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Practicality of performing medical procedures in chemical protective ensembles

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Abstract

Objective: To determine whether certain life saving medical procedures can be successfully performed while wearing different levels of personal protective equipment (PPE), and whether these procedures can be performed in a clinically useful time frame.

Methods: We assessed the capability of eight medical personnel to perform airway maintenance and antidote administration procedures on manikins, in all four described levels of PPE. The levels are: Level A — a fully encapsulated chemically resistant suit; Level B — a chemically resistant suit, gloves and boots with a full-faced positive pressure supplied air respirator; Level C — a chemically resistant splash suit, boots and gloves with an air-purifying positive or negative pressure respirator; Level D — a work uniform. Time in seconds to inflate the lungs of the manikin with bag-valve-mask, laryngeal mask airway (LMA) and endotracheal tube (ETT) were determined, as was the time to secure LMAs and ETTs with either tape or linen ties. Time to insert a cannula in a manikin was also determined.

Results: There was a significant difference in time taken to perform procedures in differing levels of personal protective equipment ($F_{21,72} = 1.75$, $P = 0.04$). Significant differences were found in: time to lung inflation using an endotracheal tube (A *vs.* C mean difference and standard error 75.6 ± 23.9 s, $P = 0.03$; A *vs.* D mean difference and standard error 78.6 ± 23.9 s, $P = 0.03$); time to insert a cannula (A *vs.* D mean difference and standard error 63.6 ± 11.1 s, $P < 0.001$; C *vs.* D mean difference and standard error 40.0 ± 11.1 s, $P = 0.01$).

Conclusions: A significantly greater time to complete procedures was documented in Level A PPE (fully encapsulated suits) compared with Levels C and D. There was however, no significant difference in times between Level B and Level C. The common practice of equipping hospital and medical staff with only Level C protection should be re-evaluated.

Key words: *cannulation, chemical suit, intubation, personal protective equipment.*

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Table 1. Levels of personal protective equipment

Level A	A fully encapsulated and chemically resistant suit with integral gloves and boots that requires the use of self contained breathing apparatus (SCBA). Provides the maximal amount of vapour and splash protection.
Level B	A chemically resistant suit, gloves and boots, with a positive pressure, full-faced respirator using either SCBA or an air-line. Offers less protection against skin, eye and mucous membrane exposure compared with Level A and should be used only where liquids or particles present are known not to contain high levels of chemicals harmful to skin or capable of absorption through intact skin.
Level C	An air purifying positive/negative pressure respirator, a chemically resistant splash suit, boots and gloves. Only suitable when the types of air contaminants have been identified, concentrations have been measured, and an air-purifying respirator is available that can remove all the contaminants. This category has been subdivided into C1, positive pressure respirators, and C2, negative pressure respirators (the standard military issue chemical mask).
Level D	A work uniform affording minimal protection, suitable for nuisance contamination only.

Introduction

Medical personnel attending patients who have been contaminated by hazardous chemical, biological or radiological agents, are at risk of secondary contamination and must take adequate precautions to ensure that they also do not become victims of the agent. Personal protective equipment (PPE) appropriate to the agent is therefore required. Four levels are generally recognized[1,2] and are described in Table 1.

Despite the likely presence of highly toxic chemicals such as nerve agents during a chemical weapons attack, military services use Level C PPE. This is due to the practical and logistical difficulties of using higher levels of PPE in the military context. Civilian occupational health and safety regulations however, mandate that higher levels of PPE be utilized. In many jurisdictions such as Australia and the USA, this must be of at least Level B and preferably Level A standard where the type of agent or concentration of agent is unknown.[1–3] These conditions are to be expected during the early management of terrorist incidents and may occur in industrial incidents where placarding has been lost or destroyed. The practicality of performing medical procedures in Level C PPE has been previously investigated in both military and civilian contexts.[4–7] However, we are not aware of any studies that have examined the practicality of performing medical procedures in either Level A or Level B PPE.

