Physiological Effects of Wearing N95 Respirator on Medical Staff During Prolong Work Hours in Covid-19 Departments

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Research Article

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Abstract

Background

Since the emergence of coronavirus disease, health care professionals in high-risk environments are mandated to wear N95 respirators for prolonged periods. The effect of this prolonged use on cardio-respiratory variables and gas-exchange is poorly defined. The objective of the current study was to determine gas exchange abnormalities and physiological changes among healthcare workers during a 4-hour emergency department (ED) shift while wearing the N95 respirator.

Methods

This was a single-center prospective observational study that consisted of medical staff working at the Sheba Medical Center ED. Physiological effects and gas exchange variables were obtained under normal breathing conditions and after 4-hour shifts while continuously wearing an N95 respirator. Comparisons of paired measurements were performed using a non-parametric Wilcoxon matched-pairs signed-rank test.

Results

Forty-one subjects were included in the study. Prolonged N95 respirator use was associated with a significant decline in plasma pH [7.35mmHg vs. 7.34mmHg, P=0.02], PvO_2 [23.2 mmHg vs. 18.6 mmHg, P<0.001] and a concurrent increase in $EtCO_2$ [32.5mmHg vs. 38.5mmHg, p<0.0001]. $PvCO_2$ and bicarbonate levels did not differ. No significant change was observed for heart rate or oxygen saturation.

Conclusion

Using an N95 respirator for prolonged periods by healthcare professionals may provoke changes in gas exchange. The clinical significance of these changes in terms of symptoms or longer-term health status is unknown and remains to be determined.

Background

Since the emergence of serious acute respiratory syndrome coronavirus 2 (SARS CoV 2), healthcare professionals are at constant risk of contracting the virus during their daily work. The primary route of transmission of SARS CoV 2 is via aerosol droplets[1], making the N95 (or FFP2) respirator an essential part of healthcare professionals' personal protective equipment (PPE). The N95/FFP2 respirator is a respiratory protective device designed to achieve a very close facial fit and filtration of greater than 95% of airborne particles greater than 0.3 microns. By comparison, the loose-fitting surgical mask used by patients and in non-high-risk medical environments creates a physical barrier to reduce the distance of spread of aerosol droplets in the immediate environment.

The effectiveness of N95 respirators and facial masks in reducing transmission of SARS CoV 2 has been demonstrated in a number of clinical studies and meta-analysis[2–4], and therefore healthcare workers internationally are mandated to wear masks during their usual daily work with patients. Prolonged mask use has been shown to be associated with various symptoms, including headache[5], dizziness, facial dermatological symptoms[6], as well as other interferences with occupational duties[7]. However, research examining potential physiologic impacts of N95 respirators during long work shifts of healthcare workers has been limited. The objective of the current study was to determine gas exchange abnormalities and physiological changes among healthcare workers during a 4-hour emergency department (ED) shift while wearing the N95 respirator.

Materials And Methods

Study design and population

This was a single-center prospective observational study approved by the Institutional Research Ethics Board. Signed informed consent was obtained from all participants. The study population comprised physicians, nurses, and medical trainees working at the Sheba Medical Center ED between September and November 2020 who were assessed during 4-hour shifts while continuously wearing an N95 respirator. Subjects with any health condition that could potentially put them at risk, such as chronic obstructive pulmonary disease, uncontrolled asthma, pulmonary hypertension, or poorly controlled heart failure, were excluded. Baseline demographic data were collected, including age, gender, medical history, and previous or active cigarette smoking.

