Impact of Personal Protective Equipment on the Quality of Chest Compressions in Prehospital Care: A Prospective Randomized Crossover Study

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Abstract

Introduction: The use of personal protective equipment (PPE) in prehospital emergency care has significantly increased since the onset of the coronavirus disease 2019 (COVID-19) pandemic. Several studies investigating the potential effects of PPE use by Emergency Medical Service providers on the quality of chest compressions during resuscitation have been inconclusive.

Study Objectives: This study aimed to determine whether the use of PPE affects the quality of chest compressions or influences select physiological biomarkers that are associated with stress.

Methods: This was a prospective randomized, quasi-experimental crossover study with 35 Emergency Medical Service providers who performed 20 minutes of chest compressions on a manikin. Two iterations were completed in a randomized order: (1) without PPE and (2) with PPE consisting of Tyvek, goggles, KN95 mask, and nitrile gloves. The rate and depth of chest compressions were measured. Salivary cortisol, lactate, end-tidal carbon dioxide ($EtCO_2$), and body temperature were measured before and after each set of chest compressions.

Results: There were no differences in the quality of chest compressions (rate and depth) between the two groups ($P > .05$). After performing chest compressions, the group with PPE did not have elevated levels of cortisol, lactate, or $EtCO_2$ when compared to the group without PPE, but did have a higher body temperature ($P < .001$).

Conclusion: The use of PPE during resuscitation did not lower the quality of chest compressions, nor did it lead to higher stress-associated biomarker levels, with the exception of body temperature.

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Keywords: chest compressions; cortisol; COVID-19; end-tidal carbon dioxide; lactate; stress

Abbreviations:
BLS: Basic Life Support
COVID-19: coronavirus disease 2019
CPR: cardiopulmonary resuscitation
$EtCO_2$: end-tidal carbon dioxide
FFP: filtering face piece
HCW: health care worker
PPE: personal protective equipment

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Introduction

The pandemic of coronavirus disease 2019 (COVID-19) has led to infections in almost 545 million people globally and nearly 6,400,000 deaths as of July 2022.[1] According to current evidence, this virus is primarily transmitted between people through respiratory droplets and contact routes.[2]

Aerosol transmission is also possible during aerosol-generating procedures, including cardiopulmonary resuscitation (CPR).[3] International organizations such as The European Resuscitation Council (Niel, Belgium), the American Heart Association (Dallas, Texas USA), and the Australasian College for Emergency Medicine (Melbourne, Australia), and many others, recommend the use of personal protective equipment (PPE) by the health care workers (HCWs) involved in resuscitation.[2–6] Few studies have demonstrated that the performance level of HCWs during life-saving procedures such as CPR, intravenous cannulation, and endotracheal intubation may decrease while wearing PPE.[2,7–9] Chen, et al found significant deterioration of chest compressions performance in HCWs with the use of level-C PPE, which may be a disadvantage for enhancing survival of cardiac arrest.[8] Sahu, et al published a systematic review in which the quality of chest compression was inferior when wearing PPE than when not wearing PPE.[2] However, these studies have been performed in single-rescuer situations, without the possibility of rest periods, and resuscitations of short durations (two-to-four minutes).[8,10] The effect of PPE on resuscitation is not consistent. While some studies have found significant changes in CPR quality,[11,12] a recent systematic review and meta-analysis showed that the rate and depth of chest compressions are not inferior when wearing PPE.[2] Kienbacher, et al published a randomized controlled non-inferiority triple-crossover study, in which the Basic Life Support (BLS; 30 compressions and two rescue breaths) was performed for 12 minutes and the providers were swapping after two minutes, as recommended by the resuscitation guidelines,[13] and reported that the quality of resuscitation when wearing PPE was not inferior to that when not wearing PPE.[14] This research was followed by Fernandéz-Méndez, et al who published the results of a randomized quasi-experimental crossover study of 20 minutes of CPR (also 30:2), where the use of PPE also showed no impact on the quality of CPR.[10]

The primary objective in this study was to determine differences in mean chest compressions rate and depth while wearing PPE and not wearing PPE during 20-minute resuscitation with proper rest phases, as recommended by the resuscitation guidelines. The secondary objectives of this study were to describe the changes in salivary cortisol, lactate, end-tidal carbon dioxide ($EtCO_2$), and body temperature when providing chest compressions.

