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Showering effectiveness for human hair decontamination of the nerve agent VX

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ABSTRACT

In this work, our goals were to establish whether hair decontamination by showering one hour post-exposure to the highly toxic organophosphate nerve agent VX was effective, whether it required the addition of a detergent to water and, if it could be improved by using the adsorbent Fuller's Earth (FE) or the Reactive Skin Decontamination Lotion (RSDL) 30 min prior to showering. Hair exposure to VX and decontamination was performed by using an *in vitro* model. Hair showering led to 72% reduction of contamination. Addition of detergent to water slightly increased the decontamination effectiveness. Hair treatment with FE or RSDL improved the decontamination rate. Combination of FE use and showering, which yielded a decontamination factor of 41, was demonstrated to be the most effective hair decontamination procedure. Hair wiping after showering was shown to contribute to hair decontamination. Altogether, our results highlighted the importance of considering hair decontamination as an important part of body surface decontamination protocols.

1. Introduction

Recent history has demonstrated that civilian populations could be exposed to highly toxic chemicals, radioactive agents or pathogenic microorganisms following natural catastrophes, industrial incidents or terrorist acts [1–3].

First aid to contaminated victims includes body surface decontamination. This should be implemented as quickly as possible following hazardous substance exposure in order to prevent absorption of agents by victims and to limit transfer of contamination to "clean" individuals, materials and environment.

During the last decade, effectiveness of emergency decontamination procedures and kits which were firstly designed for military have been evaluated for civilian use [4], the specificities of which generally being the lower degree of hazards knowledge, the population heterogeneity (age, language…) and the longer delay between exposure and decontamination, *i.e.* less than 5 min for military vs 30 min or more for civilian.

It has been clearly established that beneficial effect of decontamination for contaminated victims is highly dependent of the delay between exposure and decontamination, *i.e.* the shorter the better [5]. However, it was shown that most persistent contaminants are still available to decontaminants more than 30 min post-exposure [6,7]. Consequently, decontamination could be effective and required even after more than 1 h delay following exposure.

Guidelines for emergency decontamination procedures include removal of external layer of clothes [8]. Without any source of water available on an incident site, the emergency skin and hair decontamination procedure could firstly be performed with any absorbent/adsorbent materials available such as sponge or powder [4]. For instance, according to the French procedure [9], it is recommended to use Fuller's Earth (FE) as adsorbing powder. The bulk powder could be directly poured on the scalp hair and skin or by using a powdering glove which consists, for a face, of a sieved pocket used to deliver FE on contaminated skin and hair and, for the other face, of a sponge used to displace from the skin and hair liquid contaminants adsorbed on FE. After FE application on hair, it is recommended to cover hair with a mobcap to avoid FE inhalation. This could be followed with total disrobing then body surface washing, if possible by showering [10], the mobcap being removed just before showering. Eye decontamination could be successfully performed by flushing with water or saline or specifically designed

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solutions [11]. Thorough scalp hair decontamination is recommended to be done by shampooing and showering [12]. Effectiveness of different skin decontamination procedures, among them showering, has been evaluated by using *in vitro* and *in vivo* skin models [12–14], including human trials [15,16]. For instance, pig skin showering with tepid soapy water for a relatively short duration (1–2 min) followed with rinsing then wiping has been shown to be an effective skin decontamination procedure even when performed up to 60 min post-exposure to the nerve agent VX [14]. Furthermore, emergency skin decontamination kits such as FE-based powdering glove (NBC-Sys, Saint-Chamond, France) and oximate-based Reactive Skin Decontamination Lotion "RSDL®" (Emergent Biosolutions Inc., Rockville, MD, USA) were demonstrated to successfully decontaminate animal skin following chemical warfare agents (CWA) exposure [17].

However, to our knowledge, effectiveness of currently recommended protocol for hair decontamination of hazardous substances has not been established, although, it was shown that hair could trap chemical agents, including VX [18,19], radioactive contaminants [20] and anthrax spores [21]. Consequently, as opposed to skin, hair decontamination by showering might require potentially longer washing cycles and the use of a specific shampoo.

