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Personal protective equipment for preventing highly infectious diseases due to exposure to contaminated body fluids in healthcare staff (Review)

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[Intervention Review]

Personal protective equipment for preventing highly infectious diseases due to exposure to contaminated body fluids in healthcare staff

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ABSTRACT

Background

In epidemics of highly infectious diseases, such as Ebola Virus Disease (EVD) or Severe Acute Respiratory Syndrome (SARS), healthcare workers (HCW) are at much greater risk of infection than the general population, due to their contact with patients' contaminated body fluids. Contact precautions by means of personal protective equipment (PPE) can reduce the risk. It is unclear which type of PPE protects best, what is the best way to remove PPE, and how to make sure HCW use PPE as instructed.

Objectives

To evaluate which type of full body PPE and which method of donning or doffing PPE have the least risk of self-contamination or infection for HCW, and which training methods increase compliance with PPE protocols.

Search methods

We searched MEDLINE (PubMed up to 15 July 2018), Cochrane Central Register of Trials (CENTRAL up to 18 June 2019), Scopus (Scopus 18 June 2019), CINAHL (EBSCOhost 31 July 2018), and OSH-Update (up to 31 December 2018). We also screened reference lists of included trials and relevant reviews, and contacted NGOs and manufacturers of PPE.

Selection criteria

We included all controlled studies that compared the effects of PPE used by HCW exposed to highly infectious diseases with serious consequences, such as Ebola or SARS, on the risk of infection, contamination, or noncompliance with protocols. This included studies that used simulated contamination with fluorescent markers or a non-pathogenic virus.

Personal protective equipment for preventing highly infectious diseases due to exposure to contaminated body fluids in healthcare staff (Review)

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We also included studies that compared the effect of various ways of donning or doffing PPE, and the effects of training in PPE use on the same outcomes.

Data collection and analysis

Two authors independently selected studies, extracted data and assessed risk of bias in included trials. We planned to perform meta-analyses but did not find sufficiently similar studies to combine their results.

Main results

We included 17 studies with 1950 participants evaluating 21 interventions. Ten studies are Randomised Controlled Trials (RCTs), one is a quasi RCT and six have a non-randomised controlled design. Two studies are awaiting assessment.

Ten studies compared types of PPE but only six of these reported sufficient data. Six studies compared different types of donning and doffing and three studies evaluated different types of training. Fifteen studies used simulated exposure with fluorescent markers or harmless viruses. In simulation studies, contamination rates varied from 10% to 100% of participants for all types of PPE. In one study HCW were exposed to Ebola and in another to SARS.

Evidence for all outcomes is based on single studies and is very low quality.

Different types of PPE

PPE made of more breathable material may not lead to more contamination spots on the trunk (Mean Difference (MD) 1.60 (95% Confidence Interval (CI) -0.15 to 3.35) than more water repellent material but may have greater user satisfaction (MD -0.46; 95% CI -0.84 to -0.08, scale of 1 to 5).

Gowns may protect better against contamination than aprons (MD large patches -1.36 95% CI -1.78 to -0.94).

The use of a powered air-purifying respirator may protect better than a simple ensemble of PPE without such respirator (Relative Risk (RR) 0.27; 95% CI 0.17 to 0.43).

Five different PPE ensembles (such as gown vs. coverall, boots with or without covers, hood vs. cap, length and number of gloves) were evaluated in one study, but there were no event data available for compared groups.

Alterations to PPE design may lead to less contamination such as added tabs to grab masks (RR 0.33; 95% CI 0.14 to 0.80) or gloves (RR 0.22 95% CI 0.15 to 0.31), a sealed gown and glove combination (RR 0.27; 95% CI 0.09 to 0.78), or a better fitting gown around the neck, wrists and hands (RR 0.08; 95% CI 0.01 to 0.55) compared to standard PPE.

Different methods of donning and doffing procedures

Double gloving may lead to less contamination compared to single gloving (RR 0.36; 95% CI 0.16 to 0.78).

Following CDC recommendations for doffing may lead to less contamination compared to no guidance (MD small patches -5.44; 95% CI -7.43 to -3.45).

Alcohol-based hand rub used during the doffing process may not lead to less contamination than the use of a hypochlorite based solution (MD 4.00; 95% CI 0.47 to 34.24).

Additional spoken instruction may lead to fewer errors in doffing (MD -0.9, 95% CI -1.4 to -0.4).

Different types of training

The use of additional computer simulation may lead to fewer errors in doffing (MD -1.2, 95% CI -1.6 to -0.7).

A video lecture on donning PPE may lead to better skills scores (MD 30.70; 95% CI 20.14,41.26) than a traditional lecture.

Face to face instruction may reduce noncompliance with doffing guidance more (OR 0.45; 95% CI 0.21 to 0.98) than providing folders or videos only.

There were no studies on effects of training in the long term or on resource use.

The quality of the evidence is very low for all comparisons because of high risk of bias in all studies, indirectness of evidence, and small numbers of participants.

Authors' conclusions

We found very low quality evidence that more breathable types of PPE may not lead to more contamination, but may have greater user satisfaction. Alterations to PPE, such as tabs to grab may decrease contamination. Double gloving, following CDC doffing guidance, and spoken instructions during doffing may reduce contamination and increase compliance. Face-to-face training in PPE use may reduce errors more than video or folder based training. Because data come from single small studies with high risk of bias, we are uncertain about the estimates of effects.

We still need randomised controlled trials to find out which training works best in the long term. We need better simulation studies conducted with several dozen participants to find out which PPE protects best, and what is the safest way to remove PPE. Consensus on the best way to conduct simulation of exposure and assessment of outcome is urgently needed. HCW exposed to highly infectious diseases should have their use of PPE registered and should be prospectively followed for their risk of infection in the field.

PLAIN LANGUAGE SUMMARY

Clothes and equipment for healthcare staff to prevent Ebola and other highly infective diseases

Healthcare staff are at risk of infections such as Ebola Virus Disease and SARS. One way of preventing infection is to use personal protective equipment, such as protective clothing, gloves, masks, and goggles to prevent contamination of the worker. It is unclear which type of equipment protects best and how it can best be removed after use. It is also unclear what is the best way to train workers to comply with guidance for this equipment.

Studies found

We found 17 studies with 1950 participants that evaluated 21 interventions. We divided the studies into three categories: comparing types of protective clothing, comparing ways to put it on and take it off, and different ways to train the healthcare workers in the use of the protective clothing. Twelve of the studies used a fluorescent marker or a harmless virus to simulate what happens in hospitals. Two studies were conducted under field circumstances: one during the SARS epidemic in 2003 and one during the Ebola epidemic in 2015. Three studies with 962 participants compared the effect of active training on the use of protective equipment to passive training. All studies had either an unclear or a high risk of bias.

Various types of clothing compared

In spite of protective clothing, the fluorescent marker was found on 10% to 100% of workers. In one study, more breathable clothing did not lead to more contamination than non-breathable clothing, but users were more satisfied. Gowns led to less contamination than aprons in another study. Four studies evaluated changes to the protective clothing to make it easier to take it off. Gowns with gloves attached at the cuff that were taken off together also led to less contamination than the gown and gloves taken off separately. Studies that modified the gloves and face masks with tabs to grip when removing the protective clothing led to less contamination. Four studies did not report enough data to enable conclusions. This evidence is very low quality.

Various types of removal of clothing compared

In one study, two pairs of gloves led to less contamination than only one pair of gloves. In another study that used two pairs of gloves, using an alcohol-based hand sanitizer for cleaning the inner gloves did not lead to less contamination than hypochlorite solution. In another study, following CDC guidance for apron or gown removal led to less contamination. One study found that those who were given spoken instructions on how to properly take off the contaminated protective clothing were less contaminated compared to those who did not have the spoken instruction. One study did not report enough data to enable conclusions. This evidence is also very low quality.

Active training

Active training, including computer simulation led to less errors with guidance on which protection to use and how to remove it among healthcare staff compared to passive training. In one study, participants who watched a video, compared to a traditional lecture on how to correctly put on the protective clothing had better scores when tested on how to put on the protective clothing.

Quality of the evidence

We judged the quality of the evidence to be very low because of limitations in the studies, indirectness, and small number of participants.

What do we still need to find out?

There were no studies on the effects of goggles or face shields. Researchers need to agree on the best way to simulate exposure. Then, more simulation studies are needed with at least 60 participants, preferably using exposure to a harmless virus, to find out which type and combination is most protective. The best way to remove protective clothing after use is also unclear. We also need studies to find out which training works best in the long-term. Healthcare staff exposed to highly infectious diseases should have their protective equipment registered and be followed for their risk of infection. We urge NGOs to organise more studies and register and record the type of PPE used by their workers.

SUMMARY OF FINDINGS FOR THE MAIN COMPARISON *[Explanation]*

PAPR versus E-RCP Attire for preventing contact with contaminated body fluids in healthcare staff

Patient or population: Healthcare staff volunteers

Settings: Simulation study

Intervention: PPE with Powered Air Purifying Respirator (PAPR) Attire

Control: Enhanced respiratory and contact precautions (E-RCP) attire according to 2005 CDC recommendation

Outcomes	Illustrative comparative risks* (95% CI)		Relative effect (95% CI)	No of Participants (studies)	Quality of the evidence (GRADE)	Comments
	Assumed risk	Corresponding risk				
	E-RCP attire	PAPR Attire				
Any contamination fluorescent marker Follow-up: post intervention	960 per 1000	259 per 1000 (163 to 413)	RR 0.27 (0.17 to 0.43)	50 (1 cross-over RCT)	⊕⊕○○ very low ^{1,2,3}	Analyses presented in this table are unadjusted for the paired nature of the cross-over design but similar to the results that the authors presented while taking the cross-over into account
Compliance with guidance - Noncompliance with donning guidance Follow-up: post intervention	40 per 1000	300 per 1000 (72 to 1000)	RR 7.5 (1.81 to 31.1)	50 (1 cross-over RCT)	⊕⊕○○ very low ^{1,2,3}	
Compliance with guidance - Noncompliance with doffing guidance Follow-up: post intervention	240 per 1000	120 per 1000 (48 to 295)	RR 0.5 (0.2 to 1.23)	50 (1 cross-over RCT)	⊕⊕○○ very low ^{1,2,3}	

Infection with EVD	See comment	See comment	Not estimable	0 (0 studies)	See comment	No studies evaluated the effect of the interventions on infection rates
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*The basis for the **assumed risk** is the control group risk. The **corresponding risk** (and its 95% confidence interval) is based on the assumed risk in the comparison group and the **relative effect** of the intervention (and its 95% CI).
CI: Confidence interval; **RR:** Risk ratio;

GRADE Working Group grades of evidence

High quality: Further research is very unlikely to change our confidence in the estimate of effect.

Moderate quality: Further research is likely to have an important impact on our confidence in the estimate of effect and may change the estimate.

Low quality: Further research is very likely to have an important impact on our confidence in the estimate of effect and is likely to change the estimate.

Very low quality: We are very uncertain about the estimate.

¹ Simulation study, downgraded one level for indirectness

² One cross-over study with 50 participants, downgraded one level for imprecision

³ High risk of bias, downgraded one level for study limitations

BACKGROUND

Description of the condition

Over 59 million people are employed in the healthcare sector worldwide (WHO 2006). Some of these healthcare workers (HCW) are at risk of developing life-threatening infectious diseases due to contact with patients' blood or body fluids such as mucus or vomit. The risk of infection and its consequences vary, but the 2013 to 2015 Ebola Virus Disease (EVD) epidemic put healthcare workers at high risk of a disease with a very high fatality rate in the epidemic areas (Ebola 2014). According to WHO, healthcare workers were between 21 and 32 times more likely to be infected with Ebola than people in the general adult population (WHO 2015a). Not only nurses and doctors are at risk, but also staff engaged in transportation, cleaning and burial of patients. Healthcare workers could also be at risk when seeing patients arriving from the epidemic areas (Forrester 2014). Due to the high risk of infection and the high fatality rate, hundreds of HCW died in the epidemic areas (Kilmarx 2014). According to the statistics from the 2013-2015 West Africa EVD epidemic, there were 1049 registered cases of HCW infected with 535 deaths (WHO 2015b). Just a decade earlier, healthcare workers lost their lives due to the Severe Acute Respiratory Syndrome (SARS) epidemic (CDC 2003). Even though the transmission routes are different, EVD and SARS are both highly infectious and they can have fatal consequences and especially affect healthcare workers.

Healthcare workers can get infected through various routes of transmission, depending on the pathogen. Infection can occur through splashes and droplets of contaminated body fluids on non-intact skin, or via needle-stick injuries through intact skin. Infection can also occur when splashes or droplets of contaminated body fluids land on the mucous membranes in the eyes, mouth or nose, or when the same mucous membranes come into contact with contaminated skin, such as when rubbing the eyes with a hand carrying pathogens after shaking hands with a patient. For EVD, this is the main route of transmission, even though there is doubt about the transmission of virus particles through aerosols,

or while performing patient care. For SARS, the highest risk of infection was due to inhalation of aerosols, but the disease was also transmitted through droplet infection. Another risk of HCW infection is that infected HCW will infect patients or that they will act as a vector for the transfer of the disease between patients. Here, we focus on highly infectious diseases which means that contamination with a small amount of infectious material can already lead to clinical disease. We also focus on those infections that have serious consequences such as a high case fatality rate because this has implications for the motivation of HCW to protect themselves.

Description of the intervention

Exposure can be best controlled by organisational measures that minimise the exposure to contaminated body fluids or infected patients. The most important preventive measure is the proper organization of the hospital or healthcare unit to avoid unnecessary contact. Once this has been implemented, the main strategy for reducing physical exposure to highly infectious diseases is through personal protective equipment (PPE). Coveralls, gowns, hoods, masks, eye shields, among others, are used to prevent skin and mucous membranes from becoming contaminated and respirators are used to prevent inhalation.

Personal protective equipment will only be effective if the equipment can form a barrier between the HCW and the exposure to contaminated body fluids. Therefore, standards have been developed that, when complied with, assure that PPE is of sufficient quality to protect against biohazards (Mäkelä 2014; NIOSH 2014). Even though the biohazard symbol (Figure 1) is widely used to indicate the presence of biohazards, it is not a label for protective clothing. For biohazards, these standards are based on laboratory tests that evaluate to what extent the fabric and the seams of protective clothing are leak-tight, that is, are they impermeable for liquids, viruses, or both at certain pressure levels. The standards in Europe and the US are different. Personal protective equipment should contain a label that specifically indicates the standards against which it has been tested.

Figure 1. International symbol indicating biohazards



In Europe, there is standard [EN 14126](#) for clothing, specifically coveralls that protect workers against biological hazards from microorganisms. Clothing compliant with the standard [EN 14126](#) is classified with the same six clothing types as chemical protective clothing. Type-I provides the most protection by complete encapsulation. Type-III clothing protects against pressurised liquid splashes, but is also very leak-tight, which makes it heavy to work in. Type-IV provides protection against non-pressurised liquid splashes, and is more breathable. There is no requirement for the type of clothing, whether it be a coverall or a gown. In addition, the clothing material should be classified according to the International Organization for Standardisation (ISO) standard 16604 ([ISO 2004](#)) test against viral penetration. Again, materials can pass the test at six levels. Class-6 is the most protective, and indicates that the test bacteriophage particles do not pass through the fabric at a hydrostatic pressure of 20 kPa (2.9 psi), but for Class-1, the fabric is protective only at a pressure of 0 kPa. There is a separate standard for surgical gowns, [EN 13795](#). However, this standard is specifically designed to protect the patient.

In the U.S., [ANSI/AAMI PB70 2012](#) standard classifies surgical and isolation gowns according to their liquid barrier performance. The standard specifies four levels of protection, in which the highest, level four, means testing for viral protection at a pressure of 2 psi. Level one means testing for water resistance, with less than 4.5 grams of water allowed to be absorbed during the test. There is also U.S. standard [NFPA 1999](#) for protective coveralls, which was specifically developed to address a range of different clothing items worn by emergency medical service first responders, and also applies to medical first receivers. [NFPA 1999](#) lists many performance requirements for garments used by emergency medical personnel, including (but not limited to) viral penetration resistance, tensile strength, liquid integrity, and seam strength.

To summarize, the qualities of garments certified by different standards are not fully comparable. Nonetheless, they all aim to ensure that garments are of a quality that prohibits water and blood-like fluids with virus particles, applied under a specified amount of pressure, from passing through. In addition, some standards have requirements that the whole garment, including the seams, must be non-permeable to liquids ([NFPA 1999](#)).

For gowns to be used with EVD, [WHO 2016](#) currently recommends [EN 13795](#) high performance surgical gowns or [ANSI/AAMI PB70 2012](#) level three (option one), or level four (option two), or equivalent. As the first option for coveralls, WHO currently recommends protection equivalent to [EN 14126](#), with clothing material that provides Class 3 protection against blood at 0.5 kPa, based on ISO 16603 ([ISO 2004a](#)), and Class 2 against viruses at a pressure of 1.75 kPa, based on ISO 16604 ([ISO 2004](#)). Both in the EU and in the U.S., it is mandatory for employers to protect their workers against blood-borne pathogens and other infections at work ([EU 2010](#); [OSHA 2012](#)).

Clothing that is manufactured according to the standards mentioned above is impermeable to body fluids and viruses and will technically prevent skin contamination. However, this review does

not deal with the technical physical standards of equipment, but rather if its use in practice will prevent contamination and infection.

There are several guidelines available for choosing proper PPE ([Australian NHMRC 2010](#); [CDC 2014](#); [ECDC 2014](#); [WHO 2016](#)). Even though all guidelines propose using similar protective clothing, there are also noticeable differences. For example, [ECDC 2014](#) proposes taping gloves, boot covers and goggles onto the coveralls to prevent leaving any openings but the other guidelines do not recommend this. More recently, most guidelines have been updated and are now more in line with each other. However, differences still exist. [WHO 2016](#) does not recommend taping, but [ECDC 2014](#) does.

Overprotection can be a problem. Some propose using three layers of gloves, because according to their experience, this is best practice ([Lowe 2014](#)). However, it may make work more difficult, and eventually lead to an increased rather than a decreased risk of infection, especially during doffing (i.e. removing the PPE). For example, the combined use of several respirators probably does not lead to more protection, but considerably increases the burden on the worker ([Roberge 2008](#); [Roberge 2008a](#)).

Despite of using proper PPE, probably the biggest risk of infection is associated with self-contamination by HCW inappropriately removing the PPE ([Fischer 2014](#)). Some types of PPE make donning and doffing more difficult, thereby increasing the risk of contamination ([Zamora 2006](#)). The highest risk time of doffing is usually managed by an assistant, who guides the worker through the process while watching for breaches, and spraying chlorine as each item is removed. There is evidence that when doffing PPE, the use of a double pair of gloves decreases the risk of contamination ([Casanova 2012](#)). How contamination of PPE occurs has also been clearly illustrated with a simulation study about cleaning up vomit ([Makison 2014](#)). The results of such simulation studies should increase HCW's confidence in executing the donning and doffing procedures correctly, and thus can also be an incentive for their uptake and compliance with the guidelines. Therefore, specific guidance has been developed for donning and doffing PPE ([CDC 2014](#); [WHO 2016](#)).

Compliance with guidance on correct PPE use in health care is historically poor. HCW sometimes distrust infection control, and using PPE is stressful ([Zelnick 2013](#)). For respiratory protection such as masks and respirators, compliance has been reported to be around 50% on many occasions ([Nichol 2008](#)). Due to lack of proper fitting and incorrect use, real field conditions almost never match laboratory standards ([Coia 2013](#); [Howie 2005](#)). Also, reports of hand hygiene show that there is still large room for improvement and guidelines recommend education and training in combination with other implementation measures ([WHO 2009](#)). From reports of HCW, it is clear that most appropriate PPE is not user-friendly in tropical conditions. It prevents heat loss through sweating because it is not made of breathable material. A common reason for a breach in the barrier of the PPE is the worker

sweating and then instinctively wiping their face (Cherry 2006). Staff are being trained on arrival to the epidemic or treatment site by repeatedly practicing donning and doffing PPE and running through drills of what they should do if the protocol is breached while in the “red zone” (i.e. the Ebola patient area, also called hot zone).

In this review, we only concentrated on PPE for highly infectious diseases that have serious consequences for health, such as EVD. We excluded other highly infectious, but less serious viral infections, such as norovirus, as we expected the effect of PPE to be different. We included SARS as it was highly infectious to HCW, sometimes fatal, and had similar recommendations on PPE use and training as EVD.

We did not specifically study the effects of hand hygiene or of respiratory protection to prevent transmission through inhalation. Hand hygiene is also crucial in preventing skin contamination, but this has already been covered in another review (Gould 2010). The protective effect of different types of respiratory protection, and effects of interventions to increase their uptake are covered in two other reviews (Jefferson 2011; Luong Thanh 2016).

How the intervention might work

First, HCW, their supervisors, or occupational health professionals should choose the proper type of PPE, as indicated in the guidance described above. Then, a HCW needs to know how to don and doff PPE according to the guidelines provided. Next, a HCW needs to comply with established procedures for correctly using, donning and doffing PPE. Education and training is used to increase compliance. The emphasis in teaching correct use of PPE is on doing everything slowly and carefully to minimise the risk of making a mistake. Often an assistant or buddy, sometimes coupled with a mirror, is used while donning PPE, while a hygienist supervises doffing.

Compliance can be increased by personal supervision and instruction, checklists, audits of performance, by providing feedback, and by allowing sufficient time for donning and doffing. Education and training on uptake and compliance with PPE should have an effect in both the short term and the long term (Northington 2007; Ward 2011). Education and training can be seen as one method to increase compliance (Gershon 2009; Hon 2008). Compliance with PPE can also be improved by providing sufficient, comfortable, well-fitting, and more user- and patient-friendly PPE. Compliance with guidelines has been studied for hand hygiene. There is some evidence that multifaceted interventions and staff involvement are important, but altogether, there is little evidence that allows firm conclusions (Gould 2010).

Why it is important to do this review

There is still uncertainty about the optimal type, composition, amount, and way of using full body PPE to prevent skin and mucous membrane contamination of HCW, while treating patients

infected with highly infectious diseases. This is also reflected in the different ways guidelines for PPE are implemented in Europe (De Iaco 2012), and acknowledged in current WHO guidelines (WHO 2016). WHO realizes that a safer, more comfortable and culturally appropriate protective system commensurate with the risk is needed and has provided guidance for industry, health workers, engineers, innovators, medical and scientific researchers and others to re-think, energize and innovate for a better PPE system for the HCW responding to Ebola and Marburg virus outbreaks in tropical climates. The results of this review were and will be used as input for this effort (WHO 2018).

Since full body protective suits have mainly evolved as a direct result of experiences gained from the recent outbreaks of deadly viruses, there are still many types available with varying types of components. The comparative effectiveness of one type against another is still unknown.

HCW working with Ebola patients and occupational health professionals still have uncertainty about which types of equipment to choose, the best procedures for doffing and how to deal with breaches of the barrier of the PPE, and with gross contamination. Regarding the equipment, there is uncertainty if visors protect as well as goggles, especially when goggles are combined with a hood. It is not immediately obvious if the strap of the goggles should go over or under the hood. There is uncertainty if triple or quadruple gloves would be more protective than double gloves. Regarding suits, it is unclear if gowns are as protective as coveralls, and how breathable and impermeable for liquids or viruses they should be. Some argue that using more breathable material would decrease the risk of contamination (Kuklane 2015).

When it comes to donning and doffing procedures, there is uncertainty about the effect of integrity checks of gloves and other equipment, and if gloves should be changed when highly contaminated. With doffing especially, it is unclear if this should be done in pairs with a helper buddy removing part of the PPE, or if this can be done alone. Another element of the doffing procedure that is uncertain is if spraying with a disinfectant chlorine spray is more protective than not using spray. It is not clear which disinfectant is the best anti viral: chlorine solution or alcohol gel, and at which concentration.

The complexity of the drill and the procedures for updating skills, retraining, and responding to individual training needs after a potential or realised breach are also important.

This review is a timely update of the Verbeek 2016b review, the results of which indicated that more research is still needed to answer the review's questions.

OBJECTIVES

To evaluate which type of full body PPE and which method of donning or doffing PPE have the least risk of self-contamination

or infection for HCW, and which training methods increase compliance with PPE protocols. In particular, we evaluated the effect of:

- different types of PPE on contamination and infection rates (one type or component of full body protection PPE versus another);
- different donning or doffing procedures on contamination and infection rates (one procedure in donning and doffing full body PPE versus another); and
- different types of education and training aiming to improve compliance with guidelines for full body PPE on compliance, contamination and infection rates, (one type of training versus another).

