Influence of personal protective equipment on the performance of life-saving interventions by emergency medical service personnel

Tae Han Kim¹, Chu Hyun Kim², Sang Do Shin¹ and Sunnie Haam³

Abstract
Prompt live-saving interventions, such as cardiopulmonary resuscitation (CPR), intravenous cannulation (IVC), and endotracheal intubation (ETI), are important for severely injured victims of chemical, biological, radiological, and nuclear (CBRN) disasters. Interventions sometime have to be performed by emergency medical service (EMS) personnel with personal protective equipment (PPE) worn in warm zones. We designed a randomized crossover simulation aimed to compare the performance of life-saving interventions in repetitive simulation of single-rescuer resuscitation wearing level-C PPE in the warm zone of a CBRN disaster. The success rate and completion time of IVC and ETI according to the presence of PPE were compared. The quality of 4-minute single-rescuer CPR was measured and compared as well. We found that the performance level of life-saving interventions performed in a simulated setting of disaster decreased when performed by EMS personnel wearing level-C PPE. Further efforts of optimizing current PPE for EMS personnel based on this study are needed.

Keywords
Simulation, personnel with personal protective equipment, emergency medical service, life-saving intervention

1. Introduction
In disastrous incidents caused by chemical, biological, radiological, and nuclear (CBRN) hazardous materials, insuring the safety of rescuers is as important as saving the lives of exposed victims. Therefore, thorough decontamination has to be carried out prior to physical examination and initial management of victims by rescuers. However, decontamination of exposed victims often requires more than 10 minutes at minimum,¹ and for critically injured patients who require immediate life-saving interventions, sometimes there is not enough time to spare in decontamination.

Cardiopulmonary resuscitation (CPR), intravenous cannulation (IVC), and endotracheal intubation (ETI) are three key life-saving interventions that should be performed immediately to save the lives of critically injured victims of CBRN disasters. Prompt CPR in cardiac arrest is known to improve survival in out-of-hospital cardiac arrests.²⁻⁴ ETI might be needed in an intoxicated patient or in a trauma patient with a suspected airway obstruction, persistent hypoxemia, hypoventilation with severe cognitive impairment, or in cardiac arrest.⁵⁻⁸ A properly administered antidote via an adequate intravenous route can be helpful to victims of toxic exposure.⁹,¹⁰ These life-saving procedures carried out in a pre-hospital setting are known to be more challenging than interventions done in a hospital setting¹¹⁻¹³ and they are more challenging when personal protective equipment (PPE) is worn.¹⁴,¹⁵

For severely injured and unstable victims of disasters, emergency medical service (EMS) personnel or medically trained rescuers might have to perform life-saving procedures wearing PPE in warm zones to incompletely decontaminated victims.¹⁶,¹⁷ In these kinds of situations, only limited human resources are permitted into the warm zone.
and often resuscitation has to be performed by only a single rescuer. Life-saving procedures will be much more challenging when performed alone and when wearing PPE as well. However, until now, only limited information has been known regarding the influence of wearing PPE on life-saving interventions, especially CPR.

We aimed to compare the performance level of life-saving interventions by wearing PPE in a repetitive simulation scenario of single-rescuer resuscitation in the warm zone of a CBRN disaster.

2. Methods

2.1 Setting

This is a randomized crossover simulation study. This study was approved by the institutional review board of the Korea National University of Transportation (IRB No. KNUT-13)

Board-certified level-1 emergency medical technicians (EMTs) currently working as EMS personnel in the field were recruited from several regional fire departments in the Chungcheongbuk-do province in Korea. The current service level of level-1 EMTs in Korea is similar to the service level of EMT-intermediate in the USA.

Every recruited participant underwent one simulation with PPE suited and another identical simulation not wearing PPE. The sequence of suiting PPE in simulation was randomized for each participant. Informed consents were obtained from all participants.

2.2 Simulation protocol

The simulation protocol was designed to reflect single-rescuer resuscitation in a CBRN disaster with limited resources. All simulations were performed by each participant alone without any help from others. A single simulation was divided into three parts. Firstly, four minutes of one-rescuer CPR was simulated on a resuscitation manikin. Participants were told to perform a 30:2 ratio of chest compression and positive pressure ventilation with a back-valve mask. Afterward, ETI was performed on an airway management trainer manikin. Lastly, IVC was performed on an IV trainer. For IVC and ETI, two minutes were given for each procedure.

