ethical approval

The research/study approved by the Institutional Ethics Committee at Vinayaka Mission's Sankarachariyar Dental College, number IEC/Approval No.296, dated 27th April, 2023.

Declaration of patient consent

Patient's consent not required as there are no patients in this study.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

Use of artificial intelligence (AI)-assisted technology for manuscript preparation

The authors confirm that there was no use of artificial intelligence (AI)-assisted technology for assisting in the writing or editing of the manuscript and no images were manipulated using AI.

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How to cite this article: Keerthana S, Jacob M, Sowndarya S, Fenn SM, Aswin BA. An *in vitro* estimation of pH of mainstream smoke from smoked tobacco products using a custom fabricated smoking device – A pilot study. J Academy Dent Educ. 2024;10:81-5. doi: 10.25259/JADE_76_2023