It may be necessary for medical staff to wear Level A or B PPE, when managing casualties in some situations. Exercises held prior to the Sydney 2000 Olympic Games involving simulated releases of military nerve agents, indicated that casualties who were not able to self-evacuate were only likely to survive if airway management could be provided prior to decontamination at the incident site. Intensive respiratory support including endotracheal intubation and initiation of mechanical ventilation are required to prevent death, which will otherwise occur within a few minutes.[8] This is similar to the Israeli civil defence model where an intubation point staffed by an anaesthetist is positioned in front of the nonambulatory decontamination station.[8] Personal protective equipement of at least Level B standard is the minimum appropriate level for civilian medical personnel staffing such an intubation point.[3]

It has been demonstrated in the military context that tasks such as blood pressure and heart rate monitoring while wearing PPE are time consuming, and likely to be inaccurate.[9] However, during the release of military nerve agents where urgent intervention is critical and medical personnel are most at risk from secondary contamination, maintenance of the airway[10] and antidote administration are the critical procedures prior to decontamination.[11] We therefore assessed the capability of medical personnel to perform these procedures specifically.

Our objective was to determine whether certain life saving medical procedures could be successfully performed while wearing different levels of PPE, and whether these procedures can be performed in a clinically useful time frame.

Methods

Eight subjects were asked to perform a predetermined set of medical procedures in each of the four levels of PPE and the time to successfully complete each procedure was recorded. The subjects were: eight prehospital medical personnel; three paramedics; three emergency physicians; and two anaesthetists. All had previously been trained and certified in the use of self-contained breathing apperatus (SCBA), negative and positive pressure filter masks and chemical suits by the New South Wales Fire Brigades Breathing Apparatus and Hazardous Materials Training Centre. The study was conducted indoors in training rooms of the centre.

Three adult intubation manikins (Ambu Ltd), and three cannulation arms were arranged on the floor and subjects were asked to perform the following tasks:

Task 1 — a size 5 geudels airway, adult face mask and self-inflating bag, were positioned next to the manikin. Time taken to connect the bag and mask, insert the geudels airway, position the airway and demonstrate lung inflation was measured.

Task 2 — a deflated laryngeal mask airway (LMA) size 4 (Intravent) lubricated with silicone lubricant appropriate for use in a manikin, a 10 mL syringe (out of packaging), self-inflating bag, and roll of adhesive tape with the end folded back, were positioned next to the manikin. Time to insert the LMA, inflate the cuff and demonstrate lung inflation was measured. The time to secure the LMA with tape and again demonstrate lung inflation was then measured.

Task 3 — a size 8 endotracheal tube (ETT), a bougie, an introducer, a 10 mL syringe, self-inflating bag, a laryngoscope with size 3 Macintosh blade and a precut length of linen tape, were positioned next to the manikin. Time required to insert the ETT into the trachea, inflate the cuff, and demonstrate lung inflation with the self-inflating bag was measured. The time to secure the ETT with linen tape and again demonstrate lung inflation was then measured.

Task 4 — an 18 gauge Intrasyte cannula (Becton and Dickensen), a non-reflux valve, alcohol swab, a roll of adhesive tape, a tourniquet, a pair of trauma shears and a preloaded 5 mL syringe were positioned next to the manikin. The time required to open the alcohol swab, cannula and valve packaging using trauma shears, apply the tourniquet, swab the insertion site, insert the cannula in the dorsum of the hand, connect the valve, secure the cannula with elastoplast and demonstrate ability to flush the cannula was measured. The manikin veins had been prefilled with red dye and an observer subsequently confirmed correct placement of the cannula in a vein by aspiration of red dye from the cannula.

Tasks 1–3 were consecutively performed once by each subject on the same manikin, and then task 4 was performed on the cannulation arm at a separate station, in each level of PPE, commencing with Level D and working through to Level A. All subjects performed the tasks in the same order. Investigators using stopwatches measured the times required to complete each procedure. None of the subjects had any previous experience performing medical procedures in PPE except for Level D, which is the normal level of protection used by prehospital personnel as part of universal infection precautions. No opportunity to practise with the manikins while wearing the various levels of PPE was provided prior to commencement of the trial, or before the measurement of individual procedures was carried out.

Use of antidote auto-injectors in PPE was not assessed. This was for two reasons. First, we were unable to source any for the trial, and second, it is likely to be substantially easier than cannulation of a vein as they are specifically made for use while wearing PPE. We thought it reasonable to assume that if a vein could be cannulated in a manikin, then use of an auto-injector would be accomplished without difficulty.

A multivariate analysis of variance (MANOVA) was used to compare the times taken to perform procedures (inflate lungs using bag-valve-mask or LMA or endotracheal tube, insert cannulae and securing LMA or endotracheal tube) by level of PPE. Scheffe multiple comparison post-hoc test was used to determine where the difference was among levels of PPE when the primary analysis was significant. Although the underlying distribution of the data was normal using the Kolmogorov-Smirnov test, the error variance was not equal across the level of PPE for two variables (inflating lungs using endotracheal tube, and insertion of cannula). Despite this, MANOVA is a robust test and can withstand small violations of these assumptions. Power calculations were not done as we considered this study to be a pilot and a convenient sample of subjects was chosen. Additionally there were no previous studies indicating that the procedures could be performed at all in Level A or B PPE. Significance was set at $P < 0.05$. Analysis was performed using SPSS version 11.0 software.

