Comparative Analysis of Showering Protocols for Mass-Casualty Decontamination

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CBR = chemical, biological, or radiological
UV = ultraviolet

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Abstract

A well-established provision for mass-casualty decontamination that incorporates the use of mobile showering units has been developed in the UK. The effectiveness of such decontamination procedures will be critical in minimizing or preventing the contamination of emergency responders and hospital infrastructure. The purpose of this study was to evaluate three empirical strategies designed to optimize existing decontamination procedures: (1) instructions in the form of a pictorial aid prior to decontamination; (2) provision of a washcloth within the showering facility; and (3) an extended showering period. The study was a three-factor, between-participants (or "independent") design with 90 volunteers. The three factors each had two levels: use of washcloths (washcloth/no washcloth), washing instructions (instructions/no instructions), and shower cycle duration (three minutes/six minutes). The effectiveness of these strategies was quantified by whole-body fluorescence imaging following application of a red fluorophore to multiple, discrete areas of the skin. All five showering procedures were relatively effective in removing the fluorophore "contaminant", but the use of a cloth (in the absence of instructions) led to a significant (~20%) improvement in the effectiveness of decontamination over the standard protocol (p <0.05). Current mass-casualty decontamination effectiveness, especially in children, can be optimized by the provision of a washcloth. This simple but effective approach indicates the value of performing controlled volunteer trials for optimizing existing decontamination procedures.

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Introduction

Recent terrorist events have highlighted the need to re-evaluate emergency response procedures to incidents involving large numbers of casualties.[1] Such mass-casualty incidents may arise from the release of hazardous substances based on chemical, biological, or radiological (CBR) agents. While a CBR incident may produce a spectrum of health effects and require a wide range of medical countermeasures, the provision of a single, effective decontamination procedure is essential for providing emergency responders with a generic means of minimizing the impact of exposure to a wide range of materials.[2] However, there is a paucity of data to support a rational, evidence-based evaluation of current decontamination procedures.

In the UK, facilities for mass-casualty decontamination are provided primarily by the Fire and Rescue Service. Decontamination involves a process of disrobing, showering, and donning fresh clothing.[3] This study is part of an extensive program evaluate and optimize existing decontamination procedures.[4] The study will address a variety of factors such as the clinical relevance of the wash-in effect,[5] the adverse effects of delayed disrobing or decontamination, and the influence of water temperature on washing efficacy.

The aim of this study was to evaluate the impact of several potential revisions of the current UK decontamination protocol, namely, the use of wash-

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Group	Treatment			Description
	Shower duration (min)	Cloth	Instructions	
A	-	-	-	Control
B	3	-	-	Standard UK shower protocol
C	3	+	-	Novel test strategies
D	3	-	+	
E	3	+	+	
F	6	-	-	

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Table 1—Summary of treatment regimes for each experimental group. The symbols "+" or "-" indicate the presence or absence, respectively, of the specific treatment.

cloths, extended showering duration, and provision of pictorial washing instructions. The effects of each were quantified by measuring the disappearance of a fluorescent skin "contaminant" using a custom-built, whole-body fluorescence imaging system.

Methods

Procedures and Participants

An ultraviolet (UV) activated fluorophore ("Invisible Red-S"; tris (3-(2,2,3,3,4,4,4- heptafluorobutyryl) bornane-2-onato-O,O') europium; excitation wavelength 365 nm, emission wavelength 616 nm) was kindly provided by Capricorn Chemicals, UK.

Absolute ethanol (>99%) was purchased from Fisher, UK. The fluorophore was dissolved in ethanol to produce a 4 mg ml^{-1} stock solution (A), with subsequent dilutions in ethanol to achieve concentrations ranging from 0.2 to 3.6 mg ml^{-1} (Solutions B – M) for calibration. The anionic detergent currently used in UK decontamination showers (Florafree®) was supplied by Deb Ltd., UK.

