NHS National Services Scotland

Existing and Emerging Technologies Used for Decontamination of the Healthcare Environment

Ultraviolet Light V2.0

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ARHAI Scotland
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Key Information

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Document information

Description: This literature review examines the available professional literature on the use of ultraviolet light for environmental decontamination in health and care settings.

Purpose: To inform the existing and emerging technologies used for decontamination of the health and care environment section on ultraviolet light decontamination systems in order to facilitate the prevention and control of healthcare associated infections in NHS Scotland healthcare settings.

Target Audience: All staff involved in the prevention and control of infection in Scotland.

Update/review schedule: Updated as new evidence emerges with changes made to recommendations as required.

Review will be formally updated every 3 years with next review in 2025

Cross reference: National Infection Prevention and Control Manual

Update level: Practice – Changes to advised practice can be summarised by the recommendation that UV light decontamination systems should only be used in Scottish health and care settings when all safety, practical, and logistical recommendations can be followed.

Research – This review calls for research into UV decontamination devices/systems that includes suitable comparisons and control methods, focusses only on UV light decontamination as an intervention without changes other IPC methods or devices, and the cost effectiveness of using these systems.

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Version history

This literature review will be updated in real time if any significant changes are found in the professional literature or from national guidance/policy.

Version	Date	Summary of changes
2.0	November 2022	Update of evidence base using the two-person methodology as described in the NIPCM Development Process. Objectives added: • What are the different types of UV light decontamination systems? • When should UV light decontamination systems by used in health and care settings? • What is the current guidance or legislation regarding the use of UV light decontamination systems in health and care settings? Removal of objective: • Have UV light decontamination systems been assessed by the Rapid Review Panel? Recommendations added under the objectives: • What is the actual or proposed mechanism of action of UV light decontamination systems? • What are the different types of UV light decontamination systems? • When should UV light decontamination systems by used in health and care settings? • What is the procedure for using UV light decontamination systems? • What is the scientific evidence for effectiveness of UV light for decontamination of the healthcare environment? • Are UV light decontamination systems currently in use in UK healthcare settings? If not, are these systems used internationally? • Are there any safety considerations associated with using UV light decontamination systems in the healthcare setting?

Version	Date	Summary of changes
		• Are there any practical or logistical considerations associated with using UV light decontamination systems in the healthcare setting? • What costs are associated with using UV light decontamination systems in the healthcare setting?
1.1	December 2016	Addition of categories for recommendations. No changes made to the content of the literature review.
1.0	May 2015	Final for publication

Approvals

Version	Date Approved	Name
2.0	November 2022	Infection Control in the Built Environment and Decontamination (ICBED) Working Group
1.1	December 2016	ICBED Working Group
1.0	May 2015	ICBED Working Group

Contents

1. Objectives

The aim is to review the extant scientific literature regarding the use of ultraviolet light (UV) systems for environmental decontamination in health and care settings to inform evidence-based recommendations for practice. The specific objectives[1-8] of the review are to determine:

- What is the actual or proposed mechanism of action of UV light decontamination systems?
- What are the different types of UV light decontamination systems?
- When should UV light decontamination systems be used in health and care settings?
- What is the procedure for using UV light decontamination systems?
- What is the current guidance or legislation regarding the use of UV light decontamination systems in health and care settings?
- What is the scientific evidence for effectiveness of UV light for decontamination?
- Are UV light decontamination systems currently in use in UK healthcare settings? If not, are these systems used internationally?
- Are there any safety considerations associated with using UV light decontamination?
- Are there any practical or logistical considerations associated with using UV light decontamination systems?
- What costs are associated with using UV light decontamination systems?

2. Methodology

This targeted literature review was produced using a defined two-person systematic review methodology as described in the National Infection Prevention and Control Manual: Development Process.

Studies that investigate air decontamination systems including both UV light and filtration were excluded from this review since the efficacy of UV light decontamination could not be separated from that of the filtration systems.

3. Discussion

3.1 Implications for practice

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

Evidence identified that addressed the actual or proposed mechanisms of action of UV light decontamination systems included five before and after studies, [3, 7, 10-12] one *in vitro* observational study, [13] one narrative literature review, [14] and three pieces of expert opinion.[15-17] In accordance with the SIGN methodology, seven of these are considered level 3 evidence (six before and after studies[3, 7, 9-12] and one *in vitro* study[13]) and four are considered level 4 evidence (one narrative review[14] and three expert opinions[15-17]).

UV light can sever the molecular bonds in DNA and RNA when used at specific wavelengths, thereby destroying micro-organisms. DNA and RNA are particularly vulnerable to UV light at 254 nanometres (nm) because DNA absorbs UV light maximally in this region, resulting in the formation of lethal photoproducts.[11-13, 15, 18] UV light decontamination devices are often described as germicidal, meaning that they are capable of destroying microorganisms, particularly organisms that are pathogenic.[16]

UV 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 rays, will not be destroyed.[7] The dose required for inactivation of microorganisms may vary depending on the microorganisms and the system used.[3, 7, 14, 17] Within the evidence identified for this review, UV light dose administered was often not reported, when reported dose ranged from 450 to 22,000 microwatt per square centimetre ($\mu W/cm^2$) and 0.9 to 1 joules per square centimetre (J/cm^2) for UV-C devices and 0.29 to 2.59×10^8 J/cm^2 for UV-A devices.[3, 6, 13, 19-22]

What are the different types of UV light decontamination systems?

