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Fluorescence Visualization as a Training Tool for Infection Control

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Abstract

Ultraviolet (UV) fluorescent tracers are a powerful training tool when used as a simulant for infectious agents. Their use is well established to teach healthcare staff effective hand hygiene and safe removal of contaminated gloves. This paper reviews the more recent use of similar techniques to create scenarios in healthcare where exposure to infectious body fluids and potential for cross-contamination occur, e.g. clean-up following Norovirus-triggered projectile vomiting, or exposure to infective body fluids when examining symptomatic patients with high consequence infectious disease. Examples are described to demonstrate the value of these techniques in ensuring safety from cross-infection in healthcare

Keywords: Healthcare; Infection control; Fluorescent; Simulant

Introduction

In most industrialized countries, healthcare is one of the largest workforces, necessary to support the medical needs of the population. While the primary focus of healthcare is the needs of those patients, a fundamental requirement is also that the care provider should be protected against exposure to pathogens to reduce the risk of infection. This is necessary not only to ensure their safety and enable them to continue their work, but also to prevent cross-infection to other patients or the wider community. The highest level of infection control is achieved by physical barriers. Especially with high consequence infectious diseases (HCID), including viral haemorrhagic fevers such as Ebola Virus Disease (EVD), it is imperative where possible to use physical barriers such as isolators, usually in combination with engineering controls such as isolation rooms with filtered air under negative pressure on a precautionary basis. The use of isolation rooms under negative pressure becomes even more important for airborne transmissible diseases such as tuberculosis. However, in the large majority of cases during treatment delivery these measures are not practicable. Therefore it is necessary to rely on other protective measures, i.e., personal protective equipment (PPE) that is appropriate for the task being undertaken.

If PPE is used for protection during a specific procedure, it must be the correct size and fit for the wearer and needs to be put on (donned) correctly. By definition of the reason for the PPE being used, there must be the assumption that it could become contaminated. Obviously at some point it must be removed (doffed), which can prove difficult to do safely and is dependent on good technique. Unsafe doffing can lead to exposure if carried out incorrectly, potentially cross-contaminating the wearer or their immediate environment. After removal, the PPE must either be disposed of safely or contained until decontaminated for re-use.

This paper reviews the use of fluorescence visualization as a training tool in developing safe practices where PPE usage is required.

Training requirements for safe PPE use

It is easy to underestimate the complexity of safe removal of PPE. Studies have shown high error rates when doffing even basic PPE [1-4], while PPE users' perception of their own proficiency often correlates poorly with correct use [5]. More positively, if contamination is closely associated with an incorrect doffing technique [6,7], this suggests that good training will result in improvement. Consequently, safe glove removal is a fundamental training requirement for all healthcare staff as part of basic infection control, with training in safe removal of other PPE dependent on the roles and tasks. At a higher level of infection control in healthcare there is a necessity to prevent nosocomial infection such as Norovirus. With this infection, especially in the hospital environment, cleaning up after projectile vomiting with the associated dissemination of infectious virus is particularly challenging to achieve without those undertaking the clean-up being exposed and potentially infected. At the highest level, medical staff may need to rely on PPE protection to ensure safe practice and minimize the likelihood of self-contamination when treating or caring for a patient with suspected or confirmed HCID. Therefore, to control their risk of infection, these medical staff needs to be well trained, with proven competence, as well as using safe PPE components.

At all these healthcare delivery levels, immersive simulation, with users engaging in exercises representing the real world [8], can augment technical and behavioral elements of PPE training. In healthcare education, simulation training ensures familiarity prior to patient care and provides a safe environment to practice routine procedural skills and management of medical emergencies [9].

