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Physiological effects of N95 respirators on rescuers during cardiopulmonary resuscitation

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ABSTRACT

Objectives: There is a lack of evidence in the medical literature reporting the physiological stress imposed by the wearing of N95 respirators during cardiopulmonary resuscitation (CPR) in healthcare providers. The aim of this study is to monitor the changes in hemodynamics and blood gas profiles in rescuers during the performance of CPR while wearing N95 respirators.
Methods: Thirty-two healthy healthcare workers performed standard CPR on manikins, each participant conducted 2 min of chest compression followed by 2 min of rest for 3 cycles. A non-invasive blood gas measuring device via a fingertip detector was used to collect arterial blood gas and hemodynamic data. Student t-test was used for comparison of various physiologic parameters before and after each session of chest compression.
Results: There were no significant differences in arterial blood gas profiles including partial pressure of arterial carbon dioxide and partial pressure of arterial oxygen before and after each session of chest compression ($p > 0.05$ for all). Heart rate and cardiac output were significantly higher after CPR ($p < 0.05$ for all), but no significant changes were found on blood pressure.
Conclusions: Our data suggest that healthcare providers wearing N95 respirators during provision of CPR in a short period of time does not cause any significant abnormalities in blood gas profiles and blood pressure. This may provide evidence to reassure the safe use of N95 respirator during performance of CPR.

1. Introduction

Provision of cardiopulmonary resuscitation (CPR) has long been the hallmark of cardiac arrest management. The 2020 American Heart Association guidelines reaffirm the importance of high-quality and effective chest compressions for both out-of-hospital cardiac arrest (OHCA) and in-hospital cardiac arrest (IHCA). When performing standard CPR, emergency medical technicians and emergency medical staff often need to wear masks for their own safety to avoid infections transmitted by aerosol droplets or air current. This precautionary practice is especially crucial during the current pandemic of COVID-19. However, the implementation of standard CPR requires a considerable amount of physical exercise and is rather demanding on the respiratory work of the rescuer. Although the application of mechanical compression devices can reduce the requirement for conventional manual chest compressions, however, these devices may not be appropriate for all clinical scenarios, e.g., morbidly obese adults, infants, children, or small adolescents [1].

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Previous studies had revealed the increase in carbon dioxide (CO_2) concentrations within N95 masks and increase in end-tidal carbon dioxide ($EtCO_2$) levels with N95 respirators use [2,3]. Elevation of CO_2 could result in hemodynamic changes in the intracranial arteries and was considered a contributor leading to fatigue, dizziness, headache, shortness of breath, generalized weakness, lethargy and drowsiness [4]. These objective findings arouse the sense of insecurity and had raised concerns in hypercapnia when wearing N95 respirators during vigorous work or exercise. The users of N95 respirators would expect more evidence-based reassurance for the safety level (in terms of physiological data) during CPR.

To date, there are no studies in the medical literature reporting the investigation of hemodynamics and blood gas profiles imposed by the wearing of N95 respirators in healthcare providers during CPR. Information on occupational hazards, including compromise in respiratory function, hemodynamic changes and safety precautions constitute an important health issue. The aim of this study is to monitor the changes in hemodynamics and blood gas profiles in rescuers during the performance of CPR while wearing N95 respirators by using a new type of miniaturized fingertip device.

2. Materials and methods

2.1. Study design

This non-randomized intervention study compared hemodynamic parameters and blood gas profiles before and after performing CPR on manikins among healthcare workers. Participants were recruited from the emergency department of the Kaohsiung Medical University Hospital, a tertiary center in southern Taiwan.

University Hospital, a tertiary center in southern Taiwan. The tested subjects were requested to wear N95 respirators and performed standard CPR on manikins. Each participant conducted 2 min of chest compression followed by 2 min of rest for 3 cycles. A non-invasive blood gas measuring device via a fingertip detector was used to collect both arterial blood gas and hemodynamic data soon after each session of chest compression (Fig. 1). This simulation scenario made up for 12 min of CPR. In real world, the median duration of resuscitation in those with return of spontaneous circulation was 13.5 min in OHCA and 12 min in IHCA [5,6].