This study was conducted in accordance with the principles of the Declaration of Helsinki and was independently approved by the UK National Health Service (NHS) Wiltshire Research Ethics Committee (WREC). Prior to inclusion in the study, each volunteer completed a health questionnaire that was reviewed by a registered health professional to exclude those adults or children with pre-existing skin conditions or other health issues that potentially could affect their safety during the trial.

The study was a three-factor, "independent" design. The three factors each had two levels: (1) use of washcloths (washcloth or no washcloth); (2) washing instructions (instructions or no instructions); and (3) shower cycle duration (three minutes or six minutes). In order to account for any incidental loss of skin contaminant during the disrobe/rerobe procedure, a group of volunteers were contaminated with the fluorescent tag but did not undergo decontamination (control group).

In total, there were six volunteer groups (Table 1). Male and female volunteers (mean age = 44 years, range = 7 to 81 years, total number = 90) were assigned randomly to each group. Dark clothing was provided to all volunteers to limit interference from exogenous sources of fluorescent (brightening) agents. Males were dressed in black shorts and females in black shorts and cropped black tops.

Images of each volunteer were acquired in a light-proofed horsebox (Space-TrekaM, Equitrek) which had been modified to incorporate a staggered array of 12 UV fluorescent tubes (model F36W/BLB-T8, Sylvania), with UV-transparent plastic diffusers. Volunteers were photographed standing 2 m from the UV array in the centre of an internal doorway (Figure 1), a process that required approximately 3 minutes exposure to the UV array. Prior to the study, the spectral output of the UV array was assessed using a calibrated spectroradiometer (USB 2000, Ocean Optics), which confirmed that the source emitted predominantly in the UVA spectrum (320–400 nm) and that the dose of UV received by each volunteer was less than 10% of recommended levels (permissible for an eight-hour time-weighted exposure as proposed by the International Commission on Non-Ionizing Radiation Protection (ICNIRP)) (average 67 mW m^{-2}, range 61–72 mW m^{-2}). Therefore, no eye protection was deemed necessary.

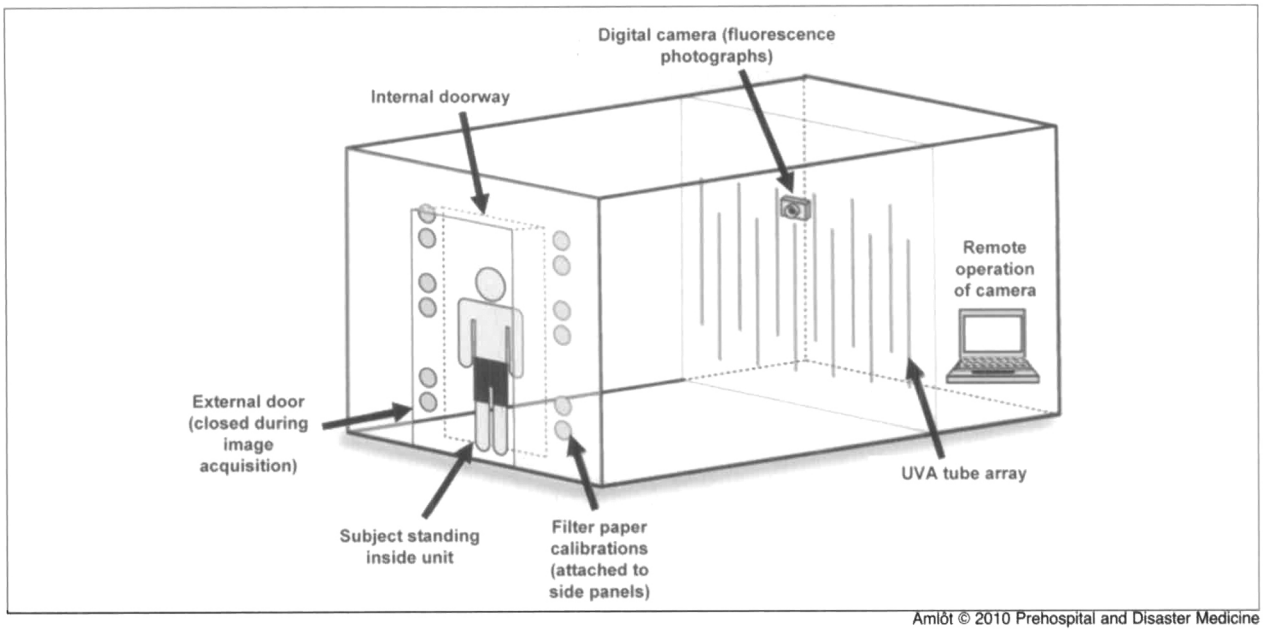
Initial (baseline) photographs were acquired under UV illumination in the horsebox prior to the topical application of the fluorophore using felt-tipped pens filled with the appropriate fluorophore solution. A Perspex® template with a countersunk (1.5 cm diameter) hole was used as a guide to "contaminate" areas of skin on each subject.

