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Evaluation of functional aerobic exercise capacity among chronic e-cigarette users compared to combustible cigarette smokers and non-smokers: a comparative study

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Abstract

Background Electronic cigarettes or e-cigarettes have gained significant popularity as an alternative to traditional combustible tobacco smoking particularly among the youth. Although there is a growing prevalence of e-cigarette usage, the effects on cardiovascular function and physical capacity have not been adequately studied. The toxic products in combustible tobacco cigarettes negatively impact functional exercise capacity. However, the available data regarding the effect of e-cigarette use on functional exercise capacity are scarce. Thus, in the current study, we aimed to evaluate the functional aerobic exercise capacity among chronic e-cigarette users compared to combustible cigarette smokers and non-smokers.

Results This comparative, cross-sectional study was conducted on 105 healthy volunteers. Participants were assigned into three study groups each consisting of 35 participants: chronic e-cigarette users, combustible cigarette smokers, and a non-smoker control group. Basal demographic and clinical data were similar in all groups. Mean heart rates and respiratory rates were significantly higher among e-cigarette smokers and combustible cigarette smokers compared to non-smoker controls ($p < 0.001$). Chronic e-cigarette users and combustible cigarette smokers had shorter 6-MWT distances compared to non-smokers (508.3, 488, and 616.6 m, respectively, $p < 0.001$). Borg scale scores after performing the six-minute walking test were significantly higher in chronic e-cigarette users and combustible cigarette smokers groups compared to non-smokers, where perceived exertion (4.9, 5.5, 2.1, respectively, $p < 0.001$), dyspnea (5.7, 6.5, 0.1, respectively, $p < 0.001$) and leg fatigue (4.2, 5.4, 1.4, respectively, $p < 0.001$).

Conclusion In this cross-sectional study, significant evidence demonstrates that e-cigarette use is not harmless. This was particularly presented in apparently healthy e-cigarette users in comparison to the healthy non-smoker control group. Chronic e-cigarette use is associated with reduced functional capacity compared to non-smoker controls. This was signified by decreased 6MWT walking distances, higher Borg scale scores, and lower oxygen saturation percentages among the chronic electronic cigarette users as compared to non-smoker controls after performing the six-minute walking test. All the evaluated parameters in the current study were similarly reduced among both the e-cigarette users group and the combustible cigarette smokers group compared to non-smokers with no statistically significant differences between both smoker groups.

Keywords Electronic cigarettes, Vaping, Combustible cigarettes, Submaximal aerobic exercise capacity, Tobacco, Nicotine, Six-minute walk test

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Background

Electronic cigarettes or e-cigarettes have gained significant popularity as an alternative to traditional combustible tobacco cigarette smoking. E-cigarettes are marketed as a safer alternative to conventional smoking forms. Many chronic smokers suppose that e-cigarettes are risk-free and can be used effectively as a smoking cessation tool. The market size of e-cigarette is increasing because of its rising popularity among the youth even though it is not an approved Food and Drug Administration (FDA) product yet [1]. Moreover, the clinical impact of e-cigarette use on various health aspects, including cardiovascular health and functional exercise capacity is not fully studied yet [2, 3].

Most daily life activities as walking and household chores that affect quality of life are performed at a submaximal aerobic level of exertion. Functional capacity refers to the ability of an individual to sustain prolonged submaximal aerobic exercise without experiencing undue fatigue or breathlessness. It is an essential marker of overall physical fitness and cardiovascular health. It evaluates the global and combined responses of all body systems interacting during exercise, including cardiovascular and pulmonary function, systemic circulation, peripheral circulation, blood, neuromuscular units, muscle metabolism and oxygen transport, and utilization within skeletal muscles [4, 5].

Although the negative impact of traditional smoking on aerobic exercise capacity is obviously recognized, few studies have focused on understanding the negative health effects of electronic cigarette use, particularly on functional capacity and exercise tolerance. The knowledge gap regarding the potential negative health effects of e-cigarettes is crucial, as e-cigarettes are newly prevailing smoking tools that are gaining rising popularity among the youth. Additionally, the false perception of the unregulated electronic cigarette smoking as a safe recreational habit may increase the prevalence among the population [6, 7].