METHODS

Criteria for considering studies for this review

Types of studies

Since the circumstances for evaluation studies are difficult during epidemics, we anticipated including a broad range of study designs. We included any prospective or retrospective controlled field study. Field study here refers to a study that tests interventions with healthcare staff in a real life exposure situation. This also includes case-control studies that compare the use of interventions retrospectively between cases that have become infected and comparable controls that did not get infected.

We also included randomised as well as non-randomised prospective controlled studies that simulated exposure to contaminated body fluids with the use of marker chemicals or harmless viruses. We excluded studies without a comparison group.

Types of participants

For simulation studies, we included any type of participants (volunteers or HCW) using PPE designed for EVD or comparable highly infectious diseases with serious consequences.

For field studies, we included studies only if they were conducted with HCW or ancillary staff exposed to body fluids from patients in the form of splashes, droplets or aerosols contaminated with particles of highly infectious diseases that have serious consequences for health such as EVD or SARS.

We excluded studies conducted with laboratory staff because the preventive measures in labs are more detailed and easier to comply with.

Types of interventions

1. We included studies that evaluated the effectiveness of different types of full body protection (PPE), or comparing different types, compositions, or amounts of the following PPE components:

- body protection such as gowns, coveralls or hazmat suits;
- eye and face protection such as glasses, goggles, face shields or visors, or masks or hoods that cover the entire head;
- hand protection: gloves; and
- foot protection: overshoes or boots.

We defined PPE as any of the equipment listed above that is designed or intended to protect healthcare staff from contamination with infected patients' body fluids.

2. We included studies that evaluated the effectiveness of different procedures or protocols for donning and doffing of the PPE.

For example, extra assistance during donning and doffing, extra disinfection or the use of extra gloves to prevent contamination in comparison to standard protocols.

3. We included studies that evaluated the effectiveness of training to increase compliance with existing guidance on the selection or use of PPE, including but not limited to:

- education (courses),
- practical training,
- information only (such as posters, guideline leaflets, etc.),
- audit and feedback, or,
- monetary or organisational incentives.

Types of outcome measures

Primary outcomes

We included all studies that had measured the effectiveness of interventions as:

- contamination of skin or clothing, measured with any type of test material to visualise contamination (e.g. stains made visible with UV light);
- infection with EVD, another viral haemorrhagic fever, or comparable highly infectious disease with serious consequences such as SARS; or
- compliance with guidance on selection of type and use of PPE measured, for example, with an observation checklist.

Secondary outcomes

1. User-reported assessment of comfort and convenience
2. Costs or resource use
3. Time to don and doff the PPE

Search methods for identification of studies

Electronic searches

We conducted a systematic literature search to identify all published and unpublished trials that could be considered eligible for inclusion in this review. We adapted the search strategy we developed for PubMed (see Appendix 1) for use in the other electronic databases. The literature search identified potential studies in all languages. We asked native speaker, AP, to assess the papers in Russian and another native speaker, CCC, to assess those in Chinese for potential inclusion in the review.

We searched the following electronic databases from inception to the dates presented underneath for identifying potential studies (search dates provided below):

- MEDLINE (PubMed) (Appendix 1) until 15 July 2018;
- Scopus (Scopus.com) (Appendix 2; Appendix 3) to 18 June 2019;
- Cochrane Central Register of Controlled Trials (CENTRAL) (Appendix 4) (Wiley Online Library) until 18 June 2019;
- CINAHL (EBSCOhost) (Appendix 5) to 31 July 2018;
- NIOSHTIC (OSH-UPDATE) (Appendix 6) to 31 December 2018;
- NIOSHTIC-2 (OSH-UPDATE) to 31 December 2018;
- HSELINE (OSH-UPDATE) to 31 December 2018;
- CISDOC (OSH-UPDATE) to 31 December 2018;

We also conducted a search of ClinicalTrials.gov (www.ClinicalTrials.gov) and the WHO trials portal (www.who.int/ictrp/en/) which includes the Pan African Registry for potential studies on EVD. We searched all databases from their inception to the present and we did not impose a restriction on language of publication.

Searching other resources

We checked reference lists of all primary studies and reviewed articles for additional references. We contacted non-governmental organisations involved in medical relief operations in the high risk EVD areas to identify additional unpublished materials:

- Médecins Sans Frontières (MSF)

- Save the Children

We also used Twitter to ask for unpublished reports from people in the field. Evidence Aid helped in locating relevant organisations and in asking them for unpublished reports.

We also contacted the following manufacturers of PPE to request unpublished studies:

- DuPont
- 3M
- Alpha Pro Tech

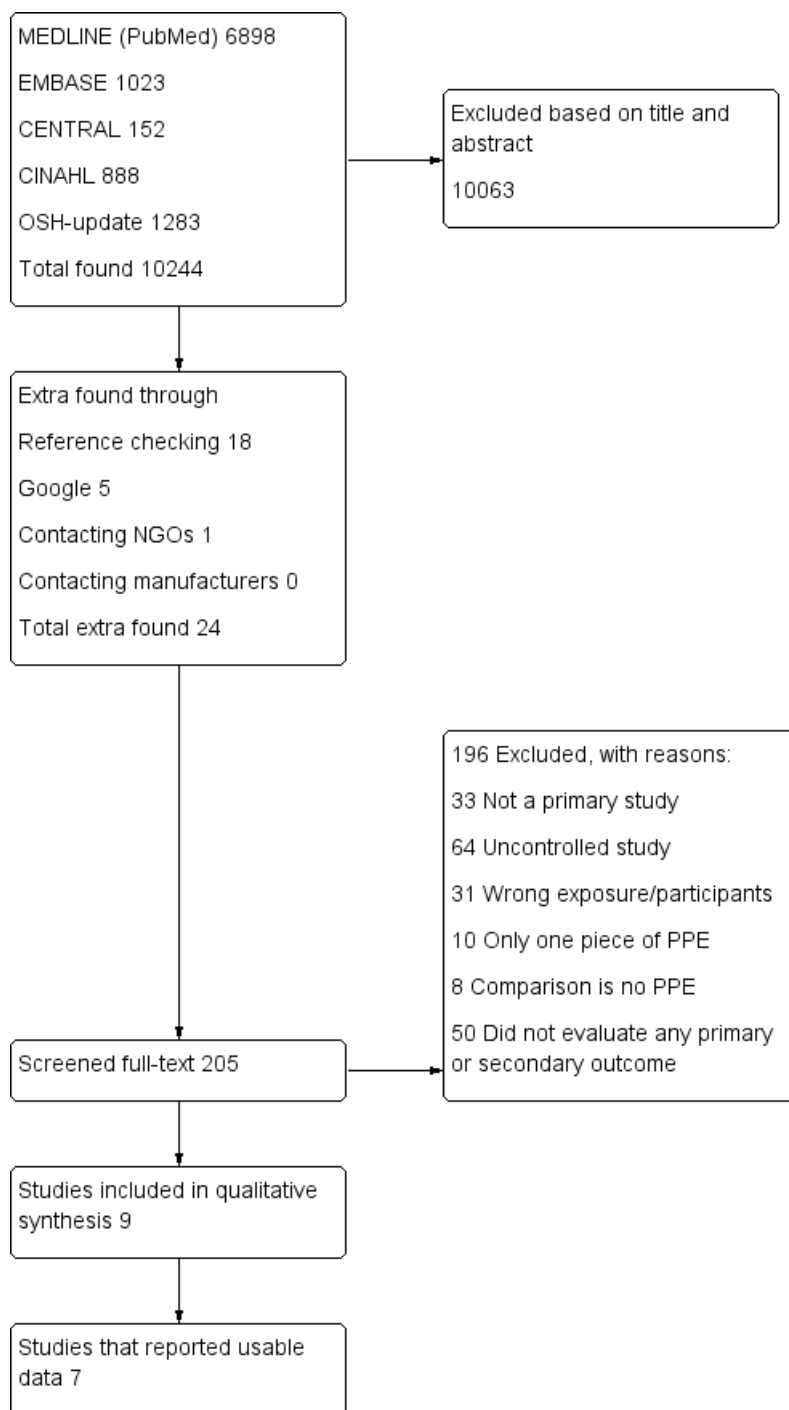
In addition, we used Google to find any unpublished or grey literature on our question that may not be available from the sources listed above by using the following terms: “personal protective equipment ebola”.

Data collection and analysis

Selection of studies

Pairs of two review authors (JV, BR, CT, SI, JR, and RS) independently screened titles and abstracts of all the potential studies that we identified with our systematic search, to identify studies for inclusion. The same authors coded them as ‘retrieve’ (eligible or potentially eligible/unclear) or ‘do not retrieve’. We retrieved the full-text study reports/publication and pairs of two review authors (JV, BR, CT, SI, JR, and RS) independently screened the full-text and identified studies for inclusion, and identified and recorded reasons for exclusion of the ineligible studies. We used the computer programme *Covidence* for the selection of references and full-text studies. We resolved any disagreement through discussion, except in one case where a third person assessment (SI) was needed. We identified and excluded duplicates and collated multiple reports of the same study so that each study rather than each report is the unit of interest in the review. We recorded the selection process and completed a PRISMA flow diagram (see [Figure 2](#)) and a ‘Characteristics of excluded studies’ table.

Figure 2. PRISMA study flow diagram for search up to Jan 2016



Data extraction and management

We used a data collection form for study characteristics and outcome data which had been piloted on one included study. Two review authors (JV, BR, CM, JR, SI, ME, KN, RS) independently extracted the following study characteristics from included studies:

1. Methods: study design, total duration of study, study location, study setting, withdrawals, and date of study.
2. Participants: N, mean age or age range, sex, severity of condition, diagnostic criteria if applicable, inclusion criteria, and exclusion criteria.
3. Interventions: description of intervention, comparison, duration, intensity, content of both intervention and control condition, and co-interventions.
4. Outcomes: description of primary and secondary outcomes specified and collected, and at which time points reported.
5. Notes: funding for trial, and notable conflicts of interest of trial authors, country where trial was conducted.

Pairs of two review authors (JV, BR, CM, SI, JR, ME, RS) independently extracted outcome data from included studies. We noted in the 'Characteristics of included studies' table if outcome data were not reported in a usable way. We resolved disagreements by consensus so there was no need to involve a third review author. One review author (JV or BR) transferred the data into Review Manager (RevMan 2014). We double-checked that data were entered correctly by comparing the data presented in the systematic review with the study reports. A second review author (CT or JV) spot-checked study characteristics for accuracy against the trial report.

Assessment of risk of bias in included studies

Pairs of two review authors (JV, BR, CM, SI, JR, ME, RS) independently assessed risk of bias for each randomised study using the criteria outlined in the *Cochrane Handbook for Systematic Reviews of Interventions* (Higgins 2011). We resolved any disagreements by discussion so there was no need to involve another author. We assessed the risk of bias according to the following domains in all randomised controlled trials.

1. Random sequence generation,
2. Allocation concealment,
3. Blinding of participants and personnel,
4. Blinding of outcome assessment,
5. Incomplete outcome data,
6. Selective outcome reporting, and
7. Other bias

We rated each potential source of bias as high, low or unclear and provided a quote from the study report or author together with

a justification for our judgment in the 'Risk of bias' table. We summarised the risk of bias judgements across different studies for each of the domains listed. For compliance, we considered blinding to PPE type significant for the outcome assessor only. Where information on risk of bias relates to unpublished data or correspondence with a trial author, we noted this in the 'Risk of bias' table.

We considered randomised studies to have a low overall risk of bias when we judged random sequence generation and blinded outcome assessment to have a low risk of bias and none of the other domains to have a high risk of bias.

We used domains three to seven listed above for all non-randomised studies. Instead of the domains one and two - random sequence generation and allocation concealment - we used the following items as suggested in the ROBINS-I tool (Sterne 2016) for the assessment of risk of bias in non-randomised intervention studies:

1. Bias due to confounding. We made an overall assessment of risk of bias based on the following questions if the signalling question "Is confounding of the effect of intervention unlikely in this study?" was answered with no.

- Did the authors use an appropriate analysis method that adjusted for all the critically important confounding domains?

- Were confounding domains that were adjusted for measured validly and reliably by the variables available in this study? For this review question, we considered baseline differences between compared groups in the following factors significant: prior experience with PPE, healthcare qualification or education of HCW, age and sex, ambient temperatures, and stressful activities.

2. Bias due to selection of participants into the study. We made an overall assessment of this risk of bias based on the following questions if the signalling questions "Was selection into the study unrelated to intervention or unrelated to outcome?" and "Do start of follow-up and start of intervention coincide for most subjects?" were answered with no.

- Were adjustment techniques used that are likely to correct for the presence of selection biases?

- For case-control studies: Were the controls sampled from the population that gave rise to the cases, or using another method that avoids selection bias?

We considered the domains of confounding and selection of participants to yield high, low or unclear risk of bias. For a non-randomised study as a whole, we considered the study to have a low risk of bias if all domains received a judgment of low risk of bias comparable to an RCT. This means receiving a low risk of bias judgment on the two domains listed above as well as domains three to seven in the previous section.

When considering treatment effects, we took into account the risk of bias for the studies that contributed to that outcome.

We judged studies to have a low overall risk of bias if we judged them to have a low risk of bias in the following domains: both random allocation and allocation concealment, or both confounding and selection bias, and incomplete outcome data and selective reporting. We considered the blinding of participants and outcome assessors less important because the outcomes were objective or we could not imagine that participants would have an interest in a certain type of attire and outcome.

Assessment of bias in conducting the systematic review

We conducted the review according to the published protocol (Verbeek 2015) and where there were deviations from it, we reported these in the 'Differences between protocol and review' section of the systematic review.

Measures of treatment effect

We entered the outcome data for each study into the data tables in RevMan 2014 to calculate the treatment effects. We used risk ratios (RRs) for dichotomous outcomes, and mean differences (MDs) or standardised mean differences (SMDs) for continuous outcomes. When only effect estimates and their 95% confidence intervals or standard errors were reported in studies, we entered these data into RevMan 2014 using the generic inverse variance method. When authors used multivariate analyses, we used the most adjusted OR (Odds Ratios) or RRs. We ensured that higher scores for continuous outcomes had the same meaning for the particular outcome, explained the direction and reported where the directions were reversed, if this was necessary. If in future updates of this review we come across studies reporting results that we cannot enter in either way, we will describe them in the 'Characteristics of included studies' table, or we will enter the data into Additional tables. For cohort studies that compare an exposed to a non-exposed population we intended to report both the RR for the intervention versus the control at baseline and at follow-up for dichotomous outcomes to indicate the change brought about by the intervention but we did not find any such studies.

Unit of analysis issues

If in future updates of this review we come across studies that employ a cluster-randomised design and that report sufficient data to be included in the meta-analysis but do not make an allowance for the design effect, we will calculate the design effect based on a fairly large assumed intra-cluster correlation of 0.10. We based this assumption of 0.10 being a realistic estimate by analogy on studies about implementation research (Campbell 2001). We will follow the methods stated in the *Cochrane Handbook for Systematic Reviews of Interventions* (Higgins 2011) for the calculations.

We intended to take the paired nature of the cross-over design in the included studies into account in our data analysis. However, the included studies did not present sufficient data to do so and the results presented here are based on the unpaired test that is implemented in RevMan 2014 which resulted in wider confidence intervals than with the use of a paired t-test.

Dealing with missing data

We contacted investigators to verify key study characteristics and obtain missing numerical outcome data where possible (e.g. when a study was identified as abstract only). If in future updates of this review we come across studies where this is not possible, and the missing data are thought to introduce serious bias, we will explore the impact of including such studies in the overall assessment of results by a sensitivity analysis.

Similarly, If in future updates of this review we come across studies where numerical outcome data are missing, such as SDs or correlation coefficients and they cannot be obtained from the authors, we will calculate them from other available statistics such as P values, according to the methods described in the *Cochrane Handbook for Systematic Reviews of Interventions* (Higgins 2011).

Assessment of heterogeneity

We assessed the clinical homogeneity of the results of included studies based on similarity of population, intervention, outcome and follow-up. We considered populations as similar when they were HCW directly engaged in patient treatment (nurses, doctors, paramedics) versus those who were not involved in patient therapy directly (cleaning and transport staff).

We considered interventions as similar when they fell into one of the intervention categories as stated in *Types of interventions*.

We considered any assessment of contamination of the skin or mucous membranes as similar enough to combine.

We considered the following follow-up times as similar: from immediately following a procedure up until the end of the work shift (short term), and any time after the incubation time (long-term).

If in future updates of this review we come across studies with results that we can pool with meta-analysis, we will use the I^2 statistic to measure heterogeneity among the trials in each analysis. Where we identify substantial heterogeneity, we will report it and explore possible causes by prespecified subgroup analysis. We will regard an I^2 value above 50% as substantial heterogeneity.

Data synthesis

In future updates of this review we will pool data from studies we judge to be clinically homogeneous using Review Manager 5.3 software (RevMan 2014). If more than one study provide usable data in any single comparison, we will perform meta-analysis. We will use a random-effects model when I^2 is above 40%; otherwise we will use a fixed-effect model. When I^2 is higher than 75% we

will not pool results of studies in meta-analysis. We will include a 95% confidence interval (CI) for all estimates.

We will describe the results in the case of skewed data reported as medians and interquartile ranges.

Where multiple trial arms are reported in a single trial, we will include only the relevant arms. If two comparisons are combined in the same meta-analysis, we will halve the control group to avoid double-counting.

Summary of findings table

Studies used numerous comparisons to measure the effect of PPE and we limited the amount of 'Summary of findings' tables to the findings of the comparisons we judged most useful. We created a series of 'Summary of findings' tables to present the primary outcomes for different types of PPE (one type versus another) and donning or doffing procedures (one procedure versus another). We used the five GRADE considerations (study limitations, consistency of effect, imprecision, indirectness and publication bias) to assess the quality of a body of evidence as it related to the studies that contributed results data for the prespecified outcomes. We used methods and recommendations described in Section 8.5 and Chapter 12 of the *Cochrane Handbook for Systematic Reviews of Interventions* (Higgins 2011), using GRADEpro software (GRADEpro 2008). We justified all decisions to down- or upgrade the quality of studies using footnotes and we made comments to aid reader's understanding of the review where necessary. With non-randomised studies, we started at low quality evidence and with randomised studies at high quality evidence. In future updates of this review, if the outcomes are measured in many different ways, we will prioritise the reporting of outcomes as follows: infection rates, contamination rates, and compliance rates.

Subgroup analysis and investigation of heterogeneity

If future updates of this review find a sufficient number of studies, we will carry out the following subgroup analyses: high income versus low and middle-income countries and PPE that is certified for biological hazards versus PPE that does not have such a certification. We will also use our primary outcomes in subgroup analyses, and we will use the X^2 test, as implemented in RevMan 2014, to test for subgroup interactions. At this time, we did not identify enough studies to allow for such a subgroup analysis.

Sensitivity analysis

If future updates of this review find a sufficient number of studies, we will perform sensitivity analyses defined a priori to assess the robustness of our conclusions. This involves including only studies we judge to have a low risk of bias. At this time we did not identify enough studies to allow such a sensitivity analysis.

Reaching conclusions

We based our conclusions only on findings from the quantitative or narrative synthesis of included studies we judged to have the lowest risk of bias. Consequently, we used findings from non-randomised studies when we did not find evidence from randomised trials. We avoided making recommendations for practice based on more than just the evidence, such as values and available resources. Our implications for research suggest priorities for future research and outline what the remaining uncertainties are in the area.

RESULTS

Description of studies

Results of the search

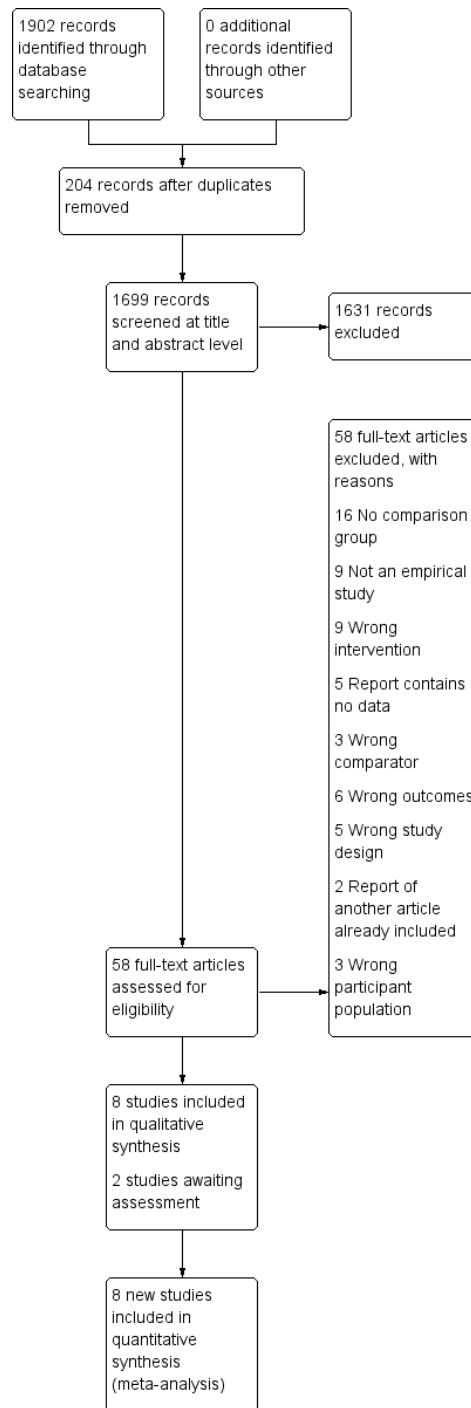
In the search until January 2016, we screened 10234 references (see Figure 2). From these references, we selected 205 articles for full-text assessment. Through checking the references of included articles we found 18 additional articles, by using Google another five, and through contacting NGOs one (Tomas 2015). Our contacts with the manufacturers did not yield any responses or data. Most of the studies that we did not locate with our electronic searches were studies of PPE use during the SARS epidemic that did not make reference to any type of PPE in the title or abstract. The same happened during the EBV epidemic where we could not locate Nyenswah 2015 because there was no reference to PPE. By using Google search, we found one additional article (Bell 2015) that wasn't indexed in any of the databases that we searched. We did not locate Tomas 2015 with our search strategy but it was brought to our attention through Twitter. We did not catch it with our systematic searches because the authors did not use any words referring to infection, disease or decontamination. Therefore we checked if there would be any other studies that only used the word contamination in addition to PPE. We did not find any other additional studies that we missed with our search strategy. Based on a request of one of the peer referees we also searched the African Index Medicus which yielded 24 references but no new studies to include. For the current update we also searched this database but it did not add any new articles. Contacting PPE manufacturers did not lead to any responses.

This added up to 205 papers that we checked full-text for inclusion. Of these, we excluded 196. This resulted in nine included studies.

We updated the searches in Medline through PubMed until 15 July 2018, in Embase until 22 May 2018, in Central until 18 June 2019, in CINAHL until 31 July 2018, and in OSH-update on 31 December 2018. We did not have access to Embase anymore after May 2018 and used Scopus to update the Embase search until 18

June 2019. This yielded 1694 new references after de-duplication. We assessed 68 articles in full-text and subsequently we excluded 58 articles. This resulted in ten new studies that fulfilled our inclusion criteria (see [Figure 3](#)) and we were finally able to include eight of them in the review and two studies are still awaiting further assessment.

Figure 3. PRISMA study flow diagram for search between 2016 and 2018



Included studies

We contacted [Bell 2015](#); [Casalino 2015](#); [Casanova 2016](#); [Curtis 2018](#); [Hall 2018](#) and we got additional information from all but [Casanova 2016](#). We entered this information in the 'Characteristics of included studies' table.

Study Types

We included 15 simulation studies of which 12 simulated exposure to contaminated body fluids and three studies simulated donning and doffing procedures.

Of these simulation studies ten were randomised trials (five with parallel groups ([Bell 2015](#); [Curtis 2018](#); [Hung 2015](#); [Tomas 2016](#); [Wong 2004](#)), four had a cross-over design ([Guo 2014](#); [Mana 2018](#); [Strauch 2016](#); [Zamora 2006](#)), one was a quasi-RCT ([Gleser 2018](#)) and five were non-randomised controlled studies (two with a cross-over design ([Casanova 2012](#); [Hall 2018](#)); and three with parallel groups ([Buianov 2004](#); [Casalino 2015](#); [Casanova 2016](#))).

In addition, we found two retrospective cohort studies. One study evaluated the effect of PPE training on SARS infection rates and noncompliance with the doffing protocol ([Shigayeva 2007](#)). In this study, the authors located all HCW that had been exposed to SARS patients and assessed, by questionnaire, compliance with PPE guidelines and PPE doffing guidelines. [Houlihan 2017](#) evaluated the risk of EVD infection according to donning and doffing practices and the use of disinfectant in HCW that had been deployed in West Africa during the EVD epidemic.

