Original Article

Prospective analysis of the physiological changes caused by prolonged use of N95-type masks

Melis E. Demirag, Mustafa Akyil[1], Merve Karasal[1], Serkan Bayram[1], Serda Kanbur Metin[1], Fatma A. Tokgoz[2], Volkan Baysungur[1], Serdar Evman[1]

Department of Otorhinolaryngology, Kartal Lutfi Kirdar Training and Research Hospital, University of Health Sciences, [1]Department of Thoracic Surgery, Sureyyapasa Training and Research Hospital, University of Health Sciences, [2]Department of Pulmonology, Yedikule Chest Diseases Hospital, University of Health Sciences, Istanbul, Turkey

Address for correspondence:
Dr. Serdar Evman, Department of Thoracic Surgery, Sureyyapasa Training and Research Hospital, University of Health Sciences, Basibuyuk Mah. No 1, 34784, Maltepe Istanbul, Turkey.
E-mail: sevman13@yahoo.com

Submission: 11-12-2022
Revised: 29-01-2023
Accepted: 09-02-2023
Published: 25-04-2023

Access this article online

Quick Response Code:

Website: www.thoracicmedicine.org

DOI: 10.4103/atm.atm_429_22

Abstract:

INTRODUCTION: The clinical and physiological effects of long-duration use of N95-type masks without ventilation valves, on health-care workers during the coronavirus disease-2019 (COVID-19) pandemic, were evaluated.

METHODS: All volunteering personnel working in operating theater or intensive care unit, using nonventilated N95 type respiratory masks, minimum for a 2-h noninterrupted duration were observed. The partial oxygen saturation (SpO_2) and heart rate (HR) were recorded before wearing the N95 mask and at 1st and 2nd h. Volunteers were then questioned for any symptoms.

RESULTS: A total of 210 measurements were completed in 42 (24 males and 18 females) eligible volunteers, each having 5 measurements, on different days. The median age was 32.7. Premask, 1st h, and 2nd h median values for SpO_2 were 99%, 97%, and 96%, respectively ($P < 0.001$). The median HR was 75 premask, 79 at 1st h, and 84/min at 2nd h ($P < 0.001$). A significant difference between all three consecutive measurements of HR was achieved. Statistical difference was only reached between premask and other SpO_2 measurements (1st and 2nd h). Complaints seen in the group were head ache (36%), shortness of breath (27%), palpitation (18%), and nausea feeling (2%). Two individuals took off their masks to breathe, on 87th and 105th min, respectively.

CONCLUSIONS: Long duration (>1 h) use of N95-type masks causes a significant reduction in SpO_2 measurements and increase in HR. Despite being an essential personal protective equipment in COVID-19 pandemic, it should be used with short intermittent time periods in health-care providers with known heart disease, pulmonary insufficiency, or psychiatric disorders.

Keywords:

Coronavirus disease-2019, health care, N95 mask, personal protective equipment

During the epidemic diseases that have emerged in recent years and the ongoing severe acute respiratory syndrome coronavirus-2 (SARS-CoV-2) pandemic, the use of respiratory personal protective equipment is essential, especially for health-care workers whom are at high risk of transmission. The most frequently used ones are N95 (American standard, CDC), FFP2 (European equivalent of N95), and FFP3 (N98) masks.[1] N95 mask is a type of respirator that filters at least 95% of very small (0.3 μ) particles from the inhaled air, including bacteria and viruses.[2]

Although uncomfortable and distressing, proper and continuous use of respiratory protective masks is vital for health-care workers fighting against the pandemics. There are underlying physiological and psychological factors for noncompliance with the mask. The main complaint of N95 mask users is difficulty in breathing. Approximately 30% of health-care

How to cite this article: Demirag ME, Akyil M , Karasal M, Bayram S, Metin SK, Tokgoz FA, *et al*. Prospective analysis of the physiological changes caused by prolonged use of N95-type masks. Ann Thorac Med 2023;18:86-9.

professionals often complain of dyspnea while wearing N95 masks.[3]

It has been reported that N95 masks can cause hypoxemia and hypercapnia, respiratory complications, self-contamination, and exacerbation of existing chronic diseases.[4,5] In our study, we investigated the clinical and physiological effects of long-term use of the N95 mask without an exhalation valve on health-care workers.