The current study aimed to evaluate the functional aerobic exercise capacity among chronic e-cigarette users compared to combustible cigarette smokers and non-smokers, providing valuable insights into the potential risks of e-cigarette smoking as a novel risk factor for cardiovascular morbidity and mortality.

The functional capacity will be assessed among apparently healthy e-cigarette users by measuring the six-minute walking test (6MWT) distances, Borg scale scores regarding perceived exertion, dyspnea and fatigue, and oxygen saturation percentage and by comparing these parameters among e-cigarette users to combustible cigarette users and non-smokers. Through achieving the previously mentioned objectives, functional capacity evaluation among e-cigarette users was accomplished [8].

Methods

The present study was conducted between January 2020 and January 2021. The participants were apparently healthy volunteers who were gathered through a convenient sample and snowball technique. Helsinki's declaration was fulfilled throughout the study, the purpose and procedure of the study were explained to all participants, and the research protocol was approved by the institutional research ethics committee. All participants signed a written informed consent.

Both males and non-pregnant females, who exclusively smoke either e-cigarettes or combustible cigarettes. Participants were allocated into three groups, namely Group 1, chronic e-cigarette users; Group 2, chronic combustible cigarette smokers; and Group 3, a healthy non-smoker control group who never smoked before, each group included 35 participants.

Participants were excluded in case of dual smoking or having co-morbid substance abuse disorder or any psychiatric illness during the previous 6 months. Somatic exclusion criteria included evidence of significant cardiovascular disease, obstructive or restrictive lung disease, renal disorders, endocrine disorders, and neuromuscular diseases.

The following data were collected from all eligible participants, demographic data including age, gender, working status, and educational level; smoking history including type of smoking and daily smoking frequency; and clinical data including vital signs and anthropometric measurements. Anthropometric measurements included body weight and height in order to calculate the body mass index. Body weight was measured using a SECA beam balance scale, and height was measured using a wall-mounted stadiometer. The BMI was calculated by dividing the weight in kilograms by the squared height in meters.

Body temperature using a digital non-touch thermometer (Medisana© Co.), resting respiratory rate, was measured clinically. Systolic blood pressure (SBP), diastolic blood pressure (DBP), and heart rate (HR) were non-invasively measured at rest before starting the 6 MWT test manoeuvers.

The 6MWT was completed as per the American Thoracic Society guidelines [4, 9]. The participants were instructed to walk on flat ground around two-colored cones 30 m apart according to the standardized protocol. The participants were instructed to walk at a quick steady pace back and forward around the cones for 6 min, without running or jogging. Rest was allowed if required, but walking was to be continued as soon as the participants

were able. The procedure required that the test will be completed in strictly 6 min.

The total walked distance in 6 min and all relevant clinical data were measured by the same study investigator who was blinded to the group of participants. Parameters recorded at the end of the 6-MWT included 6 MWT distance in meters; perceived exertion, dyspnea, and leg fatigue were measured via Borg scale (on a scale from 0 to 10); and oxyhemoglobin saturation (SpO_2) % was measured using Beurer GmbH SöflingerStraße© Co., Ltd., pulse oximeter (PO 40), Germany.

Data were analyzed in SPSS (Statistical Package for Social Science), version 22.0. The Kolmogorov–Smirnov tests were applied to assess the normality of the continuous variables, and data were found to be normally distributed. Quantitative data were expressed by mean and standard deviation (S.D.). Qualitative variables were presented as frequencies and percentages. Chi-square test and Fisher's exact test were used to determine the relationship between the smoking status and the 6MWT parameters among the three study groups, and Student's *T* test was used to compare the means of smoking duration and frequency between chronic e-cigarettes and combustible cigarette smoker groups. The one-way analysis of variance (ANOVA) test was used to determine any significant differences between the means of the continuous variables (e.g., heart rate, blood pressure, and walking distance) among the three groups, and post hoc test (LSD) was done to identify exactly which groups significantly differ from each other. The rank-based nonparametric Kruskal–Wallis *H* test, also called the "one-way ANOVA on ranks," was performed to see if there were statistically significant differences in the Borg scale scores (dyspnea, rate of perceived effort, and leg tiredness) among the three groups. The significance level for all statistical tests was set at 0.05.