Solution A of the fluorophore was applied to 12 skin sites on the front of each volunteer (forehead, both cheeks, both shoulders, both ante-cubital fossae, both hands, abdomen and both legs). Solutions A to E were applied to five sites on the back of each volunteer. After allowing the fluorophore solutions to "dry" on the skin surface, each volunteer was photographed a second time under UV illumination. The volunteers then underwent their respective decontamination treatment before being photographed for a third time.

Images of each volunteer (front and back) were acquired using a digital single lens reflex camera (40D, Canon) with 17-85 mm EF lens (Canon) and an IR/UV filter (486, Black and White) located at the center of the UV array (Figure 1). The camera was operated via EOS Utility software v1.1.0.8 (Canon) with images collected as unprocessed and uncompressed data files. The film speed (ISO) was set to 1600 and aperture to F4.0 for maximum light sensitivity. A shutter speed (Tv) of 0.5 seconds was selected to minimize blurring from accidental subject movement whilst maintaining exposure and sensitivity. The focal length was set to 17 mm and white balance set to automatic.

All raw image files were converted to JPEG files following adjustment for lens distortion using appropriate software (Digital Photo Professional v3.4.1.1, Canon) and subsequently analyzed using a commercially available image analysis software program (Image Pro Analyzer v6.2.0.424, MediaCybernetics, UK). The red channel of each JPEG image was extracted and converted to an 8-bit grayscale image and fluorescent areas ("objects") were automatically

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Figure 1—Schematic representation of the modified horsebox, indicating position of subject, calibration units, UV tube array and camera.

identified on the volunteers' skin. Each image file was analyzed using the same software settings. Spatial calibration was performed by determining the number of pixels between specific points on the internal doorway edges (which were of known dimensions). Fluorescent intensity calibration was achieved by reference to 2 x 6 sets of "standards" on each image (positioned on the internal doorway adjacent to each volunteer; Figure 1). The standards were prepared by applying 10 µl aliquots of fluorophore (Solutions A – M) to circular filter papers (Qualitative Grade 1, 11 cm diameter, Whatman) using an adjustable micropipette (P25, Microman, Gilson, UK). The calibration standards were adjusted to correct for the additional, intrinsic fluorescence of the filter paper.

The intensity of each fluorescent object was recorded and normalized by dividing by the respective object area and converted to amount (weight) of fluorophore by reference to a standard curve derived from the calibration standards. For the purposes of the statistical analysis, areas of fluorescence which were not detected by the software (being below the calibration threshold) were assigned an intensity value of zero.

