

**Literature Review and Practice Recommendations:  
Existing and emerging technologies used for  
decontamination of the healthcare environment**

**Ultraviolet Light**

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## Topic

The use of ultraviolet (UV) light systems for decontamination of the healthcare environment.

## Background

Current microbiological and epidemiological evidence indicates that contaminated surfaces in hospital settings can contribute to the transmission of nosocomial pathogens.<sup>1</sup> In particular, there appears to be a risk of pathogen acquisition from prior room occupants for methicillin-resistant *Staphylococcus aureus* (MRSA), vancomycin-resistant enterococci (VRE), *Clostridium difficile* and *Acinetobacter baumannii*.<sup>2</sup> Accordingly, existing research implies that improved surface cleaning and disinfection can reduce healthcare-associated infections.<sup>3</sup>

Manual processes for terminal cleaning are frequently sub-optimal, suggesting that automated decontamination processes might offer an opportunity to improve cleaning efficacy and consistency.<sup>4</sup> There are two major UV light systems currently in use for environmental decontamination: ultraviolet-C (UV-C) light devices that continuously deliver wavelengths of UV light in the range of 254 nm, and pulsed-xenon ultraviolet (PX-UV) light systems that emit a broader spectrum of light in short pulses.<sup>5</sup> Automated mobile UV light devices can be placed in patient rooms following discharge as an adjunct to terminal cleaning. However, UV light systems are suggested as a supplement to, rather than a replacement for, standard discharge cleaning measures due to the requirement of physical removal of dirt from surfaces.<sup>6</sup>

The advantages of UV light devices include their ease-of-use, minimal need for special training of cleaning staff, and the ability to utilise devices without sealing room doors and vents (unlike airborne hydrogen peroxide systems).<sup>7</sup> Although, their efficacy is dependent upon the organic load and pathogen, the intensity and dose of the UV light, the distance from the device and the exposure time, as well as whether the surface to be cleaned is within direct line-of-sight.<sup>8</sup> Their main disadvantages are the substantial set-up costs for equipment, the need to remove staff and patients from the room before disinfection, the time required by staff to transport equipment from room to room, and the need to physically remove dirt and debris before use.<sup>9</sup>

It has been reported that UV light systems are capable of substantially reducing the number of environmental *C. difficile* spores, indicating their applicability for the terminal cleaning of rooms following the discharge of patients under contact precautions.<sup>9</sup> The NHSScotland National Infection Prevention and Control Manual<sup>10</sup> currently recommends the use of a disinfectant solution at a dilution of 1,000 parts per million (ppm) available chlorine for routine and terminal room cleaning under transmission-based precautions. This review intends to assess the evidence base on the appropriateness of using UV light decontamination systems for both routine cleaning and terminal cleaning in the healthcare environment.

## **Aim**

To review the evidence base for using ultraviolet (UV) light for decontamination of the healthcare environment.

## **Objectives**

- To provide a generic description of UV light decontamination systems, including the proposed or actual mechanism of action and the procedure for use.
- To assess the scientific evidence for effectiveness of UV light decontamination systems.
- To explore practical and safety considerations related to the use of UV light decontamination systems.
- To explore the costs associated with UV light decontamination systems.
- To produce a concise evidence summary for UV light to assist the Equipment and Environmental Decontamination Steering Expert Advisory Group in making practical recommendations on the use of UV light decontamination systems for NHSScotland.

## **Research Questions**

The following research questions will be addressed:

1. Are UV light decontamination systems currently in use in UK healthcare settings?
2. What is the actual or proposed mechanism of action of UV light decontamination systems?
3. What is the procedure for using UV light decontamination systems?
4. What is the scientific evidence for effectiveness of UV light for decontamination of the healthcare environment?
5. Are there any safety considerations associated with using UV light decontamination systems in the healthcare setting?
6. Are there any practical or logistical considerations associated with using UV light decontamination systems in the healthcare setting?
7. What costs are associated with using UV light decontamination systems in the healthcare setting?
8. Have UV light decontamination systems been assessed by the Rapid Review Panel?

