The impact of FFP3 respirators on the blood saturation of intensive care unit medical staff.

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Abstract

Background

Recent studies support the effectiveness of filtering facepiece class 3 respirators (FFP3) during the COVID-19 pandemic in terms of protecting both health care workers (HCWs) and patients. However, wearing FFP3 respirators together with personal protective equipment (FFP3/PPE) could increase the feeling of discomfort or could even cause hypoxia. This study aims to investigate whether wearing an FFP3/PPE during work in the intensive care unit (ICU) affects the blood saturation (SpO₂), the heart rate (HR), and the well-being of HCWs, as depicted by a score scale.

Methods

The study included a group of 21 volunteers, staff nurses, students and consultants (including 16 females (76%), with a median age of 23 years (interquartile range 21-27), range 20-59 years).

We applied a counterbalanced crossover design—a self-controlled trial. Each subject served as his own control and performed the test two times: they wore the FFP3/PPE for a three-hour shift in the ICU and then did not wear the FFP3/PPE for 3 hours. To record the SpO₂ and HR in real time, we used a Nellcor PM10N (Covidien, USA) portable monitoring system. Additionally, every 30 minutes during the shift and control run, each subject completed a questionnaire concerning their well-being, with a score scale to evaluate for headaches, shortness of breath, perspiration, fatigue, and thirst.

Results

The mixed model demonstrated that working with an FFP3/PPE compared to not working with an FFP3/PPE caused a significant, but still within normal ranges, influence on the level of SpO₂, with a mean decrease of -1.43%. The highest reduction in the SpO₂ was 2.29%, and occurred after 150 minutes of work. We also found a significant increase in the HR at 60, 90, and 120 minutes after starting work. All of the score scales of the well-being markers increased consecutively but were moderate during the shift while wearing the FFP3/PPE; the side effects were mainly fatigue, thirst, and sweating.

Conclusion

We assume that a 3 hour shift rhythm –, i.e., three hours of working in the FFP3/PPE in the ICU, followed by rest or working without an FFP3/PPE is a safe and reliable solution.

Background

During the COVID-19 pandemic, there has been greater attention given to surgical masks, eye protection (safety spectacles or goggles), and personal protective equipment (PPE).

Healthcare workers (HCWs) who take care of COVID-19 patients are subjected to the direct exposure to the virus.

It is crucial during the COVID-19 pandemic that we should be focused on the intensive care unit staff who create the main line of defense in COVID-19 and who could potentially infect a large group of patients.

Several recent papers support the effectiveness of face masks in the COVID-19 pandemic in terms of protecting both HCWs and patients [1–6]. Talking or coughing generates both respiratory droplets, aerosolization, and liquid splashing. Therefore, filtering facepiece class 3 (FFP3) respirators are recommended for aerosol-generated procedures while providing a reasonable protection from COVID-19 and other viral infections. [6, 7].

FFP 3 respirators (EN149:2001. A1:2009) have a filter efficiency of 99% inward and a leakage of 2%, as well as have a reliable resistance against patients with a SARS-CoV-2 infection [8].

Additionally, single-use disposable plastic or fluid repellent aprons or gowns with helmets or medical hood covers, goggles, and masks constitute the personal protective equipment (PPE), which must be worn by all HCWs that are working in intensive care units during the COVID-19 pandemic. The gowns could impair cutaneous respiration, could cause an increase in sweating and could increase the feeling of discomfort. One of the hypotheses assumes that masks can increase resistance to inspiration and respiration, which could decrease the efficacy of breathing [9].

While most of the recent studies concern FFP2 respirators, surprisingly few reports have shown the influence of wearing FFP3 respirators on the blood saturation and the well-being of HCWs working in hospitals' intensive care units (ICU) or COVID-19 departments [10, 11].

The problem concerns intensive care specialist doctors and nurses who often spend long hours in full PPE with FFP3 respirators in emergency or COVID-19 dedicated departments.

This study aims to investigate whether wearing the face masks, FFP3 and PPE (FFP3/PPE), while working in the ICU affects the blood saturation, the heart rate (HR), and the well-being of HCWs.

Methods

Study time and participants

The study was performed in February and March 2021 in the Department of Anesthesiology and Intensive Therapy of our university.

The study included a group of 21 volunteers (including 16 females (76%) and five males), with a median age of 23 years, with interquartile ranges (IQRs) of the participants (21–27), range of 20–59.

