Evaluating the impact of decontamination interventions performed in sequence for mass casualty chemical incidents

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Research Article

Keywords: Initial Operational Response (IOR), Specialist Operational Response (SOR), decontamination, chemical incidents

Posted Date: March 29th, 2021

DOI: https://doi.org/10.21203/rs.3.rs-373547/v1

Version of Record: A version of this preprint was published at Scientific Reports on July 22nd, 2021. See the published version at https://doi.org/10.1038/s41598-021-94644-0.

Abstract

The Initial Operational Response (IOR) to chemical incidents is a suite of rapid strategies including evacuation, disrobe and improvised and interim decontamination. IOR and Specialist Operational Response (SOR) decontamination protocols involving mass decontamination units would be conducted in sequence by UK emergency services following a chemical incident, to allow for safe onward transfer of casualties. As part of a series of human volunteer studies, we examined the effectiveness of IOR and SOR decontamination procedures alone and in sequence. Specifically, we evaluated the additional contribution of SOR, when following improvised and interim decontamination. Two simulants, methyl salicylate (MeS) with vegetable oil and benzyl salicylate (BeS), were applied to participants' skin. Participants underwent improvised dry, improvised wet, interim wet, specialist decontamination and a no decontamination control. Skin analysis and UV photography indicated significantly lower levels of both simulants remaining following decontamination compared to controls. There were no significant differences in MeS levels recovered between decontamination conditions. Analysis of BeS, a more persistent simulant than MeS, showed that recovery from skin was significantly reduced following combined IOR with SOR than IOR alone. These results show modest additional benefits of decontamination interventions conducted in sequence, particularly for persistent chemicals, supporting current UK operational procedures.

Introduction

Chemical incident response in the UK has progressed from reliance on specialist assets (Specialist Operational Response (SOR)), to an Initial Operational Response (IOR) characterised by rapid interventions including evacuation, disrobe and decontamination [1]. IOR decontamination initially involves one of two methods, improvised dry decontamination using any absorbent material or improvised wet (for corrosives) following a 'rinse wipe rinse' (RWR) wet decontamination protocol [1]. As additional resources arrive at the incident scene, improvised decontamination is followed by interim decontamination, typically a short, high-volume cold-water corridor between two Fire & Rescue Service appliances.

SOR uses Mass Decontamination Units (MDUs) that take time to deploy but can decontaminate approximately 150 casualties per hour through structured showering involving, warm water, detergent and washing aids.

Improvised decontamination was shown to be efficacious at removing methyl salicylate (MeS), a simulant for sulphur mustard, from skin [2–4]. Interim decontamination after improvised provides additional benefit, facilitating MeS removal from less accessible areas [5]. Decontamination using MDUs is regularly exercised and has been systematically evaluated [6], however, since the introduction of IOR, an evaluation of any additional benefits associated with conducting SOR following IOR has not been undertaken.

We evaluate for the first time the efficacy of IOR and SOR decontamination in sequence to remove MeS and for the first-time benzyl salicylate (BeS), a simulant for less volatile chemical warfare agents such as Novichoks [7], from the skin of human volunteers. Urinary BeS levels were used as a surrogate of systemic exposure.

Methods

Ethical approval was given by Public Health England's Research Ethics Group. As part of a series of human volunteer studies eleven (power = .909, based upon [4]) participants completed a controlled cross-over study in which their skin was dosed separately with MeS (1:1 mixture with vegetable oil) and BeS (each with 4mg/ml of fluorescent marker Invisible Red S [4,8]) at sites on both shoulders (Figure S1). The shoulder was chosen as it was a site refractive to decontamination using improvised procedures [4]. For UV image analysis, additional 2µL of each simulant was added to the wrists and calves. A further 700µL MeS:oil and 300µL BeS were applied without fluorescent markers (Figure S1) to facilitate urine analysis. Total doses were 414mg MeS and 358mg BeS. Table S1 details the participant and study characteristics.

Participants completed five randomised decontamination interventions on different days (Table 1); improvised dry, improvised wet (RWR, [4]), interim (a bespoke high-volume showering corridor [8]), SOR (an MDU with detergent and flannel, [8]) and a no-decontamination control. Interventions were conducted at a time post simulant application equivalent to operational expectations (Figure S2). Control participants were treated as reported in [4].

Table 1
Trial design, the design includes 5 conditions: [1] Control, [2] Dry + Interim, [3] RWR + Interim, [4] Dry + Interim + SOR, [5] RWR + Interim + SOR. All participants (n = 11) took part in each stage of the study in random order.