Compared to the previous version of this review ([Verbeek 2016b](#)) there are now seven more simulation studies and one additional field exposure study.

Participants

In the simulation studies, researchers included 482 intervention and 323 control participants, when we take into account that four studies used a cross-over design and thus all participants were intervention participants. In the cohort studies, there were 863 intervention and 232 control participants. Altogether there were 1950 participants. There were 919 participants more in this update compared to the previous version of this review ([Verbeek 2016b](#)). The participants in all studies were healthcare workers with a mixture of occupations, but mainly physicians, nurses and respiratory technicians. There was one study that included medical students during their internships ([Casalino 2015](#)). There were no studies that included other healthcare staff such as persons working in emergency services or cleaning staff.

Exposure of participants was to the SARS epidemic in one study ([Shigayeva 2007](#)) and to the EVD epidemic in another study

([Houlihan 2017](#)). In the simulation studies the exposure was simulated by exposure to a fluorescent agent in nine studies and by exposure to a harmless virus or microbes in five studies. Studies used a wide range of different fluorescent agents and a range of exposure methods that varied from rubbing 0.5 mL over the gloved hands to throwing 100 mL onto the torso of the gown (see [Table 1](#)). The situation was similar in the studies that used viruses to simulate exposure.

Countries

Seven studies were performed in the US, two studies in Canada, three in China and Hong Kong, two in the UK, one in Germany, one in Russia and one was performed in three countries at the same time: France, Peru and Mexico ([Casalino 2015](#)). One study in Canada was performed during the SARS epidemic and one study in the UK was among HCW that returned from the West-African EVD epidemic.

Time period

All studies had been conducted after the year 2000, with six before and eleven after 2015.

Interventions and comparisons

The 17 included studies evaluated 21 interventions, with four studies ([Buianov 2004](#); [Guo 2014](#); [Houlihan 2017](#); [Shigayeva 2007](#)) evaluating two interventions. Ten studies compared one type of PPE to another. Five studies compared two different ways of donning and doffing. One of these studies named the intervention 'enforced training' but we categorized it under different ways of doffing because it entailed giving instructions during the donning and doffing process versus not giving instructions ([Casalino 2015](#)). Three studies evaluated the effect of training.

Comparison of different types or parts of full body PPE

Ten simulation studies compared different types or parts of full body PPE outfits, but all in a different way. None of them were similar enough to be combined. None of the included studies used a standardised classification of the properties of the PPE that protect against viral penetration such as the [EN 14126](#).

Three simulation studies compared different types of masks or respirators as part of full body PPE. [Buianov 2004](#) compared two different types of Powered Air-Purifying Respirator (PAPR) that were especially developed for this project in Russia to protect health care personnel against Ebola and similar viruses. [Buianov 2004](#) also compared the effect of different airflow rates that varied from

50 to 300 liters per minute. The intervention participants were required to carry out a step test that lasted for four hours. The authors did not describe the equipment they tested in sufficient detail to be able to judge their technical qualities. [Zamora 2006](#) compared PPE combined with a PAPR in use at the study hospital with PPE without a PAPR according to CDC recommendations to prevent respiratory infection at the time of the study, the so-called Enhanced Respiratory and Contact Precautions (E-RCP). [Strauch 2016](#) compared a N95 FFR to a modified FFR with tabs placed on the elastic band as a doffing aid. The authors reported having evaluated contamination of the hands and head in two different trials but they reported their results in the same article. Five simulation studies compared different types of gowns and protective clothing. [Wong 2004](#) compared four types of PPE according to their material properties. First, they tested the material according to the American Association of Textile Chemists and Colorists standards 22 and 127. We excluded the surgical gowns only category since it had no water repellency and insufficient viral barrier properties. Type A had good water repellency and water penetration resistance, but at the cost of poor air permeability. Type B had good water repellency and good air permeability, but poor water penetration resistance. Type C was the surgical gown with both poor water repellency and water penetration resistance. Type D, Barrierman®, was made of Tyvek® and had good water repellency, poor air permeability and fair water resistance. [Bell 2015](#) compared commercially available PPE compliant with CDC recommendations with locally available clothing, such as rain coats that were thought to be as protective as the commercially available ones. [Guo 2014](#) compared three types of PPE: a disposable water resistant non-woven gown, a reusable woven cotton gown, and a disposable non-woven plastic apron. The second one was a cotton, water permeable, gown-like a surgical gown. We left this arm out of the analysis because surgical gowns alone are not used for EVD. The authors tested the fabrics for water repellency and liquid penetration according to the American Association of Textile Chemists and Colorists standard 22. The gown and the apron received ratings of four and five respectively on a scale of zero to five for water repellency. [Mana 2018](#) compared a standard polyethylene gown to a modified gown with a double elastic neck closure for easier removal, more gown coverage on the palm of the hand and smaller thumb holes and elastic wrist bands to create a snugger fit. [Tomas 2016](#) compared a standard gown to a prototype seamless PPE that consisted of a polyethylene gown with nitrile gloves attached by a contact bond adhesive to enable the removal of the gown and gloves at the same time. One simulation study compared different types of gloves. [Gleser 2018](#) compared standard medical examination gloves to a modified glove with a small tab near the thumb to aid in glove removal without contamination. Both types of gloves were made of the same material from the same company. The authors did not provide more information. One simulation study compared different full body PPE ensem-

bles. [Hall 2018](#) compared five different PPE ensembles used in EVD surgery units in hospitals which all met the guidance of the Advisory Committee on Dangerous Pathogens endorsed by the Public Health of England (PHE). Three ensembles used gowns while two ensembles used coveralls. Some PPE ensembles were comprised of gowns with surgical caps and other ensembles of coveralls with hoods. Some PPE comprised boots only and others boot covers. Some taped the second pair of gloves whereas others did not.

Studies comparing different types of eye protection or footwear are missing.

Contamination rates are not only determined by the type of PPE but also by the donning and doffing procedures. All studies had a priori determined donning and doffing procedures. It should be noted that these studies evaluated the totality of the type of PPE inclusive of the donning and doffing procedure. We have described the procedures in the 'Characteristics of included studies' table.

Donning or doffing procedures (one procedure for donning or doffing versus another)

Five studies compared different donning or doffing procedures.

One simulation study compared donning or doffing procedures using different numbers of gloves. [Casanova 2012](#) compared the effect of wearing two pairs of gloves with wearing one pair of gloves on contamination rates. We classified the study under methods of doffing because the intention of the double gloving was to decrease contamination during doffing. Doffing was done as per CDC recommendation, which describes how to do both single gloving and double gloving.

One simulation study compared individual's own versus recommended procedures. [Guo 2014](#) compared the effect of doffing a gown or an apron according to an individual's own views versus the procedure recommended by CDC in the US in 2007. Participants were given the following instructions: "Gown front and sleeves are contaminated! Unfasten neck, then waist ties. Remove gown using a peeling motion; pull gown from each shoulder toward the same hand. Gown will turn inside out. Hold removed gown away from body, roll into a bundle and discard into waste or linen receptacle".

One simulation study compared following an instructor during donning or doffing versus no instructions. [Casalino 2015](#) compared standard (unassisted) donning or doffing procedure to reinforced (extra assistance). The reinforcement consisted of an instructor saying out loud the next step of donning or doffing. The authors used the reinforcement with both basic PPE (impermeable apron without a hood) and enhanced PPE (full body suit and hood).

Two studies, one simulation and one field study, compared donning or doffing procedures using alcohol-based hand rub and hypochlorite solution. [Casanova 2016](#) compared the self-contamination of skin with two surrogate viruses when either an alcohol-

based hand rub or hypochlorite solution was used for the glove hygiene step of a PPE doffing protocol. [Houlihan 2017](#) intended to compare the PPE removal with and without chlorine spray and also with and without assistance but there was collinearity between these variables and being in clinical work or in laboratory work. All those that were in clinical work reported having used chlorine spray and assistance whereas those in laboratory work did not. Therefore we could not analyse these data.

Type of training or education (one type of training or education versus another)

Three studies evaluated different training methods for donning and doffing procedures.

[Hung 2015](#), a simulation study, compared a conventional training session for donning and doffing procedures to a procedure in which the conventional session was complemented with a computer simulation later in time.

[Shigayeva 2007](#), a field study, evaluated the effect of active and passive training versus no training on compliance rates. We defined active training as training that involved any group or face-to-face interaction. We defined passive training as watching a video or receiving written instructions. This allowed us to make an indirect comparison between the effect of active and passive training. We calculated the effect of active training compared to passive training by subtracting the OR for passive training from the OR for active training, as outlined in the *Cochrane Handbook for Systematic Reviews of Interventions* ([Higgins 2011](#)). We calculated the variance of this indirect comparison by summing the variances of both direct comparisons. Then we calculated the SE by taking the square root of the combined variance. We used this as input for the generic inverse variance method in RevMan.

[Curtis 2018](#), a simulation study, compared a video-based learning session on instructions for PPE use for patient decontamination as part of a disaster medicine training to a traditional lecture before participating in a practical exercise.

Outcomes

Infection rates

One study ([Houlihan 2017](#)) evaluated the effect of interventions on infection rates. The authors measured the level of IgG specific for EVD in an oral fluid sample to assess if there have been undetected infections in HCW exposed to EVD.

Contamination outcomes

Simulation studies measured contamination either as proportion of persons contaminated, as the number of contaminated spots or as the area of the body contaminated in studies using a fluorescent marker (see [Table 1](#)). Study authors measured contamination with

the help of a UV-lamp (when using fluorescent marker), or by directly measuring viral or microbe presence or viral or microbial load (when using a non-pathogenic virus or microbes). However, across studies, different body locations were contaminated and also different body locations were measured for the contamination outcome.

Compliance with guidance: Noncompliance rates with donning and doffing procedures

Six studies evaluated the effect of interventions on noncompliance. Two contamination simulation studies ([Casanova 2012](#); [Zamora 2006](#)) measured non-compliance as the number of participants that did not follow the correct order of the protocol, omitted elements, or did not use the correct equipment.

[Shigayeva 2007](#) measured noncompliance in their training study as the number of violations against protocol as recorded from interviews. There were two different compliance outcomes. One was called consistent adherence and was calculated as the proportion of exposure episodes with full compliance with PPE. The other one was called unsafe doffing, measured if one or more of the elements of the doffing procedure were violated. We recalculated outcomes in such a way that they represented the frequency of noncompliance.

[Hung 2015](#) measured compliance as a total score on a 16-item checklist for donning and 20-item checklist for doffing. To get results comparable to the other studies we subtracted the mean compliance values from the maximum score and used these as noncompliance values.

[Casalino 2015](#) measured noncompliance as the number of errors per person for donning and for doffing and the number of persons with one or more errors as measured by the specialist trainer or instructor who also gave the spoken instructions in case of reinforcement. The authors also measured critical errors, which were those where there was contact between skin and potentially contaminated PPE, but we did not consider this a valid measure of contamination and disregarded it. We took measurement of the errors at the last training session as the effect of the intervention. We disregarded the error measurements at earlier training sessions. [Curtis 2018](#) measured compliance as the percentage of the maximum attainable score that an external evaluator gave on a practical skills test for both donning and doffing PPE.

Costs and economic outcomes

No studies reported on costs or other economic outcomes such as resource use.

Other relevant outcomes

[Buianov 2004](#) measured heart rate and body temperature. We chose to report the results of this outcome as well, as we identified

it as an additional outcome that appeared relevant to the questions being addressed.

Excluded studies

Description of case series or outbreak

One reason for excluding important studies was that the researchers only described a case-series of HCW cases' use of PPE for EVD (Muyembe-Tamfum 1999), Marburg Haemorrhagic Fever infection (MHF) (Borchert 2007; Colebunders 2004; Jeffs 2007; Kerstiens 1999), Congo Crimean Haemorrhagic Fever (CCHF) (Gozel 2013) or for SARS (Christian 2004; Ho 2003; Ofner 2003; Ofner-Agostini 2006). None of these studies described the use of PPE by the cases in such detail that they could be replicated. In combination with the lack of a control condition, it is difficult to conclude how much PPE, or the lack thereof, contributed to the infection. The only different study of a series of cases during an outbreak was the study by Dunn 2015 that contained proper descriptions of PPE.

Description of PPE use only

We excluded studies if they only described how and what PPE was used without relation to an outcome (Beam 2016; Beam 2016a; Franklin 2016; Lee 2017; Lowe 2014; Marklund 2002; Minnich 2003).

One type of PPE only, no comparison

Alraddadi 2016, Delaney 2016, Drew 2016, Elcin 2016, Luo 2011, Kwon 2017 and Tomas 2015 evaluated only one type of PPE without a comparison in a simulation study.

No infection rates or compliance outcomes

Some studies measured only performance with PPE compared to no PPE use and not infection rates or compliance (Castle 2009; Coates 2000; Hendler 2000).

Comparison with no PPE only

We excluded studies that only compared PPE use with no PPE and not with alternative PPE use (Lu 2006; Schumacher 2010; Teleman 2004).

Studies that evaluated only one type of PPE and not part of full body PPE

Ogendo 2008 measured eye protection only. Bearman 2007 measured universal glove use only. Chughtai 2013, Lindsley 2012 and Lindsley 2014 measured masks or face shields only. Even though these studies yield valuable information, it is unclear how well the results also cover the use of these items as part of full body protection and therefore we excluded these studies.

Participants not exposed to highly infectious diseases with serious consequences

Many studies evaluated PPE use for other diseases than EVD and related haemorrhagic fevers, such as HIV or other nosocomial infections that were not considered highly infectious or having serious consequences, or both, and we excluded these studies (Malik 2006; Ransjo 1979; Sorensen 2008).

Training or simulation studies without a control group

There were a number of studies that evaluated training but that did not use a control group. This makes it difficult to draw inferences about the effect of one type of training compared to another (Abrahamson 2006; Beam 2014; Hon 2008; Northington 2007; Tomas 2015).

Inconsistent use of PPE during the SARS epidemic

After intensive discussion, we excluded 11 studies that measured the use of PPE (mask, gloves, gowns, goggles) during the SARS outbreak and related that to the risk of SARS infection. One line of thinking was that these studies did not fulfil the inclusion criteria because the comparison here was not clearly one type of PPE versus another type of PPE. Another line of thinking was that the studies compared different types of PPE composition and thus would fulfil the inclusion criteria. We finally decided to deal with these studies in the discussion section only (Ho 2004; Lau 2004; Le 2004; Liu 2009; Loeb 2004; Nishiura 2005; Park 2004; Pei 2006; Scales 2003; Seto 2003; Teleman 2004).

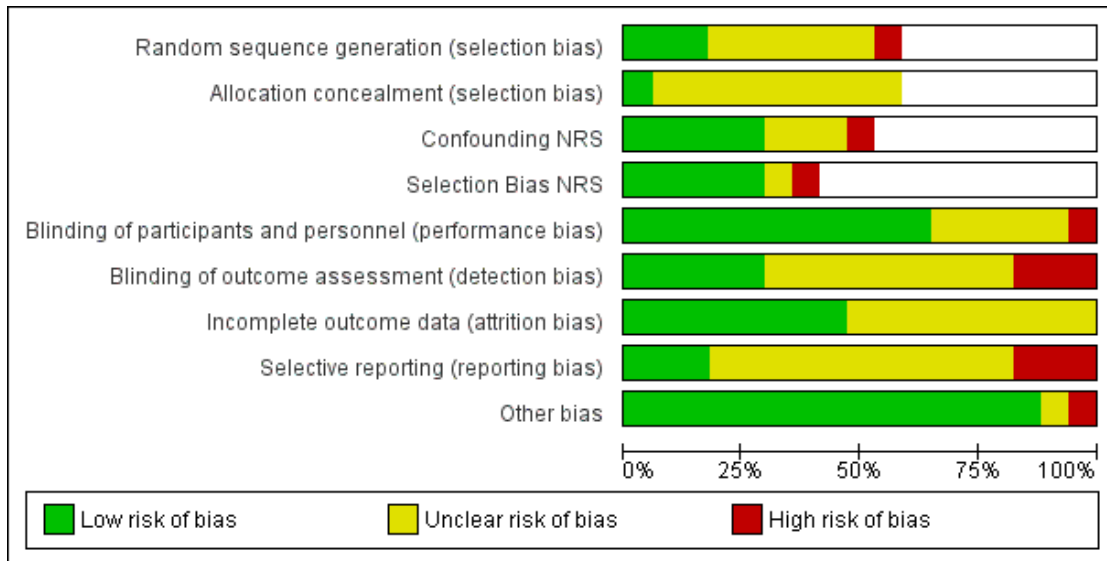
Risk of bias in included studies

See Figure 4 for an overview of our judgment of the risk of bias per study. Figure 5 gives an overview of risk of bias per domain. Since the figures contain the risk of bias assessments for both randomised and non-randomised studies, not all cells are applicable to both study types and those that are not applicable remain empty.

Figure 4. Risk of bias summary: review authors' judgements about each risk of bias item for each included study.

	Random sequence generation (selection bias)	Allocation concealment (selection bias)	Confounding NRS	Selection Bias NRS	Blinding of participants and personnel (performance bias)	Blinding of outcome assessment (detection bias)	Incomplete outcome data (attrition bias)	Selective reporting (reporting bias)	Other bias
Bell 2015	?	?			?	?	+	-	+
Buianov 2004			-	+	?	?	?	?	+
Casalino 2015			?	+	-	-	?	+	+
Casanova 2012			+	+	?	?	?	?	+
Casanova 2016			+	?	+	?	+	+	+
Curtis 2018	?	?	?		+	+	+	?	?
Gleser 2018	-	?			+	-	+	-	-
Guo 2014	?	?			+	?	+	+	+
Hall 2018			+	+	+	?	?	?	+
Houlihan 2017			+	-	+	+	?	?	+
Hung 2015	?	?			+	+	?	-	+
Mana 2018	+	+	?		+	+	+	?	+
Shigayeva 2007			+	+	+	-	+	?	+
Strauch 2016	?	?			+	?	?	?	+
Tomas 2016	?	?			+	?	?	?	+
Wong 2004	+	?			?	?	?	?	+
Zamora 2006	+	?			?	+	+	?	+

Figure 5. Risk of bias graph: review authors' judgements about each risk of bias item presented as percentages across all included studies.



Allocation

Allocation was random in 11 studies but only four of them stated what method they had used for generating the random sequence. Two studies reported an appropriate method (Wong 2004; Zamora 2006) and for one we got additional information from the authors (Mana 2018). We judged these three studies to have a low risk of selection bias. One used alternation and we rated it as having a high risk of bias (Gleser 2018). Allocation concealment was unclear in all but one (Mana 2018) of the randomised studies.

Blinding

In the simulation studies, the participants could not be blinded for the type of attire they were wearing or the type of donning or doffing procedure they were following. It is unclear if they could have contaminated themselves more with attire that they thought was not good, or they did not like, but for the majority of the studies we considered this unlikely and assessed the risk of performance bias to be low. For one study, Casalino 2015, we rated the risk of performance bias as high because the instructors who provided the intervention were very much aware if instruction was given or not and they were the assessors at the same time.

For the non-randomised SARS study (Shigayeva 2007), we considered the risk of performance bias low because the study was retrospective and the participants did not know they were part of a study.

The risk of detection bias was unclear in most studies, as they did not report whether outcome assessors were blinded. We considered the risk to be high in one study (Casalino 2015) as providers of the intervention were also the assessors of compliance, and in a second study (Shigayeva 2007) because the intervention and the outcome were assessed with the same questionnaire at the same time. We judged the risk to be low in four studies because the authors stated that assessors were blind to group status (Curtis 2018; Hung 2015; Mana 2018; Zamora 2006). We judged the risk of detection bias to be low for Houlihan 2017 because they used antibodies against Ebola, an objective outcome, which would not be affected by assessors' knowledge of treatment.

Incomplete outcome data

We judged the risk of attrition bias to be low in eight studies (Bell 2015; Casanova 2016; Curtis 2018; Gleser 2018; Guo 2014; Mana 2018; Shigayeva 2007; Zamora 2006) and unclear in nine studies (Buianov 2004; Casalino 2015; Casanova 2012; Hall 2018;

Houlihan 2017; Hung 2015; Strauch 2016; Tomas 2016; Wong 2004).

Selective reporting

It was difficult for us to judge selective reporting because none of the included studies had published a protocol. We judged two studies (Casalino 2015; Guo 2014) to have a low risk of reporting bias as the authors appeared to have reported all relevant data as specified in their articles' methods. We judged Bell 2015 to be at high risk of reporting bias because they did not report outcomes separately for the intervention and the control. We also judged Hung 2015 to have a high risk of reporting bias as the authors did not fully report the results of the computer usability questionnaire.

Other potential sources of bias

We did not consider any other sources of bias but for Gleser 2018 where we considered that there was a substantial financial conflict of interest because the first author was also the director of the company that produced the gloves that were part of the intervention.

Bias due to confounding (Non-randomised studies)

We judged there to be a low risk of bias due to confounding in five non-randomised studies (Casanova 2012; Casanova 2016; Hall 2018; Houlihan 2017; Shigayeva 2007), unclear risk in one non-randomised study (Casalino 2015), and a high risk in one non-randomised study (Buianov 2004).

Bias due to selection of participants into the study (Non-randomised studies)

We judged there to be a low risk of bias due to selection of participants into the study for five non-randomised studies (Buianov 2004; Casalino 2015; Casanova 2012; Hall 2018; Shigayeva 2007) and unclear for one study (Casanova 2016) For one study we considered the risk of selection bias to be high because participants were recruited based on snowball sampling (Houlihan 2017).

Overall Risk of Bias per study

We judged none of the included studies to be at low risk of bias overall. According to our judgment they were all at either unclear (N = 10) or at high risk of bias (N = 7).

Effects of interventions

See: **Summary of findings for the main comparison** PPE-types: One type of PPE versus another - PAPR versus E-RCP attire; **Summary of findings 2** PPE-types: One type of PPE versus another - Three types of PPE attire; **Summary of findings**

3 PPE-types: One type of PPE versus another - Gowns versus aprons; **Summary of findings 4** PPE types: One type of PPE versus another - Five types of PPE attire; **Summary of findings 5** PPE-types: One type of PPE versus another - Sealed suit compared to Traditional suit; **Summary of findings 6** Procedures: Doffing with double gloves versus doffing with single gloves; **Summary of findings 7** Procedures: Gloves with tab versus standard gloves; **Summary of findings 8** Procedures: Mask tabs versus No mask tabs; **Summary of findings 9** Procedures: Doffing according to CDC method versus individual doffing; **Summary of findings 10** Procedures: Doffing with Hypochlorite versus doffing with Alcohol-based glove sanitizer; **Summary of findings 11** Procedures: Doffing with Chlorine spray versus doffing without spray; **Summary of findings 12** Teaching: Video-based learning versus traditional lecture

1. Types of PPE

1.1 Powered air-purifying respirator (PAPR) versus PPE for Enhanced respiratory and contact precautions (E-RCP)

1.1.1 Outcome: Contamination with fluorescent marker

Zamora 2006 found that the PAPR system in use in their hospital led to less contamination than using the E-RCP system (Relative Risk (RR) 0.27; 95% Confidence Interval (CI) 0.17 to 0.43, Analysis 1.1). Other ways of measuring contamination also led to less contamination with the PAPR system: contamination more than 1 cm (RR 0.21; 95% CI 0.12 to 0.36). The total contaminated area was also less with a Mean Difference (MD) of -81.10 cm^2 (95% CI -96.07 to -66.13). This was mainly due to a lack of protection of the neck in the E-RCP system.

1.1.2. Outcomes: Compliance with guidance - Donning and doffing noncompliance

Noncompliance with donning guidelines occurred more with the PAPR system as this consists of more elements (RR 7.50; 95% CI 1.81 to 31.10; Analysis 1.4; Zamora 2006). Noncompliance with doffing guidelines was more frequent with the E-RCP system, but this was not statistically significant (RR 0.22; 95% CI 0.20 to 1.23; Analysis 1.5).

1.1.3. Outcomes: Donning and doffing time

The donning (MD = 259 seconds) and doffing time (MD = 337 seconds) were considerably longer with the PAPR system (Analysis 1.6; Analysis 1.7; Zamora 2006).

1.2 One type of PAPR versus another and different airflow rates

1.2.1 Outcome: Contamination with microbial aerosol

Buianov 2004 found that the suit that had the hood attached to the suit (C К Б -I) had a lower 'contamination penetration rate' than the suits that had separate hoods and coveralls with a percentage of 8.10^{-8} for the suit and 2.10^{-1} for the coveralls. However, we could not understand the meaning of the penetration rate and we decided that we would not use these results for our conclusions (their results are not shown in data tables).

1.2.2 Outcomes: Heart rate and body temperature

Buianov 2004 also found that beyond 250L/min airflow rates there was no contamination anymore. Body temperature and heart rates were also lower at these airflow rates.