Physiologic measurements

Subjects, at the beginning of their ED shift, were instructed to avoid any mask use for at least 15 minutes, whilst isolated away from the clinical area, to ensure baseline measurements were obtained under normal breathing. Participants were then asked to wear the N95 respirator continuously and begin their ED shift. All subjects were provided N95 respirators (Kimberly-Clark, Irving, Texas, US) for this study. Physiological measurements, including oxygen saturation and heart rate (HR), were captured at baseline and each hour up to 4 hours using an O_2 saturation oximeter (Welech allyn- Vital Signs Monitor 6000, Skaneateles Falls, NY, USA). A 2CC of venous blood sample was drawn at baseline and at 4-hours (before the N95 mask was removed), using a syringe washed with heparin. The sample was immediately analyzed using a gas analyzer machine (Siemens RAPIDPoint 500, Siemens Healthcare Limited, UK). pH level, partial pressure of venous oxygen (PvO_2), partial pressure of venous carbon dioxide ($PvCO_2$), and bicarbonate (HCO_3) level were recorded. End-tidal carbon dioxide ($EtCO_2$) level was measured through non-invasive nasal prongs (Microstream CapmoLine, Philips, UK) representing the $EtCO_2$ levels at 4-hours. After ensuring the first $EtCO_2$ level and a typical capnography waveform, participants were asked to remove the respirator while the $EtCO_2$ levels were continuously monitored. The lowest $EtCO_2$ level at room air and the time required to reach it were recorded.

Statistical analysis

Demographic characteristics were assessed as counts and percentages for categorical variables and standard measures (median and interquartile range (IQR)) for continuous variables. Comparisons of paired measurements were performed using a non-parametric Wilcoxon matched-pairs signed-rank test. All statistical analyses were performed with GraphPad Prism version 5.01 software (GraphPad Software, La Jolla, CA, USA). A p-value < 0.05 was considered statistically significant.

Power calculation

Based on a study that examined the physiological impact of wearing an N95 mask during hemodialysis[8], with a sample size of 41 pairs (of observations), we have 85% power and a level of significance of 5% (two-sided) for detecting a mean of differences of 9.0 mmHg in PaO_2 between pairs, assuming a standard deviation of the differences to be 18.5.

Results

Study cohort

Forty-one subjects completed the study. Fifteen (36%) were nurses, 12 (30%) physicians, 9 (22%) medical trainees, and 5 (12%) were domestic workers. Forty (52%) were male. Median age was 34 (interquartile range 29, 37). Baseline characteristics are summarized in Table 1.

Physiological variables

Wearing an N95 respirator for 4-hour shift was associated with a significant decrease in PH [7.35mmHg (7.32,7.37) at baseline vs. 7.34mmHg (7.32,7.35) at 4 hours, $P = 0.02$] and PvO_2 [23.2 mmHg (18.2,34.5) at baseline vs. 18.6 mmHg (14.6, 23.8) at 4 hours, $P < 0.001$]. The change in PCO_2 [49.5mmHg (44.9, 53.1) at baseline vs. 50.5mmHg (47.1, 56.9) at 4 hours, $P = 0.22$] or bicarbonate [26.2mEq/L (25.3, 28.6) at baseline vs. 26.6mEq/L (24.5, 28.7) at 4 hours, $P = 0.53$)] did not reach statistical significance. Results are summarized in Fig. 1. There was no significant change in HR or oxygen saturation. Median $EtCO_2$ under normal unmasked conditions and at 4 hours was 32.5mmHg (29.8, 35) vs. 38.5mmHg (34, 41), respectively ($p < 0.0001$).

Discussion

During this SARS CoV 2 pandemic, global healthcare systems have quickly realized the importance of protecting front-line workers with effective PPE. To reduce the risk of transmission to staff, N95 respirators (or the equivalent FFP2 standard) are typically worn by medical and paramedical staff in high-risk environments for prolonged periods of time without removal. The effect of this prolonged use on cardio-respiratory variables such as heart rate and gas-exchange are poorly defined. Our findings suggest

that gas exchange is influenced by prolonged wearing of the N95 respirator, as demonstrated by a decline in plasma pH, PvO_2, and a concurrent increase in $EtCO_2$. There were no significant changes in $PvCO_2$ or bicarbonate levels. Heart rate, as well as oxygen saturation determined by pulse oximetry, were unaffected.