Evidence that addressed the different types of UV light decontamination systems available included one guidance document,[23] three systematic literature reviews,[24-26] four cohort studies,[9, 27-29] one single case study,[30] thirty two before and after studies,[2-4, 7, 8, 11, 20, 31-53] five observational studies,[6, 19, 54-56] nine *in vitro* studies,[13, 21, 22, 57-62] two case reports,[63, 64]

two narrative reviews,[14, 65] and five pieces of expert opinion.[15, 17, 66-69] In accordance with SIGN methodology, three are considered level 1 evidence (three systematic literature reviews[24-26]), fifty one are considered level 3 evidence (five cohort studies,[9, 27-29, 53] one single case study,[30] thirty one before and after studies,[2-4, 7, 8, 11, 20, 31-52] five observational studies,[6, 19, 54-56] nine *in vitro* studies[13, 21, 22, 57-62]), and nine are considered level 4 evidence (two case reports,[63, 64] two narrative reviews,[14, 65] five expert opinions[17, 66-69]). The guidance document included in this section was assessed using the AGREE tool as Recommended.[23]

There are several different types of UV decontamination systems that are presented across the evidence included in this review, often referred to as ultraviolet germicidal irradiation (UVGI) devices/systems. These include UV-A, UV-C, far-UV, and pulsed-xenon ultraviolet (PX-UV) systems.[15] The main difference between these systems is the wavelength of light emitted, letters following UV (e.g. -A, -B, -C) can be used to indicate these wavelengths. UV light falls within the spectrum of 100 to 400 nm, between 315 and 400nm is designated UV-A, between 280 and 315nm is UV-B and between 100 and 280nm is UV-C (peak at 254nm).[66] Far-UV systems also emit light within the UV-C range, with a peak around 222nm.[15, 18] Hand-held UV devices emitting UV-C light are also mentioned within the literature.[18, 31] PX-UV systems emit a broad spectrum of light that is filtered to produce mainly UV-C wavelengths.[14, 15] Different wavelengths of UV light emitted may impact upon the germicidal efficacy of the device.[15]

UV-C devices have the ability to deliver UV doses that have been shown to be effective against vegetative bacteria and spores, between the wavelengths of 100 and 280 nm, and are described within the literature as being germicidal.[15, 65-67, 70, 71] Devices are available that emit specific or broad wavelengths of UV light.[15] Low-pressure mercury lamps emit UV at a peak of 254nm, in a continuous manner, and are used within these systems.[15, 65, 66, 68] UV-C systems are investigated in 34 studies included in this review; two systematic literature reviews,[24, 25] one single case study,[30] eighteen before and after studies,[3, 4, 8, 11, 20, 31-43] five observational studies,[6, 19, 54-56] four *in vitro* studies,[13, 21, 57, 58] and 2 case reports. [63, 64] Three pieces of expert opinion and one guidance document also covered UV-C light devices.[23, 66-68]

PX-UV devices emit broad spectrum light (200-320nm), filtered to leave mainly UV-C wavelengths, in short pulses, in contrast to continuous UV-C devices.[14, 65] PX-UV devices also remove the need for mercury lamps. These systems were investigated in 18 studies included in this review; two systematic literature reviews,[25, 26] five cohort studies,[9, 27-29, 53] ten before and after studies,[2, 44-52] and four *in vitro* experimental studies.[59-62] One guidance document specifically covering PX-UV was also included in this review.[23] There was a much smaller

evidence base identified for UV-A (315-400nm) (two *in vitro* studies)[21, 22] and far-UV devices (280-315nm) (one before and after study).[18]

UV-B (280-315nm) and UV-A (315-400nm) light are not described as being germicidal by the International Commission on Non-Ionising Radiation Protection (ICNIRP), instead the risk they present for sunburn, skin cancer, cataracts, and skin aging are mentioned.[66, 68] These risks are also noted by the United States Food and Drug Administration (US FDA).[15] The germicidal efficacy of UV-A is assessed by Heilingloh *et al.* and Livingston *et al.* and is discussed in more detail under the objective 'What is the scientific evidence for the effectiveness of UV light for decontamination'.[21, 22]

Expert opinion from the US Centers for Disease Control and Prevention (CDC) and the ICNIRP also detail the use of upper-room UVGI devices.[17, 68, 69] These devices are installed permanently in rooms, pointing upwards to create a "disinfection zone" away from occupants of the room. Unlike other devices, it is reported that upper-room UV systems can be used when people remain in the room.[69] The CDC also mention in-duct UVGI systems, however, the majority of studies covering these devices bundle the efficacy of air filters and UV disinfection so were not included in this review.[69]

When should UV light decontamination systems be used in health and care settings?

The evidence identified that addresses when UV light decontamination systems should be used included one guidance document,[23] three cohort studies,[27, 28, 49] and six before and after studies.[8, 31, 32, 40, 48, 53] In accordance with SIGN methodology, nine of these studies are considered level 3 evidence (three cohort studies[27, 28, 49] and six before and after studies[8, 31, 32, 40, 48, 53]). The included guidance document was assessed as AGREE Recommend.[23]

In their guideline document, Beswick *et al*. state that there are a number of indicators that may trigger the use of a UV decontamination device, including availability of staff to undertake decontamination activities, and risk assessment based on the pathogenicity of potentially present organisms.[23] Outbreak situations are suggested as a possible indicator for the implementation of UV decontamination systems.[23] These indicators should be decided on and implemented via risk assessment by individual organisations and facilities.

Across the literature it is clear that UV decontamination is recommended most commonly as an adjunct to standard manual cleaning with sodium hypochlorite solutions or other regular detergents and cleaning solutions.[8, 23, 27, 28, 31, 32, 40, 48, 49, 53] Due to possible decreased efficacy of

UV decontamination devices when used on soiled surfaces, and the requirement for rooms to be cleared of staff, patients, and visitors when using certain devices, UV decontamination can often only be implemented as a terminal cleaning measure.

Ultimately, the efficacy of devices should be confirmed before use within the health and care environment. Details on scientific efficacy of UV decontamination devices is included in this review under the objective 'What is the scientific evidence for effectiveness of UV light for decontamination?'.

What is the procedure for using UV light decontamination systems?

