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ORIGINAL ARTICLE

The effect of N95 respirators on vital parameters, $PETCO_2$, among healthcare providers at the pandemic clinics

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Abstract

Background Wearing face shields and masks, which used to have very limited public use before the COVID-19 outbreak, has been highly recommended by organizations, such as CDC and WHO, during this pandemic period.

Aims The aim of this prospective study is to scrutinize the dynamic changes in vital parameters, change in end tidal CO_2 ($PETCO_2$) levels, the relationship of these changes with taking a break, and the subjective complaints caused by respiratory protection, while healthcare providers are performing their duties with the N95 mask.

Methods The prospective cohort included 54 healthcare workers (doctors, nurses, paramedics) who worked in the respiratory unit of the emergency department (ED) and performed their duties by wearing valved N95 masks and face shields. The vital parameters and $PETCO_2$ levels were measured at 0–4th–5th and 9th hours of the work-shift.

Results Only the decrease in diastolic BP between 0 and 9 h was statistically significant ($p = 0.038$). Besides, mean arterial pressure (MAP) values indicated a significant decrease between 0–9 h and 5–9 h ($p = 0.024$ and $p = 0.049$, respectively). In terms of the vital parameters of the subjects working with and without breaks, only $PETCO_2$ levels of those working uninterruptedly increased significantly at the 4th hour in comparison to the beginning-of-shift baseline levels ($p = 0.003$).

Conclusion Although the decrease in systolic blood pressure (SBP) and MAP values is assumed to be caused by increased fatigue due to workload and work pace as well as increase in muscle activity, the increase in $PETCO_2$ levels in the ED healthcare staff working with no breaks between 0 and 4 h should be noted in terms of PPE-induced hypoventilation.

Keywords Emergency department · N95 respirators · Pandemic clinics · $PETCO_2$ · Vital parameters

Introduction

After Sars-CoV-2 virus, a novel coronavirus that appeared in China at the end of 2019, spread all over the world, this outbreak was declared a global pandemic by WHO on March 11, 2020, and the health crisis induced by this virus was defined as COVID-19 disease [1, 2]. Sars-CoV-2 infection is transmitted from human to human by means of contact routes or respiratory droplets and leads to clinical conditions in a wide spectrum, ranging from asymptomatic infection to severe pneumonia and acute respiratory distress syndrome [3].

Personal protective equipment (PPE), such as face shields and masks, is considered critically important in minimizing the risk of disease transmission [4–6]. Wearing face shields and masks, which used to have very limited public use before the COVID-19 outbreak, has been highly recommended by organizations, such as CDC and WHO, during

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this pandemic period. Moreover, an increasing number of reports are being published in relation to these enhanced infection-prevention measures.

Mask types can be primarily classified as full masks and half and quarter masks, and this mask classification is specified by the European Committee for Standardization (CEN). Surgical masks, namely filtering face piece (FFP) masks worn during the COVID-19 outbreak, are half-face masks [7]. FFP masks include mask types with varying filtering properties, such as FFP1, FFP2, and FFP3, with particle filtering at a rate of 80%, > 95%, and > 99%, respectively [7, 8]. In addition, respirator mask standards in the USA are specified as N95, N99, N100, R95, P95, P99, and P100 by the National Personal Institute for Occupational Safety and Health (NIOSH) [9]. N95 masks are FDA-approved mask models that provide filtering equivalent to FFP2 masks, because the former can filter > 95% of particles and droplets, while the latter have a protective effect at a rate of > 94% [7, 10]. Some models of these masks feature exhalation valves which reduce exhalation resistance and thus facilitate breathing out [11].

Studies documenting the efficacy of masks in suppressing the spread of viruses and recommending their widespread use were also conducted during the influenza virus pandemic [12]. In this COVID-19 pandemic, a recent study likewise revealed that using respiratory protection helped effectively to decrease the COVID-19 cases in Germany [13]. Furthermore, while WHO recommends surgical masks for general public based on local settings, resources, public preference, and culture, it encourages wearing N95-FFP2 or N99-FFP3 masks for healthcare professionals in care settings [6]. In accordance with the recommendations issued by WHO, healthcare workers in Turkey are obliged by law to wear at least N95/FFP2 medical masks during aerosol generating procedures (e.g., sampling, endotracheal intubation, mechanical ventilation, cardiopulmonary resuscitation, high flow oxygen therapy, respiratory secretion aspiration) in COVID-19 outpatient clinics [14].

