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Comparison of exhaled carbon monoxide levels and its association with nicotine dependence between electronic and tobacco cigarettes: A cross-sectional study among teenage smokers

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Abstract

Carbon monoxide (CO), resulting from incomplete combustion such as tobacco smoking, serves as an indicator of nicotine addiction. The aim of this study was to compare the levels of exhaled CO levels between electronic cigarette (e-cigarette) and tobacco smokers and to determine the association between nicotine dependence and exhaled CO levels in e-cigarette and tobacco smokers. A cross-sectional study was conducted using purposive sampling on active smokers, with 70 smokers in each group. The nicotine dependence was measured using the Penn State Nicotine Dependence Index (PSNDI) questionnaire for the e-cigarette group and the Fagerstrom questionnaire for the tobacco smoking group. The CO level was measured using the smokerlyzer piCO. To compare the mean exhaled CO levels between e-cigarettes and tobacco smoker groups, the Mann-Whitney test was used. The Mann-Whitney test and Kruskal-Wallis test were used to assess the associations between nicotine dependence and mean exhaled CO levels in the e-cigarette smoker group and in the tobacco smoker group, respectively. The majority of e-cigarette smokers were 17 years old (65.7%) and male (75.7%). Among tobacco smokers, the majority were also 17 years old (44.3%), and mostly male (91.4%). The mean exhaled CO levels in the tobacco smoker group were significantly higher than the e-cigarette smoker group, 6.86 ppm vs 1.61 ppm with $p<0.001$. There was a significant association between nicotine dependence and exhaled CO levels among tobacco smokers ($p<0.001$). Nicotine dependence was not associated with exhaled CO levels among e-cigarette smokers. This study highlights that the smokerlyzer piCO devise could be used to screen nicotine addiction in tobacco smokers.

Keywords: E-cigarette, tobacco, vape, carbon monoxide, piCO

Introduction

The Indonesian Basic Health Research (RISKESDAS) reported that tobacco smoking started at the young age of 10 in 2018 [1]. Between 2019 and 2020, there was a rise in the percentage of smokers aged 15 to 19 (from 10.54% to 10.61%) [2]. According to data from the Global Adult Tobacco Survey (GATS) in 2021, 34.5% of adults smoked electronic cigarettes (e-cigarettes), with a rising trend in women [2]. The use of e-cigarettes has also increased tenfold from 0.3% in 2011

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to 3% in 2021 [2]. A study found that the liquid of five distinct types of electronic cigarettes included many elements, including lead, nickel, manganese, and chromium [3]. Exposure to metal-laden fumes, similar to those encountered by welders, can lead to short-term systemic toxicity (metal fume fever) [4]. In other instances, it has been shown to increase the frequency of respiratory infections and also raise the risk of lung cancer [4].

Carbon monoxide (CO) is a hazardous gas due to its higher affinity to hemoglobin compared to carbon dioxide and oxygen and therefore disrupting respiratory function, in particular diffusion [5]. This gas is predominantly produced by incomplete combustion, particularly from tobacco smoke [6]. CO circulating in the blood will return to the alveoli due to the concentration gradient, and eventually, CO will be released through the expiratory pathway. This can be measured using portable CO measurement devices such as the smokerlyzer piCO [7]. Exhaled CO levels gradually rise when using electronic cigarettes, according to a study involving a 12-hour smoking cessation followed by their use [8]. However, another study indicated that exhaled CO levels will slowly decrease if one refrains from active smoking [9].

Smokers with high nicotine dependence tend to smoke more frequently, leading to the accumulation of gases due to limitations in their elimination caused by a higher CO gradient [9]. This forms the basis for objectively assessing smoking dependence through CO levels, in addition to established questionnaires in smoking cessation [7]. Exhaled CO has become a common test for patients diagnosed with chronic obstructive pulmonary disease (COPD) or smokers who have symptoms but still smoking [7]. It serves as an accurate and objective assessment of nicotine addiction, with varying sensitivity for different labels, but can reach a sensitivity of 56–88% and specificity of 91–100% in all different labels to determine the level of nicotine addiction in tobacco smokers [10]. The aim of this study was to compare the exhaled CO levels between e-cigarettes and tobacco smokers and to determine the association between the exhaled CO levels and nicotine dependence in e-cigarette and tobacco smokers.