## Methodology

### Search Strategy

The following databases and websites were searched to identify relevant academic and grey literature:

- MEDLINE
- CINAHL
- EMBASE
- NHS Evidence (<http://www.evidence.nhs.uk/>)
- Health Technology Assessment (HTA) database (<http://www.crd.york.ac.uk/CRDWeb/>)
- Database of Abstracts of Reviews of Effects (DARE) (<http://www.crd.york.ac.uk/CRDWeb/>)
- National Patient Safety Agency (NPSA) (<http://www.npsa.nhs.uk/>)
- National Institute for Health and Care Excellence (NICE) (<http://www.nice.org.uk/>)
- Medicines & Healthcare products Regulatory Agency (MHRA) (<http://www.mhra.gov.uk/>)
- Rapid Review Panel (RRP): product evaluation statements (<http://www.gov.uk/government/groups/rapid-review-panel/>)

Search terms were developed and adapted to suit each database/website. Initial literature searches were run between 24/06/2014 and 01/07/2014. For the update, the literature search was performed on 29/07/2016. The same search strategy was applied in both years. See [Appendix 1](#) for an example of the search run in the MEDLINE database.

### Exclusion Criteria

Academic and grey literature was excluded from the review on the basis of the following exclusion criteria:

- Article was released before 2004
- Article was not published in the English language
- Article does not concern ultraviolet (UV) light decontamination in the healthcare environment (off-topic)
- Article is an opinion piece, a non-systematic review or a conference abstract
- Article does not present evidence compatible with the McDonald-Arduino evidentiary hierarchy<sup>11</sup>

- Article concerns a study that did not have an appropriate comparison in the form of standard cleaning methods

## Screening

There was a two-stage process for screening the items returned from the literature searches. In the first stage, the title/abstract was screened against the exclusion criteria by the lead reviewer. Items that were not excluded at the screening stage progressed to the second screening stage. In the second stage of the screening process, the full text of remaining items was screened against the exclusion criteria by the lead reviewer. Items that were not excluded at the second screening stage were included in the review.

## Critical Appraisal

Critical appraisal of the studies included in this review and considered judgement of the evidence was carried out by the lead reviewer using the Scottish Intercollegiate Guidelines Network (SIGN) methodology.<sup>12</sup> The McDonald-Arduino evidentiary hierarchy was used as a framework for assessing the evidence.<sup>11</sup>

## Results

The original search found 130 articles. After the first stage of screening this was reduced to 46 articles, and after the second stage there were four articles to critically appraise.<sup>13-16</sup> The update search retrieved a further 65 articles, of which 21 passed the first stage of screening, and five were critically appraised.<sup>17-21</sup> The nine included studies used two different types of UV light disinfection: seven studies used pulsed-xenon ultraviolet (PX-UV) light<sup>13;15-20</sup> and two studies used continuous ultraviolet-C (UV-C) light.<sup>14;21</sup> Eight of the nine studies were conducted in the United States of America (USA),<sup>13;15-21</sup> with the one study outside the USA conducted in Norway.<sup>14</sup>

Standard cleaning methods in the studies differed considerably. Among the original four studies: one study used 0.55 % sodium hypochlorite solution and a quaternary ammonium compound disinfectant,<sup>13</sup> another study used 5 % chloramine solution,<sup>14</sup> one stated that an unspecified germicide had been used,<sup>15</sup> and the fourth study used a 1:10 premixed, ready-to-use bleach solution.<sup>16</sup> Of the five additional studies: two studies used sodium hypochlorite solution<sup>17;20</sup> (of which one also used an activated hydrogen peroxide disinfectant<sup>20</sup>), one study used an unspecified bleach,<sup>19</sup> one study used an unspecified “chemical disinfectant”,<sup>18</sup> and the last study did not describe their standard cleaning practices in any detail.<sup>21</sup>

Five of the studies monitored the effect of UV light on patient infection rates for the following: multi-drug resistant organisms (MDROs) and *Clostridium difficile*;<sup>13</sup> *Clostridium difficile* infections (CDIs);<sup>17</sup> surgical site infections (SSIs);<sup>18</sup> MDROs including methicillin-resistant *Staphylococcus*

*aureus* (MRSA), vancomycin-resistant enterococci (VRE) and CDIs;<sup>19</sup> and, healthcare-associated infections (HAIs) caused by *Acinetobacter baumannii*, *Klebsiella pneumoniae*, MRSA, VRE and *C. difficile*.<sup>21</sup> The other four studies evaluated the impact of UV light on the reduction of environmental bioburden, as measured in colony-forming units (CFUs).<sup>14-16;20</sup>

There were a range of UV light disinfection systems available that exhibited varying levels of effectiveness. In the nine studies included, six of the studies demonstrating greater levels of effectiveness than standard manual cleaning used PX-UV light disinfection devices,<sup>13;15-19</sup> while only one of the studies used UV-C light.<sup>21</sup> Of the two studies demonstrating similar levels of effectiveness to standard cleaning methods, one used a continuous UV-C disinfection method<sup>14</sup> and the other used PX-UV light.<sup>20</sup>

## **Research Questions**

### **Are UV light decontamination systems currently in use in UK healthcare settings?**

There is no mention of UV light decontamination systems in the NHSScotland National Cleaning Services Specification,<sup>22</sup> the National Patient Safety Agency (NPSA) Revised Healthcare Cleaning Manual,<sup>23</sup> the Association of Healthcare Cleaning Professionals (AHCP) Revised Healthcare Cleaning Manual<sup>24</sup> or the NHSScotland National Infection Prevention and Control Manual.<sup>10</sup>

These findings suggest that UV light decontamination systems are not widely in use within UK healthcare settings.