Evidence regarding the procedure to be followed when using UV light decontamination systems consists of one guidance document,[23] three cohort studies,[27-29] eighteen before and after studies,[2-4, 6, 11, 12, 18, 31, 32, 34-36, 38, 39, 42, 44, 47, 65, 72] six *in vitro* studies,[13, 21, 22, 58, 59, 62] one narrative reviews,[14] and one expert opinion.[66] In accordance with SIGN methodology, twenty seven are considered level 3 evidence (three cohort studies,[27-29] eighteen before and after studies,[2-4, 6, 11, 12, 18, 31, 32, 34-36, 38, 39, 42, 44, 47, 72] six *in vitro* studies[13, 21, 22, 58, 59, 62]) and three were considered level 4 evidence (two narrative reviews[14, 65] and one expert opinion[66]). The included guidance document was assessed as AGREE Recommend.[23]

Standard facility cleaning procedures should be undertaken prior to the UV device entering the space requiring decontamination. Varma *et al*. and Nerandzic *et al*. noted that while using a hand-held UV-C device, their operators wear personal protective equipment (PPE).[18, 36] This requirement was not reported for automated devices, where operators leave the room while devices are in use, however, if required/recommended by the manufacturer, relevant PPE should be donned prior to use of the UV device. Safe limits for UV radiation (180-400nm) exposure were published by the ICNIRP in 2004 and state that over an 8 hour period, exposure of unprotected eyes and skin should not exceed 30 Joules per meter squared (Jm^{-2}).[66]

Since UV-C light travels in a straight line, it is important the surfaces to be disinfected using UV light systems are in direct line of sight of the devices to ensure optimal exposure.[14, 23] In order to achieve this, there may be a requirement to open drawers and cabinets, and place high touch items (such as remotes, call buttons, and blood pressure cuffs) in positions of exposure.[4, 27, 31, 34] A number of papers indicate that a number of decontamination cycles in different positions, or different lengths of cycle, are required to achieve this.[6, 14, 27, 28, 31, 35, 65] The number of UV cycles is determined by the size of the room requiring decontamination.[3, 32, 58] Lowman *et al*. states that

there should be a maximum of 2.5 meter radium from the centre of the UV device per cycle, however this may differ between UV devices.[32] Manufacturer's instruction should be followed when determining number of, or length of, cycles required in a given space. Efficacy of UV decontamination devices could also be impacted by the distance surfaces are from the light source, this is further discussed under the objective 'Are there any practical and logistical considerations associated with using UV light decontamination systems?'.

Prior to decontamination using continuous UV-C and PX-UV, rooms should be cleared of people, including patients, staff, and operators. For this reason devices are often automatic, commencing a UV decontamination cycle after a set time without movement in the room, or remotely operated, and can be turned on from outside the room being treated.[3, 11, 12, 32, 35, 42, 47, 72] Operators should set up the UV device, ensuring correct placement, then leave the room before activating the device, closing the door securely. Signage indicating the use of a UV device within the room is recommended to ensure no one enters during the UV treatment cycle. Some devices are fitted with motion sensors that facilitate automatic shut off when motion is detected.[3, 11, 12, 23, 29, 35, 38, 39, 42, 47, 58, 72]

UV decontamination cycle times vary between devices and the size of the room being treated, however, in the studies included in this review, cycles times ranged between 3 and 7 minutes.[2, 28, 31, 35, 42] Nottingham *et al*. stated that the UV device used in their study used cycle times of 20 minutes in small rooms (20m^2) and 55 minutes in large rooms (56.6m^2).[6] Anderson *et al*. reported cycles times when using 12,000 micro-watt per square centimetre (µWs/cm^2) as 25 minutes, and 45 minutes when using 22,000 µWs/cm^2.[4] Mahida *et al*. reported time taken for disinfection between 27 and 49 minutes with a dose of 12,000 µWs/cm^2, and 23 and 93 minutes with a dose of 22,000 µWs/cm^2, depending on size of the room being treated.[3] For *in vitro* studies, exposure time was as little as 20 seconds and as long as 40 minutes.[13, 21, 58-60, 62] Furthermore, Livingston *et al.* ran the UV-A device tested in their *in vitro* study for 4, 8, or 12 hours.[22] Across the literature it was indicated that UV-C and PX-UV devices automatically shut off following the set cycle time or when an adequate reflective dose of UV light has been emitted.

Following use, devices should be decontaminated following manufacturer's instructions, portable devices should be returned to their storage area, and rooms should be set up for the next incoming patient.

What is the current guidance or legislation regarding the use of UV light decontamination systems in health and care settings?

One British Standard,[73] two pieces of UK Government legislation,[74, 75] and one guidance document[23] were identified that cover the use of UV light decontamination systems in health and care settings. Three of these are mandatory pieces of legislation[73-75] and the guidance document was assessed as AGREE Recommend.[23] The British Standard BS 8628 relates to the method of determining disinfection efficacy of UV devices used in human health settings, that claim microbial inactivation of vegetative bacteria, bacterial spores, yeasts, fungal spores, viruses, and bacteriophages.[73] It should be noted that hand-held devices and air and water disinfection devices are excluded from this standard.[73]

Both the Health and Safety at Work etc Act 1974 and the Control of Artificial Optical Radiation at Work Regulations 2010 are applicable to the use of UV decontamination devices.[74, 75] Employers are required to remove or reduce risk to workers health and safety as far as is reasonably practicable.[74] UV light decontamination systems are identified as a hazard in the Control of Artificial Optical Radiation at Work Regulations 2010 and methods for removing or reducing the risk of these devices are covered under the objective 'What are the safety considerations associated with using UV light decontamination systems?'.[75]

High quality guidance on the use of UV light decontamination devices in health and care settings is limited. Beswick *et al.* published guidance covering the use of automated room decontamination systems, including UV light decontamination systems.[23] Within these guidelines, recommendations and good practice points for indications for use, procedure, and practical considerations are provided. This document was produced by a Healthcare Infection Society Working Party made up of Infection Prevention and Control (IPC) experts and professionals from the UK, making the recommendations provided applicable to Scottish health and care settings.[23]