Methods

Study design and participants

A cross-sectional study design was conducted among adolescents from a senior high school in Medan, Indonesia, to compare the exhaled CO levels between e-cigarette and tobacco smokers, and to analyze the correlation between exhaled CO levels and nicotine dependence. Data was collected from January to February 2023. Samples were active smoker students of both e-cigarettes and tobacco cigarettes. Regular e-cigarette smokers were participants who used e-cigarettes exclusively on a daily basis for ≥1 month, with or without a history of conventional smoking. Regular tobacco smokers were students who had smoked at least 100 cigarettes in a lifetime and continued to smoke until the examination during the study. Students with acute or chronic respiratory diseases (e.g., chronic bronchitis, emphysema, bronchiectasis, asthma, and cystic fibrosis) and engaging in vigorous physical activity for forty minutes per day and five days per week, were excluded from the study. The students were categorized into two main groups: e-cigarette smokers and tobacco smokers. The sample size was determined using the Lemeshow formula and the minimum sample size was 63 students for each group.

Study variables and data collection

Nicotine dependence as the independent variable in this study was measured using questionnaires, the Penn State Nicotine Dependence Index (PSNDI) was employed for the e-cigarette group and the Fagerstrom questionnaire was for the tobacco smoking group. While the dependent variable in this study, CO levels was measured using the smokerlyzer piCO. Other co-variables were age, gender, history of tobacco smoking, duration of using electronic cigarettes, model of electronic cigarettes and type of smoker (e-cigarettes and tobacco cigarettes).

Examination of exhaled CO levels

The exhaled CO levels of the participants were measured using the smokerlyzer piCO following the manufacturer's guidelines (Bedfont Technical Instruments Ltd., Harrietsham, England). The smokerlyzer piCO was created in 1976 by John Marron in England and Wales (**Table 1**) [11]. To use the smokerlyzer piCO, the respondents inhaled and then exhaled slowly into the device for 15 seconds and the CO level was measured.

Table 1. Pre-set breath testing thresholds for the smokerlyzer piCO

Traffic light color	Description	Reading (ppm)
Green	Non-smoker	0–6
Amber	Borderline	7–9
1 Red	Smoker-low addicted	10–15
2 Red	Smoker-moderately addicted	16–25
3 Red	Smoker-heavily addicted	26–35
3 Red flashing	Smoker-very heavy addicted	>36

Nicotine dependence assessment

The PSNDI questionnaire was used to measure the nicotine dependence categories of e-cigarette smokers. The PSNDI questionnaire consisted of ten questions with weighted values for each question. The sum of the values provided the nicotine dependence categories: no dependency (0–3), low dependency (4–8), and moderate to high dependency (≥9) [12].

The Fagerstrom questionnaire was used to assess nicotine dependence levels among tobacco smokers. This questionnaire contained six questions with weighted values for each question. The level of nicotine dependence was determined by adding the values and is interpreted into low dependency (0–3) and moderate to high dependency (4–10) [13].

Statistical analysis

Mann-Whitney test was used to compare the mean exhaled CO levels between e-cigarette and tobacco smoker groups. Mann-Whitney test was used to assess the association between nicotine dependence and mean exhaled CO levels in the tobacco smoker group. To determine the association between nicotine dependence and mean exhaled CO levels in the e-cigarette smoker group, the Kruskal-Wallis test was used. The data were analyzed using the SPSS Statistics version 21 (IBM Inc., Chicago, USA).

Results

Characteristics of participants

A total of 140 participants were included in the study, the two groups of tobacco smokers and e-cigarette smokers had 70 students each. As seen in **Table 2**, the majority of tobacco smokers were 17 years old (44.3%), and among all of the tobacco smokers, more than 90% were males. Based on the Fagerstrom questionnaire, a greater proportion was seen in the mild category for nicotine dependence.

Table 2. Characteristics of tobacco smokers (n=70)

Characteristics	Frequency (%)
Age (years)	
14	5 (7.1)
15	7 (10.0)
16	20 (28.6)
17	31 (44.3)
18	2 (2.9)
19	5 (7.1)
Gender	
Female	6 (8.6)
Male	64 (91.4)
Nicotine dependence levels based on Fagerstrom	
Mild	51 (72.9)
Moderate	19 (27.1)

Out of all e-cigarette smokers, it was observed that the majority were also 17 years old (65.7%). There was a larger percentage of female e-cigarette smokers when compared to tobacco smokers. It can be seen that 78.6% of e-cigarette smokers had no prior history of tobacco smoking. Over 50% of e-cigarette smokers had been smoking for 6–12 months. The third and fourth generation were the most commonly used e-cigarette models. Based on the PSNDI score, 34 e-cigarette smokers had no nicotine dependence, followed by 31 e-cigarette smokers had mild nicotine dependence (**Table 3**).