### **What is the actual or proposed mechanism of action of UV light decontamination systems?**

UV light is able to sever the molecular bonds in DNA and RNA when used at specific wavelengths, thereby destroying micro-organisms. They are particularly vulnerable to UV light at 254 nm because DNA absorbs UV light maximally in this region, resulting in the formation of lethal photoproducts.<sup>16;25-28</sup> Double-stranded DNA viruses are more resistant to UV light than single-stranded RNA viruses.<sup>14</sup>

UV-C light disinfection systems deliver doses of UV light at 254 nm, as a variety of microorganisms including spore-forming bacteria are vulnerable to UV light at this wavelength; however, the doses needed to inactivate them can vary.<sup>14;29;30</sup> UV-C light disinfection systems use mercury gas bulbs to produce continuous UV-C light at a wavelength of 254 nm. UV-C light is able to inactivate microorganisms on surfaces, in air and in water, but the UV rays must be able to strike directly. Organisms below the surface of water, or not in the direct path of the UV-C rays, will not be destroyed.<sup>14</sup>



PX-UV light disinfection systems use xenon gas bulbs to emit intense flashes of white light that has a broad spectrum ranging from 200 – 1100 nm.<sup>31</sup> This range covers the germicidal spectrum of 200 – 280 nm as well as the visible light spectrum. It differs from continuous UV-C light disinfection in that it has greater intensity and uses a broader range of radiation to achieve more effective decontamination.<sup>15;32</sup>

### **What is the procedure for using UV light decontamination systems?**

UV-C light travels in a straight line and is less effective on surfaces lying out of the direct path of the light rays, so the device should be placed in the centre of the room and high-touch mobile items should be arranged close to the device for optimal exposure. Otter *et al.*<sup>29</sup> state that some manufacturers recommend multiple cycles from different locations to ensure sufficient disinfection. Some UV-C light systems contain sensors to measure the amount of UV-C light reflected back to the device to confirm the delivery of a specified dose.<sup>29</sup>

A number of studies used the Tru-D™ room decontamination unit which uses UV-C light at a wavelength of 254 nm. Rutala *et al.*<sup>33</sup> report that the unit is fully automated and is activated by a handheld remote, and that room ventilation does not need to be modified. It measures UV-C light reflected back from the walls, ceilings, floors, and items within the room, thereby calculating the time required to deliver the programmed lethal dose for pathogens. Following decontamination, it will power down, and an audible alarm will notify the operator. Boyce *et al.*<sup>34</sup> note that the operator can choose the dose of UV light to be administered to the room. Anderson *et al.*<sup>35</sup> mention in their study that drawers and cabinets were opened before using the machine and the device was placed in a location to ensure that light was emitted into the room's bathroom whenever possible. Rutala *et al.*<sup>33</sup> discuss the use of a special coating which is 65 % UV light-reflective compared to standard paint which is 3 to 7 % UV light-reflective. This coating is white in colour and can be applied in the same way as normal indoor paint. Using this paint, the authors were able to significantly reduce the time required for decontamination.

Upper-room UV light disinfection also uses light at a wavelength of 254 nm, but it focuses on the upper regions of rooms and has been used for airborne infections, e.g. tuberculosis. It can be used with patients present in the room, but as it operates at a height it is able to lower the concentration of organisms in the room without exposing the room occupants to a significant amount of UV radiation.<sup>36</sup>

PX-UV light disinfection systems are operated in a similar way. They can be operated remotely by personnel outside the patient room and can include safety features such as motion sensors which turn the device off if the door has been opened.<sup>32</sup>

## What is the scientific evidence for effectiveness of UV light for decontamination of the healthcare environment?

Two cohort studies<sup>16;20</sup> and seven before-and-after studies<sup>13-15;17-19;21</sup> evaluated the efficacy of UV light for decontamination of the healthcare environment. It was demonstrated that this intervention could reduce environmental surface contamination and decrease the incidence of healthcare-associated infections.

As detailed in the methodology, the McDonald-Arduino evidentiary hierarchy<sup>11</sup> was used as a framework for assessing the evidence relevant to this research question.