Results

This comparative study was conducted on 105 volunteers with age ranges from 19 to 57 years old, mean = 31.16 ± 10.65 years with male gender predominance (55.2%).

There was no significant difference between the three study groups regarding demographic data and smoking history (P value > 0.05) (Tables 1 and 2).

Table 3 compares the recorded vital signs in chronic e-cigarette users, combustible cigarette smokers, and non-smokers.

A statistically significant higher heart rate (71.7, 73.4, 64.2 bpm, respectively), respiratory rates (15.27, 16.23, 13.9, respectively), and BMI (23.57, 22.6, 25.02, respectively) was shown similarly in both smoker groups compared to non-smoker control group ($P < 0.001$).

On comparing means of systolic and diastolic blood pressure and body temperature, no statistically significant

Table 1 Socio-demographic characteristics of the three study groups ($N = 105$)

Variable	Group (1) ($n = 35$)	Group (2) ($n = 35$)	Group (3) ($n = 35$)	*p* value
Age (years) (mean ± SD)	28.97 ± 7.1	30.83 ± 1.56	23.69 ± 1.04	0.2*
Gender				
Male	20 (57.1%)	19 (54.2%)	19 (54.2%)	0.962 χ^2
Female	15 (42.9%)	16 (45.7%)	16 (45.7%)	
Residence area				
Urban	23 (65.7%)	22 (62.8%)	21 (60%)	0.885 χ^2
Rural	12 (34.3%)	13 (37.2%)	14 (40%)	
Marital status				
Single	19 (54.3%)	20 (57.1%)	25 (71.4%)	0.655 χ^2
Married	16 (45.7%)	15 (42.9%)	10 (28.6%)	
Educational level				
Secondary (students)	12 (34.2%)	8 (22.8%)	12 (34.2%)	0.422 χ^2
Technical institutes	1 (2.8%)	0 (0%)	2 (5.7%)	
High education (university graduates)	22 (62.8%)	27 (77.1%)	21 (60%)	
Working status				
Unemployed (students)	19 (54.3%)	5 (14.3%)	17 (48.6%)	0.085 χ^2
Part-time	4 (11.43%)	7 (20%)	7 (20%)	
Full-time	12 (34.3%)	23 (65.7%)	11 (31.4%)	

Group 1: electronic cigarette smokers, Group 2: combustible cigarette smokers, Group 3: non-smokers control group, *One-way ANOVA, χ^2 chi-square test

Table 2 Smoking history among electronic cigarette users and combustible cigarette smokers ($N=70$)

Variable	Group (1) ($n=35$)	Group (2) ($n=35$)	*p* value
Smoking duration (years) (mean ± SD)	2.17 ± 0.7	3.74 ± 1.46	**< 0.0001*** [t]
Smoking frequency (cigarettes or puffs per day)	14.7 ± 4.84	15.1 ± 4.78	0.710 [t]

Group 1: electronic cigarette smokers, Group 2: combustible cigarette smokers

[t] Independent sample *T* test, χ^2 chi-square test. *Statistically significant at *p* value < 0.05

difference was found between the three study groups ($P>0.05$).

Table 4 compares the 6MWT parameters among the three study groups. Both electronic and combustible cigarette smokers have comparable reduced exercise capacity as shown by the significantly shorter walking distance compared to non-smokers (508.3, 488, 616.6 m, respectively, $p<0.001$). Additionally, higher Borg scales of the rate of perceived exertion (4.9, 5.5, 2.1, respectively, $p<0.001$), dyspnea (5.7, 6.5, 0.1, respectively, $p<0.001$), and leg fatigue (4.2, 5.4, 1.4, respectively, $p<0.001$) and lower oxygen saturation percentages (97.9%, 97.8%, 98.1, respectively, $p<0.001$).