The study group consisted of intensive care registered nurses (RN, MSc or RN, BSc) (n = 3), nursing students (of second and third years of study) (n = 14), medical students (fifth year) (n = 3), and a senior consultant (MD, PhD) of the department. All of the students participating in the experiment were students in our university, and all were Caucasian.

All participants had valid medical examinations and were allowed to work by the recognized occupational doctor, and all were vaccinated twice with the COVID-19 vaccine (Pfizer/BioNTech). Persons with a history of pulmonary disease, anemia, vascular diseases, and other diseases that could limit respiratory function were excluded from the study.

Research Design

To evaluate the effects of wearing the respirators, we used a counterbalanced crossover design—a self-controlled trial.

We wanted to rule out the possibility of natural changes in the pulse oximetry (SpO₂) and heart rate parameters during the normal functioning of the participants. Therefore, each subject served as his own control and performed the test two times: (1) without a face mask and PPE (control) for three hours and (2) wearing an FFP3 respirator with full PPE for a three-hour shift in the intensive care unit. The first measurements ("time point 0") of the SpO₂ and pulse rate were recorded 2 minutes after fitting the FFP3/PPE to give participants time to adapt themselves.

The study was performed during the third peak of the COVID-19 pandemic. Although the department was not an isolation ward dedicated only to COVID-19 patients, all emergency admissions were made before obtaining the test for a SARS-CoV-2 infection. Therefore, the applicable unit protocol required the team to wear the PPE and masks.

During the test runs without masks and PPE, we encouraged the participants to perform each hour's same exercises for at least 10 minutes with the supervision of the study coordinator (IW).

Among the study participants, we had students; therefore, for safety and controlling reasons, we used the Nellcor PM10N monitoring system, which allows the study coordinator to assess the recorded parameters in real time (Fig. 1).

To avoid bias, each subject's sequence of interventions (test run or shift run) were randomly assigned. Strenuous physical activity was prohibited during the 24 hours preceding the test, and a night sleep of at least 6 hours was mandated [12]. We also asked the participants not to use any fingernail polish.

Equipment

Each volunteer was wearing the same type of respirators and PPE.

We used FFP3 masks – (Oxy-line respirators: X310 SV FFP3 RD, CE1437. EN149:2001 + A1:2009, PPE, made in Poland) with gowns (Disposal Medical Integrated Protective Coverall. RAEX. Hunan Xunzhao Industry, made in China), and goggles (made in Poland).

Blood saturation and HR were measured in real time for the duration of the whole testing with a pulse oximeter (Nellcor - Portable SpO₂ Patient Monitoring System. PM10N, Coviden. Mansfield USA, made in Korea) (Fig. 1).

The single-use SpO2 sensor (Nellcor. Neonatal-Adult SpO2 Sensor. MAXIN. Coviden. Mansfield USA, made in Mexico) was kept under the surgical glove on the fifth finger of the nondominant hand and connected under the gown with a PM10N device.

Additionally, every 30 minutes during the three-hour shift and during the control run, each subject completed a questionnaire concerning their well-being, with a score scale (ranging from 0 (no symptoms) to 6 points (unable to work)) for headache, shortness of breath, perspiration, fatigue, and thirst (Table 1).

Statistical methods

To analyze the results of the SpO2 and the HR in the HCWs wearing the FFP3/PPE, the patients were grouped according to sex and age, and the median values along with the rest of the quartiles were reported (Table 1). All pairwise comparisons were made using the Mann-Whitney U-test [13]. Due to the number of all the measurements over time, we expected statistically significant differences between the medians. To measure the differences between the groups, we calculated the 95% confidence intervals for the differences of the medians.

Table 2 and Table 3 present the results of the linear mixed-effects model (LMM) estimating the influence of working with the FFP3/PPE in the HCWs, the demographic factors and the levels of SpO2 [%]. LMM is a generalization of the standard linear model used, as the measurements are permitted to exhibit correlation and nonconstant variability between the individuals. LMM, therefore, provides the flexibility of modeling not only with the means but also with their variances and covariances. Moreover, LMM is recognized as a type of method that has some crucial advantages over repeated-measures ANOVA [14].

Table 4 presents a comparison of the different well-being markers between the 30-minute time points while working in the FFP3/PPE versus not working in the FFP3/PPE. In such cases, Friedman's one-way repeated measures analysis of variance by ranks (Friedman test) [15] was used to estimate the differences between consecutive groups (i.e., experiencing various ailments after 30, 60, 90, 120, 150, and 180 minutes).