Methods

This study took place in a tertiary referral hospital between October 2020 and October 2022, after retrieval of University of Health Sciences, Sureyyapasa Chest Diseases and Thoracic Surgery Hospital, Ethics committee approval (02.07.2020/092) and Republic of Turkey, Ministry of Health (2020-05-11T11_23_05) approvals. We prospectively measured the heart rate (HR) and partial oxygen saturation (SpO_2) of all volunteering health-care workers (nurses, residents, and specialists in a single surgical clinic) using nonventilated N95 type respiratory masks (ERA® FFP2 mask, EN 149:2001 + A1:2009), minimum for a 2-h noninterrupted duration, in the intensive care unit or operating room. Data were collected for premask, 1st h, and 2nd h values for each measurement and for any complaint (headache, palpitation, nausea, and dyspnea) present at the end of the planned (2 h) duration. Eligible healthy volunteers had undergone five different measurements on different days with a digital pulse oximeter, to minimize the individual bias. The results were obtained for evaluation and comparison.

Health-care workers who did not volunteer or give written permission were not taken into the study. Due to the potential of triggering a present systemic illness, volunteers with any known cardiac, respiratory, neurological, or psychiatric disease were also excluded.

Statistical analysis

Statistical analysis was conducted using the Jamovi Project Version 1.6 (2021) software (retrieved from https://www.jamovi.org). Since the cohort showed nonnormality on the Shapiro–Wilk test (<0.05), variables were given with the median and interquartile range (IQR) values. Continuous variables were reported with their medians and IQR, and categorical variables were reported with frequencies and percentages. The significance of the change in consecutive HR (bpm) and SpO_2 (%) measurements was compared with Friedman's test, and *post hoc* comparisons were performed with Conover's test. All *P* values were corrected as suggested by Bonferroni. The accepted maximum type I error in this study was 5%.

Results

A total of 210 measurements were completed in 42 (24 males and 18 females) eligible volunteers. The median age was 32.7 (IQR = 10). Premask, 1st h, and 2nd h median values for partial oxygen saturation were 99%, 97%, and 96%, respectively ($P < 0.001$). The median HR of the group was 74 before putting on the mask, 79 on the 1st h, and 86 at the end of the 2nd h ($P < 0.001$). All measurements are given and compared in Table 1.

Conover's *post hoc* comparison test revealed a significant difference between all three consecutive measurements of HR. Statistical difference was only achieved in the premask and the other (1st and 2nd h) SpO_2 measurements. No significant difference was found between SpO_2 measurements at the 1st and the 2nd h [Table 2].

Eighty (38%) of the measurements were uneventful. In the other 130 (62%), at least one complaint was seen during or at the end of the planned 2-h period [Table 3]. Most frequent complaint seen was headache in 76 measurements (36%), followed by shortness of breath in 57 (27%), palpitation in 37 (18%), and nausea feeling in 4 (2%) measurements. Two different individuals necessitated to quit the study and took of their masks to breathe, on 87th and 105th min, respectively.

Discussion

The use of respiratory protective devices is important in the coronavirus disease-2019 pandemic, where the respiratory and droplet path is defined as the main source of transmission. Surgical face masks do not provide adequate filtration against aerosolized infectious agents of 10–80 nm (nanometers), and they do not perfectly fit on the face.[6-8] N95 masks are a type of respirator that removes particles from the inhaled air. These masks filter at least 95% of very small (0.3 μ) particles, including bacteria and viruses. Therefore, in areas with infectious disease risk such as tuberculosis and SARS-CoV-2, health-care professionals are recommended to use N95 masks.[2,4] However, as stated in literature, a quantity of people in the general population and even health-care professionals who are expected to be well-educated about this issue repeatedly move their masks or do not wear them when necessary.[1,3,9]

Table 1: Distribution of measured variables

	Variable (h)	Minimum	Maximum	Median	IQR	*P*
SpO_2 (%)	Premask	97	100	99	2	<0.0001*
	1st	94	99	97	2	
	2nd	94	99	96	1.125	
HR	Premask	57	96	74	15.50	<0.0001*
	1st	68	106	79	10.00	
	2nd	72	119	86	8.25	

*Friedman test. IQR=Interquartile range, HR=Heart rate, SpO_2=Partial oxygen saturation