Results

There was a significant difference in time taken to perform procedures in differing levels of personal protective equipment ($F_{21,72} = 1.75$, $P = 0.04$), as displayed in Table 2. Significant differences were found in:

Table 2. Mean times (seconds and 95% confidence intervals) taken to do various procedures by level of personal protective equipment

Procedure	Level of personal protective equipment				P-value†
	A (n = 8)	B (n = 8)	C (n = 8)	D (n = 8)	
Inflate lungs using bag-valve-mask	13.0 (8.0, 18.0)	12.0 (8.3, 15.7)	13.5 (7.2, 19.8)	9.5 (6.5, 12.5)	0.50
Inflate lungs using LMA	38.1 (27.5, 48.8)	34.4 (25.9, 42.9)	33.3 (18.4, 48.1)	36.0 (18.1, 53.9)	0.94
Inflate lungs using endotracheal tube	119.5 (50.1, 188.9)	62.4 (28.3, 96.4)	43.9 (28.0, 59.8)	40.9 (28.0, 53.8)	< 0.01
Insert cannula	109.3 (94.8, 123.7)	77.0 (62.1, 91.9)	85.6 (55.8, 115.4)	45.6 (38.1, 53.2)	< 0.001
Secure LMA	21.8 (11.3, 32.2)	21.6 (12.6, 30.6)	19.4 (10.6, 28.1)	13.9 (9.1, 18.7)	0.39
Secure endotracheal tube	51.4 (33.9, 68.8)	46.1 (34.9, 57.4)	41.0 (24.2, 57.8)	28.6 (23.1, 34.2)	0.06

†Univariate F-tests

- Time to lung inflation using an endotracheal tube: (A *vs.* C mean difference and standard error 75.6 ± 23.9 s, $P = 0.03$); (A *vs.* D mean difference and standard error 78.6 ± 23.9 s, $P = 0.03$).
- Time to insert a cannula: (A *vs.* D mean difference and standard error 63.6 ± 11.1 s, $P < 0.001$); (C *vs.* D mean difference and standard error 40.0 ± 11.1 s, $P = 0.01$).

All tasks were completed within 5 min.

Discussion

It was possible to perform all the medical procedures tested in all levels of PPE. There were statistically significant differences in the time taken to perform intubation and cannulation, particularly in Level A, but the clinical significance of these differences is questionable. Ventilation via bag-valve-mask and via LMA appeared to be unaffected by the level of PPE, presumably as neither of these procedures require either good visualization or fine motor skill. There was no significant difference in performance of tasks between Level B and Level C PPE.

It is believed by some authors that Level A and B PPE, in comparison to Level C, are expensive, bulky, and require specialized training.[12] In reality, Level B ensembles are a third less expensive to acquire than Level C1 ensembles. Additionally, batteries on Level C1 respirators need to be cycled at least monthly and perhaps as often as weekly to ensure maximum performance,[13] whereas Level B air sets and cylinders need to be maintained only annually. A similar training time is required for competency using both types of equipment. The subjective experience of the participants in this study was that it was no more difficult to perform procedures in Level B relative to Level C, and this is reflected in the fact that no significant difference in times to completion of procedures was documented.

As Level B is the lowest level PPE for use in environments where the type or concentration of agent is not known, performance of medical procedures is no more difficult, equipment acquisition and maintenance costs are lower, and training times are similar, there appears to be little place for Level C PPE in civilian chemical/biological/radiological (CBR) response. As it is possible to perform all the tested procedures in all levels of PPE and within a clinically useful time frame, it would be reasonable to include skilled medical staff in Level A or B PPE at intubation points positioned before decontamination stations. Experience of one author (AG) in pre-Sydney Olympic Games exercises indicated that this was the only way to provide timely airway management in simulated military nerve agent releases, as mass decontamination equipment was slow to deploy, and early airway management and ventilation has been demonstrated to be critical to survival.[10]

It is commonly believed that patients presenting to emergency departments will be minimally contaminated and therefore that Level C PPE is adequate for emergency department staff. This belief is questionable as:

- Hospitals themselves can be the target of a chemical incident or attack, or the incident may occur in very close proximity to a hospital.
- Hospitals can receive casualties who have received fatal toxic exposures that represent a serious secondary contamination hazard to emergency department staff.[14,15]
- Emergency department staff have received severe, potentially fatal, secondary chemical exposures from contaminated casualties presenting to emergency departments by private transport.[16]
- Persistent military nerve agents such as VX present principally a liquid rather than vapour hazard.