Table 3. Characteristics of e-cigarette smokers (n=70)

Characteristics	Frequency (%)
Age (years)	
15	3 (4.3)
16	21 (30.0)
17	46 (65.7)
Gender	
Female	17 (24.3)
Male	53 (75.7)
Tobacco cigarette history	
Never	55 (78.6)
<12 months	10 (14.3)
12–24 months	5 (7.1)
Duration of using electronic cigarettes	
<6 months	22 (31.4)
6–12 months	38 (54.3)
13–18 months	6 (8.6)
19–24 months	4 (5.7)
Model of electronic cigarettes	
Standard refillable tank vapes	27 (38.6)
Advanced refillable generation	43 (61.4)
Penn state nicotine dependence index (PSNDI)	
No dependence	34 (48.6)
Mild dependence	31 (44.3)
Moderate to high dependence	5 (7.1)

Exhaled CO levels between e-cigarette and tobacco smokers

The average exhaled CO levels was seen higher in tobacco smokers compared to e-cigarette smokers. To compare the exhaled CO levels between e-cigarettes and tobacco smokers, the Mann-Whitney test was used because the data were not normally distributed. The mean exhaled CO levels was higher in tobacco smokers than in e-cigarette smokers with 6.86 ppm and 1.61 ppm, respectively. Our data indicated a significant difference between exhaled CO levels among the e-cigarette and tobacco smokers with a $p<0.001$ (**Table 4**).

Table 4. Comparison of exhaled CO levels between e-cigarettes and tobacco smokers

Group	n	Mean CO level (CI 95%), ppm	Standard deviation	*p*-value
E-cigarette smoker	70	1.61 (1.44–1.79)	0.748	<0.001
Tobacco smoker	70	6.86 (6.62–7.09)	0.997	

Association between nicotine dependence and exhaled CO levels

To assess the association between nicotine dependence and exhaled CO levels, the Kruskal-Wallis test was used for the PSNDI score data (e-cigarette group) and the Mann-Whitney test was used for Fagerstrom score data (tobacco smoker group) due to both data were not normally distributed. There was a significant association between tobacco smoker's nicotine dependence and their exhaled CO levels ($p<0.001$) (**Table 5**).

Table 5. Association between nicotine dependence and exhaled CO levels in e-cigarette and tobacco smokers

Nicotine dependence	Mean CO level (CI 95%), ppm	Standard deviation	*p*-value
Penn state nicotine dependence index (PSNDI) (n=70)			0.949
No dependence	1.59 (1.33–1.85)	0.743	
Mild dependence	1.65 (1.37–1.92)	0.755	
Moderate to high dependence	1.60 (0.49–2.71)	0.894	
Nicotine dependence levels based on Fagerstrom (n=70)			<0.001
Mild	6.61 (6.34–6.88)	0.961	
Moderate	7.53 (7.15–7.90)	0.772	

Discussion

Both e-cigarette and tobacco smoking age majority were 17 years old, as reported in this study. Aligning these findings were also seen in the data from RISKESDAS that there has been an increased number of smokers between the age of 15–19 [1]. Some studies reported similar trends in e-cigarette smokers, with a growth in numbers among adolescents (15–24 years old). Teenagers use e-cigarettes more frequently for a variety of reasons, such as their unique form, assortment of flavors, and convenience, often without considering the side effects of e-cigarettes [4,14]. Data from the Global Youth Tobacco Survey (GYTS) in 2019 reported that the first age of smoking initiation was between 13 and 15 years, accounting for 19.2% of tobacco and 18.8% of e-cigarettes [15].

Studies have shown high CO production, especially during cigarette combustion, with a positive correlation between the number of cigarettes smoked and the increase in exhaled CO levels [16,17]. In the human body, CO is endogenously produced as a by-product of metabolism. Excessive levels of CO exposure can result in toxicity, resulting in reduced oxygen transport by hemoglobin (Hb) and potentially causing hypoxic encephalopathy, which causes lipid peroxidation and free radical formation. A CO-Hb level of 16% can lead to symptoms due to reduced oxygen availability to tissues [16,18].