Intervention	Time from simulant application (min)		
	15	25	60
1	Control		
2	Dry	Interim	
3	RWR	Interim	
4	Dry	Interim	SOR
5	RWR	Interim	SOR

Participants provided baseline [4] and t = 80 minute post-simulant application urine samples on day 1 and collected all subsequent urine for 24h. MeS and BeS remaining on skin was determined by skin sampling

and UV image analysis [4,8]. Urine analysis, interpretation and statistics were conducted according to [4,8].

Results

Participants completed all interventions. All decontamination interventions resulted in significant decreases in the skin recovery of MeS ($p < 0.1$) and BeS ($p < 0.001$) compared to controls (Fig. 1A and 1B). Planned contrasts found no significant difference in MeS recovered between dry / wet + interim and SOR, however BeS recovery was significantly lower following SOR compared to dry / wet + interim ($p = .0189$). For both MeS and BeS there were no significant differences between the dry and wet improvised conditions, and this did not significantly change with the addition of interim and SOR. UV image analysis of both emittance (amount of simulant) and area (spread of simulant) supported the skin sampling data (Fig. 1C).

BeS was detected above baselines in all 80-minute urine samples (Fig. 1D). Interestingly, there was a marginally significant increase ($p = .057$) in BeS excreted in 80-minute samples between the decontamination interventions and controls. There was no significant change in BeS in 24-hour urine samples between the decontamination interventions and control.

Discussion

The introduction of IOR marked a paradigm shift in the UK's emergency response to chemical incidents. That casualties may now undergo improvised and interim decontamination before the arrival of SOR assets raises the question of the additional benefit of using specialist MDUs. This human study examined the cumulative efficacy of improvised dry, or improvised wet decontamination, followed by interim wet decontamination and then SOR, on the removal of MeS and BeS from skin.

Decontamination was effective at removing MeS and BeS from skin with SOR providing an additional benefit over dry / wet + interim for BeS only. The low persistence of MeS meant that a mean 1.3% of the dose was recovered from controls and < 0.1% in all decontamination interventions. This made it difficult to demonstrate any further improvement with SOR when conducted at a timepoint chosen to realistically reflect the set-up times for these specialist assets (60 mins). For volatile chemicals, the apparent diminishing returns of decontamination performed in sequence suggests additional research is needed to determine whether in this instance further decontamination is necessary prior to clinical intervention. In contrast, 68% of the more persistent BeS was recovered in controls and consequently, the addition of SOR increased decontamination efficacy.

Marginally significant increased levels of urinary BeS were observed at 80 minutes in the decontamination interventions compared to controls. Unexpectedly, none of the decontamination interventions significantly decreased 24-hour urinary BeS. Urine levels can be used as a biomarker for systemic exposure and these data therefore imply that despite effective skin decontamination, interventions were not able to decrease systemic and therefore potentially hazardous levels of these

chemicals. It is possible that skin penetration occurs prior to decontamination at 15 minutes such that skin decontamination after this point has little effect. The temporal increase in urinary BeS may be accounted for by the 'wash-in' effect whereby skin hydration enhances chemical transfer through skin [9] but further investigation is required to verify this.

This study has limitations. Participant adherence was good because they were guided through the protocols by the research team. In real incidents due to the potential ratio of casualties to responders, casualties will play a greater role in undertaking decontamination themselves; therefore, protocol adherence and by extension decontamination efficacy may be reduced. Also, whilst this is the first human study to examine skin decontamination for two physiochemically divergent simulants, caution is advised when generalising the results for other chemicals.

Here, SOR provided additional benefits beyond improvised and interim decontamination for BeS but not MeS. This implies that for chemicals less well removed by IOR due to their physicochemical character, the addition of SOR is likely to be of greater importance, but further studies with divergent simulants is required. It is also possible that SOR may play an important role where preceding decontamination protocols have either not been conducted, or there is doubt over how well they have been implemented. Whilst decontamination of skin is useful in preventing transfer of chemicals to responders and medical staff, the absence of a significant decrease in systemic simulant levels suggests that the benefits to casualties is less clear and requires further investigation.

Declarations

Acknowledgements

This paper is based on independent research commissioned and funded by the National Institute for Health Research (NIHR) Policy Research Programme (PR-ST-1015-10016). Samuel Collins and Tom James are part-funded by the NIHR Health Protection Research Unit (HPRU) in Chemicals and Radiation Threats and Hazards (CRTH) at Imperial College London, Tim Marczylo is part-funded by the HPRU in CRTH and the HPRU in Health Impacts of Environmental Hazards at Imperial College London and Richard Amlôt is part-funded by the HPRU in Emergency Preparedness and Response at King's College London. The views expressed in the publication are those of the author(s) and not necessarily those of the NHS, the NIHR, the Department of Health and Social Care, arms-length bodies or other Government departments.