1.3 Four types of PPE versus another

Wong 2004 compared four types of PPE according to their material properties. Type A had good water repellency and water penetration resistance but at the cost of poor air permeability. Type B had good water repellency and good air permeability but poor water penetration resistance. Type C was the surgical gown with both poor water repellency and water penetration resistance. Type D, Barrierman®, was made of Tyvek® and had good water repellency, poor air permeability, and fair water resistance.

1.3.1 Outcomes: Contamination, User-reported assessment of comfort and convenience - usability, donning and doffing times

There were no considerable differences in contamination (Analysis 2.1) between Type A and Type B for face, neck, trunk, foot, or hand, but Type B scored about 10% higher on usability with MD -0.46 (95% CI -0.84 to -0.08 ; Analysis 2.2); this was due especially to better breathability of the fabric. There were no considerable differences in donning and doffing times (Analysis 2.3; Analysis 2.4).

There were considerable differences in contamination of the foot (MD -4.1 spots; 95% CI -6.94 to -1.26) and the hand (MD -12.76 spots; 95% CI -21.62 to -3.9) between Type A and Type D (Analysis 2.5). Donning (MD 33 seconds, Analysis 2.7) and doffing (MD 17 seconds, Analysis 2.8) times were also much worse for Type D. Usability was rated as not considerably differently (MD 0.25; 95% CI -0.12 to 0.62, Analysis 2.6).

It was unclear how many participants had no contamination. On average, all types of PPE had some contamination.

1.4 Formal PPE versus locally available PPE

Bell 2015 compared contamination in four subjects with formal PPE with four subjects with locally available protective gear, such as raincoats. They found contamination in one participant in both study arms. The study was so small that it is difficult to draw conclusions (Analysis 3.1).

1.5 Gown versus apron

Guo 2014 compared a gown with an apron and found that the gown left less contamination than an apron, regardless of the way of doffing (Analysis 4.1; Analysis 4.2).

1.6 Five types of PPE attire compared

Hall 2018 compared post-doffing contamination of five types of PPE ensembles used in different hospital wards across the UK. No analysis of contamination rates of the different suits were available since the authors reported the data on contamination sites only and not according to type of attire. They argued that the contamination rates were too low to provide a valid comparison.

1.7 Sealed suit versus traditional suit

Tomas 2016 found that contamination with fluorescent lotion of subjects doffing a suit that had continuous coverage of skin from arm to hand (sealed suit) were less likely (RR 0.27; 95% CI 0.09 to 0.78; Analysis 5.1) to contaminate themselves compared to those doffing traditional PPE of gown and glove. The authors obtained similar results when they used MS2 bacteriophage as the contaminate (RR 0.68; 95% CI 0.47 to 0.98; Analysis 5.2).

1.8 Easy doffing gown versus traditional gown

Mana 2018 compared a gown with modified neck and wrist design to facilitate doffing with a traditional gown and found less persons with contamination with both fluorescent marker (RR 0.08, 95% CI 0.01 to 0.55; Analysis 6.1) and with harmless virus (RR 0.53, 95% CI 0.29 to 0.94; Analysis 6.2). Even though we received additional information from the authors we were unable to conduct a proper paired analysis.

1.9 Doffing with gloves with tabs versus gloves without tabs

Gleser 2018 found a decrease in persons with contamination when doffing gloves with tab near thumb and wrist compared to standard gloves (RR 0.07; 95% CI 0.15 to 0.31; Analysis 7.1).

1.10 Doffing with masks with tabs versus masks without tabs

[Strauch 2016](#) found that contamination from hands to the head was less when the subject doffed using a mask with tabs on the strap engineered as a doffing aid compared to a mask without tabs (RR 0.33; 95% CI 0.14 to 0.80; Analysis 8.1). There was no difference in contamination rates when subjects doffed a contaminated mask that either had or did not have tabs (RR 0.96; 95% CI 0.83 to 1.12; Analysis 8.2).

2. Donning or doffing procedures

2.1 Double gloving versus single gloving

2.1.1 Outcomes: Contamination with MS2 virus and Compliance with guidance - compliance errors

[Casanova 2012](#) found that contamination with the use of double gloves was less than with single gloves, if all contaminated sites were taken together (RR 0.36; 95% CI 0.16 to 0.78; Analysis 10.1). However, all participants had some level of contamination. Measured as the quantity of virus found, the hands were less contaminated after degloving when participants used double gloves but due to missing data this could not be tested (Analysis 10.2). There were no more errors in compliance with the donning or doffing protocol (RR 1.08; 95% CI 0.70 to 1.67; Analysis 10.3).

2.2 CDC's recommended versus individual doffing

[Guo 2014](#) found that the CDC's recommended way of doffing a gown or an apron led to a different decrease in contamination compared to individually chosen doffing. When doffing the gown, there were 5.4 fewer smaller contamination patches (95% CI -7.4 to -3.4) and 5.2 fewer stains in the environment (95% CI -7.3 to -3.3), but no difference in small contamination patches on the hands, shoes or underwear. With doffing the apron, there were fewer smaller stains, stains on the hands, shoes, and environment, but more large stains and a similar number of stains on the underwear (Analysis 9.1; Analysis 9.2).

2.3 Doffing with hypochlorite sanitation versus alcohol-based sanitation

[Casanova 2016](#) found a non-significant greater self-contamination of bacteriophage MS2 to the hands, face or scrubs when hypochlorite solution was used for the glove sanitizing step of the doffing protocol compared to the use of an alcohol-based hand rub (RR 4.00; 95% CI 0.47 to 34.24; Analysis 11.1). The authors did not detect contamination of bacteriophage Ph6 when using either alcohol-based hand rub or the hypochlorite solution (Analysis 11.2).

2.4. Doffing with chlorine spray versus no spray

[Houlihan 2017](#) compared the risk of HCW contracting Ebola when either using or not using a chlorine spray during the doffing of PPE. However, there was no variation in the use of chlorine spray among clinical workers. The use only varied between clinical and laboratory workers. Since it is not possible to disentangle risk of exposure and the use of hypochlorite solution, no conclusions can be drawn from this study with regard to PPE.

2.5 Additional spoken personal instructions versus no such instructions

2.5.1. Outcome: Compliance with guidance - Noncompliance

[Casalino 2015](#) found that there were substantially less noncompliance (persons with one or more errors) after additional spoken instruction compared to no instructions with RR = 0.31 (95% CI 0.11 to 0.93) and also that the mean number of errors fell with on average almost one (MD -0.89; 95% CI -1.36 to -0.41) in the group with spoken instructions (Analysis 12.1; Analysis 12.2).

2.5.2. Outcome: Infection rate

One study compared infection rates between persons who had instructions while donning and doffing versus rates in those without instructions. Due to the fact that also the exposure was different between these two groups we were unable to draw conclusions about the protective effect of instructions ([Houlihan 2017](#)).

3 Training and instructions

3a. Training and instruction for proper and complete PPE use

3a.1 Active training versus passive training

3a.1.1 Outcome: Compliance with guidance - Noncompliance with PPE guidance

[Shigayeva 2007](#) defined consistent adherence as always wearing gloves, gown, mask, and eye protection. We transformed this to inconsistent use as being non-compliant with the guidance. The study found that active training led to less noncompliance than no training (OR 0.37, 95% CI 0.2 to 0.58; Analysis 15.1). For passive training, they found a lower risk of noncompliance compared to no training (OR 0.58, 95% CI 0.33 to 1.00). For the indirect

comparison, active versus passive training, the OR was 0.63 (95% CI 0.31 to 1.30).

3b. Training and instruction for PPE donning and doffing

3b.1. Active versus passive instruction

3b.1.2. Outcome: Compliance with guidance - Noncompliance with doffing procedures

Shigayeva 2007 found no considerable effect of active (OR 0.70, 95% CI 0.45 to 1.11) or passive training (OR 1.56, 95% CI 0.83 to 2.94) compared to no training (Analysis 14.1), on the number of errors in compliance with the doffing protocol. For the indirect comparison, active versus passive training, the OR was 0.45 (95% CI 0.21 to 0.98).

3b.2 Additional computer simulation versus no additional computer simulation

3b.3.1. Outcome: Compliance with guidance - Noncompliance

Even though the number of errors was low already, Hung 2015 found that adding computer simulation reduced the number of errors with on average half an error for donning (MD = -0.52, 95% CI -0.90 to -0.14; Analysis 15.1) and with more than one

error for doffing (MD = -1.16, 95% CI -1.63 to -0.69) doffing (Analysis 15.2).

3b.3 Video based learning versus Traditional learning

Curtis 2018 compared skills in donning PPE when taught with a video-based learning method versus a traditional lecture. Those that participated in the video learning had a higher mean score on the post exam than those who attended a traditional lecture. (MD 30.7, 95% CI 20.14 to 41.26; Analysis 16.1).

4. Subgroup and sensitivity analysis



We planned a subgroup analysis of studies conducted in high versus low and middle income countries. However, there were not enough studies for such a subgroup analysis to be meaningful. We also planned a sensitivity analysis including only studies we judged to have a low risk of bias. As none of the included studies fulfilled this criterion, we could not perform this analysis.

5. Quality of the evidence

We judged if there was a reason to downgrade the quality of the evidence for each domain of GRADE. Since we judged all studies to have a high or unclear risk of bias, we downgraded the evidence for all comparisons by one level. We considered simulation studies to be indirect evidence, and downgraded the evidence yielded by these studies by one level as well. In addition, when there was only one small study, we downgraded because of imprecision. All in all, the quality of the evidence is very low for all comparisons.

ADDITIONAL SUMMARY OF FINDINGS *[Explanation]*

Three types of PPE attire compared by number of contaminated spots					
<p>Patient or population: Healthcare worker volunteers</p> <p>Settings: Simulation study</p> <p>Intervention: More protective attire, not permeable not breathable (A)</p> <p>Comparison: Less protective attire: permeable but breathable (B); fairly permeable, not breathable (D)</p>					
Outcomes	Illustrative comparative risks* (95% CI)		No of Participants (studies)	Quality of the evidence (GRADE)	Comments
	Assumed risk	Corresponding risk			
	Less protective type of PPE (B or D)	Most protective type of PPE attire (A)			
<p>Number of contaminated spots - Neck</p> <p>fluorescent marker</p> <p>Follow-up: post intervention</p>	<p>The mean number of contaminated spots in control group B was 0.12 spots</p>	<p>The mean number of contaminated spots in the intervention group was 0.7 higher (0.26 lower to 1.66 higher)</p>	50 (1 study)	⊕○○○ very low ^{1,2,3}	
<p>Number of contaminated spots - Foot</p> <p>fluorescent marker</p> <p>Follow-up: post intervention</p>	<p>The mean number of contaminated spots in the control group B was 2.86 spots</p>	<p>The mean number of contaminated spots in the intervention group was 0.96 lower (2.35 lower to 0.43 higher)</p>	50 (1 study)	⊕○○○ very low ^{1,2,3}	
<p>Number of contaminated spots - Palm</p> <p>fluorescent marker</p> <p>Follow-up: post intervention</p>	<p>The mean number of contaminated spots in the control group B was 17.83</p>	<p>The mean number of contaminated spots in the intervention group was 7.72 lower (15.65 lower to 0.21 higher)</p>	50 (1 study)	⊕○○○ very low ^{1,2,3}	

Number of contaminated spots - Foot fluorescent marker Follow-up: post intervention	The mean number of contaminated spots in the control group D was 4.96	The mean number of contaminated spots in the intervention group was 4.1 lower (6.94 to 1.26 lower)	50 (1 study)	 very low ^{1,2,3}	
Number of contaminated spots - Palm fluorescent marker Follow-up: post intervention	The mean number of contaminated spots in the control group D was 20.49	The mean number of contaminated spots in the intervention group was 12.76 lower (21.62 to 3.9 lower)	50 (1 study)	 very low ^{1,2,3}	
Infection with EVD	See comment	See comment	0 (0 studies)	See comment	No studies evaluated the effect of the interventions on infection rates
Compliance with guidance	See comment	See comment	0 (0 studies)	See comment	No studies evaluated the effect of the interventions on compliance with guidance

* The basis for the **assumed risk** is the control group risk. The **corresponding risk** (and its 95% confidence interval) is based on the assumed risk in the comparison group.
CI: Confidence interval;

GRADE Working Group grades of evidence

High quality: Further research is very unlikely to change our confidence in the estimate of effect.

Moderate quality: Further research is likely to have an important impact on our confidence in the estimate of effect and may change the estimate.

Low quality: Further research is very likely to have an important impact on our confidence in the estimate of effect and is likely to change the estimate.

Very low quality: We are very uncertain about the estimate.

¹ Simulation study, downgraded one level for indirectness

² One study with 100 participants, 25 participants per arm, downgraded one level for imprecision

³ Unclear risk of bias in the study, downgraded one level

Gowns versus aprons for preventing highly infectious diseases due to contact with contaminated body fluids in healthcare staff					
Patient or population: Healthcare worker volunteers Settings: Simulation study Intervention: Gowns versus aprons					
Outcomes	Illustrative comparative risks* (95% CI)		No of Participants (studies)	Quality of the evidence (GRADE)	Comments
	Assumed risk	Corresponding risk			
	Aprons	Gowns			
Contamination with marker; individual type of doffing Follow-up: post intervention	The mean contamination with marker in the control groups was 16.98 small spots	The mean contamination with marker in the intervention groups was 10.28 lower (14.77 to 5.79 lower)	50 (1 study)	⊕○○○ very low ^{1,2,3}	Cross-over study; the analyses were unadjusted for the paired nature of the data but similar to the analysis of the authors who took this into account
Contamination with marker; CDC recommended doffing Follow-up: post intervention	The mean contamination with marker in the control groups was 1.88 small spots	The mean contamination with marker in the intervention groups was 0.62 lower (1.75 lower to 0.51 higher)	50 (1 study)	⊕○○○ very low ^{1,2,3}	
Infection with EVD	See comment	See comment	0 (0 studies)	See comment	No studies evaluated the effect of the interventions on infection rates
Compliance with guidance	See comment	See comment	0 (0 studies)	See comment	No studies evaluated the effect of the interventions on compliance with guidance

*The basis for the **assumed risk** is the control group risk. The **corresponding risk** (and its 95% confidence interval) is based on the assumed risk in the comparison group.
CI: Confidence interval;

GRADE Working Group grades of evidence

High quality: Further research is very unlikely to change our confidence in the estimate of effect.

Moderate quality: Further research is likely to have an important impact on our confidence in the estimate of effect and may change the estimate.

Low quality: Further research is very likely to have an important impact on our confidence in the estimate of effect and is likely to change the estimate.

Very low quality: We are very uncertain about the estimate.

¹ Randomisation method unclear, downgraded one level

² Simulation study, downgraded one level for indirectness

³ Single cross-over study with 50 participants, downgraded one level for imprecision

One type of full body PPE compared to another type for preventing highly infectious diseases due to exposure to contaminated body fluids in healthcare staff

Patient or population: Preventing highly infectious diseases due to exposure to contaminated body fluids in healthcare staff
Setting:
Intervention: One type of full body PPE
Comparison: Another type

Outcomes	Anticipated absolute effects* (95% CI)		Relative effect (95% CI)	No. of participants (studies)	Certainty of the evidence (GRADE)	Comments
	Risk with another type	Risk with One type of full body PPE				
Any contamination	Study population		not estimable	(1 observational study)	⊕⊕○○ Very low ^{1,2}	There were too few events to enable comparison of contamination rates between different types of PPE
	0 per 1,000	0 per 1,000 (0 to 0)				

*The risk in the intervention group (and its 95% confidence interval) is based on the assumed risk in the comparison group and the relative effect of the intervention (and its 95% CI).

CI: Confidence interval; RR: Risk ratio; OR: Odds ratio;

GRADE Working Group grades of evidence
High certainty: We are very confident that the true effect lies close to that of the estimate of the effect
Moderate certainty: We are moderately confident in the effect estimate: The true effect is likely to be close to the estimate of the effect, but there is a possibility that it is substantially different
Low certainty: Our confidence in the effect estimate is limited: The true effect may be substantially different from the estimate of the effect
Very low certainty: We have very little confidence in the effect estimate: The true effect is likely to be substantially different from the estimate of effect

¹ The simulated exposure was very low. This resulted in a lack of power to detect differences, We downgraded with one level.

² Risk of bias in the study was unclear and so we downgraded with one level.

Sealed suit compared to Traditional suit for preventing highly infectious diseases due to exposure to contaminated body fluids in healthcare staff

Patient or population: Preventing highly infectious diseases due to exposure to contaminated body fluids in healthcare staff
Setting:
Intervention: Sealed suit
Comparison: Traditional suit

Outcomes	Anticipated absolute effects* (95% CI)		Relative effect (95% CI)	No of participants (studies)	Certainty of the evidence (GRADE)	Comments
	Risk with Traditional	Risk with Sealed suit				
Contamination fluorescent lotion	Study population		RR 0.27 (0.09 to 0.78)	30 (1 RCT)	⊕○○○ VERY LOW ¹²	
	733 per 1,000	198 per 1,000 (66 to 572)				
Contamination MS2	Study population		RR 0.68 (0.47 to 0.98)	30 (1 RCT)	⊕○○○ VERY LOW ¹²	
	1,000 per 1,000	680 per 1,000 (470 to 980)				

*The risk in the intervention group (and its 95% confidence interval) is based on the assumed risk in the comparison group and the relative effect of the intervention (and its 95% CI).

CI: Confidence interval; RR: Risk ratio; OR: Odds ratio;

GRADE Working Group grades of evidence

High certainty: We are very confident that the true effect lies close to that of the estimate of the effect

Moderate certainty: We are moderately confident in the effect estimate: The true effect is likely to be close to the estimate of the effect, but there is a possibility that it is substantially different

Low certainty: Our confidence in the effect estimate is limited: The true effect may be substantially different from the estimate of the effect

Very low certainty: We have very little confidence in the effect estimate: The true effect is likely to be substantially different from the estimate of effect

¹ This is a simulation study so we downgraded with one level because of indirectness.

² One study with 30 participants so we downgraded with one level because of imprecision.

Doffing with double gloves compared to doffing with single gloves for preventing contact with contaminated body fluids in healthcare staff						
Patient or population: Healthcare staff volunteers Settings: Simulation study Intervention: Doffing with double gloves Comparison: Doffing with single gloves						
Outcomes	Illustrative comparative risks* (95% CI)		Relative effect (95% CI)	No of Participants (studies)	Quality of the evidence (GRADE)	Comments
	Assumed risk	Corresponding risk				
	Doffing with single gloves	Doffing with double gloves				
Contamination: virus detected - All body parts Follow-up: post intervention	778 per 1000	280 per 1000 (124 to 607)	RR 0.36 (0.16 to 0.78)	18 (1 cross-over study)	⊕○○○ very low ^{1,2}	Non-randomised cross-over study; the analyses were unadjusted for the paired nature of the data but the results are similar to those analysed taking into account the paired nature of the data
Compliance with guidance - Noncompliance: any error Follow-up: post intervention	667 per 1000	720 per 1000 (467 to 1000)	RR 1.08 (0.7 to 1.67)	18 (1 cross-over study)	⊕○○○ very low ^{1,2}	
Infection with EVD	See comment	See comment	Not estimable	0 (0 studies)	See comment	No studies evaluated the effect of the interventions on infection rates

*The basis for the **assumed risk** is the control group risk. The **corresponding risk** (and its 95% confidence interval) is based on the assumed risk in the comparison group and the **relative effect** of the intervention (and its 95% CI).

CI: Confidence interval; **RR:** Risk ratio;

GRADE Working Group grades of evidence

High quality: Further research is very unlikely to change our confidence in the estimate of effect.

Moderate quality: Further research is likely to have an important impact on our confidence in the estimate of effect and may change the estimate.

Low quality: Further research is very likely to have an important impact on our confidence in the estimate of effect and is likely to change the estimate.

Very low quality: We are very uncertain about the estimate.

¹ This is a simulation study so we downgraded with one level because of indirectness.

² One cross over study with 18 participants so we downgraded with one level because of imprecision.

Gloves with tab compared to standard gloves for preventing highly infectious diseases due to exposure to contaminated body fluids in healthcare staff

Patient or population: Preventing highly infectious diseases due to exposure to contaminated body fluids in healthcare staff
Setting:
Intervention: Gloves with tab
Comparison: Standard gloves

Outcomes	Anticipated absolute effects* (95% CI)		Relative effect (95% CI)	No. of participants (studies)	Certainty of the evidence (GRADE)	Comments
	Risk with standard gloves	Risk with Gloves with tab				
Any contamination of hands	Study population		OR 0.07 (0.04 to 0.12)	317 (1 RCT)	⊕○○○ VERY LOW ¹²	
	733 per 1,000	161 per 1,000 (99 to 248)				

***The risk in the intervention group** (and its 95% confidence interval) is based on the assumed risk in the comparison group and the **relative effect** of the intervention (and its 95% CI).

CI: Confidence interval; RR: Risk ratio; OR: Odds ratio;

GRADE Working Group grades of evidence

- High certainty:** We are very confident that the true effect lies close to that of the estimate of the effect
- Moderate certainty:** We are moderately confident in the effect estimate: The true effect is likely to be close to the estimate of the effect, but there is a possibility that it is substantially different
- Low certainty:** Our confidence in the effect estimate is limited: The true effect may be substantially different from the estimate of the effect
- Very low certainty:** We have very little confidence in the effect estimate: The true effect is likely to be substantially different from the estimate of effect

¹ Clusters of health care workers who were present at work were allocated to intervention or control on alternating days and so we we downgraded with one level because of study limitations.
² This is a simulation study so we downgraded with one level because of indirectness.

Mask tabs compared to No mask tabs for preventing highly infectious diseases due to exposure to contaminated body fluids in healthcare staff						
Patient or population: Preventing highly infectious diseases due to exposure to contaminated body fluids in healthcare staff Setting: Intervention: Mask tabs Comparison: No mask tabs						
Outcomes	Anticipated absolute effects* (95% CI)		Relative effect (95% CI)	No. of participants (studies)	Certainty of the evidence (GRADE)	Comments
	Risk with No mask tabs	Risk with Mask tabs				
Contamination of mask from hands	Study population		RR 0.33 (0.14 to 0.80)	20 (1 RCT)	⊕○○○ VERY LOW ¹²³	Analyses presented in this table are unadjusted for the paired nature of the cross-over design but similar to the results that the authors presented while taking the cross-over into account
	1,000 per 1,000	330 per 1,000 (140 to 800)				
Contamination of head from hands	Study population		RR 0.96 (0.83 to 1.12)	120 (1 RCT)	⊕○○○ VERY LOW ¹²³	Analyses presented in this table are unadjusted for the paired nature of the cross-over design but similar to the results that the authors presented while taking the cross-over into account
	867 per 1,000	832 per 1,000 (719 to 971)				

* **The risk in the intervention group** (and its 95% confidence interval) is based on the assumed risk in the comparison group and the **relative effect** of the intervention (and its 95% CI).

CI: Confidence interval; **RR:** Risk ratio; **OR:** Odds ratio;

GRADE Working Group grades of evidence

High certainty: We are very confident that the true effect lies close to that of the estimate of the effect

Moderate certainty: We are moderately confident in the effect estimate: The true effect is likely to be close to the estimate of the effect, but there is a possibility that it is substantially different

Low certainty: Our confidence in the effect estimate is limited: The true effect may be substantially different from the estimate of the effect

Very low certainty: We have very little confidence in the effect estimate: The true effect is likely to be substantially different from the estimate of effect

- ¹ The randomisation procedure was unclear and the cross-over procedure was unclear so we downgraded with one level because of study limitations.
- ² This is a simulation study so we downgraded with one level because of indirectness.
- ³ One study only with 20 participants and so we downgraded with one level because of imprecision.

CDC method versus individual doffing for preventing contact with contaminated body fluids in healthcare staff						
Patient or population: Healthcare staff volunteers Settings: Simulation study Intervention: CDC method in doffing Control: Individual method of doffing						
Outcomes	Illustrative comparative risks* (95% CI)		Relative effect (95% CI)	No of Participants (studies)	Quality of the evidence (GRADE)	Comments
	Assumed risk	Corresponding risk				
	Individual method	doffing CDC recommended doffing method				
Contamination with fluor marker when using gowns Follow-up: post intervention	The mean contamination with fluor marker in the control group was 6.7 small spots	The mean contamination with fluor marker in the intervention group was 5.44 lower (7.43 to 3.45 lower)		50 (1 study)	⊕○○○ very low ^{1,2,3}	Cross-over study; the analyses were unadjusted for the paired nature of the data but similar to the analysis of the authors who took this into account
Contamination with fluor marker when using aprons Follow-up: post intervention	The mean contamination with fluor marker in the control group was 16.98 small spots	The mean contamination with fluor marker in the intervention group was 15.1 lower (19.28 to 10.92 lower)		50 (1 study)	⊕○○○ very low ^{1,2,3}	
Infection with EVD	See comment	See comment		0 (0 studies)	See comment	No studies evaluated the effect of the interventions on infection rates

Compliance with guidance	See comment	See comment	0 (0 studies)	See comment	No studies evaluated the effect of the interventions on compliance with guidance
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*The basis for the **assumed risk** is the control group risk. The **corresponding risk** (and its 95% confidence interval) is based on the assumed risk in the comparison group.
CI: Confidence interval;

GRADE Working Group grades of evidence

High quality: Further research is very unlikely to change our confidence in the estimate of effect.