A study conducted in Greece on e-cigarette smokers found that e-cigarettes had a limited role in increasing CO levels due to indirect combustion within the device [19]. In this e-cigarette generation IV without tanks, commonly known as mods, are more preferred due to the practicality and the absence of dust caused by combustion [4]. This could be attributed to the atomization model used, which produced lower CO levels compared to tobacco cigarettes. This process also allows for the occurrence of Electronic Nicotine Delivery Systems (ENDS), which enable nicotine to enter the body directly without the need for combustion [4,19,20]. Our study reported that the most commonly used e-cigarette models among participants were generation III and IV. These generations essentially use atomization systems for combustion and nicotine delivery [4]. However, e-cigarettes with ENDS deliver a substantial amount of nicotine in the aerosol form, which is inhaled into the lungs and enters the bloodstream, ultimately reaching cholinergic receptors in the brain. Dopamine is released as a result, elevating mood, reducing stress and anxiety, and increasing enthusiasm. These effects form the basis of nicotine addiction [21,22].

Tobacco cigarettes, on account of incomplete combustion and direct contact with the lungs, deposit smoke particles, including nitrous oxide (NO) and CO, which form the basis for CO measurement as a monitor and consideration for tobacco dependence [14,19]. Smokers with high nicotine dependence tend to smoke more frequently, leading to the accumulation of gases due to limitations in their elimination caused by a higher CO gradient [9]. This forms the basis for objectively assessing smoking dependence through CO levels, in addition to questionnaires on smoking cessation [7]. Exhaled CO has become a common test for patients diagnosed with COPD or smokers displaying symptoms but still smoking. It serves as an accurate and objective assessment, with varying sensitivity for different devices, but can reach sensitivities of 56–88% and specificities of 91–100% in determining the level of nicotine addiction in tobacco smokers. [10,11].

This study found the mean exhaled CO levels were significantly higher in tobacco smokers ($p<0.001$) than in e-cigarette smokers. In e-cigarettes, apart from using ENDS, atomizers play a crucial role in achieving more complete combustion than tobacco cigarettes. This leads to a reduction in toxic substances, including CO, in the aerosol generated by e-cigarettes [20,23].

A statistically significant association between nicotine dependence of tobacco smokers and the increase of CO levels. This contrast, nicotine dependence in e-cigarette smokers had no significant association with the level of CO. This suggests that the smokerlyzer piCO device was unable to accurately assess nicotine dependence e-cigarette smokers. An explanation would be that e-cigarette uses ENDS with no combustion, and therefore, the CO measured by the smokerlyzer did not reflect specific dependence on e-cigarettes. Unlike tobacco cigarettes, still involving combustion, results in measurable CO levels and serves as a reference for nicotine addiction. A study examined daily e-cigarette smokers and found that the average CO levels were 3 ppm, ranging from a minimum of 1 ppm to a maximum of 22 ppm [24]. Interestingly, these smokers had a history of tobacco smoking, and the study found a significant increase in urinary nicotine levels [24].

There were some limitations in this study that could bias the research results. The study did not measure the body weight of the smokers which could affect the work of respiration, and the particular generation of the e-cigarette device (model of electronic cigarette) was not specified in this study which might have effects on the results. In addition, smokers with a previous history of tobacco smoking were still included in this study.

Conclusion

There was an increase in CO levels measured by the piCO device that corresponds with the Fagerstrom questionnaire on nicotine dependence statistically, depicting an elevation in CO levels in tobacco smokers. This allows for an assessment of the extent of nicotine dependence in tobacco smokers. Conversely, in the statistical analysis of electronic smokers, it was observed that the increase in CO levels was less significant compared to tobacco smokers. Additionally, a noteworthy finding was that the increase in CO levels is more pronounced in tobacco smokers compared to e-cigarette smokers.

Ethics approval

This research was approved by the Health Research Ethics Committee of Sumatera Utara University prior to conducting the study (No: 1266/KEPK/USU/2022).

Competing interests

The authors declare that there is no conflict of interest.

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Underlying data

Derived data supporting the findings of this study are available from the first author on request.

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