Author contributions

All authors conceived the experiments. SC, TJ, FS, LD, NW and EO performed the experiments. All authors analysed the data. SC and NW wrote the main manuscript with input from all authors. All authors reviewed the manuscript.

Additional information

The authors declare no financial or non-financial competing interests.

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Figures

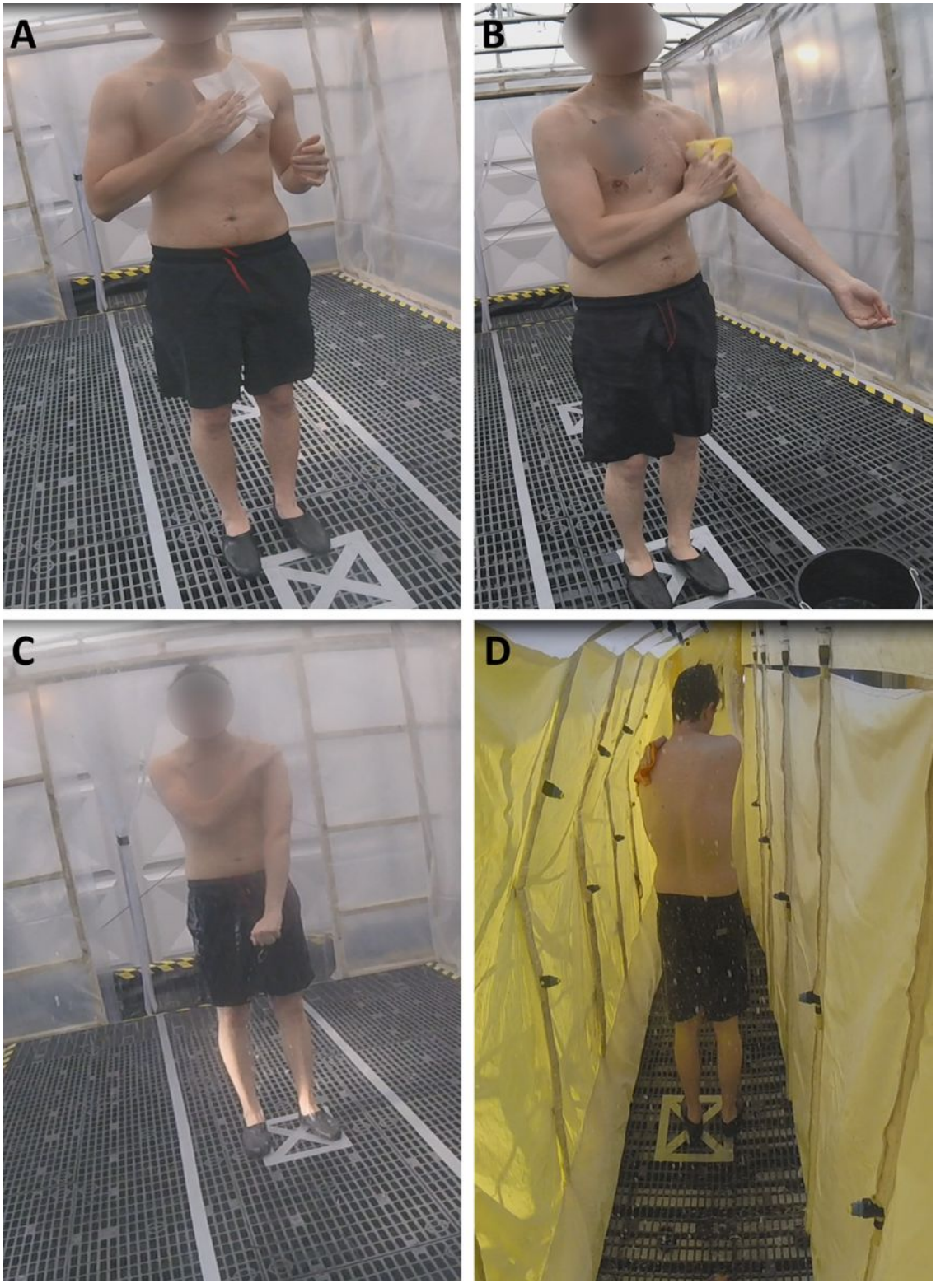

Figure 1

A participant undergoing each of the decontamination conditions. A = dry decontamination using white roll sheets, B = RWR using a sponge, bucket and soapy water, C = interim using a bespoke showering corridor and D = SOR using an MDU.

