A Simulation Study Using a Quality Cardiopulmonary Resuscitation Medical Manikin to Evaluate the Effects of Using Personal Protective Equipment on Performance of Emergency Resuscitation by Medical Students from the University of Silesia, Katowice, Poland and Non-Medical Personnel

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Background: During the Coronavirus disease 2019 (COVID-19) pandemic, personal protective equipment (PPE) is used during medical resuscitation aerosol-generating procedures (AGP). This simulation study aimed to evaluate the effects of PPE on the performance of emergency resuscitation by medical students from the University of Silesia, Katowice, Poland and non-medical personnel, and used a quality cardiopulmonary resuscitation (Q-CPR) medical manikin.

Material/Methods: A simulation study was conducted using the Resusci Anne quality cardiopulmonary resuscitation (Q-CPR) medical manikin (Laerdal Medical AS, Norway). Participants were divided into 2 groups: a medical group of 50 and a non-medical group of 52, matched in pairs. Each pair performed 10 min of manual CPR with a compression-ventilation ratio of 30:2 wearing PPE for AGP. The reference method was manual CPR wearing casual clothes along with surgical masks and latex gloves. Data about compression and ventilation were gathered using the QCPR Training application from Laerdal Medical.

Results: Data analyses indicated statistically significant differences between medical students using PPE for AGP and basic protection: average rate of chest compressions (123 vs 114 per min; \(P=0.004\)), chest recoil (69 vs 93; \(P=0.0050\)), correct depth of chest compressions (86.5 vs 97; \(P=0.0081\)), quality of ventilation (85 vs 89; \(P=0.0041\)). Among non-medical personnel however, a statistically significant difference was in the quality of ventilation (69-85.5; \(P=0.0032\)).

Conclusions: The findings from this study showed that the use of PPE for AGP during CPR was associated with slower average speed of chest compressions, less chest recoil, incorrect depth of chest compressions, and lower quality of ventilation.

Keywords: Cardiopulmonary Resuscitation • Emergency Medicine • SARS-CoV-2 • Simulation Training

Full-text PDF: https://www.medscimonit.com/abstract/index/idArt/936844
Background

Cardiopulmonary resuscitation (CPR) is regarded as one of the medical procedures that generate aerosols [1]. The novel pathogen, severe acute respiratory syndrome Coronavirus type 2 (SARS-CoV-2), causing the global Coronavirus disease 2019 (COVID-19) pandemic is to our misfortune transmitted by aerosols defined as droplets <5 μm in diameter [2]. This foregoing feature generates not only the possibility of infection during CPR, but also contributes to changes in its procedure. Emergency workers are at high risk of SARS-CoV-2 infection, which can lead to severe and life-threatening complications [3]. The chances of transmission of infection are relatively high [4]. One study showed that as many as 20% of patients in out-of-hospital cardiac arrest during the start of the pandemic in Europe were infected with SARS-CoV-2 [5]. The European Resuscitation Council (ERC) in its resuscitation guidelines adapted for COVID-19 notes deployment of personal protective equipment (PPE) as an airborne-precaution [6]. Other organizations, such as the International Liaison Committee on Resuscitation (ILCOR), American Heart Association (AHA), and UK Resuscitation Council, have published generally consistent guidelines [7]. The ERC recommends wearing PPE before CPR, consisting of at least a filtering facepiece 3 (FFP3) mask (if FFP3 is not available, then FFP2 or N95), gloves, eye and face protection, and a long-sleeved gown [6]. Concerns about the deterioration of quality of CPR arise when we consider data indicating impairment of medical procedures due to the use of PPE [8,9]. Those associated with medical education (ie, medical students, physicians, nurses, paramedics) are not the only people responsible for administering CPR, but there are others, especially those involved in rescue operations (ie, soldiers, firefighters, water and mountain rescuers).

Therefore, this simulation study aimed to evaluate the effects of PPE on the performance of emergency resuscitation by medical students from the University of Silesia, Katowice, Poland and non-medical personnel.

Material and Methods

This prospective simulation study did not require bioethics committee approval because it was performed on mannequins. All participants voluntarily consented to participate in the study. There were no gratuities for participation in the study. The study was conducted from March to June 2021. Due to standardization of their knowledge, participants were divided into 2 groups: 25 pairs of medical students and 26 pairs of non-medical personnel. The study group consisted of: 50 medical students (32 5th-year students and 18 6th-year students from the Medical University of Silesia in Katowice and 52 non-medical personnel from Silesia and Lower Silesia districts, including General Tadeusz Kościuszko Military University of Land Forces in Wrocław students (14), volunteer firefighters (14), and volunteer water rescuers (24).