Some recent clinical reports have addressed the adverse effects induced by N95 mask use both in various patient populations and in frontline healthcare providers. While N95 face masks reportedly impair cardiopulmonary exercise capacity in medical staff, they might also impose physiological stress on some parameters during dialysis, such as hypoxemia, reduced PaO_2, increased respiratory distress, and rate as well as chest discomfort [15, 16]. Among the most frequent complaints by healthcare providers concerning respiratory protection equipment are headache, facial sensitivity, persistent erythema, and acne [17].

Against this background, the ultimate aim of this prospective study is to scrutinize the dynamic changes in vital parameters, change in end tidal CO_2 levels, the relationship of these changes with taking a break, and the subjective complaints caused by respiratory protection, while healthcare providers are performing their duties with the N95 mask.

Methods

Study design and study population

The ethical approval of this prospective cohort study was granted by the Ethics Committee of Pamukkale University (reference no E-6016787–020-11,772). The written informed consent forms were filled out and gathered from each subject prior to the study.

The prospective cohort included the healthcare workers (doctors, nurses, paramedics) who worked in the respiratory unit of the emergency department (ED) between the dates of 09.01.2021 and 22.01.2021, performed their duties by wearing valved N95 masks (Fig. 1) and face shields, and overall in accordance with WHO guidelines [18] had no history or symptoms of any known disease, and were not on any drugs. In the emergency pandemic clinic, working hours were scheduled as shifts of 8–16 h. This study was carried out between 8 a.m. and 5 p.m. in the daytime shift. All measurements were made by the same person, who had no knowledge of the study, at the beginning of the working shift, before and after the lunch break, and at the end of the shift.

The dataset of this report consisted of the information on the subjects' age, gender, and smoking status, their vital parameters, and the total number of minutes when they took a break with the mask removed between the 0–4th and 5–9th hours. The primary outcome was the effect of using the N95

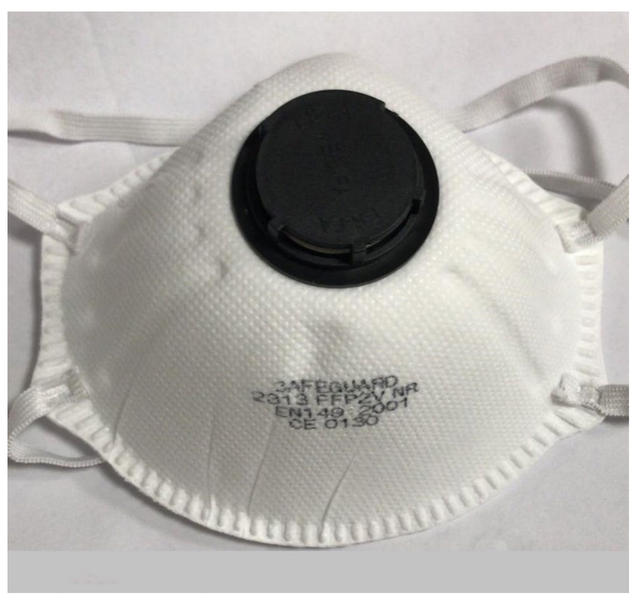

Fig. 1 A valved N95 respirator

respirators on vital parameters and $PETCO_2$, while the secondary outcome was the effect of wearing the N95 respirators on the comfort of the healthcare providers.

Vital parameters and $PETCO_2$ measurement

Fever, heart rate, systolic and diastolic blood pressures (BP), fingertip oxygen saturations (sPO_2), and $PETCO_2$ levels were measured at the beginning of the shift (0th hour), before lunch (4th hour), at the return of lunch (5th hour), and at the end of the shift (9th hour). The shock index and MAP values were computed.

Body temperature measurement

As described in previous publications, fever of the subjects was measured by an infrared thermometer at a 0.5-cm distance from the mid-forehead [19].

Blood pressure measurement

Blood pressure measurement was performed on the right arm with a manual sphygmomanometer using the auscultatory method after a 5-min rest [20].

Heart rate and sPO_2 measurement

The heart rate and sPO_2 levels of the subjects were measured, waiting for 2 min after the device was attached to the fingertip, and the value displayed on the screen at the end of the 2nd min was recorded in the dataset.

Shock index and mean arterial pressure calculation

The measurement of both shock index and MAP values was performed in accordance with previous studies. The shock index was calculated using the heart rate/systolic blood pressure formula, while the MAP value was identified by the formula [21].

$$MAP = DP + 1/3\,(SP - DP)$$

[22].