2.2. Participants

Healthcare providers between 20 and 65 years old were eligible for enrollment in the study by convenience sampling. Exclusion criteria include recent diseased conditions of any kinds, current pregnancy, and recent use of medications of any types. Participants provided written informed consent prior to enrolment. Thirty-two healthcare providers, including 25 nurses (78%) and 7 doctors (22%), were enrolled in this study from March 2021 to August 2021. Among the 32 participants, the mean age was 38.63 ± 8.07 years, 19 (59%) of them were female, and 13 (41%) were male. None of the recruited healthcare workers refused to participate or were excluded.

2.3. Measurements

2.3.1. Equipment

All participants wore a N95 respirator (F550, Champak Enterprise Co., Ltd, Taiwan) while performing standard CPR. A non-invasive blood gas measuring device, Tensor Tip MTX (Cnoga Medical Limited, Israel), was used for hemodynamics and blood gas profiles collection via a fingertip detector instead of traditional invasive arterial puncture. The device contains four monochromatic light sources in the visual to infrared spectrum (~600 to ~1000 nm) and radiates light at different wavelengths traversing the finger capillary tissue. It was then being projected onto the real time color image sensor and analyzed by dedicated Digital Signal Processor

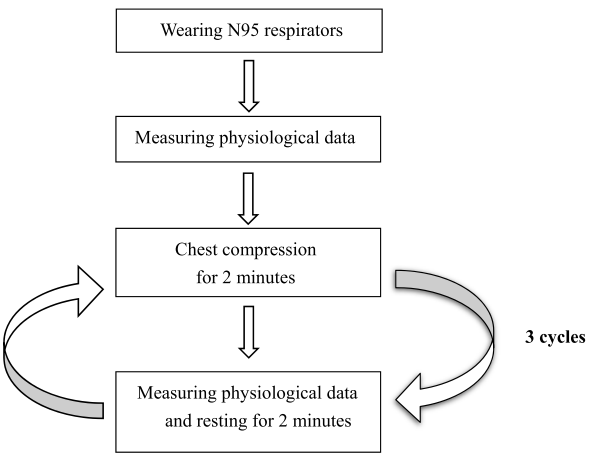

Fig. 1. Schematic diagram of the study design.

algorithms for computing various bio-parameters including hemodynamics, blood gases and hematology [7].

2.3.2. Measurement of physiological parameters

We recorded the various physiologic parameters as determined noninvasively by the device on the participant's finger according to the instructions for use. Physiological data including heart rate (HR), systolic blood pressure (SBP), diastolic blood pressure (DBP), mean arterial blood pressure (MAP), cardiac output (CO), hematocrit (Hct), blood oxygen saturation (SpO_2), partial pressure of arterial carbon dioxide ($PaCO_2$), and partial pressure of arterial oxygen (PaO_2) were collected via this non-invasive device. The aforementioned physiological data were collected before and soon after each session of chest compression. The hematocrit data served as a "housekeeping data" that guarantees the reliability of the non-invasive physiologic monitor, since wearing N95 during CPR should not bring about any change in hematocrit.

2.4. Statistical analysis

Continuous variables are expressed as mean ± standard deviation (SD). Statistical analyses were performed using SPSS version 19.

Table 1
Hemodynamic, hematocrit and arterial blood gas data before and after chest compression.