Non-medical professionals are obligatorily trained in first aid. The training program is regulated by the Minister of Health [10]. The training lasts 66 h, during which participants learn high-quality CPR and ventilation with BMV (bag-mask-ventilation devices). Students of medical universities must acquire the skills related to conducting high-quality CPR and proper ventilation of the patient using bag-mask-ventilation devices. The training program for students of the medical faculty is regulated by the Regulation of the Minister of Science and Higher Education [11].

The study used simple randomization. The Research Randomizer program was used for this purpose. Medical and non-medical participants within their groups were randomly assigned to pairs. Within each pair, the type of protection (PPE for AGP/basal protection) used in first attempt and the participants’ role (chest compression/ventilation) in the first cycle of CPR were randomized (Figure 1).

The study investigated how effectively participants performed cardiac compressions with and without PPE for AGP. Accordingly, participants were asked to perform 2 resuscitation attempts. One required the use of PPE for AGP while the other required basic personal protection.

PPE for AGP included double nitrile gloves (Light Nitrile Powder-Free Examination Gloves, Sri Trang Gloves Public Company Limited, Bangkok, Thailand), mask Air-purifying Respirator (APR) high protection level (Panoramamasque EPDM/PMMA with filter, Honeywell, Charlotte, United States), eye protection goggles (Uvex Goggles, Honeywell, Charlotte, United States), and biological protection suit type 5 and 6 antistatic PROTEX 4000 (Irudek, Poland).

Basic personal protection consisted of casual outfits along with nitrile gloves (Light Nitrile Powder-Free Examination Gloves, Sri Trang Gloves Public Company Limited, Bangkok, Thailand) and N95 masks (Med Mask, Poland).

Before starting the trial, each participant was trained on how to correctly wear PPE for AGP. During each trial, participants were supervised by researchers to ensure that the participants properly wore PPE and to supervise them during the trial.

Consecutively, each pair performed 10-min manual CPR (ventilation was performed using a bag-mask ventilation device) in each form of protection. Resuscitation was performed according to the guidelines of the European Resuscitation Council 2021 [12]. The person performing compressions was changed...
every 2 min. The interval between each attempt was 20 min and was followed by a second attempt of CPR in a different form of protection. The simulation was performed using a Resusci Anne quality cardiopulmonary resuscitation (Q-CPR) medical manikin (Laerdal Medical AS, Norway).

Data about compression and ventilation quality were gathered from the QCPR Training application manufactured by Laerdal Medical AS, Norway.

The inclusion criteria for participants included: no COVID-19 symptoms in the last 14 days, no quarantine, and a negative test for SARS-CoV-2 in the last 14 days.

The database was collected in Microsoft 365 Excel, Microsoft Corporation, and statistical analyses were performed using MedCalc for Windows version 19.4 (MedCalc Software, Ostend, Belgium). Differences between quantitative variables were assessed using the t test (for paired variables) or the Wilcoxon test, depending on the character of distribution. Correlations were assessed by Pearson’s linear correlation coefficient or Spearman’s rank test.

**Results (Tables 1, 2)**

A correlation was revealed among the group of medical students wearing PPE for AGP between chest compression fraction (CCF) and compression quality (CQ) (R=0.544; P=0.005). According to the QCPR application, appropriate compression is indicated when the depth of compression is at least 50 mm. The percentage that meets the above criteria has been calculated in the total chest compressions. There was also a correlation between CQ and the average speed of compression (avg. soc) in the medical students’ group wearing basic protection (R=0.809; P<0.0001). Moreover, in the non-medical personnel group with PPE for AGP, there was a statistically significant correlation between CQ and avg.soc (R=0.907; P<0.0001). Among the personnel in basic protection, CQ and avg.soc were correlated (R=0.872; P<0.0001) (Figures 2-5).

**Discussion**

This study showed the impact of using PPE for AGP on quality of CPR among medical students. According to the results, most of the determinants of CPR, including average speed of chest compressions, chest recoil, correct depth of chest compressions, and quality of ventilation, had deteriorated.

Resuscitation among non-medical personnel showed no significant differences during CPR between PPE for AGP and basic personal protection attempts. For non-medical personnel, the fact of performing CPR in PPE for AGP does not significantly differ in the quality of the medical procedures, which may indicate a lower initial level of CPR skills. Unfortunately, 2 independent studies by Baldi and Willmore showed that the level of knowledge of medical students is not sufficient [13,14].

Therefore, both medical and non-medical personnel require regular improvement of CPR skills in PPE for AGP with the use of feedback devices along with full debriefing of the results achieved. Regular training can provide medical and non-medical personnel with adequate skills to perform high-quality CPR in case of highly transmissible diseases in the future. This is all the more important to consider in view of the results of the Saad’s study, where it was observed that the retention of skills in medical students remains at 61% 42 months after 10 h of training in basic life support [15].