Methods

Study Design

This randomized, quasi-experimental crossover study compared the quality of chest compressions with and without PPE. When analyzing CPR with and without PPE, the frequency and depth of chest compressions were evaluated according to the European Resuscitation Council Guidelines 2021. The recommended frequency of chest compressions is 100-120/minute, and the depth of chest compressions is five-to-six centimeters (50-60 mm).[13] The CPR tests with PPE were performed using PPE consisting of a protective coverall (Tyvek), protective goggles, a KN95 mask (filtering face piece [FFP]2 level), and nitrile gloves. The CPR tests without PPE were performed in usual work clothes while wearing one pair of gloves. The order of the CPR test with or without PPE was determined based on the initial randomization (Figure 1). Each participant underwent a CPR test, with and without PPE.

The CPR test was initiated with uninterrupted chest compressions without ventilation for two minutes, followed by a two-minute rest. The participant performed a total of five two-minute cycles of uninterrupted chest compressions (0-2 minutes, 4-6 minutes, 8-10 minutes, 12-14 minutes, and 16-18 minutes). In between the two-minute periods of resuscitation were two-minute breaks (2-4 minutes, 6-8 minutes, 10-12 minutes, 14-16 minutes, and 18-20 minutes). This setup follows the recommended change in rescuers providing chest compressions every two minutes.[13] The total resuscitation time per CPR test was 20 minutes. The second (crossover) test was performed after 60 minutes to avoid bias from fatigue and to allow the physiological biomarker values to settle.

The tests were carried out in a simulation center (an emergency training box simulating the ambulance environment) of Emergency Medical Services of the Usti Region (Czech Republic) under the following conditions: environmental temperature of 22.2°C (SD = 0.6°C) and environmental humidity of 65% (SD = 3%). The environmental temperature was monitored using a Garni 210T One Care thermometer and hygrometer (GARNI Technology; Czech Republic).

Participants

The participants (n = 35) were professional HCWs in the Emergency Medical Services of the Usti Region. The baseline characteristics of the study population are shown in Table 1.

Inclusion criteria were participants had to have at least one year of experience in Emergency Medical Services and be trained according to the European Resuscitation Council Guidelines 2021.

Exclusion criteria were chronic disease of the cardiovascular and respiratory systems, having experienced COVID-19 in the previous 60 days, and injury to the musculoskeletal system.

This study adhered to the ethical principles of the Helsinki convention. Each participant authorized their participation and the transfer of necessary data, and each provided written consent to participate. The study protocol was approved by the ethics committee of the Emergency Medical Services of the Usti Region, code EK-01-2021, and was not registered.

Experimental Procedure and Materials

The participants accessed the emergency training box, where a team of two researchers performed anthropometric measurements (height and weight). After the measurements, participants waited for 50 minutes until the beginning of the CPR test. This time was intended for physiological adjustment to environmental conditions and to allow cortisol and lactate concentrations to adjust to a resting state.[10] During this timeframe, the participants remained seated in a chair. The study took place from 8:30AM to 11:30AM (time of relatively higher levels of cortisol). The participants were asked to refrain from eating, drinking caffeine-containing beverages and fruit juices, smoking, and sleeping four hours prior to the CPR tests. They were also asked to avoid drinking any alcohol or doing any heavy, physically demanding activity for 24 hours prior to CPR testing.[15]

Immediately before the start of the CPR test, salivary cortisol and capillary lactate samples were taken from the participants, body temperature was measured, and $EtCO_2$ monitoring began.

Based on the initial randomization, either chest compressions with or chest compressions without PPE were initiated. The

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Population (n = 35)		
	Range	Mean (SD)
Age (years)	20-45	34.17 (SD = 6.84)
Length of Practice (years)	1-26	10.09 (SD = 6.85)
Gender	**n (%)**	
* Female	4 (11.4)	
* Male	31 (88.6)	
Level of Training	**n (%)**	
* EMT	13 (37.2)	
* Paramedic	20 (57.2)	
* Advanced Care Paramedic	2 (5.6)	

Table 1. Baseline Characteristics of the Study Population
Abbreviation: EMT, emergency medical technician.