In this work, our goal was firstly to establish whether one hour post-exposure hair decontamination of VX could be effective following a relatively quick shower, *i.e.* 1-min, secondly, whether addition of a detergent to water could improve hair decontamination effectiveness and thirdly, whether applying FE or RSDL on hair 30 min prior to showering could improve the decontamination effectiveness. We also aimed at evaluating the importance for decontamination effectiveness of hair wiping after showering.

For obvious ethical reasons, hair scalp contamination with toxic agents cannot be performed on human volunteers. Consequently, we designed and used an *in vitro* model which was as similar as possible to the material used in the field for hair showering. This model allowed for modulation of water temperature (15–50 °C), of composition and concentration (0.2–10%) of additives to water and of water flow rate (0.1–2 L/min).

2. Materials and methods

2.1. Chemicals

O-ethyl-s-[2(di-isopropylamino)ethyl]methyl phosphonothioate (VX, 99% pure, CAS Registry number 50782-69-9) was synthesized and provided by DGA-MNRBC (Vert-le-petit, France). Hanks' Balanced Salt Solution (HBSS) was from Invitrogen, Horse butyrylcholinesterase (BChE) and butyrylthiocholine iodide were provided by Sigma (Saint Quentin Fallavier, France). The decontamination powder Fuller's Earth was obtained from Paul Boyé Technologies (Le Vernet, France) and the Reactive Skin Decontamination Lotion RSDL® was from Ouvry (Lyon, France). The detergent Argos 700® was from Argos Hygiene (Villefontaine, France).

2.2. Experimental conditions

In vitro studies were conducted within a fume hood (face flow rate of 0.7 m s^{-1}) at room temperature (20 ± 2 °C) and with relative humidity of 50 ± 10%. Butyl gloves were worn during the entire experimental procedure.

2.3. Hair samples

Locks of human hair (~30 cm long) were obtained from Sécher Fesnoux (Chaville, France). They were untreated caucasian hair of different colours (blonde, gray, brown, black).

2.4. Hair contamination

Hair locks (~10 g) were attached together at one end then, hooked to a metallic stand. A single droplet of VX (density of 1.0083 at 25 °C [22]) (applied dose (Q0) of 10 µl ~ 9.98 mg ~ 37 µmoles) was applied in one discrete location, *i.e.* about 5 cm below the hooked end of the hair lock (as shown in Photo 1).

2.5. Hair decontamination

Hair decontamination with FE or RSDL (*i.e.* "pre-showering" decontamination procedure) was performed 30 min following VX exposure. Hair was showered 60 min post-exposure to VX.

2.5.1. Hair pre-showering

Hair locks were horizontally disposed on a Teflon plate. FE (~10 g) was poured on the hair then spread as evenly as possible on the entire hair surface with gauze; or, a gauze was soaked into 20 g of RSDL then was used to spread RSDL on the hair surface as evenly as possible and this was repeated 3 times, each time with a clean gauze. As it might be expected in a real exposure situation, FE and RSDL were used in large excess relative to the amount of contaminant on hair, *i.e.* a few grams of decontaminant vs a few mg of contaminant.

2.5.2. Hair showering

Hair showering was performed for 1 min with water heated at a temperature of 34 ± 1 °C, containing or not 0.5% detergent, applied on the hair surface at a flow rate of 2 L/min. The water tank, heater, mixer of additive to water and water delivery system were made and provided by UTILIS S.A.S. (Ennery, France) (Photo 2).

As shown in Photo 3, prior to showering, hair lock was hooked on a Teflon stand fixed at one open end of a plastic cylinder which was slightly larger than the nozzle diameter. This cylinder was placed above a beaker that was used to collect the contaminated water and allowed for prevention of any water projection in the hood.

As can be seen in Photo 4, the cylinder was oriented with a tilt angle of about 30° with respect to a vertical plan. As a result, during the showering process, wet long hair was stuck in the inner wall of the cylinder in much the same way they would be on the head during a normal shower (Photo 5).

Each set of hair locks ($n \geqslant 7$ per set) were decontaminated according to one of the following protocols: showering with water ("SHOWER"); showering with water containing 0.5% detergent ("SHOWER DET"); pre-showering with FE then showering with water containing 0.5% detergent ("FE + SHOWER DET");

Photo 1. *In vitro* hair contamination.