Discussion

According to the published literature, little is known about the cardiovascular effects of e-cigarette use which may not be safe as claimed by manufacturers. While most studies regarding smoking as a cardiovascular risk factor targeted regular combustible tobacco cigarettes, the current study investigated the effect of the newly widespread e-cigarette use on functional exercise capacity [10–12].

This is the first study to assess functional exercise capacity among healthy e-cigarette users via the reliable, valid, and non-invasive 6MWT. The reported significant results may reshape the attitude and behavior of e-cigarette users and healthcare providers and will aid in developing preventive cardiovascular medicine programs to discourage e-cigarette use [9].

The current study compared the six-minute walk test distance, Borg scale scores, oxygen saturation, and clinical vital signs between chronic e-cigarette users, chronic combustible cigarette smokers, and healthy

Table 3 Comparison between clinical vital signs of electronic cigarette smokers, combustible cigarette smokers, and non-smoker control group ($N=105$)

Vital signs (mean ± SD)	Group (1) ($n=35$)	Group (2) ($n=35$)	Group (3) ($n=35$)	*P* value between Group (1) and group (2) #	*P* value
Heart rate	71.71 ± 9.23	73.43 ± 5.2	64.23 ± 3.4	0.26 [#]	**< 0.001*** [$]
Respiratory rate	15.27 ± 1.4	16.23 ± 1.3	13.9 ± 0.97	**< 0.001*** [#]	**< 0.001*** [$]
Temperature (℃)	37 ± 0.4	37.1 ± 0.4	36.8 ± 0.5	0.76 [#]	0.892 [$]
Blood pressure (mmHg)					
Systolic	115.71 ± 5.4	114.86 ± 5.6	114.29 ± 5.2	0.55 [#]	0.537 [$]
Diastolic	75.4 ± 9.2	78.8 ± 8.9	70.57 ± 8.8	0.84 [#]	0.736 [$]
BMI (kg/m^2)	23.57 ± 1.94	22.63 ± 1.97	25.02 ± 1.5	0.89 [#]	**< 0.001*** [$]

Group 1: electronic cigarette smokers, Group 2: combustible cigarette smokers, Group 3: non-smokers control group. [$]One-way ANOVA, #LSD post hoc test, *statistically significant at *p* value < 0.05

Table 4 Parameters of six-minute walk test (6-MWT) among electronic cigarette smokers, combustible cigarette smokers, and non-smoker control groups ($N=105$)

Variables (mean ± SD)	Group (1) ($n=35$)	Group (2) ($n=35$)	Group (3) ($n=35$)	*P* value between group (1) and group (2) #	*P* value
Walking distance	508.3 ± 35.8	488 ± 32.5	616.6 ± 31.9	0.59 [#]	**< 0.001*** [$]
Rate of perceived exertion (RPE)	4.9 ± 0.3	5.5 ± 1	2.1 ± 0.5	0.31 [¥]	**< 0.001*** [¥]
Dyspnea	5.7 ± 0.1	6.5 ± 0.2	0.1 ± 0.5	0.25 [¥]	**< 0.001*** [¥]
Leg fatigue	4.2 ± 0.5	5.4 ± 0.9	1.4 ± 0.8	0.78 [¥]	**< 0.001*** [¥]
SPO_2 (oxygen saturation %)	97.9 ± 0.26	97.8 ± 0.47	98.1 ± 0.15	0.99 [#]	**< 0.001*** [$]

Group 1: electronic cigarette smokers, Group 2: combustible cigarette smokers, Group 3: non-smoker control group, [$]One-way ANOVA, #LSD post hoc test, [¥]Kruskal–Wallis test; *Statistically significant at *p* value < 0.05

non-smokers to investigate the cardiovascular effects of chronic e-cigarette use and the potential of e-cigarette as a new risk factor for cardiovascular health.