Simulation Based Training Using UV Fluorescence

Hand hygiene

An example of simulation that has expanded greatly in recent years is the use of UV fluorescent markers. This is well established for healthcare worker training as a means to visualize contamination easily and thus assess compliance with hand hygiene. Using harmless fluorescent liquids or gels rubbed onto the hands, the efficiency of washing can be assessed by examining the hands under UV light to reveal any residual 'contamination' left behind [10,11]. This can also be used to assess cross-contamination of the environment and equipment [12-16]. While the trainees concentrate on removing all traces of fluorochrome from

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their hands, shining a UV torch around the hand wash area may reveal fluorescent deposits on taps, soap and towel dispensers. A further use for fluorescent markers is to train staff in safe glove removal. This is done by covering the gloved hands in fluorescent gel then, after using established safe glove removal techniques [17], examining hands post-glove removal for traces of cross-contamination to skin or clothing [18] **(Figures 1A and B)**. In all of the above examples, the instant feedback achievable provides a powerful training tool, enabling the trainees to immediately associate cross-contamination with technical errors, and enables trainers to correct systematic errors and to implement corrective actions. A video using fluorescence visualization to compare a good glove removal technique, with an incorrect technique leading to cross-contamination, can be viewed on the HSE website at http://www.hse.gov.uk/skin/videos/gloves/removegloves.htm.

Cross contamination during clean-up of body fluids

A more specialized use of fluorochrome tracers was developed by HSE to examine the potential spread and cross-contamination of Norovirus to the environment and personnel. One of the symptoms of Norovirus infection is projectile vomiting. The very low infectious dose [19] and the potential for widespread environmental contamination both contribute to the reasons why healthcare-associated outbreaks can affect large numbers of patients and require quarantine of premises. A device was designed to mimic human projectile vomiting [20]. This comprised an anatomically correct medical training dummy head, used in healthcare as an adult airways management trainer to practice intubation, ventilation, suction and CPR techniques. This was connected to a plastic cylinder of sufficient volume to mimic human adult stomach content, and a piston with a pneumatic ram delivering a representative pressure to achieve simulated projectile vomiting. The system (termed Vomiting Larry) stood 1.6 m from the floor to the top of the mannequin head and thus was able to mimic the consequences of a standing adult human projectile vomiting as a result of Norovirus infection. With the 'stomach' filled with a UV fluorescent solution, the device was set up to projectile vomit in a test chamber equipped with UV lighting to measure and visualize spread. Under normal lighting conditions, the fluid released during a simulated episode and deposited on floor surfaces extended to around 1.2 m, but under UV light the experiments revealed that splashes and droplets can travel greater distances equating to >3 m forward spread and 2.6 m lateral spread **(Figure 2A)**. This work highlighted the difficulty in seeing small droplets, consequently healthcare staff undertaking a clean-up tend to start too close to the exposure event and potentially cross-contaminate themselves and the wider environment. This was again demonstrated by visualizing fluorescent contamination on the footwear and clothing of the person cleaning the surfaces **(Figure 2B)**. Evidence from the study suggested that areas of at least 7 m^2 should be decontaminated following an episode of projectile vomiting. These data have been used in guidance [21] to advice and train healthcare staff as well as care staff in leisure facilities, on cruise ships and oil and gas platforms.

Training in the use of PPE for protection against HCID

Where reliance on PPE is at its most critical, in caring for patients with suspected or confirmed HCID, training tools are vital to assess PPE and user competence. A Cochrane review previously concluded there was a lack of clear evidence for safe use of PPE components and training methods required for their correct use and doffing [22], more recent research has now addressed this. In this context, visualization of cross-contamination provides powerful, instant feedback to users.