### **Level V – Demonstration of reduced microbial pathogen acquisition (colonisation or infection) by patients via *non-outbreak* surveillance testing and clinical incidence:**

Haas *et al.*<sup>13</sup> investigated the implementation and impact of PX-UV light environmental disinfection in an acute care setting using a before-and-after study. The rates of hospital-associated MDROs and CDIs were monitored for 30 months before the study started and for 22 months while UV light disinfection was in place. During the intervention period, there was a 20 % reduction in hospital-associated MDRO infections and CDIs. The authors concluded that the use of UV light disinfection was feasible as an adjunct to routine discharge cleaning. However, it is worth noting that this study took place in a single institution, and that the use of a before-and-after study has inherent weaknesses. The authors note that there were other interventions occurring simultaneously, so the reduced rates may reflect a combination of these interventions. Nagaraja *et al.*<sup>37</sup> have since published a more in-depth analysis of their findings on the reduction in CDIs.

Miller *et al.*<sup>17</sup> conducted a before-and-after study that introduced a PX-UV light disinfection device into a long-term acute care hospital (USA) as an adjunct to standard cleaning, using a sodium hypochlorite solution for rooms of patients with CDI. Following a baseline period of 12 months, in which a multidisciplinary care team had been trialled with no statistically significant impact, PX-UV light was utilised for a further period of 15 months. During the pre-UV light period, the CDI rate was 19.3 per 10,000 patient days. Over the subsequent UV light intervention period, the infection rate fell by 56.9% to 8.3 per 10,000 patients ( $p = 0.02$ ). The authors concluded that using PX-UV light in combination with standard cleaning was more effective than standard cleaning alone. Despite these findings, it is important to recognise that the combination of multiple interventions and the lack of a control group risk the possibility of confounding factors. The authors themselves note that patients are discharged less frequently in long-term acute care; hence, there would probably have been less use of the device in terminal room cleaning and proportionally greater use in the cleaning of communal areas. Such a consideration might limit the findings of the study to the application of non-terminal cleaning practices.

Catalanotti *et al.*<sup>18</sup> embarked upon a before-and-after study in a community hospital (USA) in which a PX-UV light disinfection device was utilised by dedicated personnel for terminal cleaning each night, following the completion of standard cleaning with a chemical disinfectant. After the 15-month baseline period, the PX-UV light system was incorporated in the cleaning schedule for 21 months. Over this time, the rate of class I (clean) procedure SSIs decreased by 44.6 % from 0.48 per 100 cases to 0.26 per 100 cases ( $p = 0.0496$ ). However, for class II (clean-contaminated) procedures the rate demonstrated no statistically significant change. The authors concluded that PX-UV light in conjunction with standard cleaning was more effective for low-contamination procedures than standard cleaning on its own. It was considered likely that the typically higher contamination rate of class II procedures led to this apparently inconsistent result. Once again, the investigators combined multiple interventions, impairing the ability of the study to determine which intervention was effective. There is also a possibility of investigator bias due to financial support received from 'Xenex Disinfection Services': a manufacturer of PX-UV light disinfection devices.

Vianna *et al.*<sup>19</sup> undertook a before-and-after study that incorporated a PX-UV light disinfection system into the traditional cleaning routine (including the use of non-specified bleach for CDI isolation rooms) for selected rooms in a community hospital (USA). These rooms included the ICU for all discharges and transfers, but only CDI isolation rooms for non-ICU discharges and transfers. Standard terminal cleaning was applied for a baseline period of 22 months, after which PX-UV light was implemented for another 22 months. Facility-wide, there was a 29 % decrease ( $p = 0.01$ ) in all three MDRO infection rates (MRSA, CDI and VRE), driven by a 41 % decrease in CDIs ( $p = 0.01$ ). In the ICU, there was a 61 % decrease ( $p = 0.01$ ) in all three MDRO infection rates, while for non-ICU wards there was only a decrease in CDIs of 40 % ( $p = 0.03$ ). The authors account for the differential change in infection rates between wards by the substantially greater risk of infection within the ICU. The statistical analysis of the study involved multiple comparisons which were not factored into the analysis (e.g. by using a Bonferroni correction); it is therefore not unlikely that a false positive result occurred. It should also be borne in mind that the investigators received financial support from 'Xenex Disinfection Services'.