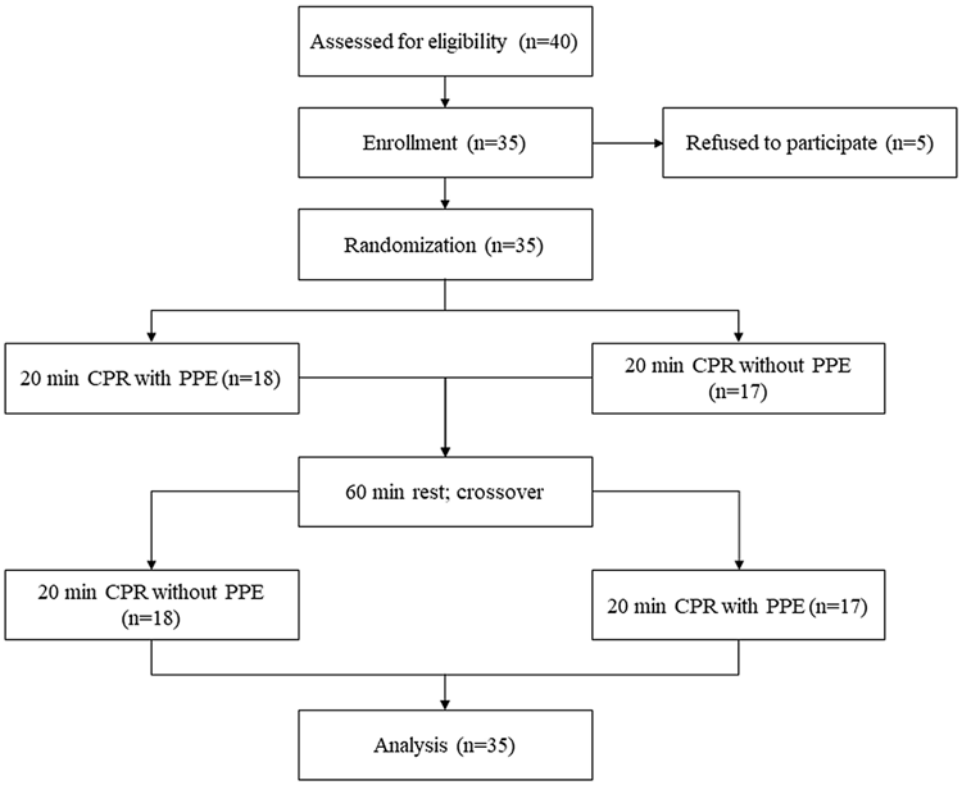

Figure 1. Flow Chart of the Study Design and Recruitment of Participants.
Abbreviations: CPR, cardiopulmonary resuscitation; PPE, personal protective equipment.

CPR test was performed as described in the Study Design section on the Resusci Anne Simulator (Laerdal Medical; Norway) programmed according to the 2021 European Resuscitation Council Guidelines. Resuscitation variables were recorded using the Laerdal Simpad Plus Handheld Remote (Laerdal Medical; Norway). The average frequency and depth of chest compressions were recorded after each two-minute cycle. Body temperature and $EtCO_2$ levels were recorded after each 20-minute period of resuscitation. In the tenth minute after the end of each CPR test, salivary cortisol and capillary lactate levels were measured. After the end of the first resuscitation period, the participant rested for 60 minutes.

Physiological Variables

Body temperature was measured using a tympanic thermometer (Braun IRT6515 ThermoScan 6, B. Braun Melsungen AG; Germany) in the right ear canal.[16] Temperatures were recorded in degrees Celsius and based on the average of three continuous measurements.