Moderate quality: Further research is likely to have an important impact on our confidence in the estimate of effect and may change the estimate.

Low quality: Further research is very likely to have an important impact on our confidence in the estimate of effect and is likely to change the estimate.

Very low quality: We are very uncertain about the estimate.

¹ The randomisation procedure was unclear and so we downgraded with one level due to study limitations.

² This is a simulation study so we downgraded with one level because of indirectness.

³ One cross-over study with 50 participants and so we downgraded with one level due to imprecision.

Doffing with Hypochlorite compared to doffing with Alcohol-based glove sanitizer for preventing highly infectious diseases due to exposure to contaminated body fluids in healthcare staff						
Patient or population: Preventing highly infectious diseases due to exposure to contaminated body fluids in healthcare staff Setting: Intervention: Doffing with Hypochlorite Comparison: Doffing with Alcohol-based glove sanitizer						
Outcomes	Anticipated absolute effects* (95% CI)		Relative effect (95% CI)	No. of participants (studies)	Certainty of the evidence (GRADE)	Comments
	Risk with doffing with Alcohol-based sanitizer	Risk with Doffing with Hypochlorite glove				
Contamination MS2	Study population		RR 4.00 (0.47 to 34.24)	15 (1 observational study)	⊕○○○ VERY LOW ¹²³	
	100 per 1,000	400 per 1,000 (47 to 1,000)				
Contamination Ph6	Study population		not estimable	15 (1 observational study)	-	
	0 per 1,000	0 per 1,000 (0 to 0)				

* **The risk in the intervention group** (and its 95% confidence interval) is based on the assumed risk in the comparison group and the **relative effect** of the intervention (and its 95% CI).

CI: Confidence interval; **RR:** Risk ratio; **OR:** Odds ratio;

GRADE Working Group grades of evidence
High certainty: We are very confident that the true effect lies close to that of the estimate of the effect
Moderate certainty: We are moderately confident in the effect estimate: The true effect is likely to be close to the estimate of the effect, but there is a possibility that it is substantially different
Low certainty: Our confidence in the effect estimate is limited: The true effect may be substantially different from the estimate of the effect
Very low certainty: We have very little confidence in the effect estimate: The true effect is likely to be substantially different from the estimate of effect

- ¹ Allocation to intervention was based on belonging to last five participants, which is an unclear selection procedure and so we downgraded with one level because of study limitations.
- ² This is a simulation study so we downgraded with one level because of indirectness.
- ³ The study had a small number of participants and so we downgraded with one level because of imprecision.

Doffing with Chlorine spray compared to doffing without spray for preventing highly infectious diseases due to exposure to contaminated body fluids in healthcare staff

Patient or population: Preventing highly infectious diseases due to exposure to contaminated body fluids in healthcare staff
Setting:
Intervention: Doffing with Chlorine spray
Comparison: Doffing without spray

Outcomes	Anticipated absolute effects* (95% CI)		Relative effect (95% CI)	No. of participants (studies)	Certainty of the evidence (GRADE)	Comments
	Risk with doffing without spray	Risk with Doffing with Chlorine spray				
Infection Rate (IgG level)	Low 0 per 1,000	0 per 1,000 (0 to 0)	not estimable	0 cases 0 controls (1 observational study)	⊕○○○ VERY LOW ¹²	There was collinearity between PPE-use and other variables which precluded analysis

* **The risk in the intervention group** (and its 95% confidence interval) is based on the assumed risk in the comparison group and the **relative effect** of the intervention (and its 95% CI).

CI: Confidence interval; RR: Risk ratio; OR: Odds ratio;

GRADE Working Group grades of evidence

- High certainty:** We are very confident that the true effect lies close to that of the estimate of the effect
- Moderate certainty:** We are moderately confident in the effect estimate: The true effect is likely to be close to the estimate of the effect, but there is a possibility that it is substantially different
- Low certainty:** Our confidence in the effect estimate is limited: The true effect may be substantially different from the estimate of the effect
- Very low certainty:** We have very little confidence in the effect estimate: The true effect is likely to be substantially different from the estimate of effect

¹ The study used a convenience sample and it was unclear who was selected. Consequently we downgraded with one level because of study limitations.
² Protection measures collided with risk of exposure and so we downgraded with one level because of study limitations.

Video-based learning compared to traditional lecture for preventing highly infectious diseases due to exposure to contaminated body fluids in healthcare staff

Patient or population: Preventing highly infectious diseases due to exposure to contaminated body fluids in healthcare staff
Setting:
Intervention: Video-based learning
Comparison: Traditional lecture

Outcomes	Anticipated absolute effects* (95% CI)		Relative effect (95% CI)	No. of participants (studies)	Certainty of the evidence (GRADE)	Comments
	Risk with traditional lecture	Risk with Video-based learning				
Skills in PPE donning assessed with: Assessment scale Scale from: 0 to 100%; Higher is better	The mean skills in PPE donning was 47.4 Percent	MD 30.7 percent higher (20.14 higher to 41.26 higher)	-	26 (1 RCT)	⊕○○○ VERY LOW ¹²³	

* **The risk in the intervention group** (and its 95% confidence interval) is based on the assumed risk in the comparison group and the **relative effect** of the intervention (and its 95% CI).

CI: Confidence interval; RR: Risk ratio; OR: Odds ratio;

GRADE Working Group grades of evidence

- High certainty:** We are very confident that the true effect lies close to that of the estimate of the effect
- Moderate certainty:** We are moderately confident in the effect estimate: The true effect is likely to be close to the estimate of the effect, but there is a possibility that it is substantially different
- Low certainty:** Our confidence in the effect estimate is limited: The true effect may be substantially different from the estimate of the effect
- Very low certainty:** We have very little confidence in the effect estimate: The true effect is likely to be substantially different from the estimate of effect

¹ The randomisation and allocation procedures were unclear and so we downgraded with one level because of study limitations.
² This is a simulation study so we downgraded with one level because of indirectness.
³ One study with only 26 participants and so we downgraded with one level because of imprecision.

DISCUSSION

Summary of main results

We found two retrospective cohort studies conducted under field circumstances. One study was conducted among HCW exposed to EVD and assessed the effect of different PPE donning and doffing procedures on infection rates but the data could not be used because of collinearity. Another study was conducted among HCW exposed to SARS and provided data on the effect of active training on compliance. We found twelve studies of simulated exposure and three that simulated the donning and doffing procedure. In all simulation studies, contamination happened both in the intervention arm and in the control arm for most participants.

There are ten studies that have compared various types of PPE to one another but we could not combine their results due to clinical differences and thus all conclusions are based on single studies. There is very low quality evidence that it may be possible to improve breathability of protective suits without increasing the risk of contamination. Improved breathability of protective suits may also increase user satisfaction. Changes to PPE such as adding tabs to masks or gloves or better closure of the neck or wrist regions may decrease contamination during doffing procedures.

There are four studies that have compared donning and doffing procedures. For doffing, there is very low quality evidence that double gloving as part of full body PPE may reduce the risk of contamination and reduce the viral load on the hands without increasing the frequency of noncompliance with the doffing protocol. Following CDC recommendations for doffing gowns and aprons compared to individually chosen ways may decrease the risk of contamination. Instructions during doffing may increase compliance. There is no difference in contamination between using alcohol-based hand rub during doffing and using chlorine based disinfection.

There are three studies that have compared training models. There is very low quality evidence from one SARS-related study and two simulation studies that more active training in PPE use decreases noncompliance with donning and doffing guidance more than passive training. The active training used in the studies was video or computer simulation or face-to-face training compared to lectures (passive) only.

We found no audit reports or other unpublished reports or data from our contact efforts to manufacturers and other organisations.

Overall completeness and applicability of evidence

Most studies provided sparse descriptions of the level of chemical protection (ISO 2013) or viral protection (EN 14126; ISO 2004) of the PPE they used or the outfits used varied so much in their components that it was impossible to make uniform comparisons.

Even though doffing procedures are fairly easy to evaluate in simulation studies, we found only one small study that has evaluated the effects of double gloving, CDC recommendations for gowns and aprons, disinfection procedures, and spoken instructions. There are no studies on what to do in a case of an obvious breach of barrier protection, such as a tear in gown. It seems that it would not be difficult to perform more and better simulation studies to find out how important these procedures are.

Because studies seem feasible and because we searched exhaustively, there must be other reasons why there is such little evidence available. One of these is probably the highly politicised context in which such a study has to be performed during an epidemic. However, retrospective cohort and case-control studies are possible as has been shown during the SARS epidemic. The studies conducted after the SARS epidemic show that the consistent use of PPE rather than type of PPE was most important (see Appendix 7). At the start of the epidemic, SARS patients were not appropriately diagnosed, and the importance of PPE was not immediately clear. Personal protective equipment compliance was higher in the later stages, and infections occurred less frequently (Nishiura 2005). SARS also affected comparatively richer countries- China, Hongkong, Canada. The experiences from retrospective studies during Ebola epidemics are similar. During the 1995 Ebola epidemic in Kikwit in the Democratic Republic of the Congo, a study also reported that once PPE and other control measures were used, there were very few HCW infections (Kerstiens 1999). Dunn 2015 is a case study from the Ebola epidemic that also provided systematic information on the use of PPE and infection rates. We reanalyzed the excluded study by Dunn 2015 as a cohort study of exposed HCW (Verbeek 2016a). The relative risk of contracting Ebola infection for HCW using gloves only versus those not using PPE was 0.16 (0.04 to 0.71) indicating that using gloves already provides a lot of protection. For using gloves or a gown or more compared to no PPE, the RR was 0.03 (95% CI 0.00 to 0.57) (Verbeek 2016a). This is very similar to the findings of the SARS studies mentioned above. It is also, to a certain extent, reassuring for those situations in low- and middle- income countries that do not have sufficient PPE available (see Levy 2015) that some PPE already decreases the risk of infection considerably. In this version of the review we could include one retrospective cohort study from the 2015 West Africa Ebola epidemic. Unfortunately, the information on PPE was not detailed enough to be able to draw conclusions.

While the included studies show that more active training prevented errors, it is not clear how long the effects of training last. Northington 2007 showed that at six months after training, only 14% of participants were able to correctly don and doff PPE. It is unclear from the included studies, if fit-testing of masks is part of training. This is a commonly accepted prerequisite for proper functioning of respiratory protection.

There is only one study that had been conducted in a low- and middle-income (LMI) country. Since most serious haemorrhagic fever epidemics occur in some parts of Africa, this is a serious

disadvantage of the current evidence. However, in such resource poor settings, appropriate research is the lowest priority for the local decision makers. Consequently, the initiative has to come from the likes of WHO and international organisations that work in these epidemics.

Quality of the evidence

We rated the quality of the evidence as very low for all comparisons, mainly because our conclusions are based on single studies and all the included studies had a high or unclear risk of bias. The retrospective cohort studies have a high risk of recall bias because participants had to recall their use of PPE after the epidemic occurred. The simulation studies had small sample sizes or very few events across compared groups.

One of the major problems is that most of the studies did not indicate if the PPE that they used complied with one or more of the international standards for protective clothing and whether they used viral barrier fabrics. The lack of attention to the designation of PPE as being protective for viruses is problematic also in practice. The many different labels and standards that are in use to designate protection against contamination with viral diseases such as EBV make it almost impossible for a HCW in practice to make the right choice. The confusing language of infection control has also been reported for isolation practices in general. This is why [Landers 2010](#) called for the adoption of internationally accepted and standardised category terms for isolation precautions. Others have tried to improve the standardisation by providing HCW with a summary card of the various types of precautions that have to be taken and indicated that this increased the implementation of precautionary measures ([Russell 2015](#)).

In simulation studies, it is not clear how well the exposure represents real life exposure. Some studies used 'high volume exposure to simulate splash' ([Bell 2015](#)), whereas other studies only used a powdered fluorescent marker spread in the room ([Beam 2011](#)). It is also not clear how well the fluorescent marker can indicate that there is no viral contamination. [Casanova 2008](#) showed that in spite of no fluorescent marker being detected, there could still be viral contamination with bacteriophage MS2. Therefore, in simulation studies, the objective should be to reach zero contamination.

Only one of the case studies that we collected ([Dunn 2015](#)) properly described the use of PPE. Better description would enable better analysis.

Potential biases in the review process

We excluded all studies that evaluated only one piece of PPE, such as goggles or masks. However, none of these excluded studies would have answered the questions that in our current review remained unanswered. From [Casanova 2012](#), it became clear that

using double gloves as part of full body PPE is important, because it facilitates the removal of the other pieces of PPE without contaminating the hands. This shows that it is important to consider the effect of one piece of PPE as part of full body PPE. In addition, seldom is there only one clear transmission route. Even with SARS which, as a respiratory infection, was spread by droplets and aerosols, consistent use of other pieces of PPE besides respiratory protection was still important. Therefore, we think that our strict inclusion criteria did not bias the results of our review.

We assumed that adherence to PPE use and training would work in a similar way between SARS, EVD and simulation studies. However, there is an important difference. At the start of the SARS epidemic, the causal virus and its transmission were unclear and workers were probably not instructed well enough to protect themselves. On the other hand, it has been known for years that EVD is a highly contagious disease with a very high fatality rate. Thus, compliance and effectiveness of training concerning EVD might be higher than we concluded from the SARS study. In the SARS studies that we excluded, there was high heterogeneity in the effects of consistently wearing PPE that we could not explain. The heterogeneity in effect is also underpinned by studies that did not find any SARS infections in spite of imperfect protection with PPE. This means that at best the effectiveness of PPE is not fully understood. This requires further research to understand the mechanisms of PPE protection against Ebola.

Five of the included simulation studies are cross-over studies where the authors analysed the data with tests that took into account the paired nature of the data: [Zamora 2006](#) used the Mailand-Gart test, [Guo 2014](#) used repeated measures, and [Casanova 2012](#) and [Strauch 2016](#) the paired t-test but the methods used in [Mana 2018](#) were unclear. We could not use the results of these tests in our analyses in RevMan, which resulted in wider confidence intervals than using a paired analysis. There were insufficient data in the studies to properly adjust for the cross-over effect in our analyses. However, all results that were reported as being statistically significant were also statistically significant in our analyses. Therefore we think that this has not biased our results.

With the simulation studies the way exposure was simulated is an important element to consider. This varied highly between the studies. However, most studies used a worst case scenario, spraying fluorescent marker over large parts of the body but some studies applied only small amounts. One study used a sophisticated manikin with an internal mechanism simulating exposure ([Hall 2018](#); [Poller 2018](#)) Future studies urgently need consensus from experts in the field on how exposure can be best simulated. This is best possible under the auspices of WHO or other internationally recognised bodies.

With the included non-randomised studies, we assessed risk of bias with a hybrid version of the Cochrane risk of bias tool and the recently developed ROBINS-I tool. This might not have been the most optimal way to assess risk of bias. However, we believe that the limitations of the available studies are profound and a

more rigorous risk of bias assessment could not have lowered (or improved) our confidence in the evidence any further.

Agreements and disagreements with other studies or reviews

We found two other reviews that have evaluated the effect of PPE for highly infectious diseases with serious consequences in HCW: [Hersi 2015](#) and [Fischer 2015](#). [Hersi 2015](#) was commissioned by WHO to underpin the PPE guidelines issued for HCW exposed to EVD. The authors originally included only controlled studies of interventions to protect HCW against EVD and similar haemorrhagic fever infections with infection rates as outcomes. During the review process the authors decided to also include case studies and case series but they were not able to draw conclusions from these studies because the PPE use was not well described. [Fischer 2015](#) took a more pragmatic but unsystematic approach and included all articles pertaining to filovirus transmission and PPE and in addition articles that evaluated donning and doffing strategies. They conclude that there is a lack of evidence but that simulation studies could provide evidence for guidelines.

Heat stress and breathability is an important issue in PPE especially for Ebola. [Kuklane 2015](#) argued that using other materials would substantially reduce the heat stress but these come at a tenfold higher price. Other researchers that have looked into this problem have found inconsistent results. [Coca 2015](#) found that PPE on manikins led to a critical body core temperature of 38.4°C in one hour. On the other hand, [Grélot 2015](#) found that HCW caring for Ebola patients had only a 0.46°C rise in core body temperature after being at work for one hour. Of the 25 workers studied only four reached a core body temperature over 38.5°C.

An independent panel of experts that evaluated the Ebola response concluded, among many other things, that a coordinated research effort is needed to build a better global system for infectious disease outbreak and response ([Moon 2015](#)). Their recommendation is that research funders should establish a worldwide research and development financing facility for outbreak-relevant drugs, vaccines, diagnostics, and non-pharmaceutical supplies (such as PPE). This is very much in line with what we experienced and found in this review.

[Missair 2014](#) reviewed implications of EVD patient management for anaesthetists based on a literature review of all types of studies on EVD. This is why their inclusion criteria were very broad and non-specific. Finally the authors relied on PPE guidelines as provided by WHO and MSF to make recommendations with no evidence of their comparability. This makes their results difficult to compare to ours.

[Moore 2005](#) reviewed all measures to prevent healthcare workers from SARS and other respiratory pathogens in a narrative format, from 168 publications. They concluded that a positive safety climate is the most important factor for adherence to universal precautions. They recommend using adequate PPE, but they do

not define 'adequate'. Their inclusion criteria were much broader and the results are difficult to compare with ours. The same research group formulated valuable advice about research gaps based on this review but focused only on respiratory protection ([Yassi 2005](#)). They corroborate the findings of [Jefferson 2011](#), that N95 respirators may not be all that superior, citing the early containment of the SARS epidemic without these in Hanoi.

The Cochrane review by [Jefferson 2008](#), updated in [Jefferson 2011](#), evaluated the effect of physical interventions to interrupt the spread of respiratory viruses for all populations. Even though they only included studies on respiratory infections and any type of protection for any person at risk, 10 studies in their review are about SARS and protecting healthcare workers. The authors did not conduct a subgroup or additional analysis of these HCW studies. Because the infection risk for HCW is substantially different from the populations they protect, the [Jefferson 2011](#) results are not applicable to HCW.

AUTHORS' CONCLUSIONS

Implications for practice

In addition to other infection control measures, consistent use of full body PPE can diminish the risk of infection for HCW. EN and ISO standards for chemical protective clothing and fabric permeability for viruses are helpful to determine which PPE should technically protect sufficiently against highly infectious diseases. However the risk of contamination depends on more than just these technical factors. In simulation studies, contamination happened in almost all intervention and control arms.

There is very low quality evidence, based on single exposure simulation studies, that more breathable fabric may still lead to similar levels of contamination protection as less breathable fabric, and may be preferred by users. The lack of using currently accepted standards in the included studies prevents the extrapolation of results of studies comparing PPE types to PPE in current use. Changes to PPE such as adding tabs to gloves or masks or closer fit at the neck or the wrist may facilitate doffing without contamination.

For different procedures of donning and doffing, there is very low quality evidence based on a single study each that double gloves, as part of PPE and following CDC guidelines, may reduce the risk of contamination. The protection obtained from use of alcohol-based hand rub during doffing did not differ from the protection obtained by using chlorine-based disinfection.

For various training procedures there is very low quality evidence that more active training (including video or computer simulation or spoken instructions) may increase compliance with instructions compared to passive training (lectures or no added instructions).

There are no studies that have compared methods to retain PPE skills needed for proper donning and doffing in the long term.

The quality of the evidence is very low for all comparisons because conclusions are based on single studies and a high or unclear risk of bias in studies, indirectness of evidence, and small numbers of participants. This means that we are uncertain about the estimates of effects, and it is therefore likely that the true effects may be substantially different from the ones reported in this review.

Implications for research

We concur with WHO that there is a need to carry out a re-evaluation of how PPE is standardised, designed and tested (WHO 2018). What is missing is a harmonized set of PPE standards and a unified design for PPE to be used when taking care of patients with highly infectious diseases.

We call on NGOs in medical relief work to organise studies and to raise awareness about the lack of evidence for the effect of specific PPE. We also call upon them to develop a more transparent and uniform labeling of infection control measures and the protection level of PPE for HCW. We believe that this is an important prerequisite for the universal implementation of infection control measures for HCW.

Simulation studies are a feasible and relatively simple way to compare different types of PPE and to find out which protects best against contamination. It is a prerequisite for a reliable answer that methods of simulation studies are standardised in terms of exposure and outcome measurement. Viral marker Bacteriophage MS2 seems to be the most sensitive marker and we would advocate to use this. Studies should have sufficient power. To be able to detect a relatively large RR of 0.5 with a large control group rate of contamination of 0.7, assuming $\alpha = 0.05$ and $\beta = 0.80$, a sample size of 62 would be needed.

To find out how PPE behaves under real exposure, we need prospective follow-up of HCW involved in the treatment of patients with highly infectious diseases, with careful registration of PPE and risk of infection. Because different NGOs use different PPE guidance, cohorts of workers would be relatively simple to

establish if there would be sufficient political will. Here, the effect sizes would be smaller and thus the sample size should be bigger than 60.

In addition, case-control studies comparing PPE use among infected HCW and matched healthy controls, using rigorous collection of exposure data, can provide information about the effects of PPE on the risk of infection. The sample sizes should be much bigger than the current case studies because we would like to detect small but important differences in effect between various combinations of PPE such as gowns versus coveralls. There is a need for collaboration between organisations serving epidemic areas to carry out this important research in circumstances with limited resources, and during the throes of an outbreak.

We also need more randomised controlled studies of the effects of one type of training versus another, to find out which training works best, especially at long-term follow-up of one year or more. Also here, the effect size seems to be quite large and thus a sample size of around 60 seems to provide adequate power.