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

As mentioned under the objective covering legislation and guidance, the British Standard BS 8628 relates to the disinfection efficacy of UV devices used in health settings that claim microbial inactivation of vegetative bacteria, bacterial spores, yeasts, fungal spores, viruses, and bacteriophages.[73] Any devices (other than those excluded from this Standard) used within

Scottish health and care settings should have been tested using the methods of this Standard and have proven disinfection capability before use.[73]

There is a great deal of evidence relating to the efficacy of UV decontamination devices, however the majority of this is of low quality. Evidence for this objective was informed by three systematic literature reviews with meta-analyses,[24-26] three cohort studies,[27-29] nine before and after studies,[3, 8, 20, 42, 46, 49, 50, 52, 76] one in situ observational study,[19] and seven *in vitro* studies.[6, 13, 21, 22, 59, 60, 62]

The outcome measure used to demonstrate effectiveness of UV decontamination is either a reduction in environmental contamination (experimental or real-life) and/or incidence of hospital associated infections (HAIs). Assessing reduction in incidence of HAIs provides evidence of the impact of interventions at a patient level, it also allows analysis to focus on targeted patient groups, often those that are vulnerable to HAIs. However, this outcome measure often allows for confounding factors, including the implementation of other interventions within the same study period which may also impact on HAI rates. These studies typically fail to specify HAI routes of transmission, further limiting analysis of the impact interventions may be having.

Reduction in environmental contamination is often measured using reduction in colony forming units (CFU) or plaque forming units (PFU) of target pathogens. Using this as an outcome measure allows for assessment of specific areas within the care environment, such as high touch surfaces. These studies also prove the presence of HAI pathogens on surfaces and can support the need for robust cleaning methods, sometimes targeted to specific pathogens. However, this outcome measure does not capture the infectivity of organisms found within the environment and is limited by not linking to real time infection rates. Additionally, these studies are typically setting specific so may not be applicable to all health and care settings, or all variations of treatment areas. Ten studies assessed HAI rates,[24-29, 49, 50, 52, 76] and fourteen assessed environmental contamination,[3, 8, 19, 20, 42, 46, 77] including seven *in vitro* studies undertaken in laboratories or experimental settings.[6, 13, 21, 22, 59, 60, 62]

HAI Rates

The studies that assessed the impact of implementation of UV decontamination devices on HAI rates included three systematic reviews with meta-analysis,[24-26] three cohort studies,[27-29] and three before and after studies.[49, 50, 52] Three systematic literature reviews with meta analyses found significant decreases in *C. difficile* infection (OR = 0.43, 95% CI 0.25 - 0.74, I^2 = 0%[24]; pRR 0.6, 95% CI 0.49-0.84[25]; IRR 0.73, 95% CI 0.57–0.94, I^2 = 72%, P = 0.01)[26] when using UV light decontamination devices (both UV-C and PX-UV) in addition to standard cleaning with

sodium hypochlorite solutions. One of these found that UV decontamination was also associated with reduction in environmental contamination with *C. difficile*(OR 0.79, 95% CI 0.53-1.19, I^2=0%).[24] Additionally, Dong *et al.*, found UV light decontamination treatment resulted in significant reduction of MRSA infections (IRR: 0.79, 95% CI 0.64–0.98, I^2 = 35%, P = 0.03).[26] Two papers analysed the impact of UV decontamination on VRE infections, with one finding a significant reduction (pRR 0.42, 95% CI 0.28-0.65)[25] and the other finding an insignificant reduction (IRR: 0.80, 95% CI 0.63–1.01, I^2 = 60%, P = 0.06).[26] Of the 20 papers pooled for meta-analysis across these studies, 5 did not meet the criteria for inclusion in this review and were therefore not included as stand-alone studies.

Two of the included cohort studies assessed the impact of UV light decontamination on hospital-associated *C. difficile* infection (CDI), reductions were found in both when compared to standard cleaning only, however significance was only reported by Samathkumar *et al.* (p=0.034).[27, 29] Sampathkumar also reported significant reductions in rate of CDIs per 10,000 patient days in the study units from 21.3 to 11.2 (p=0.03).[27] Brite *et al.* assessed the impact of a PX-UV decontamination device on the rate of toxigenic *C. difficile* (TCD) in a bone marrow transplant unit. They found no significant change compared to standard cleaning alone (p=0.5).[28]

Two of these also assessed the impact of UV decontamination on the rates of VRE.[27, 28] Sampathkumar *et al.* found a significant reduction in rate of VRE per 10,000 patient days from 25.6 to 12.3(p=0.02).[27] Brite *et al.* found no significant change in the rate of VRE infections between their pre- and post-intervention periods (p=0.4).[28]

Three of the included before and after studies used rates of hospital associated infections (HAIs) as their outcome measure and used PX-UV devices. In three of these studies a significant reduction in CDI was reported.[49, 50, 52] Significant reductions in MRSA, VRE and MDR gram negative bacteria infections were also seen across these before and after studies.[49, 50, 52]

All of these before and after studies have similar limitations. All were undertaken within the United States meaning their applicability to Scottish health and care settings may be limited.[49, 50, 52, 76] They were all undertaken in specific areas of the facilities (ICU, paediatric, and contact precaution rooms) meaning their findings may not be applicable across all areas of health and care settings.[49, 50, 52, 76] The use of antibiotics and other medications, that would have assisted in reducing rates of HAIs, was not addressed by any of these studies. Other environmental cleaning initiatives were reported within the baseline or intervention period of two of these

studies.[49, 50] Additionally, authors of two studies were employed by the manufacturer of the UV light decontamination device assessed within the studies.[49, 52]

Environmental Contamination

Studies that assessed environmental contamination included one cohort study,[77] five before and after studies,[3, 8, 20, 42, 46] and one observational study.[19] The included cohort study assessed the impact of UV decontamination on MRSA, finding that 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.[77]