$PETCO_2$ measurement

$PETCO_2$ measurement was performed with a sidestream capnography device (GE Medical Systems, USA), and the $PETCO_2$ level at the end of 2nd min was recorded in the dataset [23].

Statistical analysis

The obtained data and information were evaluated for statistical analysis using the IBM SPSS 21.0 (Statistical Package for the Social Sciences) (SPSS Inc. Chicago, IL, USA) package data program. As clinical investigations with similar design focusing on the prolonged use of N95 face masks in ED were not available in the literature, a power analysis was run to obtain a hypothetical effect size. Assuming a hypothetical effect size of 0.5 at the standard 0.05 alpha error probability, a sample size of at least 54 people needed to be enrolled in the study to achieve 95% power. The normality of the original data was checked by the Kolmogrov-Smirnov test. The dependent variables with parametric distribution were expressed as mean ± standard deviation and analyzed by the paired *t*-test.

For evaluation of variations between measurements, repeated measure anova (with Bonferroni correction) and Greenhouse Geisser tests were performed. For evaluation of variation between complaints of attendees and whether they take a break, chi square test was performed. Since the effect of the suitability of the breaks on vital parameters is important in the study, the effect power of the study was also evaluated by measuring the $PETCO_2$ levels in the people who took a break in the first 4 h and those who did not. A p value of < 0.05 was set as the limit for statistical significance.

Results

Baseline data and break times

28 (51.9%) males and 26 (48.1%) females were enrolled in the study, and the average age of these subjects was 25.1 ± 3.48 years. 11 (20.4%) of the subjects were smokers. The participants were followed for 9th hours in their shifts. The average break time between 0–4 h and 5–9 h turned out to be 10.83 ± 8.5 min and 53.33 ± 27.47 min, respectively. 15 (27.7%) subjects continued working uninterruptedly between 0 and 4 h, whereas nobody preferred to work without a break between 5 and 9 h (Table 1).

Considering the 0–4th hour $PETCO_2$ levels of those working with no break between 0 and 4 h, the effect size turned

Table 1 Baseline characteristics of the study population

Gender	**Male,** *n* (%)	28 (51.9%)
	Female, *n* (%)	26 (48.1%)
Age, year		25.1 ± 3.48
Smokers, *n* (%)		11 (20.4%)
Break time (min)	**0–4th hours**	10.83 ± 8.5
	5–9th hours	53.33 ± 27.47
Nonbreakers *n* (%)	**0–4th hours**	15 (27.8%)
	5–9th hours	0

BP blood pressure, *$PETCO_2$* partial end-tidal CO_2 pressure, *MAP* mean arterial pressure out to be high ($f = 0.95$) in the post-hoc power analysis, and 99.9% power was reached at the 95% confidence level.

Regarding the dynamic changes of vital parameters in the 0–4 and 5–9 h, only the decrease in diastolic BP between 0 and 9 h was statistically significant ($p = 0.038$). Besides, MAP values indicated a significant decrease between 0–9 h and 5–9 h ($p = 0.024$ and $p = 0.049$, respectively) (Table 2).

15 (27.7%) individuals in the study group, all of whom were nonsmokers, continued performing their duties without a pause between 0 and 4 h. While baseline $PETCO_2$ level was measured as 35.13 ± 2.64 mmHg in those working without breaks, this level increased to 36.66 ± 3.33 mmHg at the 4th hour. When it comes to those working by taking breaks, their baseline $PETCO_2$ level, which was 34.92 ± 4.63 mmHg, rose to 36.07 ± 3.24 mmHg at the end of the 4th hour. In terms of the vital parameters of the subjects working with and without breaks, only $PETCO_2$ levels of those working uninterruptedly increased significantly at the 4th hour in comparison to the beginning-of-shift baseline levels ($p = 0.003$) (Table 3). When the relation between state of taking break and PETCO2 levels was evaluated by measure anova (with Bonferroni correction) and greenhouse tests, it was observed that taking a break was effective in the measurements between 0 and 4th hours at PETCO2 level ($p = 0.04$).