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* Indicates the major publication for the study

CHARACTERISTICS OF STUDIES

Characteristics of included studies [ordered by study ID]

Bell 2015

Methods	Randomised two parallel groups; simulation study
Participants	N = 8, nurses (6), physicians 2; women 7/8 Intervention: 4 Control: 4 Volunteer healthcare providers, no further details provided Location: USA
Interventions	<i>Intervention:</i> Commercially available PPE: neck-to-ankle coverall (type not reported), water impermeable surgical gown, knee length impermeable leggings, Stryker hood, double gloves with outer arm-length surgical gloves, N95 masks; meeting CDC recommendations; each participant was assisted in PPE donning by an experienced trainer <i>Control:</i> Local readily available attire: two plastic gowns worn over the front and the back of the torso, rain-suit pants and hood, spark-shield as face-cover, ankle length shoe covers, double gloves with outer arm-length surgical gloves, N95 masks; meeting CDC recommendations; each participant was assisted in PPE donning by an experienced trainer
Outcomes	Contamination: measured in ml of fluorescent agent with LED black light after doffing Random order of two types of exposure: high volume or standard. High volume meant 100 ml of fluorescent agent splashed on the torso. Standard meant working on a manikin contaminated with fluorescent agent. Fluorescent liquid mimicked body fluids and consisted of fluorescent powder, clothes detergent, fluorescent tablets
Notes	No funding or conflict of interest reported Apparently tape was used to put attire together; this resulted in more difficult doffing but no figures reported; costs of locally available equipment was 36 US dollars, that of commercial material not reported

Risk of bias

Bias	Authors' judgement	Support for judgement
Random sequence generation (selection bias)	Unclear risk	"randomized to one of two PPE ensembles"
Allocation concealment (selection bias)	Unclear risk	not reported
Blinding of participants and personnel (performance bias) All outcomes	Unclear risk	not reported

Bell 2015 (Continued)

Blinding of outcome assessment (detection bias) All outcomes	Unclear risk	not reported
Incomplete outcome data (attrition bias) All outcomes	Low risk	no incomplete outcome data
Selective reporting (reporting bias)	High risk	Contamination outcomes reported but no separate outcomes for high or normal exposure, however small sample and no statistical analysis by study authors
Other bias	Low risk	No indication

Buianov 2004

Methods	Controlled simulation study, not randomised; probably cross-over study
Participants	N = 9 volunteers that carried out a 4-hour step test of average workload at a temperature of 20° C and 60% relative humidity, no further details provided
Interventions	<p><i>Intervention:</i> Positive pressure suit (special biological suit, с к ь -1) consisting of a rubber hood connected to a powered air-purifying respirator and a 'dust-proof' coverall in one piece with different rates of air supply: initially 250 L/min, then 50, 100, 150, 200, 250, 300 L/min. No information about the filtering piece. PPE was especially developed for highly infectious diseases such as Ebola, Marburg and Lassa fever intended for use by health care staff, such as doctors, nurses and orderlies</p> <p><i>Comparison:</i> Two different types of positive pressure hoods (п и з -4 and п ш б -3) together with a coverall type Biotekhnolog -1</p> <p><i>Procedure:</i> Tests are carried out in a so-called Meltserovsky room (individual room with quarantine). The pressure suit or hood and coverall is put on before entering and checked whether it functions by attaching the connecting pipe to the air supply system. Then the worker enters the buffer zone (gateway with entrance and exit) and proceeds to the individual measurement room. After the step test in the individual room the worker goes to the buffer zone in order to treat the outside surface of the pressure suit. The worker attaches the suit to the connecting pipe of the air supply system and treats the suit with the help of aerosol disinfectant, usually 3-6% hydrogen peroxide (2-3 aerosol generators are situated at different heights). After the aerosol rests are pumped out of the buffer zone the worker leaves through the gateway, takes off the pressure suit and places it in the special container for final disinfection</p>
Outcomes	<p>Contamination exposure: Participants were exposed to a microbial aerosol with a concentration of 10⁸ colony forming units(cfu)/m³. No further details on the spray aerosol provided.</p> <p>Contamination outcome measured aerosol particles on different parts of the body (neck, shoulder, forearm, chest, loin, thigh, shin) and the suit with "washouts" and triple agar prints. Only data from triple agar prints is presented since the "washouts" resulted in unreliable data (because the textile materials used in the pressure suit were impregnated</p>

	<p>with hydrophobic materials). Triple agar prints were taken from the outside surface of the pressure suit, inside surface of the pressure suit, clothes and skin areas at different parts of the body (neck, shoulder and forearm, chest, loin, thigh and shin). The outcome was both expressed as cfu/m³ and as penetration rate as a percentage of the outside that has leaked inside the PPE. It was unclear if these outcomes were expressed as an average across the participants and what the variation was</p> <p>The authors conclude that “despite the significant concentration of microbial aerosol in the experimental room (10⁷-10⁵ cfu/m³) no microbial aerosol was measured on skin areas with air supply speeds of 250 L/min and higher”</p> <p>Additionally, the authors assessed skin temperature, heart rate, breath rate, and moisture loss</p>
Notes	<p>Article in Russian, data retrieved with help of a native speaker (AP)</p> <p>Article difficult to judge due to cultural differences in style and translation</p>

Risk of bias

Bias	Authors' judgement	Support for judgement
Confounding NRS	High risk	No confounders reported
Selection Bias NRS	Low risk	Selection of volunteers unrelated to intervention or to outcome. Start follow-up and intervention coincide for all participants
Blinding of participants and personnel (performance bias) All outcomes	Unclear risk	Not reported
Blinding of outcome assessment (detection bias) All outcomes	Unclear risk	Not reported
Incomplete outcome data (attrition bias) All outcomes	Unclear risk	Unclear if data reported for all nine participants
Selective reporting (reporting bias)	Unclear risk	All data announced in methods reported in results
Other bias	Low risk	No other biases assessed

Casalino 2015

Methods	Controlled before-after study of two training variants
Participants	<p>N = 120, 63% nursing students, 37% medical students</p> <p>Age 21.2 +/- 3.5 years, 35% male</p> <p>The authors did not present demographic data per group</p> <p>Location: Paris (France), Lima (Peru), and Guadalajara (Mexico), in December 2014</p>

	and January 2015 with no previous training in PPE use, with no special intention to be involved in Ebola care	
Interventions	<p><i>Intervention:</i> There were two intervention groups that only differed in type of PPE used: 1. <i>Basic PPE + reinforced training</i> (N = 30); basic PPE consisted of boots, goggles, surgical mask, surgical cap, impermeable apron (11 pieces of equipment) with 6 steps for donning and 13 steps for doffing 2. <i>Enhanced PPE + reinforced training</i> (N = 30); enhanced PPE consisted of boots, full body impermeable suit, hood with surgical cap and mask, double gloves, impermeable apron (9 pieces of equipment) with 6 steps for donning and 12 steps for doffing Training for all participants consisted of 60 minutes of theoretical course including 10 minutes of donning instruction and 20 minutes of doffing instruction. In addition, there were three practical training sessions per two students who mutually assisted each other observed by a specialist trainer who intervened in case of non-compliance. The sessions were held with 3 days intervals. Compared to the control group the additional intervention was that the specialist trainer “repeated aloud each of the steps and technical skills or processes necessary” to comply with the standard during the practical training sessions. The sessions were also reviewed comprehensively</p> <p><i>Control group:</i> There were two control groups that differed in type of PPE used just as in the intervention groups: 1. <i>Basic PPE + conventional training</i> (N = 30), 2. <i>Enhanced PPE + conventional training</i> (N = 30). These groups received the same training as the intervention group but the specialist-trainer did not repeat aloud the necessary steps</p>	
Outcomes	<p><i>Primary outcome:</i> number of errors per person for donning and for doffing and the number of persons with one or more errors measured by the specialist trainer. The authors also measured critical errors, which were those where there was contact between skin and potentially contaminated PPE, but we did not consider this a valid measure of contamination and disregarded this. We took measurement of the errors at the last training session as the effect of the intervention. We disregarded the error measurements at earlier training sessions</p> <p><i>Secondary outcomes:</i> errors for doffing of the gown, full body suit and boots; duration of donning and doffing in minutes at the last training session</p>	
Notes	<p>Country: France, Peru Mexico; no funding reported; no conflict of interest reported The first author, Enrique Casalino, answered some of our questions regarding the study, but we were unable to retrieve more information on the group allocation and therefore classified the study as non-randomised</p>	
Risk of bias		
Bias	Authors’ judgement	Support for judgement
Confounding NRS	Unclear risk	None of the confounders mentioned

Casalino 2015 (Continued)

Selection Bias NRS	Low risk	Students were randomly chosen and did not have any experience or intention to use the knowledge and skills
Blinding of participants and personnel (performance bias) All outcomes	High risk	Blinding not possible but students could be motivated to perform better because of knowing that they are in the intervention group and not as a result of the oral instructions
Blinding of outcome assessment (detection bias) All outcomes	High risk	Providers are also the assessors of the compliance. We asked authors for more information but did not get any information that increased our confidence in the outcome assessment
Incomplete outcome data (attrition bias) All outcomes	Unclear risk	Not reported if all data were available
Selective reporting (reporting bias)	Low risk	All outcomes in methods section reported; no protocol available
Other bias	Low risk	No other biases assessed

Casanova 2012

Methods	Controlled simulation study, non-randomised, first intervention then control condition for all participants
Participants	N = 18 volunteer healthcare providers over 18 years of age; Exclusion criteria: pregnant, latex allergy, skin disorder, previous fit-testing for N95 respirator; 17/18 right handed, 18/18 previous experience with PPE Location: USA
Interventions	<i>Intervention:</i> Two pairs of latex gloves; inner glove under the cuff of the gown sleeve, the outer glove, one size larger worn over the gown cuff; in addition, full PPE consisted of contact isolation gown, N95 respirator and eye protection <i>Control:</i> One pair of latex gloves in addition to similar full PPE as in intervention group Doffing was performed according to CDC instructions: gloves, goggles, gown, mask or respirator in case of single gloves; in case of double gloves, outer pair of gloves first and inner pair last
Outcomes	1. Contamination of the hands, face, gloves and scrubs with bacteriophage MS2 virus; hands sampled with "glove juice method", face with a swab at the edge of the N95 respirator, shirt pants and gloves were immersed in beef extract. All eluants were assayed by 'most probable number enrichment infectivity assay' (MPN). Detection level 0.15 log ₁₀ MPN; Used paired t-test for the analysis of continuous data to take the cross-over into account

	2. Noncompliance with doffing guidelines. Contamination with bacteriophage MS2 was put on front shoulder of the gown, right side of respirator, right front of eye protection and palm of dominant hand by simulated droplet contamination; before doffing participants had to perform neck and wrist pulses on manikin	
Notes	No funding or conflict of interest reported	
<i>Risk of bias</i>		
Bias	Authors' judgement	Support for judgement
Confounding NRS	Low risk	No apparent confounders for this type of study and outcome
Selection Bias NRS	Low risk	No apparent selection of participants into the study
Blinding of participants and personnel (performance bias) All outcomes	Unclear risk	no blinding, but performance bias not likely because participants would not have an interest with either intervention
Blinding of outcome assessment (detection bias) All outcomes	Unclear risk	Not reported
Incomplete outcome data (attrition bias) All outcomes	Unclear risk	Not reported
Selective reporting (reporting bias)	Unclear risk	Some data only in figures and not in tables
Other bias	Low risk	no other biases anticipated

Methods	<p>Non-randomised simulation study</p> <p><i>How was the simulation performed?</i></p> <p>Each participant was verbally guided through the donning process of EVD PPE using the CDC protocol. After the exposure contamination was applied to the PPE worn, all participants performed a gown change on a mannequin. Participants were then verbally guided through the doffing process using the CDC checklist either using a hypochlorite spray or an alcohol-based hand rub for all six hand or glove cleaning steps during doffing</p> <p><i>How was the exposure simulated?</i></p> <p>Exposure to a mixture of MS2 and 6 suspended in phosphate-buffered saline was applied to 4 sites: (1) the palm of the dominant hand, (2) the shoulder of the gown opposite the dominant hand, (3) the top side of the face shield on the same side as the dominant hand, and (4) the toe of the rubber boot opposite the dominant hand. A total of 25 µL was applied to each site in 5 drops of 5 µL each to simulate droplet exposure, particularly small droplet exposure of which the HCP may not be aware. The mean virus titre applied to each site in 25 µL was 1×10^8 for MS2 and 5×10^7 for 6, based on reports of viral load in body fluids during acute phases of EVD</p>	
Participants	<p>N= 15 (11 RNs and 4 MDs) no further details given</p> <p>Intervention: 5 Control: 10</p> <p>Study participants were all members of the Ebola care team at a large tertiary care academic medical centre. Members of the Ebola team were >18 years of age and had undergone extensive training in a simulation laboratory in the use of EVD-specific PPE, including donning and doffing</p>	
Interventions	<p><i>Intervention:</i> Hypochlorite glove sanitizer: liquid hypochlorite at a concentration of 1850 ppm was applied by spraying it on the gloves for each hand or glove sanitizing step of the 16-step doffing protocol that was used. This was the only alternation of the usual doffing protocol</p> <p><i>Control:</i> Alcohol-based hand rub: 70% ethanol gel was used for each hand or glove sanitizing step of the 16-step doffing protocol that was used</p>	
Outcomes	<p>Contamination:</p> <p>1.) MS2 bacteriophage (non-enveloped surrogate virus)</p> <p>2.) 6 bacteriophage (enveloped surrogate virus, such as Ebola)</p> <p>We took from the authors' report contamination found on scrubs, or on the bare hands or on the face of the participant</p>	
Notes	<p>Country: USA; No conflict in interests reported; Funded with CDC grant</p>	
<i>Risk of bias</i>		
Bias	Authors' judgement	Support for judgement
Confounding NRS	Low risk	<p>Differences related to:</p> <ol style="list-style-type: none"> 1. prior experience with PPE-No 2. healthcare qualification or education of HCW-No 3. age-no information, unlikely 4. sex-no information, unlikely

Casanova 2016 (Continued)

		5. ambient temperatures- No, assumed similar 6. stressful activities-No
Selection Bias NRS	Unclear risk	Allocation to group was based on belonging to the last five participants
Blinding of participants and personnel (performance bias) All outcomes	Low risk	Participants were asked to close their eyes when simulated exposure was applied to them. However, it is unlikely that they did not notice where simulation exposure was applied Participants were not blinded to the intervention, however, it is unlikely that they behaved differently with hypochlorite or alcohol sanitizer
Blinding of outcome assessment (detection bias) All outcomes	Unclear risk	no information
Incomplete outcome data (attrition bias) All outcomes	Low risk	no incomplete outcome data
Selective reporting (reporting bias)	Low risk	no protocol, unlikely
Other bias	Low risk	no other bias observed

Curtis 2018

Methods	Randomised controlled study with parallel groups <i>How was the simulation performed?</i> Participants had to demonstrate skills in donning PPE, working with PPE and doffing PPE in a simulated practice setting where they were observed. At Station One, participants were asked to don Level C PPE. At Station Two, the participants were asked to demonstrate the proper technique for administration of the Duodote auto-injector to a simulated victim of nerve agent poisoning. Participants were then asked to use the Simple Triage and Rapid Treatment triage system for six different disaster scenarios that were described on cards attached to inflatable training manikins. At Station Three, participants were asked to decontaminate inflatable training manikins simulating contaminated victims of a hazardous materials incident. Following completion of the third station, the participants doffed their Level C PPE and were asked to complete the post-exercise comfort survey
Participants	N = 30 volunteers Emergency Medicine residents were randomised, results of 26 are reported The study was conducted at an urban, academic, tertiary referral centre that provides training to Emergency Medicine residents in a four-year program. All Emergency Medicine residents who attended the weekly educational conference were recruited for

	this study. As there were not any more residents available to participate at this single-site study, the number needed to study for significance was not determined <i>Intervention: n = 13 (53% female) , Control: n = 13 (46% female)</i>	
Interventions	Intervention: Video-based learning (VBL) A training video about specific content for the training modules was watched prior to completing a knowledge quiz and the practical exercises. An Emergency Medicine resident in the residency program's disaster medicine specialty track wrote, directed, and edited the video. The VBL modality was setup and viewed without faculty interaction. Both educational modalities contained identical educational content Control: Traditional lecture (TL) A PowerPoint presentation that covered the same information as the video was presented prior to completing a knowledge quiz and the practical exercises	
Outcomes	Primary outcome: performance scores on proper donning of PPE on the practical exercises evaluated by a blinded trained evaluator	
Notes	Location: USA; No funding or conflict of interest reported	
<i>Risk of bias</i>		
Bias	Authors' judgement	Support for judgement
Random sequence generation (selection bias)	Unclear risk	"department research division consultant conducted a stratified randomisation of residents by post-graduate year class level and assigned them to either the experimental (VBL) group or the control (TL)"
Allocation concealment (selection bias)	Unclear risk	"Study participants identified themselves on all study tests and surveys using employee identification numbers rather than their names"
Blinding of participants and personnel (performance bias) All outcomes	Low risk	Study could not be blinded but unlikely that participants could have influenced the outcome because they knew to which group they belonged
Blinding of outcome assessment (detection bias) All outcomes	Low risk	"All evaluators were blinded as to which study participants had participated in the TL modality and which participated in the VBL modality."
Incomplete outcome data (attrition bias) All outcomes	Low risk	data available for 13 out of 15 participants in both groups. Missing data was not related to the intervention

Curtis 2018 (Continued)

Selective reporting (reporting bias)	Unclear risk	No study protocol provided. Probably all outcomes reported
Other bias	Unclear risk	No other bias detected

Gleser 2018

Methods	Simulation study, Quasi-randomised study based on alternation <i>How was the simulation performed?</i> A volunteer health care professional donned appropriate sized glove and then wetted each hand with fluorescent solution and distributed this solution equally on the glove's surfaces to simulate an external glove contamination. Immediately thereafter, the volunteer removed their gloves, and their hands were then examined using a UV Box (Hand Hygiene Teaching Box "Sharing Expertise; B. Braun, Melsungen, Germany) <i>How was the exposure simulated?</i> 5 mL of a fluorescent solution (Sch lke Optics Training fluorescent lotion; Sch lke & Mayr GmbH, Vienna, Austria) on each hand
Participants	N = 317 (~70% female) volunteer healthcare workers on 35 hospital wards in a tertiary care university hospital <i>intervention:</i> N = 146 (104 nurses, 53 physicians) <i>control:</i> N = 171 (118 nurses, 53 physicians)
Interventions	Intervention: Doffy glove, modified nitrile gloves with a textured small flap (doffing aid) above the thumb area positioned laterally on the wrist when worn that can be gripped during glove removal Control: Standard nitrile medical examination gloves made according to the same material formulation and manufacturing process by the same company on behalf of IP Gloves GmbH
Outcomes	Contamination: Any visible fluorescence on the volunteer's skin
Notes	Location: Germany; No funding or conflict of interest reported, however first author is also CEO of the start-up that developed and market the new types of gloves

Risk of bias

Bias	Authors' judgement	Support for judgement
Random sequence generation (selection bias)	High risk	"Participants were randomised for the use of either standard gloves or Doffy Gloves on an alternate daily basis" Quasi-randomisation; big difference in number in intervention or control group
Allocation concealment (selection bias)	Unclear risk	No description provided

Gleser 2018 (Continued)

Blinding of participants and personnel (performance bias) All outcomes	Low risk	Study could not be blinded but unlikely that participants could have influenced the outcome which was assessed by observers
Blinding of outcome assessment (detection bias) All outcomes	High risk	Assessors of contamination were aware of which glove was used and subjective assessment
Incomplete outcome data (attrition bias) All outcomes	Low risk	no missing data reported
Selective reporting (reporting bias)	High risk	No study protocol provided
Other bias	High risk	Authors have a big financial interest in a positive evaluation of their new product

Guo 2014

Methods	Randomised multiple arm cross-over simulation study
Participants	N = 50; Voluntary HCW who gave informed consent; excluded were those who were allergic to the fluorescent marker; 34/50 female, 20/50 nurses, 10/50 doctors, 15/50 support staff, 5/50 allied health workers; age 32.9 ± 5.7 years average; working experience 10.9 ± 5.1 years Location: Hong Kong China
Interventions	<i>Intervention 1:</i> N = 50 participants. Three types of protective clothing: 1. Disposable water resistant non-woven gown, 2. Reusable woven cotton gown, 3. Disposable non-woven plastic apron; and two different removal methods: individually determined or CDC recommended. Each of the 50 subjects was required to test the 3 different types of PPE followed by one of two different removal methods <i>Intervention 2:</i> First the participant should doff according to their own views (individual method), then a CDC instruction video was shown and participants were asked to perform the donning or doffing method for gowns that was recommended by CDC in 2007: Gown front and sleeves are contaminated! Unfasten neck, then waist ties. Remove gown using a peeling motion; pull gown from each shoulder toward the same hand. Gown will turn inside out. Hold removed gown away from body, roll into a bundle and discard into waste or linen receptacle <i>Control:</i> Cross-over N = 50 participants. Three types of protective clothing were compared against each other
Outcomes	1. small patches of fluorescence < 1 cm ² . 2.large patches of fluorescence > 1 cm ² . 3. patches on the hands 4.patches on the shoes 5. underwear patches 6. patches in the environment; a fluorescent powder (GloGermCo,Moab,UT) especially developed for determining hand hygiene compliance was used in this study. The Glo Germ powder was mixed with light olive oil and water to resemble human aerosol as closely as possible The authors used repeated measures analysis to take into account the cross-over design of the study

Guo 2014 (Continued)

Notes	Funding Hong Kong polytechnic University; no conflict of interest declared	
Risk of bias		
Bias	Authors' judgement	Support for judgement
Random sequence generation (selection bias)	Unclear risk	interventions were offered "in random order"; authors asked for clarification
Allocation concealment (selection bias)	Unclear risk	not reported
Blinding of participants and personnel (performance bias) All outcomes	Low risk	No blinding possible, but no performance bias expected as participants would not have an interest with any intervention
Blinding of outcome assessment (detection bias) All outcomes	Unclear risk	not reported
Incomplete outcome data (attrition bias) All outcomes	Low risk	no loss to follow-up
Selective reporting (reporting bias)	Low risk	all data reported
Other bias	Low risk	not detected

Hall 2018

Methods	<p>Simulation study, non-randomised cross-over study</p> <p><i>How was the simulation performed?</i></p> <p>Prior to donning PPE volunteers were screened using Fluorescence Interactive Video Exposure System (FIVES) to ensure that there was no pre-existing contamination on their skin or scrubs from the environment, previous tests or background fluorescence. Over disposable scrubs volunteers then donned the PPE ensembles under supervision by a buddy, and they were screened again prior to beginning the simulation exercise. After completing the exercise, volunteers were screened front and back using the FIVES system to qualitatively record contamination resulting from the simulation. PPE was then removed according to protocol under the supervision of a buddy, and screening was repeated to detect any post-doffing contamination</p> <p><i>How was the exposure simulated?</i></p> <p>'Violet' (Visualising Infection with Optimised Light for Education and Training) was a medical training manikin adapted to deliver simulants of four fluorochrome-tagged body fluids during a scenario based on a doctor and nurse undertaking clinical procedures with a suspected case patient</p>
Participants	<p>N = 11 (7 nurses, 4 doctors)</p> <p>Volunteer healthcare providers were recruited via calling notices at the participating Infectious Disease (ID) units, gave informed consent and were free to withdraw at any</p>

	time. Eleven volunteers completed the simulation exercise up to 10 times depending on their availability. Five volunteers (including one further doctor and nurse) acted as 'buddies' to assist with doffing. All volunteers were experienced in using the PPE ensembles adopted by their respective ID units, but if they used an ensemble from another unit, they had to undergo training to practice donning and doffing 10 times or until deemed competent by a staff trainer. Limiting the number of volunteers reduced user attributable variation	
Interventions	Intervention: five (5) 'suspected case' PPE ensembles used in different infectious disease units around the UK. All models met the guidance of the Advisory Committee on Dangerous pathogens endorsed by Public Health England. PPE components met their relevant material standards. All were donned and dry-doffed according to the specific protocol relevant to the ensemble. The PPE ensembles varied but could broadly be grouped as a 'gown model' or a 'coverall model' but each had slight differences (e.g. use of hood vs surgical cap, boots vs boot covers, and different glove lengths and number of pairs) Control: Basic level PPE (surgical mask, standard length apron, 1 pair short gloves, no standard footwear, scrubs and no buddy used for doffing)	
Outcomes	Contamination: fluorescent areas seen on skin or scrubs of the volunteer post-doffing	
Notes	Location: UK; No conflict of interested reported; Funding was provided by Health and Safety Executive (HSE); Bozena Poller was funded by the Healthcare Infection Society's Graham Ayliffe Training Fellowship	
Risk of bias		
Bias	Authors' judgement	Support for judgement
Confounding NRS	Low risk	Differences related to: 1. prior experience with PPE- No 2. healthcare qualification or education of HCW-Yes (nurses or physicians) 3. age-No information 4. sex- No information 5. ambient temperatures- No (restricted to one centre) 6. stressful activities- No (all performed similar tasks)
Selection Bias NRS	Low risk	Cross-over trial; 11 participants did the simulation up to 10 times
Blinding of participants and personnel (performance bias) All outcomes	Low risk	Participants knew which PPE they had on but it is unlikely that they could have influenced the outcome which was an objective assessment by an observer

Hall 2018 (Continued)

Blinding of outcome assessment (detection bias) All outcomes	Unclear risk	The judgement of the contamination is subjective and the assessors were aware of the type of equipment but it is unclear if this could have influenced the outcome assessment
Incomplete outcome data (attrition bias) All outcomes	Unclear risk	“This resulted in a non-trained volunteer participating in the role of the nurse for one simulation; their data were excluded from the final analysis, but their participation allowed data to be captured for their doctor partner. In total, 19, suspected case simulations captured 37 volunteers.”
Selective reporting (reporting bias)	Unclear risk	no protocol provided
Other bias	Low risk	No other biases detected

Houlihan 2017

Methods	Retrospective cohort study Invitations to participate were sent to individuals known to the authors, and through organisations supporting EMT deployment involving UK-based staff, including non-governmental organisations (NGOs), UK government-affiliated institutions, and the London School of Hygiene & Tropical Medicine (LSHTM). The participants filled in a questionnaire with information about PPE use. They then underwent a blood test to assess their antibody status. The researchers assessed the participants’ risk of being exposed to EVD based on an independent algorithm
Participants	N = 300 Individuals who returned to the UK or Ireland after responding to the West African EVD epidemic completed the survey. Of these N = 268 returned material for IgG assessment (median age 36 y range 30-45 y; 57% female; 35% lab staff, 26% physicians, 20% nurses, 19% other) In addition, there were N = 53 non-exposed control participants included who had not left the UK (median age 35 y range 31-40 y; 66% female)
Interventions	There were 2 interventions that were of interest. (1) PPE removal with or without chlorine spray, (2) PPE removal with and without assistance. However, almost all clinical staff had used both interventions as compared to laboratory staff which had not used them. Because there was also a big difference in the likelihood of exposure between these two occupational groups, the effect of protection of these measures could therefore not be analysed
Outcomes	Level of IgG antibody against Ebola Virus as an indicator of infection
Notes	Country: UK; Funding by Wellcome Trust: Enhancing Research Activity in Epidemic Situations. The funders had no role in study design, data collection and analysis, decision to publish or preparation of the manuscript; one author has received funding from the