Statistical analysis was performed using RStudio (Version 1.3.1073).

Ethics approval

The study was conducted according to the Helsinki Declaration (Seventh revision) and Good Clinical Practice Guidelines [16]. The study protocol was accepted by the Bioethics Committee of Poznań University of Medical Sciences, Poznań, Poland (Ref. no. : 123/21 on 04th Feb. 2021) and each participant gave informed consent. Participants were informed of the anonymous data extraction and analysis from the study files.

Results

We obtained 404,195 measurements of blood saturations (SpO₂) in general. There were 156,113 and 248,082 measurements without and with the FFP3/PPE, respectively.

The median SpO₂ without and with the FFP3/PPE was 99% (IQR 98% – 100%) and 97% (IQR 96% – 98%), respectively. The difference was significant ($p < 0.001$).

The median number of pulse beats per minute (HR) without and with the FFP3/PPE was 76 (IQR 71–84) and 104 (IQR 91–117), respectively, and the difference was also significant ($p < 0.001$).

The mean results of the SpO₂ and HR for the whole shift duration of the HCWs in the FFP3/PPE and without the FFP3/PPE with a breakdown based on sex and age category are shown in Table 1.

Men generally had a lower SpO₂ (by 1%) and a lower pulse rate (by 22 PB/min) while wearing the FFP3/PPE than women and also had a lower SpO₂ (by 2%) and a lower pulse rate (by 2 PB/min) when not wearing the FFP3/PPE. The older group showed a slightly lower SpO₂ and HR when wearing the FFP3/PPE and when not wearing the FFP3/PPE and had a slightly higher pulse rate without the FFP3/PPE than the younger group (Table 1).

Table 1

The results of blood saturation and heart rate in HCWs wearing the FFP3/PPE with a breakdown based on sex and age

RESULTS ACCORDING TO GENDER					
Variable	Female	Male	p-value	Median difference	95%CI
SpO2 (%) [median. IQR]					
With FFP3/PPE	98 (97–99)	97 (96–98)	< 0.001	0.999	0.999313–1.000051
Without FFP3/PPE	99 (98–100)	97 (96–98)	< 0.001	1.999974	1.99995–1.99997
Pulse beats per minute (HR) [median. IQR]					
With FFP3/PPE	110 (99–119)	87 (77–93)	< 0.001	22.00005	22.00005–23.00004
Without FFP3/PPE	77 (70–85)	75 (71–79)	< 0.001	2.000064	1.999942–2.000006
RESULTS ACCORDING TO AGE					
variable	Age below 35	Age equal or over 35	p-value	Median difference	95%CI
SpO2 (%) [median. IQR]					
With FFP3/PPE	97 (96–98)	96 (95–97)	< 0.001	1.000068	1.000046–1.000068
Without FFP3/PPE	99 (98–100)	97 (96–97)	< 0.001	1.99998	1.99998–1.99993
Pulse beats per minute (HR) [median. IQR]					
With FFP3/PPE	105 (92–117)	93 (81–116)	< 0.001	6.999953	6.000032–7.000004
Without FFP3/PPE	76 (70–83)	80 (75–84)	< 0.001	3.00008	3.999951–2.999947

The model demonstrated the influence of working in the FFP3/PPE on the SpO2 when sex and gender were considered, and results are shown in Table 2.

Table 2

The model showed the influence of working in the FFP3/PPE for the SpO₂, taking into consideration both age and gender. In such cases, our model has the following form: $SpO_2[\%] \sim \text{working in FFP3/PPE} + \text{Sex} + \text{Age} + (\text{Time/Person})$

	Coefficient	2,5%	97,5%	p-value
Intercept	98,44	97,67	99,22	< 0,001
FFP/PPE: yes	-1,42	-1,43	-1,41	< 0,001
Sex: male	0,33	-0,38	1,05	0,378
Age	-0,02	-0,05	0,01	0,185

The reduction of the standard deviation measured from this model due to the variability between the measurements of the individual features was equal to 32.4%. This means that working in the FFP3/PPE had a significant influence on the SpO₂, and it was associated with an average decrease in the SpO₂ by 1.42% ($p < 0.001$) in comparison to measurements done without this kind of PPE.

Additionally, we developed a mixed-effects model that considered the fact of wearing the FFP3 in an interaction with the time of measurements (periods of each consecutive 30 minutes).