Parameter Duration of chest compression	Unit	Mean	SD
HR	bpm		
0 min		74.2813	13.56997
2 min		85.2188	16.93200
4 min		86.9688	16.56947
6 min		86.9063	16.86256
SBP	mmHg		
0 min		129.8438	13.95409
2 min		131.2813	14.25852
4 min		130.1563	10.70155
6 min		130.7813	11.34143
DBP	mmHg		
0 min		81.6875	10.61477
2 min		81.7500	10.93087
4 min		80.7500	8.10018
6 min		80.7500	8.51564
MAP	mmHg		
0 min		91.3438	10.24730
2 min		92.0625	10.65269
4 min		91.5000	7.91894
6 min		88.4469	17.84838
CO	l/min		
0 min		4.7469	1.04665
2 min		5.2313	1.17650
4 min		5.4437	1.24795
6 min		5.5250	1.05861
Hct	%		
0 min		43.5625	1.50134
2 min		43.8438	1.46154
4 min		43.5625	1.58496
6 min		43.7813	1.36155
SpO_2	%		
0 min		96.8438	0.67725
2 min		97.0000	0.62217
4 min		96.8125	0.82060
6 min		96.9063	0.77707
$PaCO_2$	mmHg		
0 min		36.4375	1.21649
2 min		36.1875	0.96512
4 min		36.5625	1.38977
6 min		36.3438	1.31024
PaO_2	mmHg		
0 min		86.9688	5.67669
2 min		88.6250	5.92289
4 min		87.1563	7.27838
6 min		87.6875	6.49286

HR, heart rate; SBP, systolic blood pressure; DBP, diastolic blood pressure; MAP, mean arterial blood pressure; CO, cardiac output; Hct, hematocrit; SpO_2, blood oxygen saturation; $PaCO_2$, partial pressure of arterial carbon dioxide; PaO_2, partial pressure of arterial oxygen; bpm, beats per minute; mins, minutes; SD, standard deviation.

Student t-test was used for comparison of various physiologic parameters before and after each session of chest compression and p-values <0.05 were considered statistically significant.

2.5. Ethical considerations

We conducted this study in line with the Declaration of Helsinki. All participants received both oral and written information describing the purpose of the investigation, and they were informed that they could withdraw from the study at any time. Data were collected anonymously and were identified. The study protocols were approved by the institution review board of Kaohsiung Medical University Hospital (IRB Number: KMUHIRB-E (I)-20210031).

3. Results

Physiological parameters of the thirty-two healthcare providers recruited in this study before and after 3 cycles of chest compression are presented in Table 1.

3.1. Hemodynamic data

When comparing the hemodynamic status of the tested subjects observed before and after each session of chest compression, HR (74.28 ± 13.57, 85.22 ± 16.93, 86.97 ± 16.57, 86.91 ± 16.86 bpm) and CO (4.75 ± 1.05, 5.23 ± 1.18, 5.44 ± 1.25, 5.26 ± 1.06 L/min) were significantly higher after CPR ($p < 0.05$). The rest of the parameters including SBP, DBP, MAP and Hct were not significantly different before and after each session of chest compression ($p > 0.05$ for all) (Table 2, Fig. 2A–C).

3.2. Arterial blood gas profiles

The mean $PaCO_2$ before and after each session of chest compression were 36.44 ± 1.22, 36.19 ± 0.97, 36.56 ± 1.39 and 36.34 ± 1.31 mmHg. The mean PaO_2 before and after each session of chest compression were 86.97 ± 5.68, 88.63 ± 5.92, 87.16 ± 7.28 and 87.69 ± 6.49 mmHg. The mean SpO_2 before and after each session of chest compression were 96.84 ± 0.68, 97.00 ± 0.62, 96.81 ± 0.82, 96.91 ± 0.78% (Table 1). There were no significant differences in arterial gas profiles, including $PaCO_2$, PaO_2 and SpO_2, before and after each session of chest compression ($p > 0.05$ for all) (Table 3, Fig. 2D–F).

Table 2
Differences of hemodynamic and hematocrit data before and after CPR.