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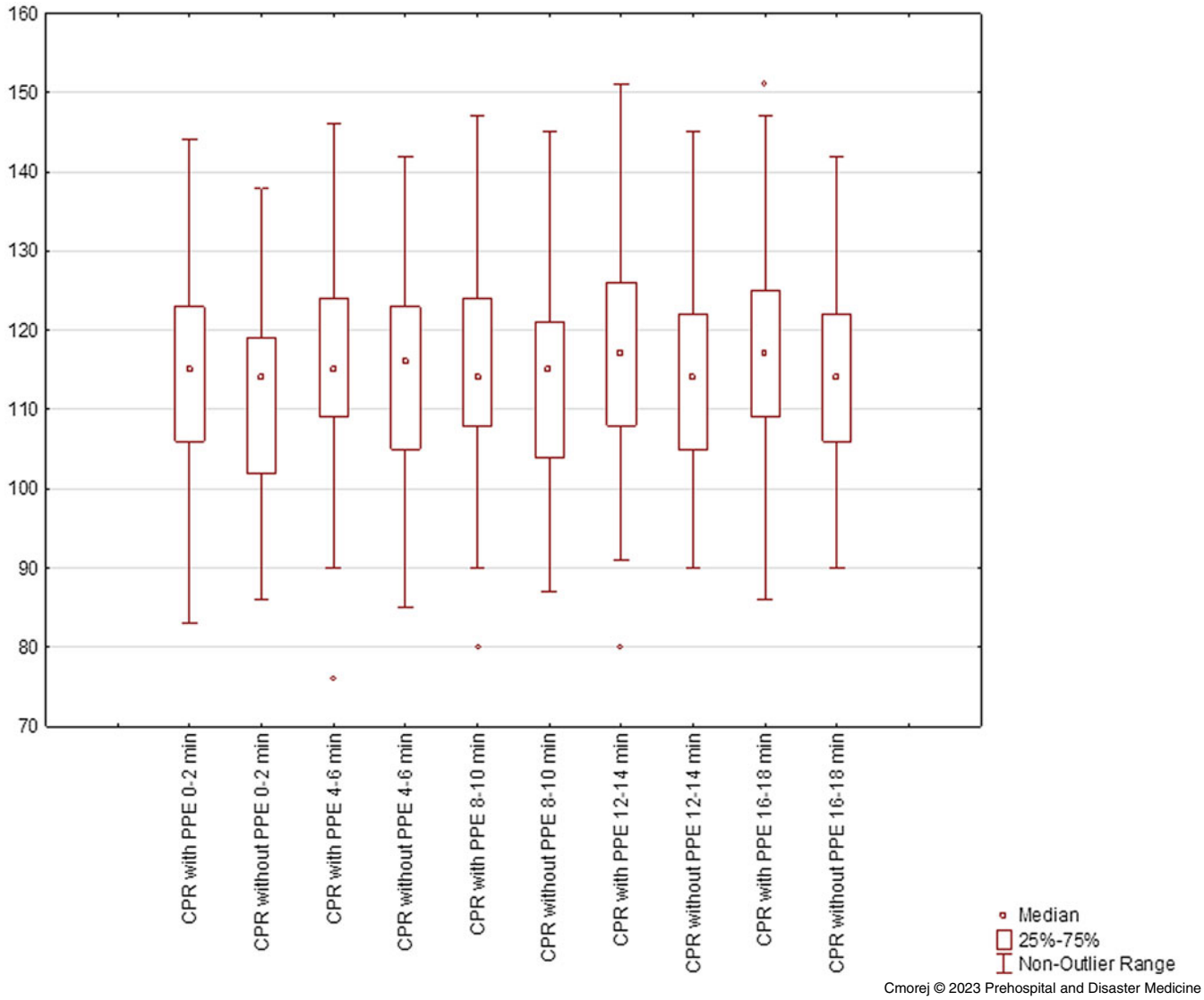

Figure 2. Box Plot Comparison of the Mean Frequency of Chest Compressions (CC) with PPE and without PPE. Abbreviations: CPR, cardiopulmonary resuscitation; PPE, personal protective equipment.

Saliva samples were collected in a special collection tube (Salivette Cortisol; Sarstedt, Germany). The saliva sample tubes were stored in an Alpicool cooling box (Foshan Alpicool Electric Appliance; China) at 4°C. After testing, the tubes were transported and analyzed at the Department of Biomedicine and Laboratory Diagnostics, Faculty of Health Studies, J.E. Purkyne University in Usti nad Labem (Czechia). Salivary cortisol levels were examined using the electrochemiluminescence method on a Cobas 6000 module e601 analyzer (Roche Diagnostics; Basel, Switzerland). Salivary cortisol levels were recorded as nmol/L.

To determine the time of salivary cortisol sampling, the method of Keitel, et al was followed,[15] who observed peak changes in cortisol concentration 30 minutes after the start of a simulated emergency in a group of students.