Where appropriate, decontamination of volunteers was conducted using a standard UK Fire and Rescue Service unit (MD1, Professional Protection Systems, UK), which comprised three sections; a disrobing area, a showering area and a re-robing area. The showering area was supplied with detergent (5% Florafree®) dissolved in water (delivered from a fire hydrant) via a boiler unit (model SF-12A, 500 btu, TVI, USA). Decontamination was conducted in groups of up to 10 volunteers (two groups of five showering concurrently). A "standard" washing cycle consisted of a 2-minute delivery of detergent solution followed by a water-only rinse for a further minute. The temperature and flow rate of the water leaving the pump were 37°C and ~6,000 L h^{-1}, respectively. This equated to a flow of ~10 L min^{-1} per person.

The percentage efficacy of each treatment was initially calculated according to Equation 1.

$$\% \text{ Efficacy} = 100 - ((Qpre - Qpost)/Qpre) \times 100$$

Where Q is the amount of fluorophore present on the skin surface of each volunteer (interpolated from the standard curve of fluorescent intensity against amount of fluorophore) before (Qpre) or after (Qpost) showering. For the purpose of this report, all of the data are expressed relative to the control (non-decontaminated) group.

Statistical Analysis

The statistical distribution of the resulting fluorophore data was assessed and this retrospective analysis resulted in the use of a one-way, parameteric ANOVA to detect differences in the decontamination efficacy between treatment groups. All statistical processing was performed using SPSS® v17 (SPSS Ltd., Chicago, IL).

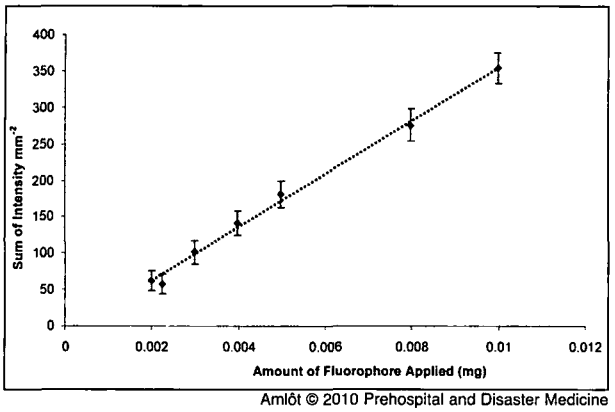
Results

The intensity calibration curve was linear ($r^2 = 0.99$) over the range of fluorescence measured on the skin of each volunteer following topical application of the fluorophore (Figure 2). Baseline photographs confirmed no exposure to a red fluorophore prior to application of the organic europium complex.

Each of the showering protocols was significantly effective in removing contamination from the front and back of volunteers in comparison with the (non-showering) control group ($p < 0.05$). Of the four novel showering strategies, only the use of a washcloth (Group C) on ventral surfaces led to a statistically significant (~20%) improvement in decontamination efficiency when compared against the current UK procedure (Group B; Figure 3).

There was a consistent trend for ventral surfaces to be cleansed more thoroughly than dorsal (Figure 3). However,

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Figure 2—Calibration curve, expressed as sum of fluorescent intensity against the total amount of applied fluorophore. All values are average ±1 standard deviation (n = 5). These data encompassed the range of intensity values measured on the skin of all volunteers.

Decontamination Facility	Treatment Group	
	Front	Back
Highest	C	C
	E	E
	F	F
	B	B
	D	D
Lowest	A	A

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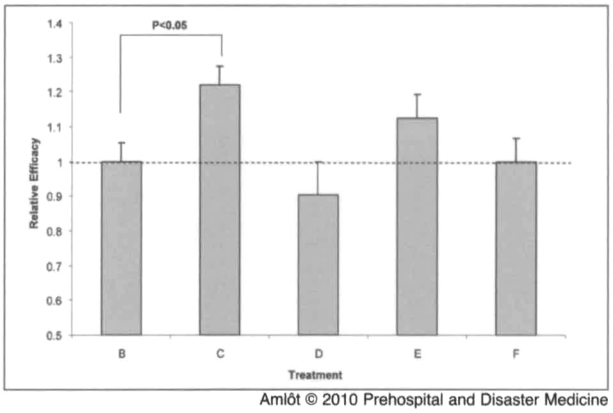
Table 2—Qualitative ranking of treatments based on cleansing of ventral (front) and dorsal (back) surfaces. Treatment groups are defined in Table 1.

this effect was not statistically significant within experimental groups. The ranking of each treatment was identical for both ventral and dorsal aspects (Table 2).