Table 2: Conover's *post hoc* (inter-group) comparisons

	1st variable (h)	2nd variable (h)	*t*-statistics	df	Wi	Wj	*P**
SpO_2	Premask	1st	4.692	198	251.000	188.000	<0.0001
		2nd	6.703	198	251.000	161.000	<0.0001
	1st	2nd	2.011	198	188.000	161.000	0.137
HR	Premask	1st	2.830	198	147.000	186.000	0.005
		2nd	8.708	198	147.000	267.000	<0.0001
	1st	2nd	5.878	198	186.000	267.000	<0.0001

*Bonferroni correction. SpO_2=Partial oxygen saturation, df=Degrees of freedom, HR=Heart rate

Table 3: Complaint incidences

Complaint	Frequency (%)
Head ache	36
Shortness of breath	27
Palpitation	18
Nausea	2

*Some individuals had multiple complaints

The presence of the exhalation valves reduce exhalation resistance and make it easier to breathe or exhale, but the surgical N95 respirators are designed without exhalation to prevent unfiltered exhaled air into the sterile area and contamination.

Proper and uninterrupted use of respiratory protective masks is crucial for health-care workers struggling with epidemics. However, it has some effects on respiratory parameters. It leads to a significant increase in respiratory effort to overcome an increase of approximately 300% in expiratory and inspiratory flow resistance and to maintain adequate expiratory flow rate.[9] It causes hypoventilation with an average of 37% reduction in air exchange volume in N95 users. In this way, respiration of CO_2 increases respiratory fatigue and physical working capacity is impaired.[9,10] In a study on patients wearing N95 masks during the hemodialysis procedure, the partial arterial oxygen pressure decreased from 101.7 to 92.7 mmHg, the respiratory rate increased from 16.8 to 18.8/min, and complaints of respiratory distress and chest pain are reported.[11] In another study, it was observed that the use of a surgical face mask during major surgery also decreased oxygen saturation by more than 1% and increased the HR by five beats/min.[12] In our study, we observed 2% and 3% drop of SpO_2 on 1st and 2nd h, respectively; statistical difference was found between the saturation measurements prior to and after wearing the mask ($P < 0.0001$). The basal median HR of the group rose from 75 to 79 at 1st, and then to 84 at the end of the 2nd h, with a significant difference between all consecutive HR measurements ($P < 0.0001$). This increase was probably linked to physiological cardiac response to hypoxemia. Twenty-seven percent of our volunteers complained of shortness of breath and 18% had palpitations, by the end of 2nd h.

CO_2 accumulation in people using N95 masks on common conditions such as rest, conversation, or low work rates ranges from 1.5% to about 3%. This is 100 times greater than expected in normal ambient air. It is well known that prolonged exposure to 2%–3% CO_2 can cause headache, sweating, dizziness, and shortness of breath, even in people without medical illness.[13] In addition, the increased dead space associated with N95-masks has been found to reduce the mean inspired O_2concentration.[14] Therefore, it may be considered that inhalation of increased CO_2 concentrations when using N95 may produce greater respiratory discomfort, suffocation, and anxiety symptoms, especially in people prone to panic disorder. In addition, decreased inhaled O_2 concentrations may result in greater breathing effort, shortness of breath, and physical fatigue, even during mild physical activity.[11,12,14]

Headache is probably the most common complaint associated with the use of masks. The incidence of headache development among health-care workers using N95 masks ranges between 37% and 81% in literature and was found to be directly correlated with the use of N95 face masks for more than 4 h.[15,16] The etiopathogenesis of headaches associated with long-term use of N95 face mask has been linked to hypoxemia, hypercapnia, stress, or mechanical compression on the superficial facial and cervical nerves.[17-19] In our study, headache was also the most common complaint with 36%. We associated this phenomenon only to hypoxemia, since we did not measure the CO_2 level alteration in our cohort; this was one of the limitations of our study.

Being a single-center study, lack of noninvasive carbon dioxide measurement, and low cohort volume were the main limitations of our study. The daily time of measurements (e.g. morning vs. afternoon) was not constant for individuals, which could also cause a bias. Repetitive assessment minimized a probable measurement error. In addition, its prospective design and operating theater setting, where proper mask use is mandatory, were the strong points of the study.

Accurate and continuous use of respiratory protective masks is very important for health-care workers fighting with epidemics. Long duration use of N95-type masks causes a significant reduction in SpO_2 and increase the HR. Despite being a crucial personal protective

equipment in, especially for health workers in sterile environments, it should be used by caution in people with known heart disease, pulmonary insufficiency, or psychiatric/panic disorders, and with short intermittent time periods.