Patients exposed to small droplets of such agents may remain ambulant for as long as 30 min before the onset of seizures, allowing ample time for self-presentation to an emergency department.[2]

It cannot therefore be assumed that Level C protection is adequate for emergency department staff in all situations, and again suggests that staff should be trained to operate in at least Level B PPE.

Our results indicate that LMAs are a very rapid way of providing ventilation and may be the airway of choice in mass contamination incidents where airway management is required. Laryngeal mask airways could then be changed for endotracheal tubes as time and resources allowed. Laryngeal mask airways do not provide the degree of airway protection afforded by an endotracheal tube, which may be particularly important in the management of exposure to agents that produce emesis and hypersecretion such as anticholinesterase poisoning.[17] Intubation should still be considered the airway management modality of first choice where there are small casualty numbers.

Taping of the LMAs was substantially faster than tying of the endotracheal tubes with linen tape. Although taping was faster, it is likely to be less secure, particularly in patients with copious secretions associated with anticholinesterase poisoning. Security of the tube is important as patients will be undergoing movement through a decontamination process, where there is a high probability of tube dislodgement. Alternative means of securing LMAs and endotracheal tubes, which are practical to use while wearing high levels of PPE, should be investigated.

The principle limitation of this study was that it was conducted on manikins. Apart from the anatomical differences between manikins and people, some of the pathological conditions, which may be associated with chemical exposure, were also not present. These include factors such as copious airway secretions, vomitus and trismus. Ethically however, it would be difficult to repeat this study in humans.

The study was conducted indoors, which may make laryngoscopy easier than if it was performed outside in bright sunlight. There are ways to improve visualization in this situation, such as covering the head of the rescuer and victim with a blanket to exclude ambient light. These manoeuvres can be expected to increase the time taken to perform intubation, regardless of the level of PPE worn. Attacks with military nerve agents in a civilian context are more likely however, in confined spaces such as subways and shopping complexes, as these environments limit dispersal of the agent.

The times to perform procedures in Level A and B suits may have been impaired by the amount of scuffing of the visors on both the SCBA sets and the Level A suits. The SCBA sets used for the trial were training sets, which receive frequent use. Sets employed in operational conditions however, are maintained with scratch-free visors. This may have been a particular factor in the increased time taken to perform procedures that were dependent on visualization in Level A PPE, such as intubation and cannulation. Level A PPE requires the wearer to see though both the scuffed visor of the SCBA set and the visor of the Level A suit. The Level C sets used were all in good condition, with scratch-free visors.

The most common complaints by participants, were the movement restrictions and the difficulty at visualizing in the mask as described in other studies.[18] The visualization in the double mask of the fully encapsulated suite (Level A) was extremely poor, due to the factors already noted.

No participants were allowed time to practice procedures in PPE prior to commencement of the trial and none had prior relevant experience. These procedures are manual skills that can be expected to improve with practice. We have determined however, that skilled prehospital medical/paramedical personnel who are familiar with performing procedures in difficult environments, were able to perform all of the procedures without prior practice. This suggests that extensive practice may not be necessary, although improvement in times taken to perform procedures in Level A PPE is desirable.

Conclusion

We have demonstrated that it is possible to perform common airway management procedures and cannulation on manikins while wearing all levels of PPE, in a clinically useful time frame. As Level B protection is the minimum appropriate level for civilian personnel where the agent is not known, medical personnel should be routinely trained to operate in this level of protective ensemble. Consideration should be given to training specific personnel in the use of Level A suits where there may be a need to manage persons at an incident site which is contaminated with super-toxic chemicals such as military nerve agents. Consideration should also be given to the routine use of LMAs as first choice for airway management in incidents involving multiple casualties, and an alternative fixation device should be developed and trialed. In the situation of mass casualties, LMAs should be replaced by an ETT once patients are decontaminated and are in a clean, stable area or as time allows. Finally, although the use of auto-injectors is likely to be easier, cannulation can be performed successfully. Limitation in the availability of auto-injectors in a civilian situation may make cannulation necessary.

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