2.3 Materials

An IVC training arm kit and airway management trainer (Laerdal, Stavanger, Norway) were used for simulation of IVC and ETI, respectively. A resuscitation manikin (Resusci Anne QCPR, Laerdal, Stavanger, Norway) with skill reporter capability via a WiFi network was used in the CPR simulation. A Macintosh laryngoscope and cuffed polyvinyl chloride endotracheal tubes were used in the ETI simulation and the same type of disposable IV catheters currently used in regional EMS were also used for IVC simulations.

A level-C PPE (Tychem® C Coverall, DuPont™) and a full face-piece reusable respirator 6800 (3M™) with chemical-resistant gloves and boots were suited to participants in the simulation with PPE worn.

2.4 Data collection and measurement

Basal demographics of all participants were collected. For IVC and ETI, success or failure of each procedure and time to completion of each procedure were measured and recorded in real time by an independent investigator with a stopwatch. ETI time was defined from picking up the laryngoscope to confirmed successful tube placement by two investigators. IVC time was defined from picking up a cannula to successful securement and fixation of the cannula with adhesive tape. Multiple attempts could be tried for each procedure within two minutes. Unaccomplished procedures within two minutes were considered as failures.

Quality variables of CPR, including chest compression depth, chest compression rate, and no-flow time, were recorded via the resuscitation manikin. Adequacy of chest compression rate and depth were defined as compression depth of more than 5 cm and compression rate between 100 and 120 per minute, according to 2010 American Heart Association (AHA) and European Resuscitation Council (ERC) guidelines. No-flow time was defined as time without chest compression of more than 1.5 seconds. The no-flow fraction was calculated by dividing the time without chest compression by the total resuscitation time (four minutes).

A brief survey of questions asking about the most disturbing joint movement during performing interventions with PPE worn was completed by all participants after the simulations.

2.5 Statistical analysis

Based on our pilot study, in order to test a mean of 20 seconds delay in the completion in each intervention with 80% power and a significance level of 0.05, at least 16 participants with paired comparison were needed for analysis. Continuous variables, such as time to completion of life-saving procedures and quality measures of CPR, were compared using a paired t-test. The mean difference of each variable in the paired comparison was calculated in a 95% confidence interval (CI). For IVC and ETI, Kaplan–Meier survival curves were estimated for analysis of the cumulative success rate associated with the time variables and a log-rank test was performed to compare the cumulative success rates between simulations. Statistical analysis was performed using Stata ver.12 software (Stata Co., College Station, TX, USA).
3. Results

Twenty EMTs were recruited for this study. Overall, 40 simulations were performed: two simulations for each participant (Figure 1). Ten participants underwent the simulation scenario with PPE first and the simulation scenario without PPE afterward. Another 10 participants underwent the simulations in the opposite sequence. The basal characteristics of total recruited participants and according to groups of randomized sequences are shown in Table 1.

Comparison of quality measures of one-rescuer CPR is shown in Table 2. In four minutes of CPR, fewer chest compressions were delivered in resuscitation with PPE on (273.1 versus 251.6, mean difference (95% CI): −21.6 (−33.2 to −9.9)). An approximately 5.7-second increase of no-flow time was shown when PPE is worn in the paired comparison (95% CI: 1.8–9.5). The proportion of chest compressions within an adequate rate decreased by 12.9% when PPE is worn compared with resuscitation without PPE (Table 2, Figure 2).

The success rates of IVC and ETI decreased when PPE was worn (95% versus 85%, 100% versus 85%, respectively), although comparison by the Fisher exact test was not statistically significant. The mean completion time of each life-saving procedure was significantly delayed when PPE was worn. The mean delay times in the paired comparison were 34.8 seconds (95% CI: 26.7–44.9) in IVC and 14.8 seconds (95% CI: 0–29.6) in ETI (Table 3). In Kaplan–Meier analysis with the log-rank test, the cumulative success rate of IVC was higher in simulation without PPE worn ($p < 0.01$, Figure 3).

4. Discussion

In the results of our brief survey from participants after simulations, most participants chose limitations of wrist and hand movement (65%) as the most disturbing factors when performing procedures with PPE on. Visual disturbances due to the face-piece and respirator (20%) were chosen as the second most disturbing factor.