Lactate concentrations were analyzed from the capillary blood of the upper extremity finger using the StartStrip Xpress Lactate device (Nova Biomedical Corporation; Massachusetts USA). Before starting the research, a Passing-Bablock regression was performed on five blood test results using a StartStrip Xpress lactometer with a certified ABL800 Flex laboratory device (Radiometer Medical ApS; Denmark) at the Department of Biomedicine and Laboratory Diagnostics, Faculty of Health Studies, J.E. Purkyne University in Usti nad Labem. Lactate levels were recorded as mmol/L. The timing of sample collection was based on a study by Hermann, et al who noted that lactate increases after 15 minutes of physical stress.[17]

End-tidal carbon dioxide was measured using a Lifepak 15 monitor/defibrillator (Stryker Company; Michigan USA). Testing was performed using a Microstream Smart CapnoLine adult. The $EtCO_2$ values were recorded at the beginning of the CPR test and at the end of each two-minute resuscitation cycle. The $EtCO_2$ was recorded in mmHg.

Statistical Analysis

To analyze the differences in the quality of CPR (chest compression rate and depth) between the groups with and without PPE, the McNemar test for 2×2 contingency tables was used to represent dependent data in a paired design. For numerical variables (cortisol,

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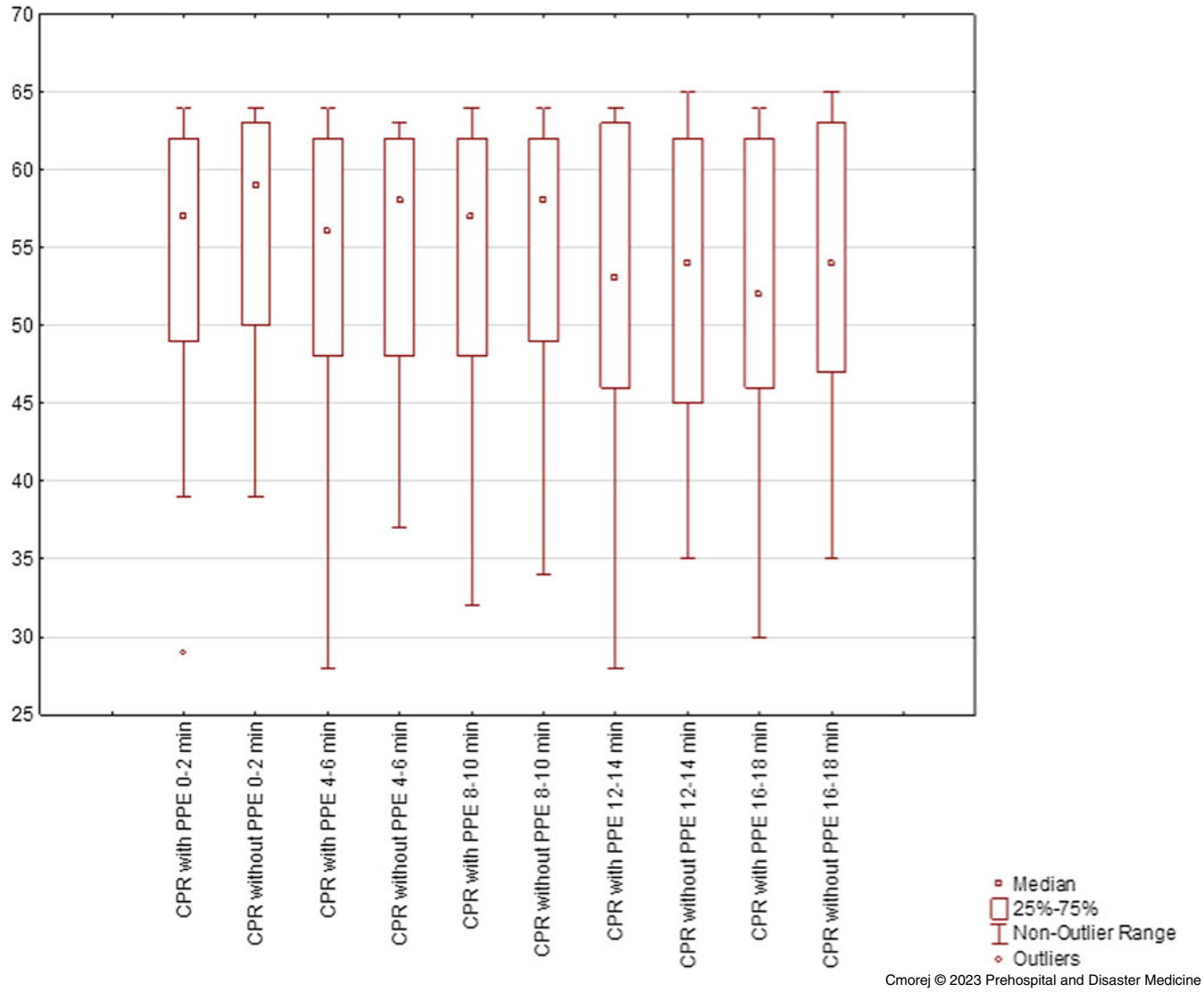