Houlihan 2017 (Continued)

	Wellcome Trust via the University of Liverpool and also received non-financial support from NHSBT, as part of the Convalescent Plasma Study	
Risk of bias		
Bias	Authors' judgement	Support for judgement
Confounding NRS	Low risk	Differences related to: 1. prior experience with PPE- No 2. healthcare qualification or education of HCW-No (clinical, lab or other role) 3. age-No 4. sex- No 5. ambient temperatures- No (all restricted to Africa) 6. stressful activities- Yes (work roles varied depending on qualifications)
Selection Bias NRS	High risk	Sample based on snowball sampling
Blinding of participants and personnel (performance bias) All outcomes	Low risk	Participants were not aware of exposure status when they reported their exposures
Blinding of outcome assessment (detection bias) All outcomes	Low risk	Researchers knew who was rated as 'high risk' but objective outcome measure. Therefore unlikely that it has been influenced
Incomplete outcome data (attrition bias) All outcomes	Unclear risk	Convenience sample; from sample 10.7% did not react
Selective reporting (reporting bias)	Unclear risk	No protocol provided
Other bias	Low risk	No other sources of bias detected

Hung 2015

Methods	Randomised two parallel groups controlled trial of two training variants
Participants	Intervention group: N = 25, Age 44% < 31 years, health care assistant 56%, nurse 44%, work experience < 6 years 44%, no gender reported Control group: N = 25, Age 28% < 31 years, health care assistant 56%, nurse 44%, work experience < 6 years 48%, no gender reported All HCW of an outpatient department of a private hospital handling infectious patients before admission; able to read English, basic computer skills

Interventions	<p>Intervention: All participants were asked to don and doff N95 respirator, face shield, cap, gown, gloves for “precautions against airborne danger”. External observers rated the procedures for errors. All participants then attended a PPE-training consisting of a 15 minutes demonstration of donning and doffing by an “infection control link nurse”. After one week the intervention group got the interactive computer simulation programme and again after one week was assessed for compliance with the donning and doffing procedures</p> <p>Control: the control group was assessed for compliance with donning and doffing procedures one week after PPE training. The group did not get the computer simulation training</p>
Outcomes	<p>Primary outcome: score on 16 item checklist for donning and 20 item checklist for doffing</p> <p>Secondary outcome: IBM computer system usability questionnaire (CSUQ) consisting of 19 items with a 7-point Likert response scale</p>
Notes	Hong Kong China; Funding: Hong Kong Research Grant Council; no conflict of interest reported

Risk of bias

Bias	Authors’ judgement	Support for judgement
Random sequence generation (selection bias)	Unclear risk	“The subjects were randomly assigned to the control and experimental group of the same size”, page 53
Allocation concealment (selection bias)	Unclear risk	Not reported
Blinding of participants and personnel (performance bias) All outcomes	Low risk	Not possible to blind participants or providers but outcome objectively assessed by observers, unlikely that this has been influenced
Blinding of outcome assessment (detection bias) All outcomes	Low risk	Nurse assessing PPE compliance “was blinded about the research”, page 53
Incomplete outcome data (attrition bias) All outcomes	Unclear risk	Not reported if all participants contributed data
Selective reporting (reporting bias)	High risk	Results of computer usability questionnaire not fully reported
Other bias	Low risk	No other biases assessed

Methods	<p>Simulation study, randomised cross-over study</p> <p><i>How was the simulation performed?</i></p> <p>Participants were instructed to don intervention or control gown and gloves in their usual manner. A lotion containing both exposures was rubbed onto the gloves and then the participants rubbed gloved hands on the front area of the gown to simulate contamination. Participants doffed the PPE again in their usual manner</p> <p><i>How was the exposure simulated?</i></p> <p>Exposure to contamination was simulated by a lotion containing 0.5 mL of phosphate-buffered saline containing 108 plaque-forming units (PFU) of the enveloped virus bacteriophage Phi X174 (American Type Culture Collection [ATCC] 13706-B1), and 0.5 mL of fluorescent lotion</p>	
Participants	<p>N = 31</p> <p>11 physicians (36%), 6 nurses (19%), 14 allied health personnel (45%)</p> <p>31 paired simulations</p>	
Interventions	<p><i>Intervention:</i> Assure Wear Gown with Flexneck technology™ (AMD Ritmed, Tonawanda, NY) designed to allow easy removal at the neck and with increased skin coverage and snugness of fit at the wrist. The gown has a double elastic neck closure system to aid in removal, thumb loops with smaller holes and provides more palm coverage and elastic band around wrist to improve snugness of gown</p> <p><i>Control:</i> Standard Safety Plus polyethylene gown (TIDI Pro-ducts, Neenah, WI). Problems can occur with hand and wrist contamination due to skin exposure at the gown-glove interface despite the presence of a thumb loop intended to keep the gown in proximity to the gloves. A loose fit at the wrist and minimal coverage of the upper palm contributes to the potential for contamination. Contamination of the neck region often occurs when gowns do not easily come apart at the posterior neck, resulting in tearing of gown material</p>	
Outcomes	<p>UV Contamination: A black light (Ultra LightUV1 by Grizzly Gear, SCS Direct, Trumbull, CT) was used to look for the fluorescent tracer on the hands, wrist, neck and chest</p> <p>Bacteriophage contamination: The participants hands and wrist were swabbed with gauze to collect potential bacteriophage. Alcohol based hand sanitizer was used for hand hygiene and sterile gloves were donned prior to the participant swabbing their neck and chest, including their clothing to collect other potential contamination</p>	
Notes	<p>Location: USA; Financial support: This work was supported by a Merit Review grant (no. 1 I01 BX002944-01A1) from the Department of Veterans Affairs to C.J.D. AMD Ritmed provided the Assure Wear VersaGowns with Flexneck technology™ for testing, but they had no role in study design, analysis or interpretation of the data, or writing of the manuscript. Potential conflicts of interest: C.J.D. has received research grants from Clorox, Merck, AvidBiotics, and GOJO, and has served on scientific advisory boards for 3M and Seres Health. All other authors report no conflicts of interest relevant to this article</p>	
<i>Risk of bias</i>		
Bias	Authors' judgement	Support for judgement

Mana 2018 (Continued)

Random sequence generation (selection bias)	Low risk	“Healthcare personnel were randomised to perform simulations of contaminated glove and gown removal using either the standard or alternative design gown.” Additional info from authors: The random sequence was generated have used a List Randomizer from the website: https://www.random.org/lists/ which provided a random listing of which gown will be used first for each participant
Allocation concealment (selection bias)	Low risk	Additional info received from authors: The allocation was irrevocable
Blinding of participants and personnel (performance bias) All outcomes	Low risk	Participants could not be blinded but this is unlikely to have an effect on the outcome because this was assessed by observers
Blinding of outcome assessment (detection bias) All outcomes	Low risk	Additional information from authors: It was not possible to blind outcome evaluators for the fluorescence evaluation because the gowns are visibly different. However, the outcome evaluators for the assessment of bacteriophage Phi X174 contamination were blinded to the identity of the study groups
Incomplete outcome data (attrition bias) All outcomes	Low risk	Additional information from authors: There were no missing data
Selective reporting (reporting bias)	Unclear risk	Additional information from authors: We did not register the study protocol
Other bias	Low risk	No indication of other biases

Shigayeva 2007

Methods	Retrospective cohort study
Participants	HCW who provided care or entered the room of a Toronto SARS patient who required intubation during the 24 hours before and 4 hours after intubation Eligible N = 879, Analysed N = 795; age (median) = 41 years (range 21 to 67 years); employment in current occupation (median) = 12 years (range 0 to 43 years); 46% nurses, 14% physicians, 14% respiratory therapists, 10% imaging staff and 16% other; 1055 exposure episodes or shifts Intervention Active training: N = 511 episodes (= 385 persons), Intervention Passive training: N = 236 episodes (= 178 persons), Comparison no active training: N = 308 episodes (= 323 persons)

	Location: Canada	
Interventions	<p><i>Intervention 1:</i> Active training: participants answered that they had received any individual or group face-to-face training sessions</p> <p><i>Intervention 2:</i> Passive training: participants watched a video or got written information</p> <p><i>Comparison:</i> no training reported</p> <p>Other predictors of PPE studied in a multivariate GEE logistic regression analysis in addition to training for both outcomes: phase of epidemic, occupation, work experience, hospital type, location of care, number of times patient's room entered, SARS diagnosis recognised, Apache II score of patient</p>	
Outcomes	<p>1. Consistent adherences as proportion of exposure episodes. Participants were interviewed based on a questionnaire 0.2 to 10 months after the exposure. Interviewers asked about consistent use of PPE: masks, gowns, gloves and eye protection and possible predictors of their use, including training. Consistent adherence was defined as always wearing gloves, a gown, a mask, and eye protection. Consistent adherence was reported in 817/1055 (77%) exposure episodes. Eye protection was least with 13.5% consistent and no PPE in 23 episodes (2.2%). PPE use increased during epidemic from 34.6% at start to 97.4% in the end</p> <p>2. Doffing as proportion of exposure episodes (safe, at some risk, or at risk). Participants were asked about their sequence of doffing PPE. Safe was defined as the sequence of removing gown and gloves, hand hygiene, mask, goggles, or safety glasses, hand hygiene. At some risk was considered if hand hygiene was performed only once. At risk if no hand hygiene was performed or hands touched potentially contaminated face. Doffing description was available for 810/1055 (77%) of exposure episodes; 15.4% qualified as safe, 63% as at some risk, and 22% as at risk</p>	
Notes	<p>Units of analysis used in studies: exposure episodes not persons exposed, based on work schedules, patient assignments and health records. There were 65 intubations of SARS patients of which 7 were not recognised as such at the time of intubation</p> <p>Funding Ontario Ministry of Health and Long term Care; no Conflict of Interest reported</p>	
Risk of bias		
Bias	Authors' judgement	Support for judgement
Confounding NRS	Low risk	Adjustment in multiple regression analysis for education, work experience, and presumably for age and sex
Selection Bias NRS	Low risk	Whole cohort assessed that was working during the epidemic. Exposure to SARS patients clearly defined
Blinding of participants and personnel (performance bias) All outcomes	Low risk	Both the intervention and the outcome were assessed at the same time

Shigayeva 2007 (Continued)

Blinding of outcome assessment (detection bias) All outcomes	High risk	Both the intervention and the outcome were assessed with the same questionnaire at the same time
Incomplete outcome data (attrition bias) All outcomes	Low risk	90% HCW participated for adherence and for 77% of shifts more or less reliable info about doffing available
Selective reporting (reporting bias)	Unclear risk	Not clear which predictors of adherence or safe doffing were tested and negative
Other bias	Low risk	No indication of other bias

Strauch 2016

Methods	Simulation study, randomised controlled cross-over trial <i>How was the simulation performed?</i> Two different simulations of contamination of the Filtering Facepiece Respirator (FFR) were performed: one in which the FFR was contaminated but not the hands and another one in which the hands were contaminated but not the FFR 1. Contamination of the FFR and clean hands: 20 subjects performed 3 trials of FFR with removal tabs (tab+) and tab- masks each in random order 2. Clean FFR and Contamination of hands: 20 subjects performed one tab+ trial and one tab- trial <i>How was the exposure simulated?</i> To contaminate the FFR, 7 mL of fluorescent tracer was brushed onto the entire outer surface of the test FFRs. As only the outer surface of the FFR was contaminated with the fluorescent tracer, transfer from the FFR to the hands would only occur if the FFR was doffed improperly by grasping the contaminated surface. 2. For the hand contamination test, 1 mL of fluorescent tracer was applied and rubbed into the hands of the test subject before removal of a clean FFR with or without tabs. The fluorescent tracer was prepared by suspending 1 g of GloGerm (GloGerm Company; Moab, UT) powder suspended in 25 mL of mineral oil
Participants	N = 20 aged 18-60 HCW Volunteers employed as HCW, that were enrolled in a respiratory protection program and experienced in wearing filtering face-piece respirators (FFRs) were preferred, but a potential subject was not excluded if all of the qualities were not met Volunteers were excluded if they had a history of skin cancer, sensitivity to Ultra Violet (UV) light, or burns from a black light Country: USA
Interventions	Intervention: Mask with tabs; N-95 mask with four red foam tabs attached to straps to assist in mask removal Control: Mask with out tabs
Outcomes	Contamination of the hands resulting from exposure to a contaminated mask Contamination of the head resulting from exposure to contaminated hands: The subject's head, face and hair were photographed under UVA light for contamination with fluorescent tracer

Strauch 2016 (Continued)

Notes	Location:USA; Funding source and conflict of interest were not published; reported on Lumens as a measure of contaminate but the written results did not match those presented in figure	
Risk of bias		
Bias	Authors' judgement	Support for judgement
Random sequence generation (selection bias)	Unclear risk	"each subject doffed one randomly assigned FFR" Unclear how randomisation was performed
Allocation concealment (selection bias)	Unclear risk	Unclear if allocation was irrevocable
Blinding of participants and personnel (performance bias) All outcomes	Low risk	not reported but unlikely to have influenced the outcome that was assessed by observers
Blinding of outcome assessment (detection bias) All outcomes	Unclear risk	not reported
Incomplete outcome data (attrition bias) All outcomes	Unclear risk	Unclear if there were missing data
Selective reporting (reporting bias)	Unclear risk	no protocol available
Other bias	Low risk	No other biases detected

Tomas 2016

Methods	Simulation study, randomised control trial; parallel groups <i>How was the simulation performed?</i> Participants removed improved gowns and gloves in their usual manner <i>How was the exposure simulated?</i> Gloved hands were inoculated with 0.5 mL phosphate-buffered saline (PBS) containing 10 ⁷ 10 plaque-forming units of MS2 and 0.5 mL fluorescent lotion and the solutions were rubbed over the gloved hands until dry. Bacteriophage MS2 was of the type 15597-B1 (American Type Culture Collection,VA)
Participants	N = 30 Healthcare personnel; No other information provided; asked authors for more information
Interventions	<i>Intervention:</i> A seamless PPE prototype in which adhesive material on the outer sleeve of the gown at the wrist attaches to the inner cuff of the gloves, providing continuous coverage of the wrist and hand. This design prevents exposure of skin and requires that gloves be peeled off as the gown is removed. The prototype seamless PPE consisted of polyethylene contact isolation gowns (SafetyPlus Polyethylene Gown, TIDI Products,

	Neenah, WI) and nitrile gloves (Denville Scientific, South Plainfield, NJ).Permanent contact bond adhesive (DAP Weldwood Contact Cement, DAP Products, Baltimore, MD) was applied circumferentially to the outer gown at the level of the wrist.Gloves were pressed to the gowns for 15 minutes and allowed to air dry for 24 hours <i>Control:</i> Only described as standard PPE and assumed as gloves and gown
Outcomes	1. Outcome assessment fluorescent: Hand and wrist skin contamination with the fluorescent lotion was assessed using a black light (Ultra Light UV1 by Grizzly Gear, SCS Direct, Trumbull, CT) 2. Outcome assessment Bacteriophage: Participants then wiped both hands and wrists with a sterile, pre-moistened 4 × 4 gauze pad that was placed into a sterile container containing 10 mL PBS and mixed in a vortex mixer for 1 minute to elute the bacteriophage. Aliquots of each elutant were serially diluted and cultured to quantify virus particles
Notes	Location: USA; Funding was provided by the Department of Veteran Affairs; One author, C.J.D. had previously received research grants from Clorox, Merck, AvidBiotics and GOJO and the same author also served on scientific advisory boards for 3M and Seres Health

Risk of bias

Bias	Authors' judgement	Support for judgement
Random sequence generation (selection bias)	Unclear risk	“Healthcare personnel were randomized to perform simulations of contaminated glove removal”; authors asked for method of generation
Allocation concealment (selection bias)	Unclear risk	unclear if irrevocable
Blinding of participants and personnel (performance bias) All outcomes	Low risk	Not blinded but objectively measured outcome
Blinding of outcome assessment (detection bias) All outcomes	Unclear risk	No information provided
Incomplete outcome data (attrition bias) All outcomes	Unclear risk	No information on missing data provided
Selective reporting (reporting bias)	Unclear risk	No protocol published
Other bias	Low risk	No other biases detected

Methods	Randomised multiple-arm parallel group simulation study
Participants	Nursing students volunteering; N = 100 nursing students who had given written consent, 82% female, age 21 ± 1.2 years, 60% completed more than one study year, all had been taught PPE use, none had been involved with SARS patients
Interventions	Ten different brands and types of PPE at the time of the study in use in Hong Kong hospitals; one type was a surgical gown and one the brand Barrierman, probably Tyvek by DuPont, the others were denoted as White A, White, Green, Y-HR-9, Yellow, Blue, Blue-9, B-NHK-9, B-HR-9. These were categorised into four categories: A: Good water repellency and penetration resistance but poor air permeability; B Good water repellency and air permeability but poor water penetration resistance; C: Surgical gown with poor water repellency and penetration resistance and fair air permeability; D Barrierman, with good water repellency, poor air permeability and fair water penetration resistance Types A,B, C, and D were compared against each other
Outcomes	<ol style="list-style-type: none"> Usability rated by the users as the mean of 5-point scales for: instructions, comfort, ease of donning and doffing, and satisfaction Donning and doffing time/durations in minutes Contamination after spraying fluorescent marker on the trunk and doffing of PPE, measured as mean number of contaminated spots that light up in UV-light
Notes	Hong Kong, China; Funded by Hong Kong Infection Control Nurses' Association, Hong Kong Polytechnic University; no conflict of interest is reported in the article

Risk of bias

Bias	Authors' judgement	Support for judgement
Random sequence generation (selection bias)	Low risk	Subjects were allocated a PPE using a random table page 91
Allocation concealment (selection bias)	Unclear risk	Not reported and information asked from authors did not lead to a higher confidence in allocation concealment
Blinding of participants and personnel (performance bias) All outcomes	Unclear risk	Not blinded; page 91 and discussion page 95 indicates that they knew what they were wearing, obviously, as PPE Type D was a one-piece construct, and they were asked to read manual for wearing
Blinding of outcome assessment (detection bias) All outcomes	Unclear risk	Not reported
Incomplete outcome data (attrition bias) All outcomes	Unclear risk	Not reported if any data were missing

Wong 2004 (Continued)

Selective reporting (reporting bias)	Unclear risk	Apparently all data reported
Other bias	Low risk	No indication of other bias

Zamora 2006

Methods	Randomised two-arm cross-over simulation study	
Participants	<p>Clinicians from Queen's Hospital, Kingston, ON, Canada volunteering to participate. N = 50;</p> <p>Powered Air Purifying Respirator (PAPR)-first N = 27, Age 34.3 ± 8.7 years, height 171.8 ± 8.1, weight 76.3 ± 16.7, Male 16/27, Anaesthesists 19/27, Prior PAPR training 15/27</p> <p>E-RCP first N = 23, Age 36.8 ± 9.8, height 172.3 ± 7.6, Male 11/23, Anaesthesist 10/23, Prior PAPR training 18/23</p> <p>Location: Canada</p>	
Interventions	<p>Intervention: PPE with PAPR, consisting of Tyvek hood (3M), Bouffant hair cover, Spartan economy impact goggle, 3M air-mate breathing tube, 3M HEPA filter unit, N95 mask, 3 pair of gloves, Tyvek coverall with hood, 2 Tyvek boot covers, Astound impervious surgical gown. Doffing order: first gloves, turbo unit hose, hood, gown, second gloves, belt and battery, shoe covers, third gloves, wash hands, new gloves, coverall, second shoe covers, gloves, new gloves, goggles, hair cover, gloves, wash hands, new mask</p> <p>Comparison: Enhanced respiratory and contact precautions (E-RCP) consisting of Bouffant hair cover, Spartan economy impact goggle, Face shield (Splash shield), N95 mask, 2 pairs of gloves, Astound impervious gown. Doffing order: outer gloves, gown, inner gloves, wash hands, new gloves, face shield, hair cover, goggles, mask, gloves, wash hands</p>	
Outcomes	<p>1. Number of participants with presence of contamination on base layer of clothes or skin. Contamination measured with fluorescein solution (5 ml in front of face shield and torso) plus invisible detection paste on forearms and palms of the hands; assessment after removing of outer layer by unblinded assessor with UV lamp; blinded evaluator then inspected all skin and clothes and measured area of contamination. Secondary outcomes were: contamination of inner layers of PAPR system, area size of contamination, number of donning or doffing violations; time required for donning and doffing</p> <p>2. Number of participants with donning or removal violation was defined as out of sequence removal, touching or tearing item of clothing, touching body part before hand washing</p> <p>Used the Mainland-Gart test for the analysis of cross-over studies</p>	
Notes	Funding: Physicians' Services Incorporated Foundation and Clinical Teachers' Association of Queen's University; no Conflict of Interest declared	
Risk of bias		
Bias	Authors' judgement	Support for judgement

Zamora 2006 (Continued)

Random sequence generation (selection bias)	Low risk	Participants randomised by coin tossing
Allocation concealment (selection bias)	Unclear risk	Once started, order was known, but unclear if subjects could still change groups and if there would be an interest to do so
Blinding of participants and personnel (performance bias) All outcomes	Unclear risk	Participants knew attire
Blinding of outcome assessment (detection bias) All outcomes	Low risk	Evaluators blind for attire
Incomplete outcome data (attrition bias) All outcomes	Low risk	Apparently all data collected and usable
Selective reporting (reporting bias)	Unclear risk	Apparently all outcomes reported
Other bias	Low risk	No indication of other bias

Characteristics of excluded studies [ordered by study ID]

Study	Reason for exclusion
Abrahamson 2006	Uncontrolled study; one type of training only
Alraddadi 2016	No comparison group
Beam 2011	No control group with an active intervention
Beam 2014	Uncontrolled study; only one type of training in donning and doffing studied with video recordings
Beam 2016	Not an empirical study
Beam 2016a	Not an empirical study
Bearman 2007	Trial of universal gloving, not as part of full body PPE
Belkin 1991	Commentary, not a primary study
Belkin 2000	Commentary, not a primary study
Belkin 2005	Description of standards and tests not a primary study

(Continued)

Biddell 2016	Not an empirical study
Borchert 2007	Description of use of PPE in MHF outbreak, not a case control or cohort study
Bosc 2016	Wrong comparator
Buianov 1991	Study compares two types of PPE for highly infectious diseases but does not measure contamination or infection as outcome, only physiological parameters (native speaker assessment AP)
Bunyan 2013	Review not primary study
Butt 2016	Wrong comparator
Casanova 2008	Not a comparative study; only studied one method of doffing
Castle 2009	Outcome only performance with PPE and not infection rate or adherence
Christian 2004	Investigation of cluster of SARS infected HCW; not a case control or cohort study
Chu 2017	Not an empirical study
Chughtai 2013	Overview focusing on mask use only, not part of full body PPE
Clay 2015	Simulation study; military HCWs; no control group
Coates 2000	Outcome performance only not infection rates or adherence
Coca 2015	Wrong type of participants, thermal manikin study
Colebunders 2004	Description of MHF outbreak; not a case control or cohort study
Cooper 2005	Simulation study, but of facial protection only, no full-body ppe involved
Delaney 2016	No comparison group
Doll 2017	No comparison group
Doshi 2016	No comparison group
Drew 2016	No comparison group
Dunn 2015	Case study of spread of infection in one hospital; used in discussion section
Elcin 2016	No comparison group
Fischer 2015	Not a primary study, literature review

(Continued)

Fogel 2017	Wrong study design
Foote 2017	Wrong intervention
Franklin 2016	Not an empirical study
Gozel 2013	Description of use of PPE among HCW exposed to CCHF; not case-control or cohort study
Grélot 2015	Measurement of thermal strain, no infection or contamination or compliance measured
Grélot 2016	Measurement of thermal strain, no infection or contamination or compliance measured
Hendler 2000	PPE versus no PPE; outcome performance only
Herlihey 2016	No comparison group
Herlihey 2017	No comparison group
Hersi 2015	Not a primary study, rapid review
Hildwine 2006	Announcement of breathable virus resistant fabric; not a primary study
Ho 2003	Descriptive study of SARS outbreak and HCWs use of PPE; not a case-control or cohort study
Ho 2004	Compares consistent versus inconsistent use of PPE, not two different types
Hon 2008	Evaluation of on-line PPE training; uncontrolled study, no comparison training
Hornbrey 1996	Description of introduction of new clothing; no infection or adherence outcome
Jaques 2016	Report contains no data
Jeffs 2007	Description of control of MHF outbreak; not a case control or cohort study
Jinadatha 2015	Wrong type of participants, investigation of disinfection on different PPE fabrics and components
Kang 2017	Wrong study design
Kang 2017a	No comparison group
Keane 1977	Description of risk of HCW only; no evaluation of PPE safety
Kerstiens 1999	Description of Ebola outbreak; not case control or cohort study
Kilinc-Balci 2016	Not an empirical study

