ORIGINAL ARTICLE

$EtCO_2$ Levels in Medical Students Wearing N95 Masks

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ABSTRACT

Introduction: N95 masks are very popular for daily use and can actively filter microparticles such as viruses. However, there are concerns that prolonged wearing of the mask may result in exhaled CO_2 accumulation between the face and the mask, which may cause increased end-tidal carbon dioxide ($EtCO_2$) levels and physiological changes. This study aimed to determine $EtCO_2$ levels in students wearing the N95 mask.
Methods: This was an experimental study with a case-control design. The subjects were divided into a treatment and a control group and were subjected to five measurements in 120 minutes. The data were analyzed using the independent samples T-test (normally distributed data) and the Mann-Whitney U test (not normally distributed data).
Results: Mann-Whitney test at minute 0 showed that $p = 0.010$, independent sample T-test at minute 30 showed that the control group $p = 0.016$, while in the treatment group $p = 0.019$. Independent sample T-test at minute 60 for the control group $p = 0.034$, while the treatment group $p = 0.037$. Independent sample T-test at minute 90 for the control group and treatment $p = 0.001$, and independent sample T-test showed that at minute 120 in the control and treatment groups $p = 0.000$.
Conclusion: The $EtCO_2$ measurements at each of the five time points showed a statistical difference ($p < 0.05$). However, medical students who wore an N95 mask did not suffer adverse effects because the $EtCO_2$ values in the control group were higher than in the treatment group.

INTRODUCTION

The N95 mask is an item of personal protective equipment (PPE) that offers protection against viruses and droplets larger than 0.3 microns. A currently active virus is the severe acute respiratory syndrome coronavirus 2 (COVID-19). The outbreak started in Wuhan, China, in 2019 and is still active. It is thought to be due to human exposure to an animal virus at the Huanan seafood wholesale market, which sells many live animals. The epidemic quickly spread to other parts of China. The emergence of this pathogen attracted global attention and resulted in a World Health Organization (WHO) announcement on 30 January 2020, declaring the COVID-19 outbreak a public health emergency of international concern.[1] The number of COVID-19 cases increased rapidly in various countries, Indonesia being one of the affected countries. On 9 November 2021, there were 249,743,428 confirmed cases of COVID-19 globally and 5,047,652 deaths.[2] In Indonesia, the total number of confirmed COVID-19 cases was 4,255,721 on 30 November 2021, with 143,796 deaths.[3] In Maluku, the total number of confirmed COVID-19 cases was 14,643 on 29 November 2021, with 265 deaths.[4] There were 8,878 confirmed cases in Ambon on 30 November 2021, with 165 deaths.[5] This resulted from a lack of awareness in some groups of people who did not use masks when leaving their homes, resulting in a rapid spread of the virus.

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COVID-19 can be transmitted in two ways, by droplets and through direct contact. Droplets are generated when someone coughs or sneezes. Everyone in close contact (in a radius of one meter) with a person who is showing symptoms of respiratory disease (coughing and sneezing) is at risk of exposure to droplets that may cause infection. The virus droplets can survive on the surface of objects, and the virus remains active. Consequently, the environment around an infected person may become a source of infection. This is why PPE is needed, and masks are currently the most popular PPE.[1,6] Wearing medical and non-medical masks is a preventive action. A popular type of mask is the N95 mask, which is made of polyurethane and polypropylene. The COVID-19 virus can be transmitted through droplets, and the N95 mask is designed with a tight seal around the nose and mouth to filter 95% of particles larger than 0.3 microns in diameter to reduce exposure to airborne contamination.[6,7]

In early June 2019, WHO appealed to governments worldwide to encourage people to wear masks.[8] The general public could use a non-medical mask, while health professionals should wear a medical mask such as the N95 mask or similar in certain situations and circumstances. In addition to wearing masks, WHO also encouraged staying away from crowds and keeping a physical distance of at least three feet (one meter) from others, especially those with coughing, flu, sneezing, and other respiratory symptoms. Some people feel discomfort while wearing a mask during respiratory and other activities such as speaking, eating, and drinking. Thus, some people choose not to wear a mask when engaging in outdoor activities or moving in crowds.[9,10]