Napolitano *et al.*<sup>21</sup> performed a before-and-after study in which a UV-C light decontamination unit was operated in conjunction with a data monitoring tool and dedicated UV-C light device technicians in a community hospital (USA). A total of 125 rooms were involved, featuring rooms within cardiac and surgical intensive care, medical/surgical wards and acute rehabilitation. Each ICU room on discharge and every non-ICU room on discharge of a patient on isolation precautions were included. In the 5-month baseline period there was a HAI incidence rate of 3.7 per 1000 patient-days, followed by a 34.2 % reduction ( $p < 0.001$ ) in the incidence rate to 2.4 per 1000 patient-days. A statistically significant reduction was seen in infections associated *A. baumannii* ( $p = 0.005$ ), *C. difficile* ( $p < 0.001$ ) and *K. pneumoniae* ( $p < 0.001$ ), but not MRSA or VRE. The authors

concluded that using UV-C light in conjunction with standard cleaning was more effective; yet they did not define the standard cleaning performed within their study site. The investigators were unable to apply complete coverage of the intervention during the first two months due to workload issues. However, the rooms that were not covered in these months were not included in the control period.

**Level IV – Demonstration of reduced microbial pathogen acquisition (colonisation or infection) by patients via *outbreak* surveillance testing and clinical incidence:**

No evidence identified.

**Level III – Demonstration of in-use bioburden reduction that may be clinically relevant:**

No evidence identified.

**Level II – Demonstration of in-use bioburden reduction effectiveness:**

Andersen *et al.*<sup>14</sup> compared the use of UV-C light with standard cleaning methods for disinfection of surfaces in hospital isolation units using a before-and-after study design. In this study, UV-C light disinfection reduced the number of bacteria on surfaces to a similar level as 5 % chloramine solution, which was used for standard disinfection. The authors concluded that UV-C light could provide a good addition to chemical disinfection to lower the biological burden of infectious agents in isolation units for high-risk infectious patients.

Stibich *et al.*<sup>15</sup> evaluated the impact of a PX-UV light room disinfection device for its impact on hospital operations and microbial reduction using a before-and-after study. The study showed significant reductions in bioburden in rooms after the use of PX-UV light, demonstrating that the use of a PX-UV light system is more effective than standard manual cleaning alone. The study also showed that the disinfection system is efficient enough to be integrated into daily hospital operations without having an adverse effect on patient throughput. It is worth noting that funding for the laboratory analysis was provided by 'Xenex Healthcare Services' and that two of the authors were shareholders in the company.

Jinadatha *et al.*<sup>16</sup> evaluated a PX-UV light room disinfection device for impact on contamination levels of MRSA on high-touch surfaces in patient rooms using a cohort study design. This study showed that a PX-UV light system was more effective than manual cleaning at reducing the bioburden of MRSA on high-touch surfaces in rooms vacated by MRSA-positive patients. The authors recognise that the delay to culture introduced by the overnight transport process may have influenced culture viability, however both manual cleaning and UV light samples were subjected to the same process, thus reducing the likelihood of systematic bias from this source of variability.

Ghantoji *et al.*<sup>20</sup> also utilised a cohort study to investigate the effect of using a PX-UV light disinfection device over standard discharge cleaning with 10% sodium hypochlorite solution on

environmental surface contamination in a cancer centre (USA). Both the rooms cleaned with PX-UV light (n = 15) and the rooms cleaned with hypochlorite solution (n = 15) were first cleaned using an activated hydrogen peroxide disinfectant. The following environmental surfaces at five high-touch sites were sampled on discharge and subsequently on completion of cleaning: the bathroom handrail, the bed control panel, the bedrail, the bedside table, and the IV pump control panel. Samples were streaked onto selective media for *C. difficile* and incubated anaerobically before colony counting. The mean number of CFUs for the hypochlorite arm decreased by 70 % from 2.39 to 0.71 (p = 0.14), a non-statistically significant change, while the mean number of CFUs for the PX-UV light arm decreased significantly by 95 % from 22.97 to 1.19 (p = 0.002). The difference in CFUs for both arms following cleaning was not statistically significant. The authors therefore concluded that using PX-UV light as an adjunct to standard cleaning was at least as effective as using hypochlorite solution. The study was limited by a small sample size; however the number of samples was comparable to that of the study by Jinadatha et al.<sup>16</sup> Importantly, the two groups were drastically dissimilar at baseline in microbial contamination – and no attempt was made to compensate for this baseline difference.

#### **Level I – Laboratory demonstration of bioburden reduction efficacy:**

No evidence identified.

To summarise the evidence, it can be concluded that there is **low- to moderate-quality evidence** to support the use of UV light decontamination as an adjunct to standard cleaning procedures in the healthcare environment. In accordance with SIGN methodology,<sup>12</sup> the two cohort studies constituted **level 2+ evidence** (well-conducted controlled analytic studies with a low risk of confounding, bias, or chance and a moderate probability that the relationship is causal). In contrast, the seven before-and-after studies were designated **level 3 evidence** (uncontrolled analytic studies).