Table 3. Linear mixed-effects model (LMM):

$SpO_2 [\%] \sim \text{FFP3/PPE} + \text{FFP3/PPE: time} + (\text{Second/person})$

FFP3/PPE SpO2 Status	Coefficient [%]	2.5%	97.5%	p-value
(Intercept)	98.193	97.582	98.804	< 0.001
FFP3/PPE: with FFP3/PPE 00:02:00	0.476	-0.171	1.123	0.151
FFP3/PPE: without FFP3/PPE:Time 00:30:00	0.085	-0.581	0.751	0.802
FFP3/PPE: with FFP3/PPE:Time 00:30:00	-1.429	-2.076	-0.781	< 0.001
FFP3/PPE: without FFP3/PPE:Time 01:00:00	0.54	-0.162	1.242	0.133
FFP3/PPE: with FFP3/PPE:Time 01:00:00	-1.762	-2.411	-1.114	< 0.001
FFP3/PPE: without FFP3/PPE:Time 01:30:00	0.461	-0.289	1.211	0.23
FFP3/PPE: with FFP3/PPE:Time 01:30:00	-2.001	-2.651	-1.35	< 0.001
FFP3/PPE: without FFP3/PPE:Time 02:00:00	-0.18	-0.931	0.572	0.64
FFP3/PPE: with FFP3/PPE:Time 02:00:00	-2.286	-2.939	-1.633	< 0.001
FFP3/PPE: without FFP3/PPE:Time 02:30:00	0.584	-0.211	1.379	0.152
FFP3/PPE: with FFP3/PPE:Time 02:30:00	-2.191	-2.848	-1.535	< 0.001
FFP3/PPE: without FFP3/PPE:Time 03:00:00	1.083	-0.501	2.667	0.182
FFP3/PPE: with FFP3/PPE:Time 03:00:00	-1.667	-2.345	-0.989	< 0.001

The mixed model demonstrated that HCWs wearing the FFP3/PPE compared to persons who did not work in the FFP3/PPE had a significant influence on the levels of SpO2. A decrease in the SpO2 was observed after 30 minutes (mean a decrease of – 1.43%, and the highest reduction in the SpO2 (– 2.29%) occurred after 120 minutes, and after 150 minutes, the decrease was – 2.19%. At 3 hours, we noticed a decrease in the SpO2 of – 1.68%, and the mean decrease in the SpO2 after a 3-hour shift was 1.43%.

We found also a significant increase in the HR after 60, 90, and 120 minutes from the start of work to 18, 8.5, and 13 PB/min., respectively. (The LMM, which investigates the influence of wearing the FFP3/PPE on the HR along with the interaction effect on the time of measurement, is shown in the supplementary materials).

The changes in the SpO2 and HR during the 30-minute episodes throughout the study time are depicted in Fig. 2.

All of the score scales of the well-being markers increased consecutively with the time spent working in the FFP3/PPE (see Table 4). The most notable differences between the beginning and the last 30 minutes of a moderate shift were observed for fatigue, thirst, and sweating. For all of the parameters, the median score

of the scale was 2 (out of a maximum score of 6). There was no score checked during test runs without the FFP3/PPE, where the median score was taken as a 0.

Table 4
Comparison of the different well-being markers between the 30-minute time points and while working in the FFP3/PPE (n = 21) Results depicted in scoring scale (score range 0 to 6).