Parameter	Paired differences				*P*-value
	Mean	SD	95% CI		
			Lower	Upper	
HR					
0–2 min	−10.93750	8.16735	−13.88214	−7.99286	**0.000**
0–4 min	−12.68750	9.72671	−16.19435	−9.18065	**0.000**
0–6 min	−12.62500	9.83329	−16.17028	−9.07972	**0.000**
SBP					
0–2 min	−1.43750	11.05394	−5.422875	2.54787	0.467
0–4 min	−0.31250	10.69349	−4.16792	3.54292	0.870
0–6 min	−0.93750	11.12375	−4.94804	3.07304	0.637
DBP					
0–2 min	−0.06250	7.70813	−2.84158	2.71658	0.964
0–4 min	0.93750	8.29278	−2.05237	3.92737	0.527
0–6 min	0.93750	8.23814	−2.03267	3.90767	0.524
MAP					
0–2 min	−0.71875	7.78847	−3.52679	2.08929	0.605
0–4 min	−0.15625	7.53533	−2.87303	2.56053	0.907
0–6 min	2.89687	18.89389	−3.91510	9.70885	0.392
CO					
0–2 min	−0.48438	1.07766	−0.87291	−0.09584	**0.016**
0–4 min	−0.69687	1.31013	−1.16923	−0.22452	**0.005**
0–6 min	−0.77813	1.04657	−1.15545	−0.40080	**0.000**
Hct					
0–2 min	−0.28125	1.11397	−0.68288	0.12038	0.163
0–4 min	−0.00000	1.27000	−0.45788	0.45788	1.000
0–6 min	−0.21875	1.8415	−0.64568	0.20818	0.304

Minutes means cumulative time of chest compression.
HR, heart rate; SBP, systolic blood pressure; DBP, diastolic blood pressure; MAP, mean arterial blood pressure; CO, cardiac output; Hct, hematocrit; SD, standard deviation; CI, confidence interval.