Dattel, *et al.* (2020) reported that some pilots in flight training expressed concern about the discomfort of wearing a mask, as they felt it could induce human fatigue.[11] During respiration, gas exchange occurs, oxygen is inhaled into the body, and carbon dioxide is exhaled. When wearing a mask, more CO_2 than usual is likely inhaled because the CO_2 that is exhaled is trapped between the face and the mask. Fatigue, when wearing a mask, can be a symptom of excess carbon dioxide in the blood, also known as hypercapnia.[12] Hypercapnia can be measured using capnography, which measures CO_2 exhaled during expiration. If a high concentration of CO_2 gets trapped inside the mask, this could result in insufficient oxygen being transferred to the lungs during inspiration. Lack of oxygen absorption can result in hypoxia.[12–14]

Previous studies examined health workers wearing a filtering facepiece respirator (FFR) or N95 mask under different workloads for one hour. No significant physiological effect was found for wearing an FFR for an hour. However, in two participants wearing the F95 mask, the carbon dioxide level reached 50 mm Hg at the end of the one-hour period, suggesting that wearing an N95 mask for over an hour may have adverse effects or cause CO_2 intoxication.[12,15] This study aimed to determine end-tidal carbon dioxide (EtCO2) levels in students wearing the N95 mask.

METHODS

This was an experimental study using a case-control design to determine $EtCO_2$ levels in students wearing the N95 mask. Data was collected in the Intensive Care Unit (ICU) of Dr. M. Haulussy General Hospital, Ambon, from August to September 2021. This hospital was chosen based on the availability of capnography equipment for collecting $EtCO_2$ and respiratory rate data from the participants. Dr. M. Haulussy General Hospital, Ambon, is a type B hospital and serves as the central referral hospital in Maluku.

The data used in this study were primary data collected from 36 participants, medical students from Pattimura University, Ambon, who met the inclusion and exclusion criteria. The inclusion criteria included a negative rapid antigen test result for COVID-19, having received vaccination, not being obese, not having heart or respiratory disorders, and being a non-smoker. The sample for this study was obtained through simple random sampling, ensuring that each member of the population had an equal chance of being selected as a research participant. The subjects were randomly assigned to either the experimental or the control group. All procedures were approved by ethical clearance no 041/FK-KOM.ETIK/VIII/2021.

The equipment used in this study included a scale, stadiometer, sphygmomanometer, timer, N95 masks type 8210 (OneMed), pulse oximeter, mainstream capnography measuring device (Capnostat, Respironics), and capnography monitor (Dräger). The participants were evenly divided into two groups, the treatment group, which wore N95 masks, and the control group, which did not wear N95 masks. $EtCO_2$ levels were measured using the capnography measuring device, and physiological changes in each participant were assessed during the specified time intervals/phases.

The data collection duration was set at 120 minutes, divided into four phases. $EtCO_2$ measurements were taken at 0, 30, 60, 90, and 120 minutes using a probe placed on the outer part of the mask directly connected to the capnography device via a tube, while oxygen saturation was measured by pulse oximetry. The $EtCO_2$ values were observed on the capnography device, and the physiological changes experienced by each participant were registered. The measurements of

$EtCO_2$, oxygen saturation (SpO_2), heart rate, respiratory rate, and any headaches and/or dizziness reported by the participants were recorded. The data was analyzed using the Statistical Package for the Social Sciences (SPSS) version 26. The data was tested for normality using the Kolmogorov-Smirnov normality test. If the data followed a normal distribution, the next step was an independent T-test. However, a Mann-Whitney U test was used if the data did not follow a normal distribution.[16] A p-value < 0.05 was considered statistically significant.

RESULTS

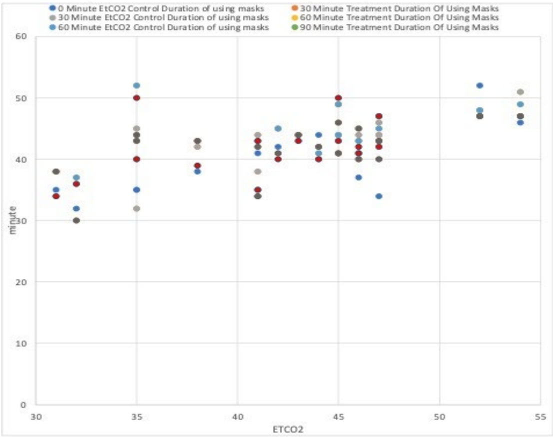

Figure 1. Comparison chart of mean $EtCO_2$ values in control and treatment groups

The average values of $EtCO_2$ in the treatment group were lowest at minute 120 (42.02 mmHg) and highest at minute 60 (43.06 mmHg). In the control group, $EtCO_2$ values were lowest at minute 30 (45.78 mmHg) and highest at minute 120 (47.06 mmHg).