Acknowledgment

We would like to thank Prof. H.A. for his meticulous statistical analysis and interpretation.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

References

1. Wizner K, Nasarwanji M, Fisher E, Steege AL, Boiano JM. Exploring respiratory protection practices for prominent hazards in healthcare settings. J Occup Environ Hyg 2018;15:588-97.
2. Center for Disease Control and Prevention. NIOSH-approved N95 Particulate Filtering Facepiece Respirators; 2020. Available from: https://www.cdc.gov/niosh/npptl/topics/respirators/disp_part/n95list1.html. [Last accessed on 2021 Nov 01]
3. Baig AS, Knapp C, Eagan AE, Radonovich LJ Jr. Health care workers' views about respirator use and features that should be included in the next generation of respirators. Am J Infect Control 2010;38:18-25.
4. World Health Organization. Advice on the Use of Masks in the Context of COVID-19: Interim Guidance; 05 June, 2020. Available from: https://apps.who.int/iris/bitstream/handle/10665/332293/WHO-2019-nCov-IPC_Masks-2020.4-eng.pdf. [Last accessed on 2021 Nov 01].
5. Kwon JH, Burnham CD, Reske KA, Liang SY, Hink T, Wallace MA, *et al.* Assessment of healthcare worker protocol deviations and self-contamination during personal protective equipment donning and doffing. Infect Control Hosp Epidemiol 2017;38:1077-83.
6. Bałazy A, Toivola M, Adhikari A, Sivasubramani SK, Reponen T, Grinshpun SA. Do N95 respirators provide 95% protection level against airborne viruses, and how adequate are surgical masks? Am J Infect Control 2006;34:51-7.
7. Chughtai AA, MacIntyre CR, Zheng Y, Wang Q, Toor ZI, Dung TC, *et al.* Examining the policies and guidelines around the use of masks and respirators by healthcare workers in China, Pakistan and Vietnam. J Infect Prev 2015;16:68-74.
8. Fisher EM, Shaffer RE. Considerations for recommending extended use and limited reuse of filtering facepiece respirators in health care settings. J Occup Environ Hyg 2014;11:D115-28.
9. Lee HP, Wang de Y. Objective assessment of increase in breathing resistance of N95 respirators on human subjects. Ann Occup Hyg 2011;55:917-21.
10. Zhang X, Li H, Shen S, Cai M. Investigation of the flow-field in the upper respiratory system when wearing N95 filtering facepiece respirator. J Occup Environ Hyg 2016;13:372-82.
11. Kao TW, Huang KC, Huang YL, Tsai TJ, Hsieh BS, Wu MS. The physiological impact of wearing an N95 mask during hemodialysis as a precaution against SARS in patients with end-stage renal disease. J Formos Med Assoc 2004;103:624-8.
12. Beder A, Büyükkoçak U, Sabuncuoğlu H, Keskil ZA, Keskil S. Preliminary report on surgical mask induced deoxygenation during major surgery. Neurocirugia (Astur) 2008;19:121-6.
13. Johnson AT. Respirator masks protect health but impact performance: a review. J Biol Eng 2016;10:4.
14. Laferty EA, McKay RT. Physiologic effects and measurement of carbon dioxide and oxygen levels during qualitative respirator fit testing. J Chem Heal Saf 2006;13:22-8.
15. Lim EC, Seet RC, Lee KH, Wilder-Smith EP, Chuah BY, Ong BK. Headaches and the N95 face-mask amongst healthcare providers. Acta Neurol Scand 2006;113:199-202.
16. Ong JJ, Bharatendu C, Goh Y, Tang JZ, Sooi KW, Tan YL, *et al.* Headaches associated with personal protective equipment – A cross-sectional study among frontline healthcare workers during COVID-19. Headache 2020;60:864-77.
17. Nash JM. Psychologic and behavioral management of tension-type headache: Treatment procedures. Curr Pain Headache Rep 2003;7:475-81.
18. Headache Classification Subcommittee of the International Headache Society. The International classification of headache disorders: 2nd edition. Cephalalgia 2004;24 Suppl 1:9-160.
19. Khoo KL, Leng PH, Ibrahim IB, Lim TK. The changing face of healthcare worker perceptions on powered air-purifying respirators during the SARS outbreak. Respirology 2005;10:107-10.