Five before and after studies used reduction in environmental contamination as an outcome measure. Four assessed UV-C devices, and one assessed a PX-UV device. Two of these studies reported complete removal of bacterial contamination.[3, 20] Dos Santos *et al*. also reported log 4 reduction of *C. albicans*.[20] Significant reductions in microbial colony counts, heterotrophic plate counts, aerobic and anaerobic bioaerosols were reported by three studies.[20, 42, 46] A non-significant reduction of MRSA was reported by Mustapha *et al*.[8]

Mahida *et al.* investigated the difference in efficacy in direct line of sight and in shaded areas of the room. They reported reductions of 99.97% of organisms when in direct sight of UV light and reductions of between 90 and 99.99% reductions in shaded areas.[3]

One *in situ* observational study was identified that assessed the efficacy of UV decontamination devices. When challenged on agar plates there was a >90% mean kill rate for MRSA, extended-spectrum beta-lactamase (ESBL)-producing *Klebsiella pneumoniae*, carbapenem-resistant *K. pneumoniae*, VRE, multi-drug-resistant (MDR) *A. baumannii*, and *Candida auris*.[19] Environmental swabbing in this study found 92% reduction after cleaning with sodium hypochlorite, was increased to 100% after UV treatment.[19] This study was undertaken in a single centre in South Africa, limiting the applicability and generalisability of its findings.

Further evidence of reduction of bioburden was provided by the findings of the seven included *in vitro* studies.[6, 13, 21, 22, 59, 60, 62] Three of these assessed the direct exposure of test organisms to UV-C light, resulting in complete inactivation of SARS-CoV-2 after 9 minutes,[21] ≥4 log reductions of *A. baumannii* after 20 minutes,[6, 13] and >2 log reduction of *E. faecalis* and *S. aureus* after 20 minutes.[6] When applied for 55 minutes ≥4 log reductions were reported for *A. baumannii, E. faecalis*, and *S. aureus*.[6] One study assessed the indirect exposure of test organisms to UV-C light and found that after a 55 minute treatment time, ≥4 log reduction was observed for *A. baumannii* and >2 log reductions were observed for *E. faecalis* and *S. aureus*.[6]

Three studies assessed direct exposure of test organisms to PX-UV light, resulting in >5 log reductions in MRSA, VRE, carbapenemase-producing *K. pneumoniae*, ESBL-producing *E. coli*, and MDRA,[59] >4 log reduction in SARS-CoV-2,[60] and 99.5% and 98.5% reductions in *C. auris* and *C. parapsilosis*, respectively.[62]

Two studies assessed the direct exposure of test organisms to UV-A light, and reported <2 log reductions for MRSA, a non-enveloped virus bacteriophage (MS-2), *C. auris* and an enveloped virus bacteriophage (Phi X174) after 24 hours exposure.[22] The second paper reported 1 log reduction of SARS-CoV-2 after 9 minutes of exposure.[21] The US FDA also mention UV-A light within a published expert opinion, stating that this wavelengths, along with UV-B, is “expected to be less effective than UV-C radiation”, specifically when used to inactivate SARS-CoV-2.[15]

The impact of distance on the efficacy of UV light decontamination devices was assessed by one *in vitro* study, without other variables also being changed. After 5 minutes of PX-UV treatment at 1 meter distance, *C. auris* and *C. parapsilosis* were reduced by 99.5% and 98.5%, respectively. After the same treatment time, but with the device 2 meters from inoculated glass slides, reductions of 90.2% and 15.7%, respectively, were reported.[62] Significance was not reported within this study.

It should be noted that across these *in vitro* studies the wavelengths and doses of UV light test organisms were exposed to varied, and often was not reported.

In vitro studies are inherently limited in their methodologies which impacts on their applicability to health and care settings. Four of the included studies focussed on one or a small number of pathogens to assess efficacy of UV light decontamination devices.[13, 21, 22, 62]. Furthermore, test surfaces (steel, aluminium, glass, plastic, paper) may not reflect surfaces present within the health and care environment that could be contaminated with potentially pathogenic organisms.[1, 6, 13, 22, 62] Additionally, the use of seeded agar plates can impact both the level of bioburden assessed and may not reflect hard surfaces commonly found in health and care settings and targeted by environmental cleaning procedures.[59] Sample sizes across the included studies are small which limits their generalisability in practice. Finally, in a number of the included studies, manufacturers are involved in funding of studies or employ authors.

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, the majority of this evidence was considered level 3 evidence (3 cohort studies [27-29], 9 before and after studies[3, 8, 20, 42, 46, 49, 50, 52, 76], 1 *in situ* observational study[19], 7 *in vitro* studies[6, 13, 21, 22, 59, 60, 62]). As

systematic literature reviews with meta-analyses Kato *et al*., Marra *et al*., and Dong *et al*. are considered level 1+ evidence. The methodologies of the included studies are variable, assessing a number of different devices that work with different doses, treatment times, and wavelengths of UV light. For this reason, their generalisability is limited. Additionally, the *in situ* studies were undertaking in various health and care settings, in a number of countries. Sample sizes across the included literature were also small, limiting how robust their findings were. These limitations impact greatly on the ability to make recommendations on efficacy.

Although available evidence is limited and of low quality, there is consistency across the evidence showing UV light decontamination as an effective method against a number of organisms. Four clinical studies demonstrated reduction in rates of common hospital associated infections,[27-29, 77] with three of these reporting these as significant.[27, 29, 77] Ten clinical studies reported reduction in bioburden,[3, 8, 19, 20, 42, 46, 49, 50, 52, 76] with six reporting these reductions as significant,[20, 42, 46, 49, 50, 52] and all seven of the included *in vitro* studies reported reductions in the test organisms following exposure to UV light decontamination devices.[6, 13, 21, 22, 59, 60, 62]

Are UV light decontamination systems currently in use in UK health and care settings? If not, are these systems used internationally?