Discussion

This study demonstrated that an evidence-based appraisal of existing procedures can effect a significant (~20%) improvement in the performance of emergency decontamination units. As expected, any procedure involving showering of an individual will result in significant removal of a fluorescent tracer from the skin surface. However, apparently logical modifications such as providing pictorial washing instructions or increasing shower duration did not result in a measurable improvement in decontamination efficiency. The most effective revision identified in this study was simply to provide users of the decontamination facility with a washcloth.

Evaluation of decontamination efficiency in this study was quantified using whole body fluorescence. Ideally, a fluorescent tracer should have similar physicochemical properties to the material for which it is employed as a surrogate. While the use of a fluorescent marker in this study was not used to model any particular skin contaminant, further



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Figure 3—Performance of treatment regimes (B-F) expressed relative to non-showering control group (Group A; n = 15) for front (ventral) and back (dorsal) surfaces. Treatments were standard protocol (Group B; n =15), standard protocol with cloth (Group C; n = 15), standard protocol with instructions (Group D; n = 13), standard protocol with cloth and instructions (Group E; n = 20) and extended shower protocol (Group F; n = 11). Each treatment was statistically differnt from the untreated controls using one-way ANOVA.

work is in progress to ascertain the similarities between this fluorophore and specific chemical, biological, or radiological agents. However, it can be stated with some confidence that the use of such fluorescent tracers can facilitate an objective and quantitative evaluation of *generic* improvements to current decontamination procedures.

Fluorescent tracers to monitor personal contamination were first utilized approximately 50 years ago,[6] and subsequent refinements have since been applied.[7-9] However, whole body fluorescence imaging may be subject to error as a result of body curvatures which affect both the homogeneity of incident UV illumination and emission of fluorescence from the skin surface. The projection of a raster grid (series of horizontal and vertical lines) onto the subject with adjustment for surface contour variation is one relatively simple means of improving accuracy.[10] Alternatively, more complex (e.g., polydecahedral) illumination arrays can be employed.[11] In the system described here (Figure 1), the problem of dealing with body curvature was mitigated, to some extent, by positioning the fluorophore on skin sites that were perpendicular to the camera/UV array and UV irradiance was confirmed as being relatively constant at the position of each volunteer (~62 mW m^{-2}).

Statistical analysis of the six washing protocols indicated that any form of showering significantly aids removal of the fluorescent simulant. The most effective showering procedure was the standard protocol combined with provision of a washcloth, which resulted in a 20% increase in the total amount of fluorophore removed from volunteers. The other four showering strategies were not significantly different to the standard protocol. It was interesting to note that the provision of simple pictorial instructions (Group D) did not improve washing efficiency. Volunteer feedback from the study (questionnaire-based interviews; data not report-

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ed) suggested that these instructions may need to be reiterated inside the shower units to elicit an appropriate effect. A doubling of the showering duration also demonstrated no significant improvement, so it is conceivable that there actually may be scope for decreasing shower duration. This is an important observation, as reducing showering time could enhance the throughput of mass-casualty decontamination units. Further work is required to determine optimum showering duration.

The average amount of fluorophore removed from the dorsal surfaces of volunteers was consistently less than the ventral aspects (Figure 3). This observation implies that a "buddy system" may be appropriate for ensuring complete cleansing within the showering units.

Conclusions

The topical application of a UV-fluorescent compound in combination with whole-body fluorescence imaging enabled a quantitative comparison of different decontamination protocols and confirmed that showering is an effective means of limiting dermal exposure to chemicals. The provision of a washcloth significantly improved the efficacy of fluorophore removal by ~20% in comparison to the current UK protocol. Provision of pictorial instructions and extension of shower duration failed to produce any statistically significant improvement. While this study confirms the value of performing controlled volunteer trials for optimizing existing decontamination procedures, further laboratory studies are required to confirm the use of fluorophore and other simulants as effective models for chemical, biological, and radiological hazards.