#### **Are there any safety considerations associated with using UV light decontamination systems in the healthcare setting?**

Chlorine-releasing agents are considered easy-to-use and the least expensive environmental disinfection method available. However, they do feature a number of limitations such as the release of irritating vapours and toxic gases which may affect the eyes and respiratory tracts of healthcare workers at high concentrations (i.e. 10,000 ppm available chlorine), and personal protective equipment is recommended for this reason. Sodium hypochlorite-based products can be corrosive to various materials and potentially cause damage to environmental surfaces. In addition, the disinfection process must be performed manually, which can be time-consuming, with the

quality of disinfection depending on the staff member performing the procedure. This has led to a renewed interest in alternative methods of environmental decontamination.<sup>38-40</sup>

UV radiation is a known mutagen – therefore, staff and patient exposure to UV light is a potential danger if they are present when disinfection is being undertaken. Automated UV light disinfection systems have sensors that are triggered if a door is opened, so there should only be a significant risk of exposure if the sensors are malfunctioning. It is important for this reason to ensure that all entrances to a room have motion sensors attached. In addition, as UV light systems do not inactivate all microbes present, those that receive a sub-lethal dose may undergo mutation, potentially leading to a greater risk of antimicrobial resistance.<sup>29;30</sup>

### **Are there any practical or logistical considerations associated with using UV light decontamination systems in the healthcare setting?**

All room decontamination technologies have advantages and disadvantages. UV light decontamination systems are easy to use, do not require sealing of doors or air vents, and have a relatively short cycle time.<sup>29;30</sup> Nerandzic *et al.*<sup>27</sup> report that a UV-C light disinfection cycle for the removal of *C. difficile* spores took approximately 45 minutes, whereas Boyce<sup>7</sup> reports that a PX-UV light system can decontaminate a room in as short a time as 15 to 20 minutes – a length of time that could more easily be integrated into healthcare settings with a high occupancy rate and rapid turnaround times.

UV light systems do not require monitoring during the decontamination process and staff should not need any special training to operate them. However, they are only effective for surfaces in their direct line-of-sight; therefore, many manufacturers recommend multiple cycle times in different locations within the room. Boyce *et al.*<sup>41</sup> have demonstrated that irradiance, dosage and antimicrobial effect received from a UV-C light device all varied significantly based on location in a room relative to the device. For this reason it has been suggested that, although faster and easier to use than a hydrogen peroxide vapour system, UV light systems are less effective at eliminating micro-organisms from surfaces, particularly when outside direct line-of-sight.<sup>42</sup>

In addition, as many UV light systems measure the reflected dose to determine the length of cycle time, surfaces that do not reflect UV light will reduce the delivered dose. The intensity of light dissipates with distance from the source, limiting its capacity to disinfect larger rooms.<sup>29;30</sup> Studies have shown that UV light does not penetrate sheets and curtains, and that high levels of UV radiation can reduce the service life of materials including fabrics and those made of plastic.<sup>14;30</sup>

A major disadvantage of UV light systems is that they can only be used for terminal disinfection because the room must be cleared of all patients and staff.<sup>33</sup> A number of studies have shown that the efficacy of UV light decontamination is affected by the presence of dirt and debris on surfaces, and results suggest that traditional cleaning should be carried out first.<sup>35</sup> However, Zhang *et al.*<sup>43</sup>

claim that extensive pre-cleaning of surfaces is not essential prior to operation of UV light devices. Jinadatha *et al.*<sup>44</sup> have since demonstrated that PX-UV light disinfection can still effectively reduce MRSA colony counts in the absence of manual cleaning; however, they continue to advocate the use of UV light disinfection as an adjunctive measure to traditional cleaning.

PX-UV light systems have similar practical considerations to UV-C light systems, including the need to use multiple room locations to address line-of-sight issues, the age of the bulbs reducing the intensity of the light emitted and the limited capacity to decontaminate areas larger than single rooms.<sup>29</sup> PX-UV light systems have been used for food and water disinfection and would be expected to provide similarly effective decontamination of wet environments in the healthcare setting.<sup>45</sup>

### **What costs are associated with using UV light decontamination systems in the healthcare setting?**

Rutala *et al.*<sup>25</sup> highlight that there are no consumables used in the employment of UV light decontamination systems, thus the only incurred expenses will be the capital costs for equipment and those of labour. As some UV light disinfection systems are quicker than others, it is worth taking this into account due to the potential economic impact in terms of staffing and labour costs.<sup>13;46</sup>