There is no mention of UV light decontamination systems in the NHS Scotland National Cleaning Services Specification, or the National Patient Safety Agency (NPSA) Revised Healthcare Cleaning Manual.[78, 79]

Four before and after studies,[2, 3, 33, 45] one observational study,[55] and one guideline document[23] included in this review were undertaken within or written for UK health and care settings. This evidence suggests that UV light decontamination systems are used or have the potential to be used to some extent within UK health and care settings. In accordance with SIGN methodology, five are considered level 3 evidence (four before and after studies[2, 3, 33, 45] and one observational study[55]) and the guidance document was assessed as AGREE Recommend.[23]

Additionally, the Scientific Advisory Group for Emergencies - Environmental and Modelling Group (SAGE EMG) published a summary paper that outlined the use of UV disinfection systems for the control of COVID-19.[67] There is also a British Standard (BSI 2628) that relates to the use of UV disinfection systems in a number of settings, including health and care.[73] These further support the use of UV decontamination systems within UK health and care settings.

What are the safety considerations associated with using UV light decontamination systems?

Two pieces of legislation,[74, 75] one guidance document,[23] one randomised control trial,[80] two cohort studies,[29, 43]one single case study,[81] sixteen before and after studies,[3, 4, 11, 12, 18, 32, 35, 36, 38, 39, 42, 44, 46, 47, 53, 72] one observational study,[55] one *in vitro* study,[58] one case report,[63] and five expert opinion pieces[17, 66, 67, 71, 82] contributed towards evidence on safety considerations that should be made when using UV light decontamination systems. In accordance with SIGN methodology, the randomised control trial was considered level 1 evidence,[80] twenty one were considered as level 3 evidence (two cohort studies,[29, 43] one single case study,[81] sixteen before and after studies,[3, 4, 11, 12, 18, 32, 35, 36, 38, 39, 42, 44, 46, 47, 53, 72] one observational study,[55] one *in vitro* study[58]), and six were considered level 4 evidence.[17, 63, 66, 67, 71, 82] The guidance document was assessed as AGREE Recommend and the legislation is considered mandatory.

Under the Health and Safety at Work Act 1974, suppliers of UV devices have the responsibility to provide devices that are safe for use.[74] Furthermore, employers are expected to remove or reduce risk of staff injury as far as is reasonably practicable. UV decontamination devices are also covered by the Control of Artificial Optical Radiation at Work Regulations (AOR) 2010.[75] These regulations state that employers are required to protect the eyes and skin of workers from exposure to potentially harmful radiation, including from ultraviolet sources. The suggested methods for this include:

- use of an alternative, safer light source that achieves the same result
- use of filters, screens and curtains, remote viewing, remote controls, and time delays
- providing workers with training on best-practice for using devices
- organise work in a way that minimises exposure and restricts access to hazardous areas
- provide staff with personal protective equipment (PPE)
- use of safety signage[75, 82]

One of the main safety considerations for using UV decontamination devices is the risk of radiation injuries following exposure, specifically eye and skin damage when exposed to UV radiation for extended periods of time, or from improperly fitted or maintained devices.[23, 63, 66, 82] UV radiation is absorbed by all components of living organisms, with peak absorption by DNA at approximately 260nm.[71]

Woods *et al*. undertook an observational study assessing the effects of a 222nm emitting UV decontamination device on healthy skin.[55] This study was conducted with a very small sample size of only four participants, however it did find that even at low doses UV light from the device had the potential to cause erythema (redness) and DNA damage (cyclobutene pyrimidine dimerization).[55]

Vaidya *et al*. published a case report detailing the condition of nine operating theatre personnel with intense tearing of the eyes and erythematous rash on exposed body parts, which developed between 2 and 4 hours following a work shift.[63] UV light radiation was concluded as the cause for these symptoms after it was discovered that germicidal lamps were accidentally switched on, exposing operating theatre personnel to 8 hours of UV radiation. This was possible due to the placement of UV device switches being located near the regular light switches. This risk is addressed by the CDC when they recommend that switches should be in restricted areas or lockable switches should be used to prevent this.[17]

The ICNIRP published expert opinion recommendations in 2004 providing limits for exposure to UV radiation (180-400nm), over an 8-hour period. For unprotected skin and eyes this limit was $30 Jm^{-2}$.[66]

Barriers between operators and UV light sources are reported to be protective against the risk of radiation. SAGE EMG stated in their summary paper that UV-C light is inhibited by double-glazed glass, and rarely passes through single-glazed panes.[67] In order to ensure safety, staff should exit rooms being treated prior to activating UV decontamination devices.[67] This is supported by a number of experimental studies included in this review that state operators leave the room before activating UV devices, or that devices are only used in empty rooms.[3, 11, 12, 32, 35, 42, 44, 72] While it is known that UV light does not usually penetrate glass, this should be confirmed by use of a light meter on the outside of glass between operators and the rooms being treated.[23] The ICNIRP recommend that UV measurements are undertaken for risk assessment, not during every use.[66]

Another safety feature fitted to minimise the risk of UV radiation exposure is motion activated shut off. Devices can include sensors that detect movement within a room being treated, triggering the device to immediately end its cycle, rather than complete the pre-set treatment time or reach acceptable reflected dose.[3, 11, 12, 23, 29, 35, 38, 39, 42, 43, 47, 58, 72]

Beswick *et al*. recommend that any personnel that will be using UV decontamination devices should receive training, particularly from the manufacturer of the device.[23] The CDC also note that staff should be trained in using UV devices.[17] It is stated by SAGE EMG that UV-C and

upper-room GUVI disinfection systems can have significant safety considerations and they should only be used by trained staff "*with appropriate risk assessment and controls in place*."[67] These statements are supported by experimental studies included in this review that include mention of staff training before implementation of a UV decontamination device.[4, 12, 43, 80, 81]