The epidemiological situation forces both groups (medical personnel and non-medical personnel) to perform CPR using personal protective equipment (PPE for AGP). Suhe Serin et al compared the effect of different personal protective equipment...
masks on health care workers, finding that use of protective masks other than surgical as PPE increased rescuer fatigue in CPR and negatively affected the quality of chest compressions. Our study showed that in the medical personnel group, the use of surgical masks was associated with better quality of CPR, which agrees with Suhe Serin’s research. Some studies explicitly say that performing CPR without PPE for AGP is associated with an increase of cardiac compression quality [16], but in our opinion, performing CPR without PPE for AGP is associated with a significant risk of infection of medical personnel and should not be used. Performing CPR in the ALS algorithm includes, apart from chest compression and ventilation, other procedures, such as intravenous cannulation (IVC) and instrumental securing the airway, for example using endotracheal intubation (ETI) or using supraglottic devices. The above procedures are known to be 3 key life-saving interventions that should be performed immediately to save the patient’s life. The study conducted by Tae Han Kim et al revealed

### Table 1. Summary of resuscitation quality parameters in the medical group.

<table>
<thead>
<tr>
<th>Variable</th>
<th>PPE for AGP</th>
<th>Basic protection</th>
<th>Comparison test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average rate of chest compression (per min)</td>
<td>123 IQR (113.7-127.3)</td>
<td>114 IQR (108-123)</td>
<td>P=0.0041</td>
</tr>
<tr>
<td>Chest recoil* (%)</td>
<td>69 IQR (64.7-96)</td>
<td>93 IQR (80.5-99)</td>
<td>P=0.0050</td>
</tr>
<tr>
<td>Correct depth** (%)</td>
<td>86.5 SD (9.6)</td>
<td>97 IQR (89-99)</td>
<td>P=0.0081</td>
</tr>
<tr>
<td>Quality of ventilation*** (%)</td>
<td>85 IQR (53-92.7)</td>
<td>89 IQR (63-96.5)</td>
<td>P=0.0041</td>
</tr>
<tr>
<td>CCF# (%)</td>
<td>81.6 SD (3.3)</td>
<td>82.4 SD (3.2)</td>
<td>P=0.0593</td>
</tr>
<tr>
<td>Correct compression depth** (%)</td>
<td>99 IQR (98-100)</td>
<td>100 IQR (99-100)</td>
<td>P=0.3894</td>
</tr>
<tr>
<td>Compressions at a good rate (%)</td>
<td>30 IQR (9-81)</td>
<td>54 IQR (16.8-82.3)</td>
<td>P=0.4926</td>
</tr>
</tbody>
</table>

* Percent of compression fully released; ** percent of compression with adequate depth; *** percent of ventilation with adequate chest rise – 1.5 mm; # chest compression fraction – the proportion of time spent performing chest compressions during CPR; ## percent of proper compression with correct recoil and depth.

### Table 2. Summary of resuscitation quality parameters in the non-medical group.

<table>
<thead>
<tr>
<th>Variable</th>
<th>PPE for AGP</th>
<th>Basic protection</th>
<th>Comparison test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average rate of chest compression (per min)</td>
<td>123 SD (14.8)</td>
<td>125 IQR (121-132)</td>
<td>P=0.0552</td>
</tr>
<tr>
<td>Chest recoil* (%)</td>
<td>56.9 SD (29)</td>
<td>52 SD (28.6)</td>
<td>P=0.2632</td>
</tr>
<tr>
<td>Correct depth** (%)</td>
<td>81.5 IQR (62-92)</td>
<td>75 IQR (59-89)</td>
<td>P=0.1752</td>
</tr>
<tr>
<td>Quality of ventilation*** (%)</td>
<td>69 SD (20.3)</td>
<td>85.5 IQR (62-95)</td>
<td>P=0.0032</td>
</tr>
<tr>
<td>CCF# (%)</td>
<td>77.6 SD (4.3)</td>
<td>77 SD (3.9)</td>
<td>P=0.6391</td>
</tr>
<tr>
<td>Correct compression depth** (%)</td>
<td>99 IQR (91-100)</td>
<td>99 IQR (99-100)</td>
<td>P=0.0946</td>
</tr>
<tr>
<td>Compressions at a good rate (%)</td>
<td>28.5 IQR (2-72)</td>
<td>16 IQR (3-56)</td>
<td>P=0.0883</td>
</tr>
</tbody>
</table>

* Percent of compression fully released; ** percent of compression with adequate depth; *** percent of ventilation with adequate chest rise – 1.5 mm; # chest compression fraction – the proportion of time spent performing chest compressions during CPR; ## percent of proper compression with correct recoil and depth.
that using PPE for AGP is associated with a decrease not only in the chest compression quality but also the success rate of IVC and ETI [17].