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### Table 1. Basal characteristics of participants according to randomized groups.

<table>
<thead>
<tr>
<th></th>
<th>Total participants (n = 20)</th>
<th>PPE first group (n = 10)</th>
<th>PPE later group (n = 10)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male (%)</td>
<td>12 (60%)</td>
<td>6 (60%)</td>
<td>6 (60%)</td>
<td>1.00</td>
</tr>
<tr>
<td>Mean age (years)</td>
<td>33.4 ± 4.6</td>
<td>33.9 ± 4.3</td>
<td>32.8 ± 4.9</td>
<td>0.60</td>
</tr>
<tr>
<td>Body weight (kg)</td>
<td>63.6 ± 11.4</td>
<td>63.9 ± 12.7</td>
<td>63.2 ± 10.6</td>
<td>0.89</td>
</tr>
<tr>
<td>Length of career as EMT (months)</td>
<td>97.6 ± 51.8</td>
<td>103.3 ± 47.2</td>
<td>91.8 ± 57.9</td>
<td>0.63</td>
</tr>
</tbody>
</table>


### Table 2. Paired comparison result of quality measures of CPR simulations.

<table>
<thead>
<tr>
<th>CPR simulation (4 minutes)</th>
<th>PPE off (n = 20)</th>
<th>PPE on (n = 20)</th>
<th>Mean difference in paired comparison (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean number of compressions delivered</td>
<td>273.1 ± 34.3</td>
<td>251.6 ± 41.0</td>
<td>−21.6 * (−33.2 to −9.9)</td>
</tr>
<tr>
<td>No-flow time (seconds)</td>
<td>100.8 ± 10.3</td>
<td>106.4 ± 12.5</td>
<td>5.7* (1.8–9.5)</td>
</tr>
<tr>
<td>Mean compression rate (/min)</td>
<td>117.8 ± 13.8</td>
<td>112.2 ± 13.4</td>
<td>−5.6* (−9.6 to −1.5)</td>
</tr>
<tr>
<td>Mean compression depth (mm)</td>
<td>50.2 ± 6.1</td>
<td>50.5 ± 5.9</td>
<td>0.3 (−1.3 to 1.8)</td>
</tr>
<tr>
<td>Mean leaning depth (mm)</td>
<td>4.1 ± 1.6</td>
<td>4.5 ± 2.1</td>
<td>0.4 (−0.1 to 0.8)</td>
</tr>
<tr>
<td>Proportion of adequate depth (%)</td>
<td>55.5 ± 40.1</td>
<td>57.1 ± 43.6</td>
<td>1.6 (−7.4 to 10.6)</td>
</tr>
<tr>
<td>Proportion of adequate rate (%)</td>
<td>49.6 ± 37.6</td>
<td>62.4 ± 34.7</td>
<td>12.9* (0.5–24.2)</td>
</tr>
</tbody>
</table>

*Indicates $p < 0.05$.

CPR: cardiopulmonary resuscitation; PPE: personal protective equipment; CI: confidence interval.
one-rescuer resuscitation in a warm zone wearing PPE compared to interventions done without wearing PPE. The result of our study shows an adverse influence of wearing PPE on essential life-saving interventions. Chest compressions performed at a suboptimal rate are known to be associated with a decreased rate of survival in cardiac arrest. Intermittisons in chest compressions causing longer no-flow time are known to have negative effect on cardiac output, coronary, cerebral perfusion pressures, and the success rate of subsequent defibrillation and are therefore considered as an important quality measure in CPR. Prolonged hypoxia due to failure or delayed establishment of an advanced airway could cause severe hypoxic damage to the brain and other vital organs. Fluid resuscitation for hypotensive or proper antidote administration for intoxicated patients cannot be performed without a properly secured IV route. Therefore, the negative influence of wearing PPE during life-saving procedures could result in deterioration of the clinical aspect of unstable patients. The adverse effect was larger in interventions that require fine movements of extremities, such as IVC, rather than in transferring of blunt forces to patients, such as chest

**Figure 2.** Comparison of total compressions delivered, no-flow time, mean chest compression depth, and mean chest compression rate according to wearing personal protective equipment (PPE).