These findings add to previous work evaluating the impact of prolonged N95 respirator use on blood gases and physiology. Overall, available data suggest that changes in blood gases and other physiological parameters caused by N95 respirators during physical activity are small even during very heavy exercise[9]. In 2004, during the severe acute respiratory syndrome (SARS) outbreak in Taiwan, Kao et al. investigated the physiological impact of wearing an N95 respirator during hemodialysis on 39 patients with end-stage renal disease. 70% of participants had a reduction in the partial pressure of oxygen in arterial blood (PaO_2), and 19% developed various degrees of hypoxemia[8]. The physiological effect of N95 respirators among healthcare professionals was investigated by Rebmann et al., who demonstrated a small but significant increase in CO_2 levels among ten intensive care unit nurses who used N95 respirators for 12-hour shifts[10]. Although CO_2 concentration differences were not statistically significant in our study, there was an upward trend after a 4-hour shift. A lack of power due to the small sample size may explain the variance between these findings and those of the present study.

The physiological impact of N95 respirator use during physical effort has been previously evaluated during exercise using a treadmill[11,12] with findings supporting mild increases in CO_2 levels but no impact on respiratory rate, tidal volume, or breathing pattern. In the current study, we did not demonstrate a change in HR or pulse oximetry, possibly implying the physiological effects in healthy individuals are small and unlikely to lead to any adverse consequences. However, the changes in pH, PvO_2, and $EtCO_2$ suggest a degree of hypoventilation and/or CO_2-rebreathing that may be provoked by wearing N95 respirators for prolonged, uninterrupted periods. The effect of these changes during longer shifts or where additional tape is used to seal the mask further and in those workers with pre-existing cardio-respiratory disease has not been defined. Several studies have suggested mechanistic links between chronic intermittent hypoxemia and increased production of reactive oxygen species, endothelial dysfunction, systemic inflammation, and pulmonary hypertension[13,14], which may lead to longer-term consequences in susceptible individuals.

Strengths of this study include the use of N95 respirators by healthcare professionals in a typical setting of a 4-hour ED shift and the use of invasive blood gas assessment as well as non-invasive indices such as $EtCO_2$ and pulse-oximetry for comparison. Limitations include the use of venous rather than arterial blood gas measurements to make it more comfortable for the study participants and provide an approximation to arterial values. Venous pH and pCO_2 correlate well with arterial values (although they are not interchangeable) but are unsuitable for determining patient oxygenation[15,16]. The study also did not capture self-reported symptoms, so correlations with physiological changes could not be explored. Of course, a control group without N95 masks was not possible due to safety concerns. Future studies should include healthcare workers wearing these respirators for longer shifts, including those in ‘Corona

units' where additional precautions such as hoods and tape may increase the seal on the face. Also, the effect of prolonged use of these respirators in smokers and those with pre-existing cardiorespiratory disease or obesity is not known and is relevant as these PPE devices will be widely used for the foreseeable future in hospitals.

Conclusion

Using an N95 respirator for prolonged periods by healthcare professionals may provoke changes in gas exchange. The clinical significance of these changes in terms of symptoms or longer-term health status is unknown and needs to be determined.

Abbreviations

ED: emergency department

PvO2: partial pressure of oxygen tension in Mixed venous blood

PvCO2: partial pressure of Carbon Dioxide In Mixed Venous Blood

EtCO2: End tidal CO2

PPE: Personal protective equipment

HR: heart rate

IQR: interquartile range

SARS CoV 2: Severe acute respiratory syndrome coronavirus 2

Declarations

Ethics approval and consent to participate: This was a single-center prospective observational study approved by the Institutional Research Ethics Board. Signed informed consent was obtained from all Participants.

Consent for publication: the manuscript doesn't contain any individual person's data in any form.

Availability of data and material: The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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Authors' contributions: LS carried out the conceptualization and the data curation. GBH participated in the collection of the data and the recruitment of participants. SC helped in writing and reviewing the draft. IBZ participated in the design and the review of the study. AI participated in study design and coordination. LS participated in study design and coordination. EH participated in the design of the study and performed the statistical analysis. LL conceived of the study, and supervised its coordination.

All authors read and approved the final manuscript.