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Improving Decontamination Procedures: A Priority for Chemical Incident Management

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The management of the release, either accidental or deliberate, of toxic chemicals continues to be a matter of concern and debate. The HAZMAT model[1] of hot, warm, and cold zones operated by most fire and rescue services around the world assumes that the released chemical is persistent, and therefore, likely to give rise to contamination that increases the dose to those directly exposed to the release as well as increasing the risk of secondary harm from transmission of the hazard to emergency responders and those further away, such as hospital emergency department personnel.

Decontamination of those exposed to a persistent chemical agent is a fundamental stage in the management of any chemical incident. However, since decontamination is a time-consuming process, there are immediate problems both in terms of the capabilities available and the potential delays that the decontamination process causes to providing emergency medical care. The latter problem has been addressed by putting protected medical teams into the warm zone to provide essential life support before and during decontamination.[2,3] However the potential delays in decontamination for a large number of persons remain. Given that this increases the potential exposure dose from a toxic agent, efforts are required to reduce the time of decontamination and to increase its effectiveness.

In their article in the current issue, Amlôt and colleagues[4] have demonstrated in an elegant scientific study that substantial improvements to a standard decontamination procedure can be achieved using simple measures. Employing modern whole-body fluorescence imaging, the authors have shown that the effectiveness of a simple showering decontamination technique can be significantly improved by the use of a washcloth. As expected, any procedure involving showering of an individual will result in significant removal of a fluorescent tracer from the skin surface. However, apparently logical modifications such as providing pictorial washing instructions or increasing shower duration did not result in a measurable improvement in decontamination efficiency. Since doubling of the showering duration demonstrated no significant improvement, it is conceivable that there actually may be scope for decreasing shower duration during decontamination. This is an important observation, since reducing showering time could enhance the throughput for mass-casualty decontamination units

Concerning their technique, the authors note that it can be stated with some confidence that the use of fluorescent tracers can facilitate an objective and quantitative evaluation of generic improvements to current decontamination procedures. However, further laboratory studies are required to confirm the use of fluorophore and other simulants as effective models for chemical, biological, and radiological hazards.

Amlot and colleagues have illustrated well the effectiveness of apparently simple gestures in improving decontamination, together with the value of performing well-designed, controlled, volunteer studies and a modern assessment technique to optimize existing decontamination procedures. Until recently, decontamination procedures have been largely empirical with little scientific backing. There is a further need to review the position of decontamination in

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standard HAZMAT protocols and how these affect patient care. In the absence of clear identification of the released risk, the only safe pathway is to assume that the chemical released is both highly toxic and persistent. However, given that a large number of toxic industrial chemicals are not persistent, there may be a risk of automatically providing decontamination where it is not required. Along with this uncertainty is the question of the level of personal protective equipment worn by medical responders, which is appropriate to the release that allows freedom to provide essential medical care. This has been the subject of previous comment.[5] These issues illustrate the need to refine our current stance on the management of chemical releases using measures that are appropriate to the degree of risk. This will involve considerable development of detection, identification, and monitoring procedures used in conjunction with the provision of appropriate life support and other therapy.

The problem of decontamination has been highlighted in the emergency departments that may have to receive casualties who have been incompletely decontaminated at the release site or who have escaped through the cordon without being decontaminated.[6] In a mass-exposure incident, there is a possibility that hospitals may be overwhelmed. Thus, any procedures that can improve decontamination and the time it takes to be effective are welcome.

It is to be hoped that further studies of the type reported by Amlot and colleagues, will investigate all aspects of decontamination further to confirm the validity of current protocols and to evaluate new procedures, particularly in the use of active rather than passive gestures.

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