Nerandzic *et al.*<sup>26</sup> note that after the initial purchase of a Tru-D™ UV-C light device, the operational and maintenance costs are minimal, with electricity and annual bulb replacements costing approximately \$ 20 each and no requirement of dedicated staff. Levin *et al.*<sup>32</sup> report that leasing two machines in the USA in 2013 cost less than \$ 5,000 per month. Ghantaji *et al.*<sup>20</sup> estimate that the operational costs of a PX-UV light disinfection device in the USA are \$ 3 for each room cleaned per month, excluding labour costs, assuming a rate of at least 30 rooms disinfected per day using a cycle of 15 minutes (the device was leased for approximately \$ 3000 per month).

### **Have UV light decontamination systems been assessed by the Rapid Review Panel?**

The Rapid Review Panel<sup>47</sup> (RRP) is a panel of UK experts established by the Department of Health to review new technologies with the potential to aid in the prevention and control of healthcare-associated infections. The RRP has reviewed a number of UV light disinfection products between 2005 and 2013:

- 2005: Stinger UV Light Emitter (Growtech Ltd) and Fresh Air UV (Fresh Air UV)
- 2006: Steril-Aire UVC Emitters (Vandelay Imports Ltd)
- 2011: UVC Emitter for use with HVAC systems (Generation E Ltd trading as E-CO)
- 2013: UV-C Miracle Wand (MBR UV-C Light Products)

All of these products have been assigned either a grade 4, 4a or 4b recommendation. This entails:

*“Potentially useful product but insufficient evidence presented; further research and development with the product as intended to be used in the NHS is required to demonstrate improvements in infection prevention and control interventions to reduce healthcare associated infections before it is ready for in use evaluation within the NHS.”*

No PX-UV light disinfection systems have been reviewed by the RRP.

## **Discussion**

This systematic review incorporated the results of nine studies into its findings. The quality of included studies was predominantly of **level 3 (low-quality) evidence**; however, there were two studies classified as **level 2+ (moderate-quality) evidence**. The study design of choice was either a before-and-after study or a cohort study. They primarily concerned either in-use bioburden reduction (level III) or reduced microbial pathogen acquisition in a non-outbreak setting (level V). The findings identified by the review were used to develop the following recommendations for clinical practice.

## **Recommendations for Clinical Practice**

This review makes the following recommendations based on an assessment of the extant professional literature on ultraviolet (UV) light systems for environmental decontamination:

- UV light systems can be used as an additional measure when performing terminal room decontamination.  
**(Grade C recommendation)**
- The use of UV light systems for environmental decontamination should only be undertaken following completion of a manual clean as residual dirt can reduce efficacy.  
**(Grade D recommendation)**
- Prior to a UV light system being considered, an assessment of the area to be decontaminated must be undertaken to ensure the area can be sealed and the use of UV light made safe.  
**(Grade D recommendation)**
- UV light systems must only be used in an area which has been cleared of all patients and staff. No entry to the decontamination area is allowed once the decontamination process has commenced.  
**(Grade D recommendation)**



- Manufacturers' instructions for use must be followed to ensure all surfaces are adequately decontaminated to reduce the risk of sub-optimal UV light dosage on micro-organisms. This could result in mutation of the remaining microbes.  
**(Grade D recommendation)**
- UV light systems in use must be maintained in good working order and a system of programmed maintenance in place with documented evidence.  
**(Good Practice Point)**
- A quality assurance mechanism should be in place to monitor the functionality of the UV light system using samples before and after cleaning.  
**(Good Practice Point)**
- UV light systems should **not** be used for routine cleaning.  
**(Grade D recommendation)**
- Risk assessments should be in place for possible exposure of staff or patients to UV light.  
**(Good Practice Point)**
- Ensure appropriate time is given to the UV light decontamination process. Use of UV light systems will increase the overall decontamination time for cleaning. Additional time should be included in cleaning specification guidance.  
**(Grade D recommendation)**
- No rapid reviews of PX-UV light systems have been undertaken and only five have been produced for UV-C light systems. NHS Boards opting for UV light decontamination systems must be aware if they have not been reviewed or approved by the Rapid Review Panel.  
**(Grade D recommendation)**

### **Implications for Research**

The review identified several gaps in the literature in relation to UV light decontamination systems. Many of the relevant studies identified could not be included in this review as they did not make a suitable comparison in the form of standard cleaning as recommended for NHSScotland in the National Infection Prevention and Control Manual.<sup>10</sup> These studies variously compared the use of UV light disinfection with sodium hypochlorite, quaternary ammonium compounds, chloramine and hydrogen peroxide; in some cases not even specifying the type of cleaning agent used. Future studies assessing the clinical effectiveness of UV light systems for decontamination should include suitable comparison groups to enable the results to be transferable to clinical practice within NHS Scotland.