It was not our intention to check the level of fatigue during cardiopulmonary resuscitation, but the participants of the study raised the aspect of physical exhaustion after the simulation in a biological protection suit. Our observations are supported by Rauch et al, in which the participants also subjectively felt more exhausted [18]. In addition, fatigue has been shown to have a physiological basis in the form of increased heart rate and mean arterial pressure [19]. Interestingly, Badaki-Makun et al suggested that peak power output during the performance of CCs is comparable to that generated during intense physical exertion.

Figure 2. Comparison of the value of chest recoil in the medical (med) group and non-medical (non) group, distinguishing basic protection (basic) and personal protective equipment for aerosol-generating procedures (advanced). (MedCalc Software, Ostend, Belgium).

Figure 3. Comparison of the value of correct depth in the medical (med) group and non-medical (non) group, distinguishing basic protection (basic) and personal protective equipment for aerosol-generating procedures (advanced). (MedCalc Software, Ostend, Belgium).

Figure 4. Comparison of the value of quality of ventilation in the medical (med) group and non-medical (non) group, distinguishing basic protection (basic) and personal protective equipment for aerosol-generating procedures (advanced). (MedCalc Software, Ostend, Belgium).

Figure 5. Comparison of the value of average speed of chest compressions in the medical (med) group and non-medical (non) group, distinguishing basic protection (basic) and personal protective equipment for aerosol-generating procedures (advanced). (MedCalc Software, Ostend, Belgium).
exercise such as running (154 W for a 70-kg man running on a level surface at 9 km/h) or swimming (158 W for a 70-kg man swimming at high intensity in a pool) [20,21]. Our study found the least decrease in the quality of chest compressions in students of the Land Forces Academies. This is most likely due to the significantly greater amount of time devoted to adequate training and maintaining good physical performance in this group of people.

In our study, we also demonstrated a statistically significant difference in resuscitation effectiveness in PPE compared to no PPE in the medical group. This observation is consistent with meta-analyses conducted by Sahu et al [4] and in the Randomized Crossover Simulation Study conducted by Chen et al [19]. In contrast, the non-medical group showed no difference in efficacy with or without PPE. This conclusion is consistent with the study by Donoghue et al [22], but there are significant differences between these studies. In the study cited above, chest compression was the only activity performed by the participants and was performed continuously for 5 min. Moreover, the manikin on which the tests were conducted was a pediatric manikin, in contrast to the adult simulator used by us. Only medical personnel were tested, whereas our group included of non-medical personnel with training.

When considering resuscitation procedures among people with suspected or confirmed infection with SARS-CoV-2 or any other infectious disease, the primary consideration should be the safety of rescuers. However, we should also focus on maintaining adequate quality of CPR. We agree with the suggestions of Malysz et al, which emphasizes the need to adapt resuscitation algorithms to the situation when PPE is required [23].

Certainly, regular shifts of those performing the most exhausting activities should be implemented and perhaps consideration should be given to reducing the length of the chest compression cycle. The situations where CPR providers are exhausted and no longer have the strength to continue may be dangerous for patients and themselves. Cekmen’s study showed that changing the rescuer every 1 min instead of every 2 min during full PPE resuscitation can prevent the reduction in compression quality that can occur as resuscitation time increases [24]. Therefore, the use of automatic chest compression devices should be considered. There is no doubt that further research comparing the effectiveness of resuscitation using PPE is needed, including comparing the quality of resuscitation by people using PPE versus the use of automated chest compression devices.

A limitation of this study is its simulation structure. In a non-simulation setting, the stress of a life-threatening situation plays a major role. The mannequin does not mimic human anatomy or size, which is another limitation of our work. Moreover, participants had unlimited time to put on personal protective equipment, which certainly in real life would be shorter and could determine the quality of protection. Another limitation of our work is the lack of a survey to allow participants to evaluate the influence of the protection on their fatigue. Another limitation is that participants had to perform only CPR; activities related to securing the airway or administering medications were omitted.

Conclusions

The findings from this study showed that the use of PPE for AGP during CPR was associated with lower average speed of chest compressions, less chest recoil, less correct depth of chest compressions, and lower quality of ventilation.

Acknowledgments

The authors would like to thank the volunteers who participated in the study: 5th and 6th year medical students from the Medical University of Silesia in Katowice, non-medical personnel from Silesia and Lower Silesia districts, students from General Tadeusz Kościuszko Military University of Land Forces in Wrocław, and volunteer firefighters and water rescuers.

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