Table 1 shows the mean and median results at minute 0. The median in the control group was 46.50 mmHg, against 43.50 mmHg in the treatment group. The Mann-Whitney U test showed a p-value = 0.010, meaning there was a significant difference between the two groups.

Table 1. Minute 0 $EtCO_2$ measurement results (mmHg)

Group	Minute 0		
	Mean	Median	p-value
Control	46.44	46.50	0.010
Treatment	42.44	43.50	

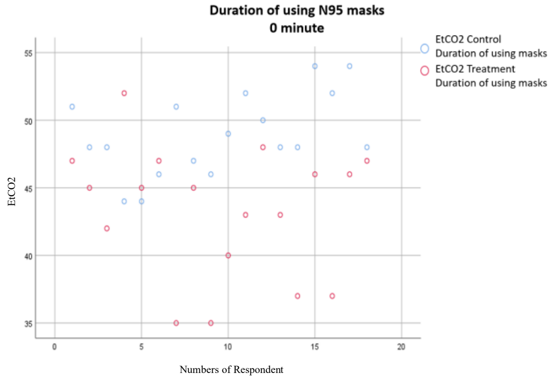

Figure 2. Minute 0 scatter plot $EtCO_2$

At minute 30, the mean values for the control and treatment groups were 46.00 and 44.00 mmHg, respectively (Table 2). The difference was significant.

Table 2. Minute 30 $EtCO_2$ measurement results

Group	Minute 30		
	Mean	Median	p-value
Control	45.78	46.00	0.016
Treatment	42.92	44.00	0.019

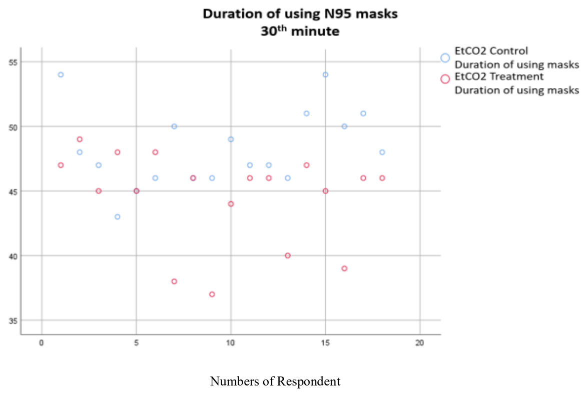

Figure 3. Minute 30 scatter plot $EtCO_2$

At minute 60, the mean values for the control and treatment groups were 46.00 and 43.00 mmHg, respectively (Table 3). The difference was significant.

Table 3. Minute 60 $EtCO_2$ measurement results

Group	Minute 60		
	Mean	Median	p-value
Control	45.83	46.00	0.034
Treatment	43.06	43.00	0.037

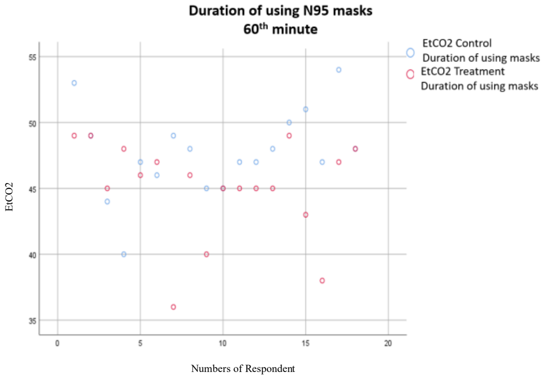

Figure 4. Minute 60 scatter plot $EtCO_2$

At minute 90, the mean values for the control and treatment groups were 46.50 and 42.00 mmHg, respectively (Table 4). The difference was significant.