With respect to the subjective mask-driven complaints of those working with and without a pause between 0 and 4 h, 11 subjects (73.3%) suffered from shortness of breath, 11 (73.3%) individuals reported increased fatigue, 10 (66.7%) complained of headaches, and 15 (100%) came down with skin-bound complications, including persistent erythema and mask-induced scarring. The incidence of these perceived complaints among the subjects working with breaks remained significantly lower than their counterparts working without breaks ($p = 0.005$; $p = 0.0001$; $p = 0.029$, and $p = 0.002$, respectively) (Table 4).

Table 2 Vital parameter measurements of the study population

	0th hour	4th hours	5th hours	9th hours	p values
Heart rate (beat/min)	88.75 ± 13.85	89.24 ± 11.8	87.81 ± 11.1	88.27 ± 9.93	0.729* 0.772** 0.697*** 0.912
Body temperature (°C)	36.4 ± 0.16	36.42 ± 0.16	36.46 ± 0.18	36.4 ± 0.16	0.422* 1** 0.104*** 0.308
Systolic BP (mm/Hg)	129.09 ± 12.8	128.62 ± 12.64	128.07 ± 11.44	126.31 ± 12.69	0.737* 0.069** 0.272*** 0.512****
Diastolic BP (mm/Hg)	73.55 ± 11.1	72.59 ± 8.98	3.22 ± 9.57	70.35 ± 9.1	0.516* **0.038**** 0.056*** 0.673****
sPO_2	97.16 ± 1.29	97.37 ± 1.15	97.27 ± 1.12	97.42 ± 1.46	0.296* 0.284** 0.459*** 0.933****
$PETCO_2$ (mm/Hg)	35.4 ± 4.35	35.81 ± 3.09	35.85 ± 2.98	35.61 ± 3.51	0.492* 0.721** 0.513*** 0.931****
Shock index	0.69 ± 0.13	0.7 ± 0.11	0.69 ± 0.11	0.7 ± 0.09	0.704* 0.589** 0.369*** 0.714****
MAP	92.06 ± 10.01	91.27 ± 8.6	91.5 ± 8.83	89 ± 9.18	0.488* **0.024**** **0.049***** 0.483****

BP blood pressure, *$PETCO_2$* partial end-tidal CO_2

*p values are derived from paired sample t test and it refers to comparison between first measurement and second measurement; **p values are derived from paired sample t test and it refers to comparison between first measurement and forth measurement; ***p values are derived from paired sample t test and it refers to comparison between third measurement and forth measurement; ****p values are derived from repeated measure anova test (with Bonferroni correction) and Greenhouse Geisser test

Table 3 Vital parameter measurements of breaker and nonbreaker subgroups

		0th hour	4th hours	*p* values
Nonbreakers ($N=15$)	**Heart rate** (beat/min)	83.46 ± 10.57	81.8 ± 9.87	0.429*
	Fever (°C)	36.38 ± 0.18	36.43 ± 0.15	0.496*
	Systolic BP (mm/Hg)	129.13 ± 13.92	127.13 ± 13.75	0.275*
	Diastolic BP (mm/Hg)	72.46 ± 10.04	71.73 ± 8.72	0.794*
	sPO_2	97.6 ± 1.21	97.4 ± 1.21	0.567*
	$PETCO_2$ (mm/Hg)	35.13 ± 2.64	36.66 ± 3.33	**0.003*** **0.04****
	Shock index	0.65 ± 0.11	0.65 ± 0.12	0.876*
	MAP	91.35 ± 9.59	90.2 ± 8.82	0.978*
Beakers ($N=39$)	**Heart rate** (beat/min)	90.79 ± 14.52	92.1 ± 11.31	0.457*
	Fever (°C)	36.41 ± 0.16	36.42 ± 0.17	0.628*
	Systolic BP (mm/Hg)	129.07 ± 12.53	129.2 ± 12.33	0.943*
	Diastolic BP (mm/Hg)	73.97 ± 11.58	72.92 ± 9.17	0.555*
	sPO_2	97 ± 1.33	97.35 ± 1.18	0.128*
	$PETCO_2$ (mm/Hg)	34.92 ± 4.63	36.07 ± 3.24	0.141*
	Shock index	0.71 ± 0.14	0.71 ± 0.1	0.676*
	MAP	92.34 ± 10.27	91.68 ± 8.59	0.641*

BP blood pressure, *$PETCO_2$* partial end-tidal CO_2, *MAP* mean arterial pressure

*p values are derived from paired samples t test, and it refers to comparison the parameters between 0th hour and 4th hours; **p value is derived from repeated measure anova test (with Bonferroni correction) and Greenhouse Geisser test

The subjects, all of whom worked with a break between 5 and 9 h, were divided into two subgroups as those taking breaks of ≤ 30 min and > 30 min. Shortness of breath ($n=12$, 63.2%), increased fatigue ($n=11$, 57.9%), headaches ($n=16$, 84.2%), and skin-bound complications ($n=19$, 100%) accounted for the complaints of the subgroup with a break of ≤ 30 min. The incidence of these complaints in the > 30 min subgroup was significantly lower than that of the ≤ 30 min subgroup ($p=0.043$, $p=0.017$, $p=0.04$, and $p=0.0001$, respectively) (Table 4).