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Kilinc-Balci 2015	Report contains no data
Kim 2015	No control group, HCWs infected with MERS CoV
Ko 2004	Description of risk of EMT staff; no evaluation of PPE safety
Kratz 2017	Report contains no data
Kwon 2017	No comparison group
Lai 2005	Study of SARS IgG prevalence in HCWs who did not become sick, no PPE use measured
Lai 2011	Simulation study of glove removal, no full-body PPE tested.
Lange 2005	Letter to the editor; not primary study
Lau 2004	Compares consistent versus inconsistent use of PPE, not two different types
Le 2004	Compares consistent versus inconsistent use of PPE, not two different types
Lee 2017	Report contains no data
Lindsley 2012	Test respiratory protection only; not part of full-body PPE
Lindsley 2014	Tests respiratory protection only; not part of full-body PPE
Liu 2009	Compares consistent versus inconsistent use of PPE, not two different types
Loeb 2004	Compares consistent versus inconsistent use of PPE, not two different types
Low 2005	A review of SARS and HCW; not a primary study
Lowe 2014	Description of PPE use only; no adherence or infection outcomes
Lu 2006	Comparison of viral load in patients infected outside and inside hospital; comparison is with no PPE
Luo 2011	Simulation study of one Tyvek® (duPont) suit only, no comparison suit or no comparison doffing method
Ma 2004	Retrospective case-control study about PPE for SARS, compares consistent versus inconsistent use not two types
Malik 2006	Participants not exposed to highly infectious diseases
Marklund 2002	Description of Ebola patient transportation; not an intervention study
Matanock 2014	Description of risk of infection of HCW compared to general population; no evaluation of PPE

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McLaws 2016	Not an empirical study
Mehtar 2015	No control group, two IPC training courses
Minnich 2003	Description of ambulance adaptation for transport of highly infected patients; not evaluation or intervention study
Mollura 2015	Review; EVD within radiology wards and on imaging equipment
Moore 2005	Review not intervention study
Morgan 2009	Review of adverse effects of contact precautions
Mumma 2018	No comparison group
Muyembe-Tamfum 1999	Description of Ebola outbreak; not case-control or cohort study
Nikiforuk 2017	wrong patient population
Nishiura 2005	Compares consistent versus inconsistent use of PPE, not two different types
Northington 2007	No comparison group; only one type of education with follow-up
Nyenswah 2015	Case study of EVD cluster including HCWs, but insufficient information on PPE to draw any conclusions
Ofner 2003	SARS case series only; no healthy controls; not case control or cohort study
Ofner-Agostini 2006	SARS case series only; no healthy controls; not case control or cohort study
Ogendo 2008	Eye protection only; not part of full-body PPE
Ong 2013	No exposure to highly infectious diseases
Park 2004	Compares consistent versus inconsistent use of PPE, not two different types
Pei 2006	Compares consistent versus inconsistent use of PPE, not two different types
Phan 2018	Wrong intervention
Phrampus 2016	No comparison group
Quinn 2018	Wrong outcomes
Ragazzoni 2015	No control group, virtual reality simulation training study
Ransjo 1979	No exposure to highly infectious diseases

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Reynolds 2006	Case control study evaluating SARS risk in HCWs in Vietnam but no inclusion of PPE use
Rosenberg 2016	Report of another article already included
Russell 2015	No control group, no outcome, before/after summary card
Scales 2003	Compares consistent versus inconsistent use of PPE, not two different types
Schumacher 2010	Comparison is no PPE; outcome is performance time only
Scott Taylor 2017	Wrong outcomes
Seto 2003	Compares consistent versus inconsistent use of PPE, not two different types
Shao 2015	Not a primary study, Chinese review
Sorensen 2008	No exposure to highly infectious diseases
Su 2017	No comparison group
Tartari 2015	No control group, infection control readiness checklist (from 45 countries), no outcome
Teleman 2004	Compares consistent versus inconsistent use of PPE, not two different types
Tomas 2015	No comparison used only description of contamination in a simulation study
Tomas 2016a	Wrong intervention
Torres 2015	Not a primary study, literature review
West 2014	Not a primary study but a commentary
Xi 2016	No comparison group
Yin 2004	Case-control study of use of PPE for SARS, not comparing two different types of PPE
Zellmer 2015	No control group, checklist for removing PPE
Zhou 2003	Follow-up of HCWs exposed to SARS and their PPE and protection measures, not comparative study

Characteristics of studies awaiting assessment *[ordered by study ID]*

Chugtai 2018

Methods	RCT, simulation study
Participants	Volunteers from university
Interventions	10 different donning/doffing protocols with different PPE composition
Outcomes	Exposure simulated with fluorescent lotion; outcome measured as patches that light up under UV light on the skin
Notes	

Suen 2018

Methods	RCT cross-over, simulation study
Participants	59 health care workers
Interventions	Three PPE ensembles, namely, Hospital Authority (HA) Standard Ebola PPE set (PPE1), Dupont Tyvek Model, style 1422A (PPE2), and HA isolation gown for routine patient care and performing aerosol-generating procedures (PPE3) to prevent EVD transmission
Outcomes	Non-compliance with donning/doffing procedures; exposure simulated with fluorescent solution; outcome measured as patches on the skin that light up under UV light
Notes	

DATA AND ANALYSES

Comparison 1. PAPR versus E-RCP Attire

Outcome or subgroup title	No. of studies	No. of participants	Statistical method	Effect size
1 Any contamination	1		Risk Ratio (M-H, Random, 95% CI)	Totals not selected
2 Contamination > 1 cm	1		Risk Ratio (M-H, Random, 95% CI)	Totals not selected
3 Contamination area	1		Mean Difference (IV, Fixed, 95% CI)	Totals not selected
4 Donning noncompliance	1		Risk Ratio (M-H, Random, 95% CI)	Totals not selected
5 Doffing noncompliance	1		Risk Ratio (M-H, Random, 95% CI)	Totals not selected
6 Donning time	1	100	Mean Difference (IV, Fixed, 95% CI)	0.0 [0.0, 0.0]
7 Doffing time	1	100	Mean Difference (IV, Fixed, 95% CI)	0.0 [0.0, 0.0]

Comparison 2. Four types of PPE attire compared

Outcome or subgroup title	No. of studies	No. of participants	Statistical method	Effect size
1 A vs B Contamination, mean number of spots	1		Mean Difference (IV, Fixed, 95% CI)	Totals not selected
1.1 Face type A vs type B	1		Mean Difference (IV, Fixed, 95% CI)	0.0 [0.0, 0.0]
1.2 Trunk type A vs type B	1		Mean Difference (IV, Fixed, 95% CI)	0.0 [0.0, 0.0]
1.3 Neck type A vs type B	1		Mean Difference (IV, Fixed, 95% CI)	0.0 [0.0, 0.0]
1.4 Foot type A vs type B	1		Mean Difference (IV, Fixed, 95% CI)	0.0 [0.0, 0.0]
1.5 Palm type A vs type B	1		Mean Difference (IV, Fixed, 95% CI)	0.0 [0.0, 0.0]
2 A vs B Usability score (1-5)	1		Mean Difference (IV, Fixed, 95% CI)	Totals not selected
3 A vs B Donning time	1		Mean Difference (IV, Fixed, 95% CI)	Totals not selected
4 A vs B Doffing time	1		Mean Difference (IV, Fixed, 95% CI)	Totals not selected
5 A vs D Contamination, mean number of spots	1		Mean Difference (IV, Fixed, 95% CI)	Totals not selected
5.1 Face type A vs type D	1		Mean Difference (IV, Fixed, 95% CI)	0.0 [0.0, 0.0]
5.2 Trunk type A vs type D	1		Mean Difference (IV, Fixed, 95% CI)	0.0 [0.0, 0.0]
5.3 Neck type A vs type D	1		Mean Difference (IV, Fixed, 95% CI)	0.0 [0.0, 0.0]
5.4 Foot type A vs type D	1		Mean Difference (IV, Fixed, 95% CI)	0.0 [0.0, 0.0]
5.5 Palm type A vs type D	1		Mean Difference (IV, Fixed, 95% CI)	0.0 [0.0, 0.0]
6 A vs D Usability score (1-5)	1		Mean Difference (IV, Fixed, 95% CI)	Totals not selected
7 A vs D Donning time	1		Mean Difference (IV, Fixed, 95% CI)	Totals not selected
8 A vs D Doffing time	1		Mean Difference (IV, Fixed, 95% CI)	Totals not selected

Comparison 3. Formal versus local available attire

Outcome or subgroup title	No. of studies	No. of participants	Statistical method	Effect size
1 Contamination	1		Risk Ratio (M-H, Fixed, 95% CI)	Totals not selected

Comparison 4. Gown versus apron

Outcome or subgroup title	No. of studies	No. of participants	Statistical method	Effect size
1 Contamination with marker; individual doffing	1		Mean Difference (IV, Fixed, 95% CI)	Totals not selected
1.1 small patches	1		Mean Difference (IV, Fixed, 95% CI)	0.0 [0.0, 0.0]
1.2 large patches	1		Mean Difference (IV, Fixed, 95% CI)	0.0 [0.0, 0.0]
1.3 hand	1		Mean Difference (IV, Fixed, 95% CI)	0.0 [0.0, 0.0]
1.4 shoe	1		Mean Difference (IV, Fixed, 95% CI)	0.0 [0.0, 0.0]
1.5 underwear	1		Mean Difference (IV, Fixed, 95% CI)	0.0 [0.0, 0.0]
1.6 environment	1		Mean Difference (IV, Fixed, 95% CI)	0.0 [0.0, 0.0]
2 Contamination with marker; CDC doffing	1		Mean Difference (IV, Fixed, 95% CI)	Totals not selected
2.1 small patches	1		Mean Difference (IV, Fixed, 95% CI)	0.0 [0.0, 0.0]
2.2 large patches	1		Mean Difference (IV, Fixed, 95% CI)	0.0 [0.0, 0.0]
2.3 hand	1		Mean Difference (IV, Fixed, 95% CI)	0.0 [0.0, 0.0]
2.4 shoe	1		Mean Difference (IV, Fixed, 95% CI)	0.0 [0.0, 0.0]
2.5 underwear	1		Mean Difference (IV, Fixed, 95% CI)	0.0 [0.0, 0.0]
2.6 environment	1		Mean Difference (IV, Fixed, 95% CI)	0.0 [0.0, 0.0]

Comparison 5. Sealed suit versus traditional suit

Outcome or subgroup title	No. of studies	No. of participants	Statistical method	Effect size
1 Contamination fluorescent lotion	1		Risk Ratio (M-H, Fixed, 95% CI)	Totals not selected
2 Contamination MS2	1		Risk Ratio (M-H, Fixed, 95% CI)	Totals not selected

Comparison 6. Gown easy to doff versus standard gown

Outcome or subgroup title	No. of studies	No. of participants	Statistical method	Effect size
1 Contamination with fluorescent marker	1		Risk Ratio (M-H, Fixed, 95% CI)	Totals not selected
2 Contamination with bacteriophage	1		Risk Ratio (M-H, Fixed, 95% CI)	Totals not selected

Comparison 7. Gloves with tab versus standard gloves

Outcome or subgroup title	No. of studies	No. of participants	Statistical method	Effect size
1 Any contamination of hands	1		Risk Ratio (M-H, Fixed, 95% CI)	Totals not selected

Comparison 8. Mask with tabs versus no mask tabs

Outcome or subgroup title	No. of studies	No. of participants	Statistical method	Effect size
1 Contamination of head from hands	1		Risk Ratio (M-H, Fixed, 95% CI)	Totals not selected
2 Contamination of hands from mask	1		Risk Ratio (M-H, Fixed, 95% CI)	Totals not selected

Comparison 9. CDC versus individual doffing

Outcome or subgroup title	No. of studies	No. of participants	Statistical method	Effect size
1 Gown; Contamination with fluor marker	1		Mean Difference (IV, Fixed, 95% CI)	Totals not selected
1.1 small patch	1		Mean Difference (IV, Fixed, 95% CI)	0.0 [0.0, 0.0]
1.2 large patch	1		Mean Difference (IV, Fixed, 95% CI)	0.0 [0.0, 0.0]
1.3 hand	1		Mean Difference (IV, Fixed, 95% CI)	0.0 [0.0, 0.0]
1.4 shoe	1		Mean Difference (IV, Fixed, 95% CI)	0.0 [0.0, 0.0]
1.5 underwear	1		Mean Difference (IV, Fixed, 95% CI)	0.0 [0.0, 0.0]
1.6 environment	1		Mean Difference (IV, Fixed, 95% CI)	0.0 [0.0, 0.0]
2 Apron; Contamination with fluor marker	1		Mean Difference (IV, Fixed, 95% CI)	Totals not selected
2.1 small patch	1		Mean Difference (IV, Fixed, 95% CI)	0.0 [0.0, 0.0]
2.2 large patch	1		Mean Difference (IV, Fixed, 95% CI)	0.0 [0.0, 0.0]

2.3 hand	1	Mean Difference (IV, Fixed, 95% CI)	0.0 [0.0, 0.0]
2.4 shoe	1	Mean Difference (IV, Fixed, 95% CI)	0.0 [0.0, 0.0]
2.5 underwear	1	Mean Difference (IV, Fixed, 95% CI)	0.0 [0.0, 0.0]
2.6 environment	1	Mean Difference (IV, Fixed, 95% CI)	0.0 [0.0, 0.0]

Comparison 10. Doffing with double gloves versus doffing with single gloves

Outcome or subgroup title	No. of studies	No. of participants	Statistical method	Effect size
1 Contamination: virus detected	1		Risk Ratio (M-H, Fixed, 95% CI)	Totals not selected
1.1 All body parts	1		Risk Ratio (M-H, Fixed, 95% CI)	0.0 [0.0, 0.0]
1.2 Face	1		Risk Ratio (M-H, Fixed, 95% CI)	0.0 [0.0, 0.0]
1.3 Shirt	1		Risk Ratio (M-H, Fixed, 95% CI)	0.0 [0.0, 0.0]
1.4 Pants	1		Risk Ratio (M-H, Fixed, 95% CI)	0.0 [0.0, 0.0]
2 Contamination: virus quantity	1		Mean Difference (IV, Fixed, 95% CI)	Totals not selected
2.1 Dominant hand	1		Mean Difference (IV, Fixed, 95% CI)	0.0 [0.0, 0.0]
2.2 Non-dominant hand	1		Mean Difference (IV, Fixed, 95% CI)	0.0 [0.0, 0.0]
2.3 Face	1		Mean Difference (IV, Fixed, 95% CI)	0.0 [0.0, 0.0]
2.4 Shirt	1		Mean Difference (IV, Fixed, 95% CI)	0.0 [0.0, 0.0]
2.5 Pants	1		Mean Difference (IV, Fixed, 95% CI)	0.0 [0.0, 0.0]
3 Non-compliance: any error	1		Risk Ratio (M-H, Fixed, 95% CI)	Totals not selected

Comparison 11. Doffing with hypochlorite versus doffing with alcohol-based glove sanitiser

Outcome or subgroup title	No. of studies	No. of participants	Statistical method	Effect size
1 Contamination MS2	1		Risk Ratio (M-H, Fixed, 95% CI)	Totals not selected
2 Contamination Ph6	1	15	Odds Ratio (M-H, Fixed, 95% CI)	0.0 [0.0, 0.0]

Comparison 12. Donning and doffing with instructions versus without instructions

Outcome or subgroup title	No. of studies	No. of participants	Statistical method	Effect size
1 Persons with one or more errors	1	120	Risk Ratio (M-H, Random, 95% CI)	0.31 [0.11, 0.93]
1.1 Basic PPE	1	60	Risk Ratio (M-H, Random, 95% CI)	0.15 [0.04, 0.62]
1.2 Enhanced PPE	1	60	Risk Ratio (M-H, Random, 95% CI)	0.47 [0.22, 0.98]
2 Mean errors	1	120	Mean Difference (IV, Random, 95% CI)	-0.89 [-1.36, -0.41]
2.1 Basic PPE	1	60	Mean Difference (IV, Random, 95% CI)	-0.70 [-1.15, -0.25]
2.2 Enhanced PPE	1	60	Mean Difference (IV, Random, 95% CI)	-1.2 [-1.87, -0.53]

Comparison 13. Active training in PPE use versus passive training

Outcome or subgroup title	No. of studies	No. of participants	Statistical method	Effect size
1 Noncompliance with PPE	1		Odds Ratio (Fixed, 95% CI)	Totals not selected

Comparison 14. Active training in PPE doffing versus passive training

Outcome or subgroup title	No. of studies	No. of participants	Statistical method	Effect size
1 Noncompliance doffing protocol	1		Odds Ratio (Fixed, 95% CI)	Totals not selected

Comparison 15. Computer simulation versus no simulation

Outcome or subgroup title	No. of studies	No. of participants	Statistical method	Effect size
1 Number of errors while donning	1		Mean Difference (IV, Random, 95% CI)	Totals not selected
2 Number of errors while doffing	1		Mean Difference (IV, Fixed, 95% CI)	Totals not selected

Comparison 16. Video-based learning versus traditional lecture

Outcome or subgroup title	No. of studies	No. of participants	Statistical method	Effect size
1 Skills in PPE donning	1		Mean Difference (IV, Fixed, 95% CI)	Totals not selected

ADDITIONAL TABLES

Table 1. Exposure and outcome in simulation studies

Study ID	Exposure						Outcome		
	Agent	Name	Solution	Amount	Additions	Expo method	Detection	Photographs	Measure

Table 1. Exposure and outcome in simulation studies (Continued)

Bell 2015	fluorescent	Glogerm, Tide, Bright Dyes Orange Dye	water	100 mL	oatmeal, chocolate powder, crushed cereal	100 mL splashed on the front torso of their garment	UV LED black light, chauvet	yes	contaminated yes/no
Gleser 2019	fluorescent	Schulke	?	5 mL	no	distributed equally on the gloves	UV box	no	hand contamination (yes/no)
Guo 2014	fluorescent	Glogerm	oil and water	?	no	sprayed 3.8 g of the lotion onto the upper body of the subject at a distance of 60 cm from the subject	UV scan	no	number of stains
Hall 2018	fluorescent	VIOLET-tool	water, glycerol	800 mL (blue UV)	flour, salt	manikin vomited, produced diarrhoea, sweat and cough	UV-A strip lights	yes	yes/no and location (n = 12)
Mana 2018	fluorescent	?	?	0.5 mL	no	rubbed over gloved hands; then contaminated front of the gown	Ultra light UV1	no	any contamination yes/no
Strauch 2016	fluorescent	Glogerm	oil	25 mL	no	1. brushed on masks 2. 1 mL on the hands	UV-A light	yes	contaminated yes/no; intensity of UV light reflection
Tomas 2016	fluorescent	?	?	0.5 mL	no	rubbed over gloved hands	Ultra light UV1	no	contaminated hands/

Table 1. Exposure and outcome in simulation studies (Continued)

									wrist yes/ no
Wong 2004	fluorescent	?	water	100 mL	no	sprayed the ex-posed part with an atomiser (subjects were blind-folded during this process)	UV scan	yes	number of stains
Zamora 2006	fluorescent	Detection Paste	?	100 mL	no	paste on forearms and palms of the hands	UV lamp	no	areas mea- sured
Buianov 2004	microbes	?	10 ⁸ CFU/m ³	?	?	?	?	?	?
Casanova 2012	virus	MS2	10 ⁵ PFU /5 muL	25 muL	?	shoulder, respirator, eye protection, hand 5 drops of 5 muL	swabs of face and hands; ex-traction gloves, scrubs	na	any contami- nation yes/ no; mean Log10 PFU recovered
Casanova 2016	virus	MS2, Phi6	10 ⁸ MS2, 10 ⁷ Phi6 / 5 muL	25 muL	?	hand, shoulder, face-shield, boot	swabs of face and hands; ex-traction gloves, scrubs	na	any con- tamination yes/no
Mana 2018	virus	Phi X174	10 ⁸ PFU/ 0.5 mL	0.5 mL	?	rubbed over de gloved hands for 10 sec	swabs of hands and wrist; swabs of neck and chest	na	any contami- nation yes/ no; mean Log10 PFU recovered
Tomas 2016	virus	MS2	10 ¹⁰ PFU /0.5 mL	0.5 mL	?	gloved hands were inoculated	swabs of hands and wrist	na	contami- nated hands/

Table 1. Exposure and outcome in simulation studies (Continued)

										wrist yes/ no; mean log ₁₀ PFU recovered
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na = not applicable
 MS2 = harmless virus
 Phi6 = harmless virus
 CFU/PFU = colony forming units/ plaque forming units
 µL = microliter
 mL = milliliter

WHAT'S NEW

Date	Event	Description
20 June 2019	New citation required and conclusions have changed	We updated the search and included eight new studies of which one is a field study and seven are simulation studies. This extended the evidence to other types of PPE

CONTRIBUTIONS OF AUTHORS

Conceiving the protocol: JV, SI, CM, JR, KN.
 Designing the protocol: JV, CM, JR, KN, ME, EM, RS.
 Coordinating the protocol and the review: JV, SI.
 Designing search strategies: KN.
 Data extraction: JV, BR, SI, CM, JR, KN, ME, EM, RS.
 Data analysis: JV.
 Writing the protocol and the review: JV, BR, SI, EM, FSKB, JR.
 Providing general advice on the protocol and review: EM, ME, RS, FSKB.

DECLARATIONS OF INTEREST

Jos Verbeek: None known.

Blair Rajamaki: None known.

Sharea Ijaz: None known.

Christina Mischke: None known.

Jani Ruotsalainen: None known.

F Selcen Kilinc Balci: None known.

Erja Mäkelä: None known.

Kaisa Neuvonen: None known.

Michael Edmond: I have given several lectures to non-profit professional associations (e.g. APIC) on topics related to infection control that in some instances provide an honorarium. None of these lectures were for industry.

Riitta Sauni: None known.

Raluca C Mihalache: None known.

SOURCES OF SUPPORT

Internal sources

- Cochrane Collaboration, UK.
Bursary to Sharea Ijaz
- Finnish Institute of Occupational Health, Finland.
Salary for Jos Verbeek, Christina Mischke, Jani Ruotsalainen, Erja Mäkelä and Kaisa Neuvonen
- National Institute for Occupational Safety and Health, USA.
Salary for F Selcen Kilinc Balci

External sources

- No sources of support supplied

DIFFERENCES BETWEEN PROTOCOL AND REVIEW

- We changed the title from “Personal protective equipment for preventing highly infectious diseases due to contact with contaminated body fluids in health care staff” to “Personal protective equipment for preventing highly infectious diseases due to exposure to contaminated body fluids in healthcare staff” to avoid confusion with the term “contact precautions”.
- We replaced the statement in the methods section: “We will also include audit reports or case reports of PPE failure in which there are no comparisons. We will not use these for drawing conclusions but only to compare with findings produced by the above study types. For audit reports, we will examine any reports of failed PPE or audits of health care staff being infected or contaminated” with “We intended to also include uncontrolled audit reports or case reports of PPE failure for descriptive purposes, but we did not find any. If we find any such reports in future updates of this review, we will not use them for drawing conclusions, but only to compare with findings produced by the above study types”.
- We added the following definition of PPE in the methods section because it was lacking: “We defined PPE as any of the above equipment designed or intended to protect health care staff from contamination with body fluids”.
- We added an extra outcome “Time to don and doff the PPE” because we stated in our protocol that we would add outcomes that we had not defined in advance and that we considered important.

- We added a more detailed description of the specific resources that we searched in addition to the electronic databases, i.e. the specific non-governmental organisations (MSF and Save the Children), and specific manufacturers (DuPont, 3M, and Alpha Pro Tech). We could not foresee in advance which parties we would be contacting.
- When using the GRADE considerations to assess the quality of the evidence, for non-randomised studies, we started at the 'low-quality' level, rather than the 'moderate-quality' level outlined in the protocol, as per the recommendations of the Cochrane Handbook.

NOTES

Disclaimer: The findings and conclusions in this Cochrane systematic review are those of the authors and do not necessarily represent the official position of the National Institute for Occupational Safety and Health, Centers for disease Control and Prevention. Mention of product names does not imply endorsement.

INDEX TERMS

Medical Subject Headings (MeSH)

*Body Fluids; *Health Personnel; *Personal Protective Equipment; Gloves, Protective; Hemorrhagic Fever, Ebola [transmission]; Infectious Disease Transmission, Patient-to-Professional [*prevention & control]; Respiratory Protective Devices; Severe Acute Respiratory Syndrome [transmission]; Surgical Attire

MeSH check words

Humans