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Figures

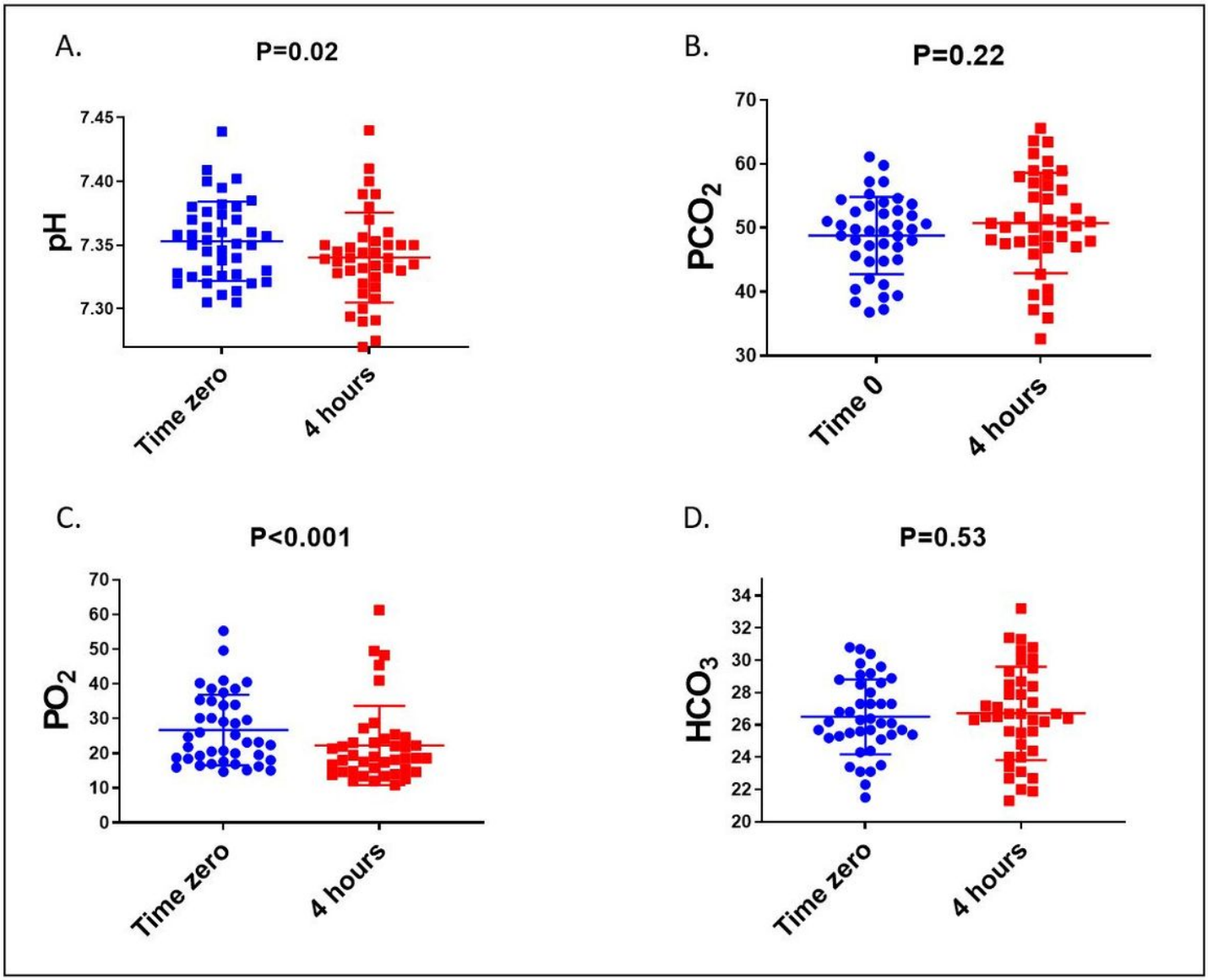

Figure 1

Effects of prolonged N95 respirator use on pH level (A); partial pressure of venous carbon dioxide (PCO2) (B); partial pressure of venous oxygen (PO2) (C); bicarbonate level (HCO3) (D).