Table 4 Complaints of study population

Complaints		Nonbreakers (0–4th hours) ($N=15$)	Breakers (0–4th hours) ($N=39$)	*p* values
Shortness of breath	*Yes*	11 (73.3%)	11 (28.2%)	0.005*
	No	4 (26.7%)	28 (71.8%)	
Quick fatigue	*Yes*	11 (73.3%)	4 (10.3%)	0.0001*
	No	4 (26.7%)	35 (89.7%)	
Headache	*Yes*	10 (66.7%)	12 (30.8%)	0.029*
	No	5 (33.3%)	27 (69.2%)	
Skin problems	*Yes*	15 (100%)	23 (59%)	0.002*
	No	0	16 (41%)	
		Break time ≤ 30 min between 5 and 9th hours ($N=19$)	**Break time > 30 min between 5 and 9th hours** ($N=35$)	
Shortness of breath	*Yes*	12 (63.2%)	24 (58.6%)	0.043[a]
	No	7 (36.8%)	11 (31.4%)	
Quick fatigue	*Yes*	11 (57.9%)	8 (22.9%)	0.017[a]
	No	8 (42.1%)	27 (77.1%)	
Headache	*Yes*	16 (84.2%)	14 (40%)	0.004*
	No	3 (15.8%)	21 (60%)	
Skin problems	*Yes*	19 (100%)	13 (37.1%)	0.0001*
	No	0	22 (62.9%)	

*p values are derived from Fisher exact test

[a]p values are derived from chi square test

Discussion

This study reveals both the changes in vital signs of healthcare providers wearing N95 facemasks in the COVID-19 pandemic zones of ED and the subjective mask-induced complaints of these individuals. Accordingly, their diastolic BP and MAP values overall manifested a marked decrease between 0 and 9 h during the study, and the $PETCO_2$ levels of those not taking a break in the first 4 h were observed to remain higher those working with a break. In addition, those taking breaks while performing their duties were less likely to suffer from shortness of breath, increased fatigue, headache, and skin-bound problems than those working uninterruptedly. Furthermore, the same complaints were expressed less frequently by the individuals with a break time of > 30 min than the ones taking shorter breaks.

Cardiac output and peripheral vascular resistance are the major determinants of diastolic BP (DBP). During some exercise, such as running, cycling, and swimming, cardiac output increases in response to vasodilation of arterioles in exercising skeletal muscles, while peripheral vascular resistance decreases, thereby reducing DBP to some extent [24]. Moreover, Sainas et al. argued that MAP values tended to decrease following intense physical exertion [25]. Shahraki et al. likewise documented a decrease in DBP and MAP values of their subjects after 5 min of exercise [26]. Based on the measurements of vital signs and pCO2 levels of healthcare workers using N95 facemask after 1 h of treadmill exercise, Roberge et al. noted no significant difference in the physiological parameters between those wearing filtered and unfiltered masks [27]. Another trial in which surgical masks and N95 facemasks were tested on a total of 10 people found some clinical evidence for the impact of mask wearing on thermal stress and increased heart rate [28]. As identified by previous reports, while the overall patient population in ED showed a downward trend during the pandemic process, the burden of emergency services shifted dramatically to pandemic zones [29]. In the healthcare facility where the study data was collected, there was heavier workload and faster work pace during the period from the beginning of the morning shift to the noon time than in the afternoon period. On the other hand, our findings suggested that lower diastolic pressure and MAP values at the end of the shift than baseline measures might be attributed to the decreased peripheral vascular resistance and DBP as the individuals exerted physical effort. Though the systolic pressure and DBP did not drop significantly between 5 and 9 h, a slight decrease of both led to a significant reduction in the MAP values during this period. We also reckon that during the time interval of 5–9 h when all the healthcare providers took a break and relatively few patients visited the ED, the systolic and diastolic pressure levels did not manifest a decrease since they had the opportunity to rest longer.