Factor	Averages	30 minutes	60 minutes	90 minutes	120 minutes	150 minutes	180 minutes	p-value*
Shortness of breath (dyspnea)	Mean (SD)	0.33 (0.58)	0.43 (0.6)	0.57 (0.75)	0.57 (0.75)	0.76 (0.89)	0.86 (0.96)	< 0.001
	Median (IQR)	0 (0–1)	0 (0–1)	0 (0–1)	0 (0–1)	1 (0–1)	1 (0–1)	
	Range	0–2	0–2	0–2	0–2	0–3	0–3	
Fatigue	Mean (SD)	0.19 (0.4)	0.43 (0.51)	1 (0.77)	1.19 (0.81)	1.52 (0.93)	1.76 (0.83)	< 0.001
	Median (IQR)	0 (0–0)	0 (0–1)	1 (0–2)	1 (1–2)	1 (1–2)	2 (1–2)	
	Range	0–1	0–1	0–2	0–3	0–3	1–3	
Thirst	Mean (SD)	0.19 (0.51)	0.62 (0.8)	0.95 (1.02)	1.43 (1.12)	1.86 (1.06)	2.1 (1.26)	< 0.001
	Median (IQR)	0 (0–0)	0 (0–1)	1 (0–2)	2 (0–2)	2 (1–2)	2 (2–3)	
	Range	0–2	0–2	0–3	0–3	0–4	0–5	
Headache	Mean (SD)	0.05 (0.22)	0.14 (0.48)	0.29 (0.56)	0.29 (0.72)	0.52 (0.98)	0.67 (1.02)	< 0.001
	Median (IQR)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–1)	0 (0–1)	
	Range	0–1	0–2	0–2	0–3	0–3	0–3	
Perspiration (sweating).	Mean (SD)	0.62 (0.8)	0.9 (0.7)	1.48 (0.81)	1.67 (0.66)	2 (0.84)	2.19 (0.93)	< 0.001
	Median (IQR)	0 (0–1)	1 (0–1)	2 (1–2)	2 (2–2)	2 (2–3)	2 (2–3)	
	Range	0–2	0–2	0–3	0–2	0–3	0–3	
*Assessed by Friedman’s test								

Additionally, we did not find any differences between women and men or between younger and older (> 35 years) HCWs in terms of the results of the above scoring scale that depicted the well-being of the HCWs (for well-being markers see Table 4).

Discussion

The main finding of this study was that working in an FFP3/PPE caused a moderate but significant decrease in the SpO₂. The median decrease in the SpO₂ within 3 hours of the shift was approximately 2–3% (dropping from 99–97% or 96%, depending on the time after the shift start), but this did not reach the levels that are recognized as dangerous for health. We also found that the HR increased from 77 to 110 pulse beats/minute (PB/min) within the same periods in the shifts. The decrease in the SpO₂ could be observed after the first 30 minutes of a shift. The difference was significant until the end of shift, i.e., after 150–180 minutes of working. However, after a significant drop in the SpO₂ within the first period (2–30 minutes), the following 30-minute consecutive periods did not differ significantly, demonstrating a stable decrease in this parameter (see Fig. 2).

To a lesser extent, we observed an increase in the HR. It was noticed to be the most prominent by 13 to 18 PB/min, compared the first 30-minute period to the periods between 60 and 120 minutes of the shift (see Fig. 2).

We found lower SpO₂ and pulse rates in men than in women (Table 1).

Normal SpO₂ readings usually range from 95–100% [17]. Values under 90% are considered low, and values of 92% are sufficient to predict adequate oxygenation in Caucasian persons (a saturation of 95% is usually required in persons of African descent) [18].

Therefore, the obtained results do not exceed the level that is considered safe.

Regarding the question of how wearing masks influence the SpO₂, there is high heterogeneity in the literature. Different kinds of masks were tested under different experimental conditions [10, 11, 19–21].

Beder et al. obtained similar results while studying disposable sterile one-way surgical paper face masks and revealed a consecutive decrease in the SpO₂ during the 2 and 3 hours of surgical operations (drop by 1% and 1.5%, respectively) and a slight increase in HR compared to preoperative values in the surgeons. The decrease in the saturation was more prominent in surgeons aged over 35 [19].

Recently, Fantin performed an arterial blood gas analysis in a 30-year-old female resident, which was carried out during a 13-hour day shift on the COVID-19 Intensive Care Unit. This study found that during the multihour wearing of FFP3 masks, all measured values were within the normal ranges, although a trend toward an insufficient gas exchange could be seen.

She had an increase in the partial pressure of carbon dioxide (PaCO₂), from 29.3 to 36.7 mmHg, showing a continuous decrease during the shift in the partial pressure of oxygen (PaO₂), from 102 to 88.8 mmHg.

The changes could be seen within the first five hours of the trial; unfortunately, the study consisted of just one young volunteer. Therefore, no further conclusions can be drawn from the study [11].

In another study, 20 young (mean age of 29 years) oral surgeons were enrolled. The SpO₂ was measured twice, before and after oral surgeries were performed. They used disposable sterile one-way surgical paper masks and FFP2 masks combined, which could not be formally treated as a reliable substitute for FFP3 masks. Nevertheless, the results corresponded with ours. In all 20 surgeons wearing the FFP2 respirators covered by surgical masks, a reduction in the SpO₂ from approximately 97.5% before surgery to 94% after surgery was noted. Additionally, before surgery, the mean HR was 60 ± 9 beats/min, and after surgery, the dentists' HR increased to 98 ± 12 beats/min (range = 74–98). Shortness of breath and light headedness/headaches were also noted. The durations of most of the operations were between 20 and 120 min (the shortest one was less than 20 minutes, and the longest was up to 240 minutes).