The need for PPE is mentioned by Varma *et al*. and Nerandzic *et al*., where is it stated that when using a hand-held UV device, operators wore protective goggles and gloves.[18, 36] In these studies, operators were not in the line of direct exposure from the UV devices and so the risk of exposure related injuries may have been reduced, however, the use of PPE further reduced this risk.[18, 36] The ICNIRP (2004) recommend that engineering measures are preferred to PPE.[66] These engineering controls include glass and plastic shielding cabinets, curtains and barriers. Even separation by distance is mentioned as a method of protection from exposure.[66]

The CDC note that warning signage should be in place where UVGI devices are used.[17] The CDC also highlight the risk of untrained personnel accessing UV device power supplies and either turning on or off unintentionally. In response to this it is recommended that having switches in restricted areas or using lockable switches could prevent this.[17]

A safety risk that is often identified when discussing UV decontamination devices is the production of ozone gas by UV lamps. Beswick *et al*. mention that there have been anecdotal reports of ozone production by UV decontamination devices.[23] The ICNIRP note that some UVC lamps marketed for home use emit ozone "which is irritating to breathing passages (nose, throat and lungs), particularly for those who have respiratory sensitivity such as asthma or allergies."[66] Casini *et al*. noted that the PX-UV device used in their study did not produce ozone to levels above short-term exposure limits set by the Occupational Safety and Health Administration (OSHA) (USA).[47] This limit is stated to be 0.1 parts per million per 8 hours (0.1ppm/8h).[47]

One health and safety factor that should be considered prior to the use of UV decontamination systems is the size and weight of the devices. Many of these devices are portable and are expected to be moved between rooms and within rooms between treatment cycles. The weight and size of the devices should be considered before implementation since additional health and safety measures may be required to ensure safe use by all cleaning personnel. Devices used in the included studies that contained information on weight and size both weighed 68kg[29, 53], apart from the larger robotic device used by Russo *et al.* that weighed 140-180kg.[38] However, this device was equipped to self-manoeuvre between treatment positions, rooms, and storage facilities. Some devices are able to be moved on wheels to aid in transportation from storage to and between rooms being treated.[4, 11, 39, 43, 46]

What are the practical and logistical considerations associated with using UV light decontamination systems?

Four cohort studies,[27-29, 83] one single case study,[30] eleven before and after studies,[31, 35, 42] two observational studies,[19, 56] five *in vitro* studies,[13, 21, 58, 59, 62] two narrative literature reviews,[14, 85] and two expert opinions[17, 67] informed the evidence base for practical and logistical considerations that should be made when using UV light decontamination systems. In accordance with SIGN methodology, twenty four were considered level 3 evidence (Four cohort studies,[27-29, 83] one single case study,[30] eleven before and after studies,[31, 35, 42] three observational studies,[19, 56, 84] five *in vitro* studies,[13, 21, 58, 59, 62]), and four were considered level 4 evidence (two narrative literature reviews,[14, 85] and two expert opinions[17, 67]).

All room decontamination technologies have advantages and disadvantages. UV decontamination systems operation time may be an issue for some settings, particularly where patient turnover is high. Cycle times vary between devices and the size of the room being treated, however, in the studies included in this review, cycle times ranged between 3 and 7 minutes.[28, 31, 35, 42] For *in vitro* studies, exposure time was as little as 20 seconds and as long as 40 minutes.[1, 13, 21, 58, 59, 62] UV decontamination was reported to add between 15 and 60 minutes to the total room cleaning time, depending on the size of the room and number of cycles required.[2, 27, 29, 83] Total room turnaround time was reported to be between 56 and 156 minutes when UV decontamination was added to standard terminal cleaning, compared to between 44 and 69 minutes with only standard terminal cleaning.[3, 30, 56] As mentioned within the sections on procedure for using UV decontamination devices and scientific efficacy of UV decontamination devices, the use of UV decontamination systems does not remove the need for manual cleaning, and so timings for using UV decontamination devices should be added to the time taken for these procedures.

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.[4] Jinadatha *et al*. 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.[5] Due to this, and the requirement for rooms to be cleared of staff, patients, and visitors when using certain devices, UV decontamination can often only be implemented as a terminal cleaning measure.

As mentioned within the section covering safety considerations, barriers between operators and UV light sources are reported to be protective against the risk of radiation.[67] However, this means that UV devices are only effective for surfaces in their direct line-of-sight. For this reason, many manufacturers recommend multiple cycle times in different locations within the room. Boyce *et al*. 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.[85] Kitagawa *et al*. found that PX-UV decontamination is not effective against bacteria that is shielded from direct exposure.[59] However, in an in situ experimental study Nottingham *et al*. found that the use of a UV-C device at a reflective dose 12,000 μWs/cm2, resulted in similar reductions in bacterial contamination on agar plates in positions of both direct and indirect exposure.[6]

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.[3, 14] 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.[3, 7, 17]

Efficacy of UV decontamination devices could also be impacted by the distance surfaces are from the light source. Maslo *et al*. investigated the efficacy of UV light decontamination at different distances and found that greater reductions were achieved at shorter distances.[62] However, a number of studies found no significant difference in reduction of microorganisms at different distances.[6, 8, 19] Ultimately manufacturer's instructions should be followed for positioning and cycle time of any UV decontamination device.

Another consideration that should be made before implementing UV decontamination devices is the ongoing maintenance requirements. The CDC state that UVGI lamps need to be replaced every 1-2 years and replacement schedules should be agreed with the device manufacturers.[17]

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.[14]

What costs are associated with using UV light decontamination systems?

One guidance document,[23] two cohort studies,[29, 49] one before and after study,[53] and one expert opinion[17] included in this review addressed the cost of using UV light decontamination systems. In accordance with SIGN methodology, three are considered level 3 evidence (two cohort studies,[29, 49] one before and after study[53]), the expert opinion was considered level 4,[17] and the guidance document was assessed as AGREE Recommend.[23] Assessments of cost of implementing UV decontamination systems are limited due to the varying cost of devices and ongoing maintenance, facility/location specific specifications, and often do not account for additional costs associated with implementing UV decontamination systems such as staff training and cost of labour.