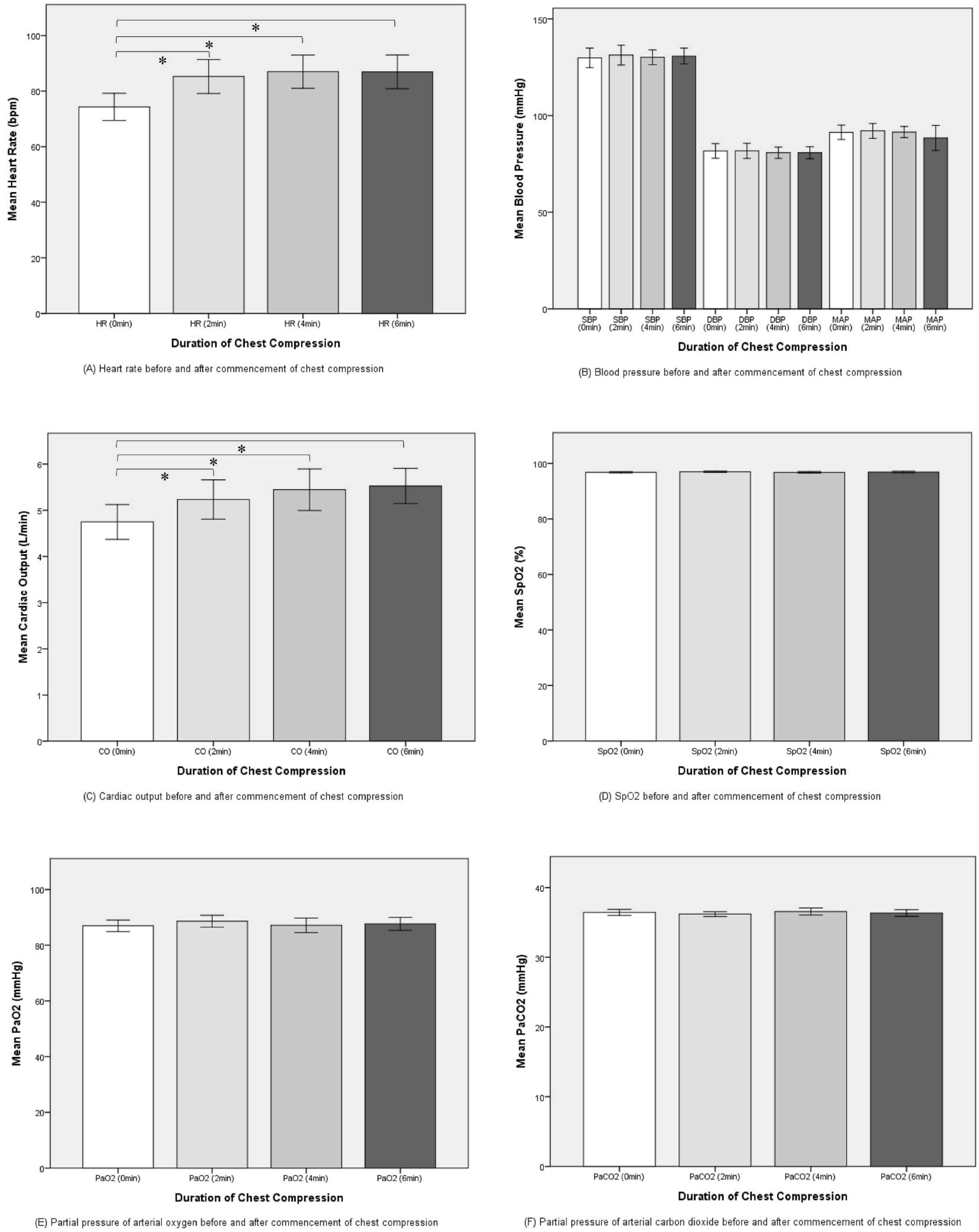

Fig. 2. Various physiological parameters before and after each session of chest compression. Mean ± two standard deviations of each parameter were shown. Asterisks (*) denote the significant differences found when comparing the means with those at 0 min ($p < 0.05$). (A) HR, heart rate. (B) SBP, systolic blood pressure; DBP, diastolic blood pressure; MAP, mean arterial blood pressure. (C) CO, cardiac output. (D) SpO_2, blood oxygen saturation. (E) PaO_2, partial pressure of arterial oxygen (F) $PaCO_2$, partial pressure of arterial carbon dioxide.

4. Discussion

In this study, we examined the changes of arterial blood gas and hemodynamic profiles of emergency medical staff wearing N95 respirators before and during CPR by using a non-invasive blood gas measuring device. There were no significant differences in arterial blood gas profiles, including $PaCO_2$, PaO_2 and SpO_2, before and after each session of chest compression. The hemodynamic data in our study revealed that heart rate and cardiac output were significantly higher after CPR, but no statistical differences in blood pressure (SBP, DBP and MAP). As far as we know, there is currently no relevant research on whether wearing N95 masks to perform CPR for

Table 3
Differences of arterial blood gas data before and after CPR.

Parameter	Paired differences				p-value
	Mean	SD	95% CI		
			Lower	Upper	
SpO_2					
0–2 min	−0.15625	0.76662	−0.43264	0.12014	0.258
0–4 min	0.03125	0.89747	−0.29232	0.35482	0.845
0–6 min	−0.06250	0.87759	−0.37890	0.25390	0.690
$PaCO_2$					
0–2 min	0.25000	1.21814	−0.18919	0.68919	0.255
0–4 min	−0.12500	1.47561	−0.65701	0.40701	0.635
0–6 min	0.09375	1.39952	−0.41083	0.59833	0.707
PaO_2					
0–2 min	−1.65625	6.64107	−4.05061	0.73811	0.168
0–4 min	−0.18750	7.57090	−2.91710	2.54210	0.889
0–6 min	−0.71875	7.09036	−3.27510	1.83760	0.570

Minutes means cumulative time of chest compression.
SpO_2, blood oxygen saturation; $PaCO_2$, partial pressure of arterial carbon dioxide; PaO_2, partial pressure of arterial oxygen; SD, standard deviation; CI, confidence interval.

patients will have a negative impact on the health of rescuers. This study can provide relevant information for frontline first responders in the face of aerosol droplets or airborne infections. The results showed that blood gas profiles or blood pressure were not significantly affected in rescuers wearing N95 masks during CPR.