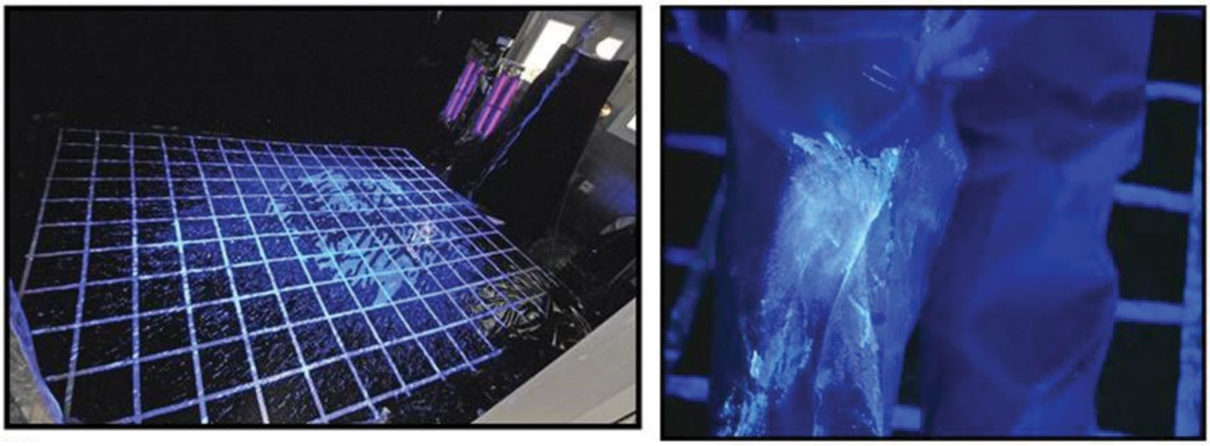
In response to the emerging EVD outbreak in West Africa in late 2014, the UK Army Medical Services were mobilized to staff Ebola Treatment Centers (ETCs) being set up in Sierra Leone. For these staff, and civilian staff who followed, using PPE was the only option to protect them from infection. A pre-deployment training programme, set up to test the protectiveness of the chosen PPE ensemble and provide training to develop competency, used fluorescent markers. People acted as patients in treatment bays to simulate those in the ETCs, and healthcare personnel were exposed to simulant body fluids with a fluorescent marker to represent the potential for exposure during clinical procedures or general healthcare provision. After simulated healthcare interventions, contamination on PPE was visualized under UV light, then after PPE doffing staff was re-examined. This evidence-based exercise facilitated the training of a large number of staff,

1A **1B**

Figure 1: Use of fluorochromes to demonstrate safe glove removal.
1A) Showing accidental cross contamination of fingers.
1B) Cross contamination of wrists during incorrect glove removal.

identified and corrected systematic failures in the doffing processes and ultimately provided staff with reassurance [23].

This use of UV fluorochromes in a simulation-based exercise was further developed by Health and Safety Executive in collaboration with Sheffield Teaching Hospitals to assess the safety of the PPE and protocols used during first assessment of a patient with any possible HCID. This included those that are known to or are suspected of presenting a risk of infection through the airborne route. This was facilitated by the use of a modified mannequin and a scenario-based exercise. The mannequin was adapted to deliver synthetic bodily fluids (via vomit, sweat, diarrhoea and cough), each with a different colored fluorescent tracer, invisible unless under UV light [24]. A hospital training suite was set up to represent an isolation ward, and doctors and nurses, in pairs, undertook a variety of simulated clinical tasks such as routine clinical observations while protected by PPE. The exercise was overseen and contaminant delivery mechanisms operated remotely, from a control room by the researchers, with observations made via a one-way vision window. The doctor and nurse were exposed to simulated cough via a remotely operated spray, exposed themselves to simulated sweat and diarrhoea while examining and cleaning/changing the 'patient' and, towards the end of the scenario, were exposed to a simulated vomiting episode again operated remotely, after which they changed the patient's gown as their last task **(Figure 3A)**. After exposure, while still wearing the now potentially contaminated PPE, they were examined under UV light to locate fluorescent contamination which was recorded on a 35-grid body map and photographed **(Figure 3B)**. They were screened again after PPE doffing to detect any personal contamination. As the exercise



2A **2B**

Figure 2: Use of fluorochromes to investigate spread of projectile vomiting.
2A) Shows splash and droplet dispersal in a test chamber after simulated projectile vomiting.
2B) Shows cross contamination on clothing of person undertaking clean-up.

3A **3B**

Figure 3: Use of fluorochromes to train healthcare staff in safe removal of PPE contaminated by simulated body fluids.
3A) Shows mannequin used in medical examination scenario.
3B) Shows visualisation of PPE contamination (blue fluorescence=vomit; orange=sweat; red=cough; green=diarrhoea).

was videoed, this allowed retrospective analysis of contamination events and user errors. This exercise was used to assess a number of PPE ensembles. The evidence gathered was used by the hospitals potentially assessing patients with HCID and led to a consensus approach to a unified PPE ensemble, together with a doffing protocol, to ensure safe removal of the PPE without cross-contamination [25].

Conclusion

The above examples demonstrate the power of visualization using UV markers as a training tool to develop and reinforce safe working practices and procedures to prevent worker infection. Based around simulations of real life work scenarios, the ability to provide rapid feedback to trainees is additionally beneficial to enable working practices to be improved.

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