Figure 3. Box Plot Comparison of the Mean Depth of Chest Compressions (CC) with PPE and without PPE. Abbreviations: CPR, cardiopulmonary resuscitation; PPE, personal protective equipment.

lactate, $EtCO_2$, and body temperature), the paired t-test was used to compare the difference between the pre- and post-test scores between the two groups (with and without PPE). These paired tests were performed using the non-parametric version (Wilcoxon test). Body temperature data met the criteria for normality, and the parametric Student's t-test was used. Differences were considered statistically significant at $P < .05$. TIBCO Statistica (version 13.0, TIBCO Software Inc.; California USA) was used for all the statistical analyses.

Results

The comparative results for the chest compressions quality variables are shown in Table 2 and in Figure 2 and Figure 3. The chest compression rates segregated by intervals are shown in Table 2. No differences were noted in any of the five cycles of resuscitation when comparing the average frequency of chest compressions during CPR with and without PPE.

The comparative results for the physiological variables are presented in Table 3. There was a statistically significant difference in mean salivary cortisol levels observed pre- and post-CPR test between the two groups, such that the with PPE group was 0.6nmol/l lower post-test ($P < .041$).

There was no significant difference in lactate levels between the two groups.

A difference was observed in the mean pre- and post-test $EtCO_2$ levels between the two groups ($P = .044$). Post-test $EtCO_2$ was 1.83mmHg higher than pre-test $EtCO_2$ in the PPE group. The post-test $EtCO_2$ was 3.05mmHg higher than the pre-test value in the group without PPE.

Differences in body temperature were also observed between the two groups ($P < .001$). There was a mean 0.58°C increase in the post-test body temperature in the PPE group compared to the group without PPE, where the post-test body temperature was 0.09°C higher.

Discussion

This study aimed to analyze the impact of PPE on the quality of resuscitation (chest compressions) and select physiological

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N=35	CPR with PPE			CPR without PPE			P Value
Cortisol (nmol/l)	**Mean (95% CI)**	**Min**	**Max**	**Mean (95% CI)**	**Min**	**Max**	
Pre-Test	9.56 (7.96-11.16)	1.5	20.5	9.34 (6.89-11.79)	2.7	42.4	
Post-Test	10.16 (8.55-11.77)	2.7	21.2	10.48 (7.66-13.30)	2.5	48.4	
Pre-Test/Post-Test Difference	-0.60 (-1.81-0.60)	-9.9	8.3	1.14 (-0.12-2.40)	-5.8	13.9	.041
Lactate (mmol/l)	**Mean (95% CI)**	**Min**	**Max**	**Mean (95% CI)**	**Min**	**Max**	
Pre-Test	2.58 (1.87-3.29)	0.5	9.4	2.55 (2.10-3.00)	1.1	5.9	
Post-Test	3.61 (2.88-4.34)	0.9	11.8	4.67 (3.46-5.87)	0.8	13.12	
Pre-Test/Post-Test Difference	1.03 (0.17-1.90)	-3	9.4	2.12 (0.75-3.49)	-4.8	12.1	.116
End-Tidal CO_2 (mmHg)	**Mean (95% CI)**	**Min**	**Max**	**Mean (95% CI)**	**Min**	**Max**	
Pre-Test	42.54 (41.40-43.68)	35	48	40.17 (38.94-41.40)	33	47	
Post-Test	44.37 (42.95-45.79)	33	52	43.23 (42.01-44.44)	34	49	
Pre-Test/Post-Test Difference	1.83 (0.57-3.09)	-8	7	3.06 (1.88-4.23)	-9	10	.044
Body Temperature (°C)	**Mean (95% CI)**	**Min**	**Max**	**Mean (95% CI)**	**Min**	**Max**	
Pre-Test	36.60 (36.48-36.72)	36	37.5	36.61 (36.48-36.75)	35.8	37.5	
Post-Test	37.19 (37.08-37.29)	36.6	37.9	36.71 (36.58-36.84)	36	37.9	
Pre-Test/Post-Test Difference	0.59 (0.46-0.71)	0	1.5	0.10 (-0.01-0.20)	-0.4	0.7	< .001