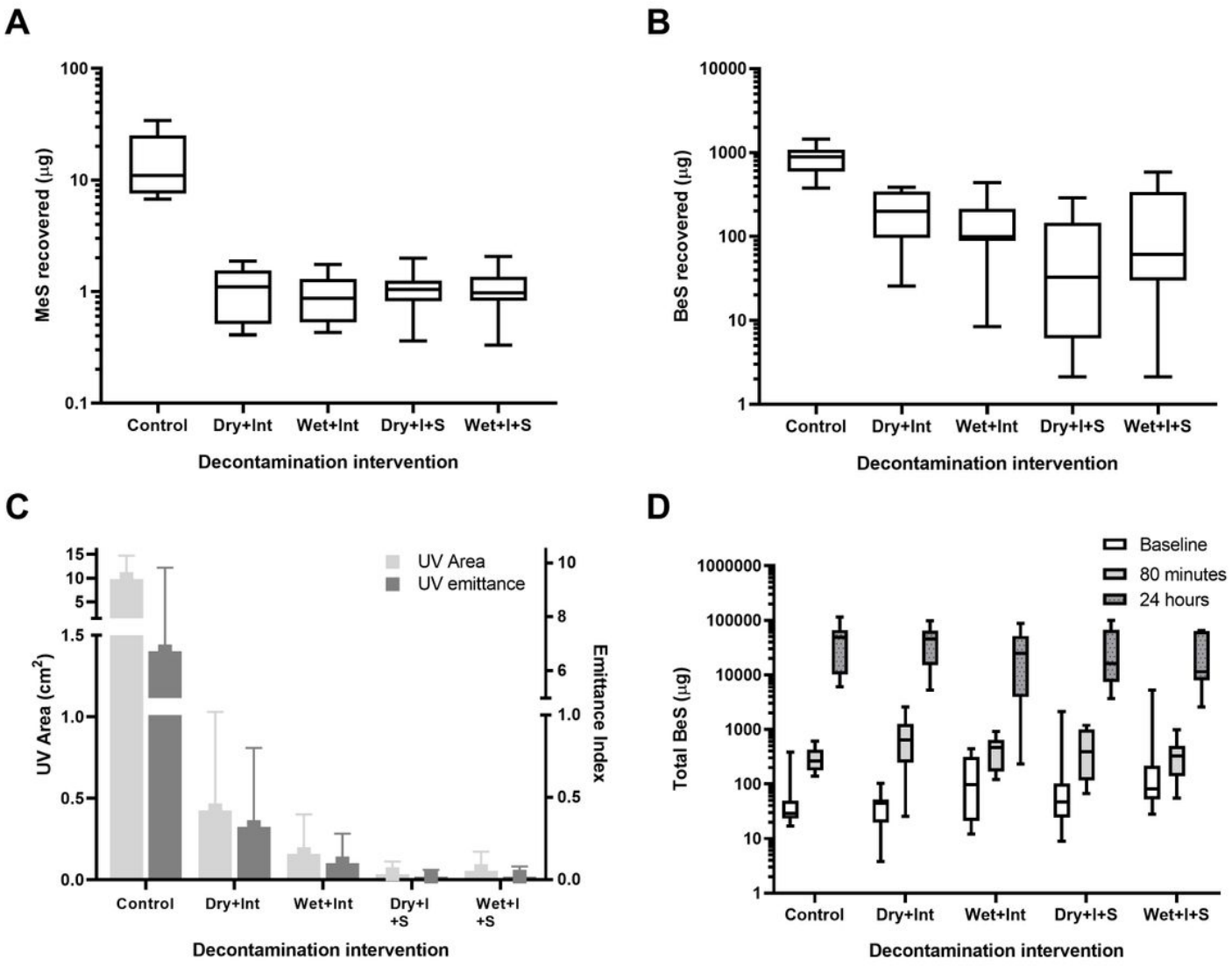

Figure 2

A) MeS recovered from skin for each decontamination condition, B) BeS recovered for each decontamination condition, C) Total simulant area (spread) and emittance (simulant amount) detected by UV image analysis, D) Total BeS excreted in urine for baseline, 80 minute and 24 hour samples. Box and whisker plots show median and inter–quartile range, together with the maximum and minimum values.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- SupplementarydataFINAL.docx