PETCO2, which refers to partial pressure of CO_2 in the air exhaled during expiration, is one of the parameters considered in management of intubated patients in ED. Under normal circumstances, the value measured by the capnography at the end of expiration ranges between 35 and 45 mmHg. PETCO2, which is closely associated with pCO_2 level in arterial blood, is also known to provide an indication for pCO_2 levels [30]. In addition, previous literature reports established a direct correlation between $PETCO_2$ levels and the decrease in cardiac output [31, 32]. However, physiological parameters were reported not to signify a marked change between wearing a mask with and without filter after 1 h of treadmill exercise amongst healthcare providers using N95 facemask [27]. A study conducted on children noted no marked difference in their $PETCO_2$ levels measured while wearing N95 mask both at rest and during light exercise. Furthermore, hypoventilation developing after a prolonged use of PPE is considered to present major health concerns [33]. For instance, hypoventilation induced by long-term use of respiratory protection is likely to elevate $PETCO_2$ levels [34]. Therefore, hypoventilation may account for increased $PETCO_2$ levels relative to baseline in the healthcare providers working without rest in the first 4 h in our study. This assumption can be validated by the lack of change in $PETCO_2$ levels among those taking breaks and between 5 and 9 h when everyone took a break. Though working without resting sounds inhumane, it may not always be possible to give a break during hectic hours in ED over the course of the pandemic. The healthcare providers who work at pandemic polyclinics should be employed in appropriate shifts, with appropriate breaks.

PPE, especially protective masks, which has been re-introduced to the working life of medical staff through COVID-19 outbreak, affect working comfort, though they offer protection to healthcare workers against viral transmission. A substantial body of research in the literature draws attention to device-related discomfort of users while wearing N95 masks. For example, mask-induced complaints, such as shortness of breath, headache, and light-headedness, were reported to increase gradually among nurses wearing only an N95 or a surgical mask overlay with an N95 [35]. Besides, PPE-associated headache developed in 81% of healthcare providers based at pandemic outpatient clinics [36]. Another study likewise revealed that long-time wearing of N95 respirators was closely associated with headache complaints [37]. A recent study established that relatively long exposure time to N95 respirators (more than 6 h) also doubled (95%CI 1.35–3.01, and $p < 0.01$) the risk of developing skin damage among healthcare providers in addition to headache [38]. There was also some clinical evidence that healthcare staff reported increased fatigue and chest compression quality suffered when they performed cardiopulmonary resuscitation on manikin with an N95 respirator [39]. In line with the literature, complaints such as shortness of breath, increased fatigue, headache, and skin-related complications were expressed more frequently by those working without a break in the first 4-h period as well as those completing their shift with less than 30-min break. Even though these high rates declined substantially after giving a break, the fact that a total of 32 (59.25%) individuals reported persistent skin-related complaints is another aspect deserving attention in our study. We predict that the production materials of N95 respirators may be an underlying reason for such skin damage.

The primary limitation of our study was the absence of arterial blood gas analysis of the subjects because we did not explore the effect of changes in vital parameters upon blood gas values. Another limitation was the lack of relevant information on their baseline effort capacity. Although this seems to have posed a drawback for between-group analyses, these subjects were assumed to be above a certain effort capacity due to practicing in the same facility and at a similar pace for a long time. Since their vital signs during the day were taken into consideration, the effect of absence of required information on their effort capacity must have been relatively minor.

Conclusion

Even though the wearing of N95 facemasks may cause physical discomfort, such as headache, shortness of breath, and increased fatigue among ED healthcare providers, such discomfort might not impose stress on vital signs if appropriate rest breaks are taken. However, lack of a significant effect of wearing respiratory protection on vital parameters does not necessarily entail the ignorance of comfort-related complaints. Hospital management and local authorities as well as policy makers should consider that mask-induced problems might impair the physical performance of healthcare providers who afflicted with various complications. Accordingly, appropriate rest periods should be provided to frontline health workers.

Although the decrease in SBP and MAP values is assumed to be caused by increased fatigue due to workload and work pace as well as increase in muscle activity, the increase in $PETCO_2$ levels in the ED healthcare staff working with no breaks between 0 and 4 h should be noted in terms of PPE-induced hypoventilation.

Data availability All the data (other than patient names) are available to share.

Declarations

Conflict of interest The authors declare no competing interests.

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