It was also notable that several of the studies combined multiple infection control interventions with the use of UV light disinfection, such as outsourced cleaning personnel, the introduction of multidisciplinary infection control teams, the use of cleaning checklists, and environmental monitoring using ATP bioluminescence or fluorescent markers. Ideally, studies that evaluate the effectiveness of UV light decontamination systems should exclude other infection control interventions in order to minimise the risk of confounding factors producing a spurious result.

It is well-established that UV-C light devices require a longer cycle time than PX-UV light devices; however, it is yet to be determined whether one device is more effective than the other. Nerandzic *et al.*<sup>48</sup> have found that continuous UV-C light achieves a significantly greater log<sub>10</sub> CFU reduction than PX-UV irradiation on glass carriers. These results only indicate a reduction in environmental bioburden and would need to be confirmed within a clinical context before any decisive conclusions could be inferred.

Finally, very few studies thus far have evaluated the cost-effectiveness of UV light decontamination systems. Of the few that have, the majority have primarily considered the cost-savings acquired from reducing the incidence of HAIs and the associated expense of treatment. Others have contemplated the capital costs of the necessary equipment, having excluded the cost of manual labour to operate the devices, most frequently measured in US dollars. It can therefore be seen that a comprehensive cost-effectiveness evaluation for the use of UV light decontamination systems in NHSScotland would be timely.

## **Conclusion**

The contribution of environmental contamination in healthcare settings to the cross-transmission of nosocomial infections has been thoroughly demonstrated: firstly, by interventional studies in which improved surface cleaning has reduced the incidence of HAIs;<sup>1</sup> and secondly, by observational studies which have evidenced the higher risk of pathogen acquisition in patients admitted to rooms where the prior occupant was known to be infected or colonised.<sup>2</sup> Ultraviolet (UV) light decontamination systems provide an example of a novel technology that may supplement standard cleaning practices and potentially further reduce the transmission of nosocomial pathogens. This review aimed to provide a concise evidence summary outlining: the evidence of effectiveness for, the practical and safety considerations of, and the costs associated with, the use of UV light decontamination systems.

The review found that there was a larger quantity of evidence supporting the use of pulsed-xenon ultraviolet (PX-UV) light systems than ultraviolet-C (UV-C) light systems, although this evidence was of low- to moderate-quality. Seven of the studies demonstrated that using UV light systems after standard cleaning was more effective than standard cleaning alone. Two of the studies showed that UV light systems were at least as effective as standard cleaning. However, the studies often lacked a concurrent control group and frequently combined multiple infection control interventions within a single study. In addition, the standard cleaning measures adopted did not always reflect current best practice recommended for use in NHS Scotland.

To achieve maximal efficacy, it is suggested that UV light devices should be utilised in multiple locations within a room and that manual cleaning should be completed prior to operation. To ensure staff and patient safety, it is recommended that all personnel should be cleared from the room before use and that the room should be closed to entry for the duration. The use of UV light decontamination will require a significantly longer length of time than standard cleaning alone, and this is particularly marked for UV-C light devices; although there have been few direct comparisons of efficacy made between UV-C and PX-UV light systems. There has also been little in the way of cost-effectiveness evaluations of UV light systems in the UK.

The Rapid Review Panel (RRP) has evaluated five UV-C light disinfection systems, which have all been assigned a recommendation grade of either 4, 4a or 4b. These classifications advise that the product has the potential to be useful, but that insufficient evidence has been presented to advocate its use within the NHS. No PX-UV light disinfection systems have been reviewed by the RRP. If NHS Boards wish to adopt UV light decontamination systems, they must be aware if the system has not been reviewed or approved by the RRP.

## Appendix 1: MEDLINE Search

Ovid MEDLINE(R) 1946 to present with daily update

AND

Ovid MEDLINE(R) In-process & other non-indexed citations

### Search dates

24/06/2014 and 25/06/2014

29/07/2016

1 (all "OR")		2 (all "OR")		3 (all "OR")
Ultraviolet rays/ UV light.mp. ultraviolet light.mp.	AND	Sterilization/ Decontamination/ Disinfection/ Housekeeping, Hospital/ clean*.mp.	AND	Hospitals/ Patients' Rooms/ hospital*.mp. health care.mp.

### Limits

English Language

Publication Year 2004 – 2014                      Results: 65

Publication Year 2014 – Current   Results: 27

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