Table 4. Minute 90 $EtCO_2$ measurement results

Group	Minute 90		
	Mean	Median	p-value
Control	46.67	46.50	0.001
Treatment	42.19	42.00	0.001

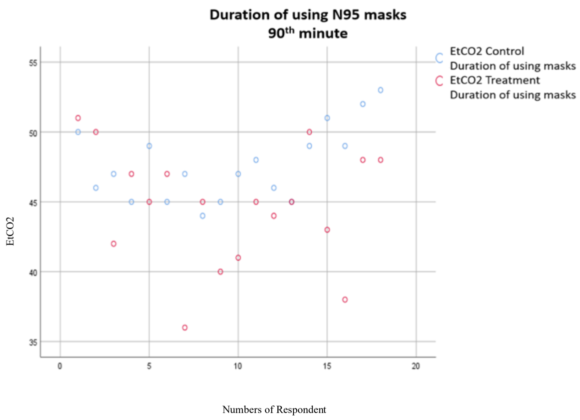

Figure 5. Minute 90 scatter plot $EtCO_2$

At minute 120, the mean values for the control and treatment groups were 47.50 and 42.50 mmHg, respectively (Table 5). The difference was highly significant.

Table 5. Minute 120 $EtCO_2$ measurement results

Group	Minute 120		
	Mean	Median	p-value
Control	47.06	47.50	0.000
Treatment	42.02	42.50	0.000

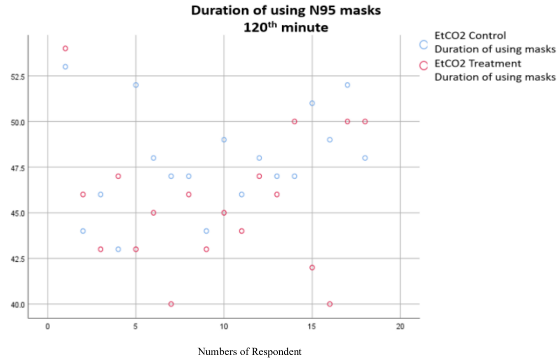

Figure 6. Minute 120 scatter plot $EtCO_2$

Table 6 and Table 7 show that there was almost no effect on SPO_2. The heart rate in the treatment group at minute 0 was slightly increased to 91 beats/minute. At minute 30, it increased to 96 beats/minute. Meanwhile, at minutes 60, 90, and 120, it increased from 92 beats/minute to 94 beats/minute. However, these figures were still within normal limits.

The average respiratory rate in the treatment group at minute 0 was 14 breaths/minute. At minute 30, it decreased to 13 breaths/minute. At minute 120, the average respiratory rate increased to 21 breaths/minute. This means that at minutes 0, 30, 60, and 90, the average values for the participants indicated some bradypnea. No participants complained about subjective symptoms such as headaches and dizziness, indicating that physiological changes remained within normal limits.

Table 6. The average results of the measurement of signs and symptoms at minutes 0, 30, 60, 90, and 120

Group	Time Point	Signs and Symptoms		
		SpO_2	Respiratory Rate	Heart Rate
Control	Minute 0	98.67	17.50	84.28
	Minute 30	98.50	17.22	86.22
	Minute 60	98.39	17.56	81.50
	Minute 90	98.56	17.44	84.67
	Minute 120	98.61	17.67	86.39
Treatment	Minute 0	99.00	14.00	91.00
	Minute 30	98.90	17.00	88.00
	Minute 60	98.30	15.00	86.00
	Minute 90	99.00	14.00	87.00
	Minute 120	98.08	16.00	86.00

Table 7. The average results of the measurement of signs and symptoms at minutes 0, 30, 60, 90, and 120

Group	Time Point	Signs and Symptoms	
		Headaches	Dizziness
Control	Minute 0	0	0
	Minute 30	0	0
	Minute 60	0	0
	Minute 90	0	0
	Minute 120	0	0
Treatment	Minute 0	0	0
	Minute 30	0	0
	Minute 60	0	0
	Minute 90	0	0
	Minute 120	0	0

DISCUSSION

Effect of the Duration of Wearing an N95 Mask on $EtCO_2$

The $EtCO_2$ values in the control group (not wearing a mask) were significantly higher than in the treatment group (wearing a mask) during the two hours, with five measurements at minutes 0, 30, 60, 90, and 120.

Scheid, *et al*. (2020) found that prolonged wearing of an N95 mask did not interfere with the respiratory system.[17] This study found that, although respiratory resistance was slightly increased when wearing a mask, this did not affect the tidal volume or respiratory rate. The respiratory resistance that occurs is small enough not to cause clinical symptoms.