The main finding in this study was the decreased functional exercise capacity and oxygen saturation percentage among chronic e-cigarette users. The 6MWT distance which is highly related to functioning in daily life was similarly shortened in e-cigarette users and combustible cigarette smokers compared to non-smokers. Accordingly, e-cigarette use must be considered as a new cardiovascular risk factor and has no health advantage over conventional combustible cigarettes.

Regarding 6MWT distance, e-cigarette users showed decreased walking distance compared to the control group. This is consistent with past results published by Melliti's and Saetia's studies, where chronic tobacco cigarette smokers walked less distance than non-smokers in 6MWT [12, 13].

The 6MWT parameters (dyspnea, rate of perceived exertion, and leg fatigue) were evaluated via Borg scale scores (on a scale from 0 to 10). The recorded scores in electronic cigarette smokers were higher than non-smoker controls which indicates a compromised functional capacity among healthy e-cigarette smokers [14]. This is consistent with previous studies on tobacco cigarettes and waterpipe smoking by Lee Chang and Hawari who documented higher Borg scale scores among chronic smoker groups when compared to non-smoker controls during aerobic activity [15, 16].

This may reflect the multifactorial negative consequences of e-cigarette use on respiratory, cardiovascular, peripheral circulation, and neuromuscular systems involved during aerobic exercise capacity [17]. The negative impact of e-cigarette use was expressed as shorter distances recorded in 6MWT, dyspnea, increased perceived exertion, leg fatigue, and decreased SpO_2 after the 6MWT. Borg scale scores were similarly higher among e-cigarette users and combustible cigarette smokers compared to non-smokers [18–21].

The strength of the present study is attributed to the novelty of the study subject because the impact of e-cigarette use on physical capacity was not studied before, the strict selection criteria for including or excluding study participants, the choice of reliable, valid, simple, objective, replicable, and reproducible methods as the 6MWT and oxygen saturation percentage and importance of the yielded data to the preventative cardiovascular medicine field to discourage the youth from all forms of smoking.

There are some limitations to the present study, despite revealing objective data with statistically significant differences in results. The main limitation of our study was its cross-sectional design which cannot establish a cause-and-effect relationship. Moreover, this study was a single-center study which limits the generalizability.

Conclusions

Based on the results from the present study, e-cigarette use reduces functional exercise capacity and aerobic activity and consequently impairs the quality of life. This was denoted by decreased 6MWT walking distances, higher Borg scale scores, and lower oxygen saturation percentages among apparently healthy electronic cigarette users compared to non-smokers while performing the 6MWT. Considering the current study results, it is important to report that the use of e-cigarettes does have adverse effects on cardiovascular health and physical capacity like combustible tobacco cigarettes, and it is not risk-free as alleged. E-cigarette use should be considered a risk factor for cardiovascular health. It is recommended to quit all types of smoking.

Hence, the current study contributes to the available body of knowledge regarding the potential risks of e-cigarette use and will aid in developing targeted health educational programs focused on quitting smoking in every form to promote cardiovascular health among the population.

Abbreviations

E-cigarettes	Electronic cigarettes
6MWT	Six-minute walk test
Spo2	Oxygen saturation
HR	Heart rate
SBP	Systolic blood pressure
DBP	Diastolic blood pressure
BMI	Body mass index
ANOVA	Analysis of variance
RPE	Rate of perceived exertion
FDA	Food and Drug Administration

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Authors' contributions

AH, RH, and HA proposed the idea and designed the study. HA collected the data. AS collected clinical data and recorded the six-minute walk test parameters. HA has performed the statistical analysis and wrote the initial draft. AH, RH, ShA, and AS shared in revising the final manuscript. All authors have approved the manuscript.

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Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

This study was approved by the research ethics committee of the Faculty of Medicine, Suez Canal University. A written informed consent had been taken from all participants.

Consent for publication
This study does not include the publishing of personal data.

Competing interests
The authors declare that they have no competing interests.

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