The general subjective impression of wearing N95 respirators is usually described as "stuffy" or even "smothering" by most healthcare workers during daily practice. One study has shown that the microclimate temperature, humidity, skin temperature inside the facemask, together with perceived humidity, heat, breathing resistance, fatigue and overall discomfort, were significantly higher for N95 masks than for surgical masks [8]. Wearing N95 respirators can result in an increase in anatomic dead space, with estimated experimental dead space volumes ranging from 98.4 to 165.7 ml. Increasing dead space can lead to decreased clearance of CO2 and reduced oxygenation, as a result of elevated alveolar CO2 levels [9]. Rebreathing of CO_2 rich expired air and impair air exchange will result in increased levels of CO_2 and decrease in oxygen levels within the N95 respirators. Significant increase in CO_2 concentrations within N95 masks with routinely used for 15 min in healthy subjects had been reported, although such levels still remain within the National Institute for Occupational Safety and Health limits for short-term use [3]. Another study revealed exercising with N95 mask was associated with minor changes in physiological parameters, particularly a mild increase in EtCO2 levels after short-term moderate-strenuous aerobic physical activity in healthy subjects [2]. Additionally, the efficiency of ventilation decreases, causing an increase in the work of breathing. This can result in higher minute volume requirements [10]. One study showed a mean increment of 126 and 122% in inspiratory and expiratory flow resistances, respectively, and an average reduction of 37% in air exchange volume with the use of N95 respirators [11]. Despite the respiratory effects associated with N95 respirators mentioned above, our study did not reveal significant abnormalities in the level of PaCO2. $EtCO_2$ is normally 2–5 mm Hg lower than $PaCO_2$. Many factors may affect the $PaCO_2$-$EtCO_2$ difference, including increased dead space, rebreathing of expired CO_2 or during vigorous exercise. Thus, $EtCO_2$ may not be a reliable surrogate for measured arterial CO_2 when wearing N95 respirators during strenuous exercise. This may explain the difference between our results and previous studies.

Arterial blood gas analysis has the advantage of precise assessment of ventilation, gas exchange and acid-base status [12]. Unfortunately, it could only be measured conventionally by collecting arterial blood samples from the tested subjects, which, is ethnically unacceptable due to the invasiveness of the procedure itself in our study. To the best of our knowledge, there is only very limited data reporting the effects of real arterial blood gases by arterial puncture when wearing N95 respirators. Kao et al. measured arterial blood gas by blood sampling during hemodialysis in 39 patients with end-stage renal disease during the SARS outbreak, which revealed significantly reduced PaO_2 and increased respiratory distress during hemodialysis [13]. Fikenzer et al. collected capillary blood from the earlobe instead of arterial puncture in 12 healthy males. He reported that the partial pressure of carbon dioxide and partial pressure of oxygen did not differ significantly after an incremental exercise test [14]. To overcome these challenges, previous studies used non-invasive methods to indirectly measure physiological responses. Subjective symptoms, vital signs, and pulse oximetry have been commonly used to evaluate the effects of N95 respirators. Such indirect clues provide a far-from-comprehensive picture of physiologic effects including arterial blood gas and hemodynamic changes when the rescuers put on their air-tight N95 respirators during CPR.