In addition, the decrease in $EtCO_2$ in this study was caused by ill-fitting masks. A mask that fits well adjusts to the shape of the face of the mask wearer to provide a maximum protective effect.[18] O'Kelly, *et al*. (2021) reported that, of the four masks used in the study, the N95 mask provided the highest protective effect.[18] Still, most of the participants who wore N95 masks in this study found that the N95 mask did not adjust to the shape of their faces. With good compatibility between the mask wearer and the N95 mask, the filtering effect of the N95 mask is 95%. However, if it is ill-fitting, the protection from an N95 mask is equivalent to wearing a surgical or cloth mask.[18] This is because the raw materials of N95 masks are stiffer than other types of masks. Therefore, the N95 mask cannot adjust to the face shape of each wearer.[18]

An increase in $EtCO_2$ may cause discomfort to people wearing masks. This discomfort arises in the short and long term when wearing an N95 mask.[17] Among the feelings of discomfort caused by prolonged wearing of the mask are headaches, which occur when the mask is worn for more than six hours. In the short term, discomforts such as itching, rash, or irritation and discomfort may be associated with increased facial temperature.[17]

Luximon, *et al*. (2016) found that wearing an N95 mask for five minutes increased skin temperature more than wearing a surgical mask.[19] In addition to the increased temperature, they reported increased humidity and difficulty breathing, and respondents expressed more discomfort during active verbal communication than moments of less active verbal communication. An N95 mask worn for one hour increases the temperature of the facial skin to above 34.5°C, but this is still within the normal temperature range.[19]

Effects of Wearing an N95 Mask on Signs and Symptoms of Carbon Dioxide Retention

The results showed that the average signs and symptoms were within the normal range, both in the control and treatment groups. This study is similar to a meta-analysis by Shaw, *et al*. (2021), which showed that wearing surgical and N95 masks did not affect heart rate.[20] However, the N95 mask increased respiration rate, while surgical masks did not.

A study by Scheid, *et al*. (2020) on the physiology and psychology of wearing masks showed no relationship between wearing masks and abnormalities in clinical symptoms such as pulse rate, breathing, and others.[17] This is because wearing the N95 mask does not affect the wearer's respiratory system.[17]

LIMITATIONS

A limitation of this study is that it was conducted in a closed indoor environment. All measurements on all participants were performed in the same room, as there was no room available to do so individually. In addition, the participants were not continuously monitored, meaning they could potentially slightly open or loosen the mask for easier breathing. Mask fitting was not performed to adjust the mask to the individual participants' facial features or shape.

CONCLUSION

Based on the results and discussion of this study on the effects of N95 mask usage duration on $EtCo_2$ in medical students of Pattimura University, Ambon, it can be concluded that there was a significant difference (p-value $< \alpha$). This study also indicated that there was no significant effect of N95 mask usage duration on $EtCo_2$ levels within a two-hour timeframe with five measurements at minutes 0, 30, 60, 90, and 120. This is because the results in the group wearing masks were lower compared to the group not wearing masks. This study did not find any physiological or psychological signs or symptoms that emerged from N95 mask usage during the two-hour period.

FUTURE RECOMMENDATIONS

For future research, we suggest studies on wearing the mask during various activities that may affect $EtCO_2$ and cause physiological signs and symptoms, explore other factors that may influence

$EtCO_2$ levels when wearing N95 masks, investigate variables such as ambient temperature, humidity, and physical exertion to determine if they have an impact on respiratory parameters, conduct a longitudinal study to assess the changes in $EtCO_2$ levels over an extended period of time, which would provide more insight into the long-term effects of wearing N95 masks on respiratory parameters, investigate the impact of mask fit on $EtCO_2$ levels, compare the $EtCO_2$ levels of students wearing properly-fitted N95 masks with those wearing loosely-fitted masks, which would help to understand the importance of mask fit in maintaining appropriate respiratory parameters. It is expected for educational institutions to educate students regarding the safe use of N95 masks for a maximum two-hour duration continuously.

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Conflict of Interest
The authors declared there is no conflict of interest.

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Authors' Contributions
Designed the study: SEPM, OWA, BJQ. Data collection: SEPM, CRT. Performed the analysis: SEPM, OWA, FDL, CRT. Prepared the manuscript: SEP. Reviewed the manuscript: SEPM, OWA, BJQ, FDL, CRT. All authors contributed and approved the final version of the manuscript.

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