The main difference between our methodology and the study performed in the oral surgeons was that the SpO₂ and HR were measured twice at the beginning and after the surgery. Therefore, we cannot exclude any fluctuations of the SpO₂ and HR levels during surgery [10].

Another recent review demonstrated that face masks, including N95 respirators, surgical masks, and cloth face masks, may have some but relatively small and often difficult-to-detect effects on the work of breathing (which could cause dyspnea), blood gases, and other physiological parameters during physical activity, even with heavy exercise [20–22].

Our model is easy to repeat and to perform comparative tests but has some shortcomings. Our study results should be considered preliminary. In the Department where the study was conducted, we have a rather young team of HCWs. We did not find any important, from a clinical point of view, differences between the older and younger HCWs (HCWs over 35 years of age had their SpO₂ drop from 97–96%, while the younger HCWs had their SpO₂ drop from 99–97% without and with the FFP3/PPE, respectively (see Table 1 for details)).

However, we cannot exclude the possibility that a higher number of participants at an older age, especially those over 50 or 60 years of age, could have different results.

The next problem is that we performed this study during only one 3-hour shift. However, another “real world” study, which evaluated staff wearing the PPF2/PPE and working in the COVID-19 Isolation Ward, demonstrated that during the next 3 hours of a shift (after 3 hours of rest), the results of physiological parameters and well-being score scales did not differ from the first shifts. Therefore, we can assume that 3 hours of rest between 3 hours of shifts was sufficient to regenerate the health of the staff members, while taking into consideration a 12-hour shift (with the pattern: 3 hours of working-3 rest-3 working-3 rest, (unpublished data)).

Conclusions

In our study, SpO₂ and HR were measured continuously (we collected over 400,000 measurements for all 21 participants). This allowed us to construct more reliable mixed model formulas.

Despite small physiological changes, most HCWs complained about the moderate discomfort of working in an FFP3/PPE, and they complained mostly fatigue, thirst, and perspiration.

We did not find any differences in well-being parameters between the gender or age groups; additionally, there was no correlation between the SpO2 and HR and the well-being factors in the study workplace.

We note that although the parameters changed and the changes were statistically significant during the shift, they did not exceed the norm.

However, we should take into consideration that HCWs have been working in shifts throughout the whole pandemic period that has now exceeded one year. Therefore, to avoid burn-out and chronic fatigue syndromes, we should seek to ensure as much comfort as possible while working [23–25]. In particular, rules should be taken to avoid extensive working hours, to ensure the provision of advanced equipment—especially more comfortable gowns and respirators—and to maintain a high level of occupational safety, health care, proper social conditions and compliance for the rules of the law and other health and safety requirements.

We assume that a 3 hour shift rhythm –, i.e., Three hours of working in the FFP3/PPE in the isolation ward (red zone), followed by rest or working without an FFP3/PPE (in positions that do not require them) is a safe and reliable solution.

Additionally, we should bear in mind that any of the disadvantages connected with wearing an FFP3/PPE should be considered in the context of the significant reduction of threats and the risks of contracting a SARS-CoV-2 infection by HCWs and significantly decreasing the risk of the transfer of infection to our patients in hospital wards [1–4].

Declarations

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Authors' contributions

IW and RK designed the study and wrote the manuscript.

IW, PS, AD, DD collected study data.

Data management was performed by IW, PS, KJ, DD and RK.

IW, RK and KJ performed the statistical analyses.

All authors contributed to critical revision of the final

version of the manuscript for important intellectual content.

All authors approved the final manuscript.

Competing interests

The authors have not disclosed any potential competing interests:

ADDITIONAL INFORMATION

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All authors have given their consent for publication.

Availability of data and materials

Data and materials are available on request to the corresponding authors.

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Figures

Figure 1

Nellcor PM 10N monitoring system on a volunteer's hand. Such localization for safety and controlling reasons allowed the study coordinator to assess the recorded parameters in real time.

Figure 2

Changes in the SpO₂ and the heart rate (PB/min) in the HCWs working in the FFP3/PPE and without the FFP3/PPE throughout the whole shift time (medians and interquartile range are shown).

Supplementary Files

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