A portable pulse oximeter is convenient for noninvasive measurement of blood oxygen saturation. Previous study had reported that the blood oxygen saturation measuring by a portable pulse oximeter was not associated with significant change in healthcare workers wearing N95 respirators during routine clinical duty [15]. Our research results also show no significant differences in SpO_2 and PaO_2 after CPR. However, pulse oximeter cannot measure $PaCO_2$, an essential indicator of ventilation and respiratory function, and is not a complete measure of respiratory sufficiency. Transcutaneous carbon dioxide is a non-invasive surrogate measure correlates well with $PaCO_2$ in health subjects and acute respiratory disease [16,17]. It is now a useful tool in many clinical applications like sedation monitoring in procedures and for respiratory and hemodynamic monitoring in neonatology or critical care units [18,19]. Noninvasive transcutaneous carbon dioxide monitors have been developed since the late 1970s. Previous challenges include calibration, site changes, elevated temperature and associated burns due to it depend on an increased capillary blood flow by increasing the temperature of underlying tissue with a heating element in the electrode [20]. During the past decade, there have been steady advances in noninvasive blood gas and hemodynamic monitoring in the clinical setting. The recent emergence of a new generation of non-invasive blood gas analyzers based on artificial intelligence engined by big data has brought about a ray of hope in scientific research that involves the investigations of blood gas profiles and hemodynamics simultaneously within a short period of time [7,21]. In order to measure both hemodynamics and blood gas profiles within 2 min in our study, we used this new fingertip measuring device, which make us could obtain rich information including $PaCO_2$, PaO_2, SpO_2 as well as CO, HR and BP within a short period of time.

In this study, the heart rate and cardiac output had significant increase after chest compression, but no significant changes were found on blood pressure. One systemic review study compared BP and HR during exercise between subjects with and without wearing N95 respirators during exercise [22]. No difference in either systolic or diastolic blood pressure were found. The use of N95 masks during exercise increased heart rate compared with not wearing a mask. This is similar to our experimental findings. Only one study assessing cardiac output found no significant effects on cardiac output [14].

Recent study revealed wearing an N95 mask have a marked negative impact on ventilation and cardiopulmonary capacity in healthy individuals [14]. It may also increase rescuer's fatigue and decrease chest compression quality during CPR [23]. The American Heart Association suggests that when performing chest compressions during CPR, the rescuers should switch duties every 2 min to minimize rescuer fatigue and maintain high-quality chest compressions. Although our study showed no obvious change of arterial gas profiles and blood pressure during performance of CPR for 3 cycles, further investigations of the timing in rescuers exchange is crucial when wearing N95 respirators.

This simulation study has several limitations. Firstly, this study collected data from a small sample size of tested subjects during a relatively short duration of CPR. The generalizability of our estimation to longer time of CPR is limited. However, more rescuers may join in the second half of the resuscitation in real world CPR. This means they could switch duties. Therefore, the time of chest compression will be shortened. Secondly, only healthy participants were enrolled in the study. Therefore, the results in our study are not generalizable to all health workers. Thirdly, although standard chest compressions were performed upon CPR manikins, the quality of chest compressions may not be the same as that of real patient scenarios. Fourthly, arterial blood gas sampling followed by partial pressures analysis is still the gold standard method for the assessment of oxygenation and ventilation that cannot be replaced by any non-invasive method. However, it is ethically impractical in human studies due to the invasiveness of arterial puncture in healthy healthcare providers such as those recruited in our study. In order to obtain various physiologic parameters within 2 min, this is the best option we can choose. Fifthly, this study is to explore the physiological impact of rescuers wearing N95 masks before and after performing CPR at different times. We did not use no mask or surgical mask as a control group, so we cannot know from this study whether rescuers experience different physiological effects when performing CPR with an N95 mask versus without a mask or surgical mask.

5. Conclusion

The results of this study are the first to provide further evidence-based support for rescuers to ensure that their blood gas profiles and blood pressure remain normal while wearing N95 respirators during CPR. Further investigations in physiological stress imposed on the rescuers wearing N95 during CPR should be conducted.

Declarations

Author contribution statement

Chi-Wei Lee takes responsibility for the overall content as guarantor. Shih-Chia Yang designed the study, planned the data collection and wrote the first draft of this manuscript. Chi-Wei Lee contributed to the data interpretation, drafted the manuscript and provided revisions. All authors approved the final version.

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Data availability statement

Data included in article/supp. material/referenced in article.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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