**Table 3.** Success rate and mean time to completion of IVC and ETI.

<table>
<thead>
<tr>
<th>Procedure</th>
<th>PPE off</th>
<th>PPE on</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Success rate</td>
<td>IVC 19/20</td>
<td>17/20</td>
<td>0.605</td>
</tr>
<tr>
<td>ETI 20/20</td>
<td>17/20</td>
<td>0.231</td>
<td></td>
</tr>
<tr>
<td>Procedure</td>
<td>PPE off</td>
<td>PPE on</td>
<td>Mean difference in paired comparison (95% CI)</td>
</tr>
<tr>
<td>Mean time to completion (seconds)</td>
<td>IVC 54.1 ± 21.1</td>
<td>89.9 ± 22.0</td>
<td>34.8 (26.7–44.9)</td>
</tr>
<tr>
<td>ETI 49.8 ± 23.1</td>
<td>64.6 ± 30.9</td>
<td>14.8 (0–29.6)</td>
<td></td>
</tr>
</tbody>
</table>

IVC: intravenous cannulation; ETI: endotracheal intubation; PPE: personal protective equipment; CI: confidence interval.
compressions. Assessing veins and inserting a catheter into the veins with protective gloves on hands is a challenging task even for experienced EMTs. Visual sight disturbance caused by the protective face-piece and ineffective posture with PPE might have interfered with the faster completion of ETI. Increased no-flow time during one-rescuer CPR in our results also suggests that the rescuer spent more time when moving toward the victim’s head and performing two positive pressure ventilations. We estimate this delay of time comes from difficulty in changing body positions, in manipulating the back-valve mask, and in securing the airway for proper positive pressure ventilation when rescuers wore PPE.

Although the overall performance level decreased by wearing PPE, the importance of the protective function of wearing PPE should not be disregarded because protecting the rescuer is as important as protecting victims. Therefore, additional efforts for improving the performance level when PPE is worn have to be made, other than just not wearing PPE in resuscitation. The result of the simulations and survey in this study suggests that modifications should be considered to optimize current PPE for EMS personnel. The modification and optimization should be made considering the main tasks of EMS personnel in a situation where PPE is needed, without compromising the original protecting function of PPE. Modification for better mobilization of joints of the upper extremities and for better visual sight should be considered based on the result of our study. Further study should be designed to test the efficacy of modified PPE compared to the current PPE on various tasks of EMS personnel.

Our study has a few limitations. Firstly, due to the simulation nature of this study, the power of extrapolation to real disaster situations is limited. However, disasters are difficult to anticipate and a prospective randomized trial, including field intervention not wearing PPE, is practically impossible. Therefore, the test had to be carried out and compared in a realistic simulation environment. Secondly, life-saving interventions were all performed on a simulation kit and simulation manikin, which might be too easy for EMTs who have more than eight years of average experience in the field (Table 1). Therefore, the negative effect of wearing PPE, such as poorer security of visual sight and difficulty in fine movement, might have been underestimated. We estimate that in real chaotic disaster incidents the time delay and failure rate of life-saving procedures would be higher than in this simulation study.

5. Conclusions
The performance level of life-saving interventions decreased when EMS personnel wore level-C PPE in a simulated setting of disaster resuscitation. The degree of disadvantage varied between types of life-saving interventions according to motions and forces used. Further efforts have to be made for optimizing currently distributed PPEs for EMS personnel, based on the result of this study, in order to achieve a higher level of performance in disaster resuscitation.

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6. References

Author biographies
Tae Han Kim is an emergency physician and a clinical fellow of Seoul national university hospital. Dr. Kim research focuses on education and training of EMS personnel using simulation technique.

Chu Hyun Kim is an associated professor of department of emergency medicine, Inje university Seoul Paik hospital. Dr. Kim is also acting as a chair of education committee of Korean society of disaster medicine Senior researcher, Laboratory of Emergency Medical Services, Seoul National University Hospital Biomedical Research Institute

Sang Do Shin is professor of department of emergency medicine, Seoul national university college of medicine. Dr.Shin is head director of laboratory of emergency medical services, Seoul national university hospital biomedical research institute. His research focuses on various field of emergency medical service and resuscitation science.

Sunnie Haam is a researcher of urban safety & security research institute, university of Seoul. Her research focuses on protective device and equipotent for EMS personnel in disaster.