Table 3. Comparative Results of Physiological Variables
Abbreviations: CPR, cardiopulmonary resuscitation; PPE, personal protective equipment.

parameters of health care providers in prehospital emergency care. The quality of resuscitation was not affected by the use of PPE. Body temperature increased during CPR with PPE; however, there was no difference in lactate levels. That salivary cortisol and $EtCO_2$ levels increased when performing CPR without PPE may be an incidental finding.

Couper, et al found that chest compressions may generate aerosols and may also be associated with infection transmission in some circumstances and thus the use of PPE during Advanced Life Support is important.[4] The results of previous studies with a longer duration (>10 minutes) of resuscitation correspond to the conclusions of this study, in which no differences were found in the quality of chest compressions during CPR with PPE compared to CPR without PPE.

Though not a specific aim of this study, it was found that only one-half of the rescuers performed the recommended frequency of chest compressions, and only one-third of the rescuers achieved the appropriate depth of chest compressions during the entire period of resuscitation. The authors surmise that the shortfalls in the quality of chest compressions may be related to the almost two-year absence of physical CPR training due consequences of the pandemic, such as physical distancing and lockdowns.

Personal protective equipment can potentiate heat stress, which may negatively impact the performance, safety, and well-being of HCWs.[18] Salivary cortisol is considered a valid indicator of free cortisol and hypothalamus-pituitary-adrenocortical axis activity.[15] In this study, salivary cortisol was used to potentially identify the stress load of the health care providers. While salivary cortisol concentrations were found to be significantly higher post-test in the group without PPE, the authors feel this to be clinically irrelevant. However, this study may be among the first to use an endocrine marker to estimate stress load during CPR with PPE.

Part of this research compared changes in lactate concentration during CPR, which is a suitable biomarker for physical exertion and sometimes stress.[19,20] Chest compressions are considered a physically demanding activity;[20] therefore, those performing chest compressions can be viewed as performing strenuous physical exercise. These facts led to the inclusion of lactate analysis in this study. The authors are unable to conclude that performing CPR with PPE is a significant physical stressor when compared to performing CPR without PPE.

An analysis of the change in $EtCO_2$ concentration when providing CPR with PPE revealed no increase in $EtCO_2$ concentrations during CPR with PPE compared to that without PPE. Even when comparing the difference between the pre- and post-test values, a higher increase in $EtCO_2$ was observed in the group without PPE. Although the difference in $EtCO_2$ concentrations between the groups was statistically significant from a clinical point of view, the differences were negligible. Similar results were published by Kienbacher, et al who analyzed $EtCO_2$ changes after 12 minutes of BLS without the use of an FFP2 mask and with the use of an FFP2 mask with and without an expiration valve.[14] In all three analyses, the post-test concentrations were lower than the pre-test concentrations. The $EtCO_2$ concentrations in the BLS group using the FFP2 mask without an expiration valve is in contradiction with the current results, where the post-test concentrations were slightly higher in both groups (but not significantly). Kienbacher, et al considered the alternation of two minutes of compression and two minutes of rest as the cause of lower post-test $EtCO_2$ concentrations.[14]

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The last parameter analyzed was body temperature. This study demonstrated a significant post-test increase in body temperature when resuscitation was performed with PPE. According to Davey, et al, PPE use can lead to thermal stress, which causes dizziness, fatigue, headache, and profuse sweating. Thermal stress may be a factor affecting the occurrence of medical errors.[19] Such symptoms depend on the duration of PPE use. In this case, resuscitation was performed for only 20 minutes, and the mean post-test value of the body temperature during CPR with PPE exceeded the limit of 37°C. Similar changes in body temperature during 20 minutes of resuscitation were also noted by Fernández-Méndez, et al.[10] Although the differences in body temperature were significant, the authors do not posit that just 20 minutes of resuscitation leads to the development of heat stress in rescuers.

Limitations

This study had some limitations. Most importantly, this was a trial using manikins inside a building away from external elements, and the study protocol was not registered beforehand. Another limitation is the absence of the physical activity and other stressors that regularly occur in real conditions, such as the route to the patient and surrounding elements. Finally, PPE products from only one manufacturer were used in this study.

Conclusions

This study found that in a controlled environment using manikins, the quality of chest compressions performed for 20 minutes by rescuers when wearing PPE was not inferior to not wearing PPE. In the same conditions, the use of PPE does not lead to an increase in the levels of stress hormones.

Author Contributions

Patrik Cmorej: Conceptualization, methodology, validation, formal analysis, investigation, resources, data curation, writing–original draft, visualization, project administration, and funding acquisition.
Karel Hrach: Conceptualization, methodology, statistical analysis, and data curation.
Ivana Argayova: Investigation, resources, data curation, writing–review, and editing.
David Peran: Conceptualization, validation, investigation, resources, and writing–original draft.
Jaroslav Pekara: Investigation, data curation, writing–review, and editing.
Olga Jarabicova: Investigation, data curation, writing–review, and editing.
Petr Kelbich: Investigation, writing–review, and editing.
Jan Spicka: Investigation, writing–review, and editing.
Dana Rebeka Ralbovska: Conceptualization, methodology, validation, formal analysis, investigation, and writing–review.

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N = 35	CPR with PPE					CPR without PPE					P Value
Chest Compressions Rate	**Mean (95% CI)**	**Median**	**Min**	**Max**	**Correct Rate***	**Mean (95% CI)**	**Median**	**Min**	**Max**	**Correct Rate***	
CPR 0-2 (min)	113.6 (109.3-118.0)	115	83	144	19/35 (54 %)	112.1 (107.6-116.6)	114	86	138	21/35 (60 %)	.773
CPR 4-6 (min)	115.1 (110.2-119.9)	115	76	146	17/35 (49 %)	113.7 (109.3-118.2)	116	85	142	22/35 (63 %)	.131
CPR 8-10 (min)	115.2 (110.2-120.2)	114	80	147	18/35 (51 %)	113.3 (108.5-118.2)	115	87	145	18/35 (51 %)	.752
CPR 12-14 (min)	116.2 (111.0-121.4)	117	80	151	16/35 (46 %)	114.2 (109.5-118.8)	114	90	145	19/35 (54 %)	.505
CPR 16-18 (min)	116.4 (111.4-121.4)	117	86	151	16/35 (46 %)	115.0 (110.8-119.2)	114	90	142	19/35 (54 %)	.450
Chest Compressions Depth (mm)	**Mean (95% CI)**	**Median**	**Min**	**Max**	**Correct Rate***	**Mean (95% CI)**	**Median**	**Min**	**Max**	**Correct Rate***	
CPR 0-2 (min)	55.0 (52.0-57.9)	57	29	64	13/35 (37 %)	55.9 (53.2-58.5)	59	39	64	11/35 (31 %)	.773
CPR 4-6 (min)	53.9 (50.7-57.0)	56	28	64	10/35 (29 %)	54.8 (51.8-57.7)	58	37	63	9/35 (26 %)	1.000
CPR 8-10 (min)	54.3 (51.2-57.3)	57	32	64	11/35 (31 %)	54.3 (51.3-57.3)	58	34	64	13/35 (37 %)	.724
CPR 12-14 (min)	53.4 (50.2-56.6)	53	28	64	9/35 (26 %)	53.6 (50.5-56.8)	54	35	65	11/35 (31 %)	.789
CPR 16-18 (min)	52.7 (49.7-55.8)	52	30	64	14/35 (40 %)	53.1 (50.0-56.3)	54	35	62	11/35 (31 %)	.546

Table 2. Results of CPR Compressions Rate and Compressions Depth Segregated by Intervals
Note: Correct CPR* highlights the percentage of paramedics who followed the correct frequency and depth in the CPR cycle (100-120/minutes, 50-60mm).
Abbreviations: CPR, cardiopulmonary resuscitation; PPE, personal protective equipment.

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