In their 2022 guidelines, Beswick *et al*. stated that purchasing an automated decontamination device outright can cost in excess of £50,000.[23] While there are limited consumables related to UV decontamination devices, additional service contracts covering risk assessment, training of staff, and maintenance would increase this cost further.[23] As is mentioned above, the cycle time of devices vary and the potential economic impact of this in terms of staffing and labour costs should also be considered when choosing a UV decontamination device.

The CDC stated in 2021 that the cost to install a system suitable for a 500 ft^2 room (two or three UV fixtures) is approximately $1,500 to $2,000.[17] There are often options for long-term hire or loan, rental, or rental with the option to purchase at the end of a set period available to spread the cost of these devices.[17] Ghantoji *et al*. stated that the PX-UV device used in their study costs $3000 per month and can disinfect more than 30 rooms per day.[53] This equates to a per-room cost of approximately $3 (excluding labour). Levin *et al*. reported that leasing two PX-UV devices for their study cost less than $5,000 a month.[29]

Potential savings from reduction in healthcare associated infection can also be considered when choosing to implement a UV decontamination system however there is little direct evidence to demonstrate this. While Miller *et al*. estimated that implementation of PX-UV disinfection resulted in savings of approximately $300,000 associated with reduction in HAI cases over the course of their 15 month intervention period, this study did not account for potential confounders that may have impacted the observed reduction in HAI rates, including compliance with IPC measures and the criteria for defining HAI cases.[49]

3.2 Implications for research

As a result of the COVID-19 pandemic, there has been an increase in research concerning the use of UV devices for the decontamination of PPE and other single-use medical equipment. This evidence was not included in this review as it did not meet the objectives (decontamination of the environment). Additionally, the decontamination of single-use equipment is not current practice in NHSScotland.

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 include a suitable comparison/control method of standard or terminal cleaning. In some cases, studies did not specify 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 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.

As mentioned above, there is a large amount of evidence regarding the use of UV devices within ventilation systems, often containing HEPA or equivalent filters. This bundled approach of reducing air bioburden limits the ability to assess the efficacy of the UV decontamination element of the system. Assessment of UV-ventilation systems on air bioburden was out with the remit of this literature review.

There are a number of practical, logistical, and safety considerations that need to be taken into account when deciding to use UV light decontamination devices, including clearing rooms of personnel to avoid exposure injuries, ease of transportation for portable devices, and time for decontamination treatment cycles. These reflect the UV decontamination evidence and technology available at the time of writing. Further advancements in this field removing these considerations or reducing the risks posed by use of UV light decontamination devices in health and care settings would be advantageous.

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, which is challenging to attribute to the UV decontamination alone. 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.

4. Recommendations

This review makes the following recommendations based on an assessment of the extant scientific literature on the use of Ultraviolet Light for environmental decontamination in health and care settings.

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

Note: Recommendations are not applicable to this objective. The below statements are summaries of the evidence relating to this objective.

UV light severs molecular bonds in DNA and RNA rendering it inactive.

UV light cannot destroy organisms when they are not in the direct line of exposure.

What are the different types of UV light decontamination systems?

Note: Recommendations are not applicable to this objective. The below statements are summaries of the evidence relating to this objective.

UV-C devices emit light within the wavelengths of 100 to 280nm, with a peak at 254nm.

Pulsed-xenon ultraviolet devices emit broad spectrum light that is filtered to mainly UV-C light, and do not require mercury lamps.

UV-A devices emit light within the wavelengths of 315 and 400nm.

UV-B/Far-UV devices emit light within the wavelengths of 280 and 315nm.

Upper-room UV decontamination devices are installed permanently and create a “disinfection zone” away from occupants of the room.

When should UV light decontamination systems be used in health and care settings?

UV decontamination devices should only be used as an adjunct to standard cleaning.

(Category B recommendation)

What is the procedure for using UV light decontamination systems?

UV decontamination devices should be used in accordance with manufacturer's instructions.

(Category B recommendation)

If manufacturer's instructions indicate, personal protective equipment should be worn while using UV decontamination devices.

(Category B recommendation)

Prior to UV light decontamination treatment, where indicated by UV type, the room should be adequately prepared e.g., opening drawers and cabinets, and placing high touch items in direct line of sight of the device.

(Category B recommendation)

Manufacturer's instruction should be followed when determining number of, or length of, cycles required in a given space.

(Category B recommendation)

No staff, patients, or visitors should be permitted to be in rooms being treated with continuous UV light decontamination and safety/no entry signage must be displayed while the device is in use.

(Category B recommendation)

Operators should leave the room, securing the area prior to activation of continuous UV light decontamination device.

(Category B recommendation)

Manufacturer's instructions must be followed to ensure appropriate UV light cycle time is delivered.

(Grade B recommendation)

What is the current guidance or legislation regarding the use of UV light decontamination systems in health and care settings?

Employers are required to remove or reduce risk to workers health and safety when using UV decontamination systems, as far as is reasonably practicable.

(Mandatory)

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

Manufacturers' instructions for use must be followed to ensure all surfaces are adequately decontaminated.

(Category B recommendation)

UV decontamination systems are effective at reducing environmental bioburden when used in addition to standard cleaning practices.

(Category B recommendation)

There is insufficient evidence available to provide recommendations on specific UV decontamination treatment dose and cycle time or specific models.

(Category B recommendation)

Are UV light decontamination systems currently in use in UK health and care settings? If not, are these systems used internationally?

UV light decontamination systems would only be recommended for use within Scottish health and care settings where all safety, practical, and logistical recommendations can be followed.

(Category C recommendation)

Are there any safety considerations associated with using UV light decontamination systems?

Employers must remove or reduce risk of staff injury as far as is reasonably practicable.

(Mandatory)

Employers are required to protect the eyes and skin of workers from UV radiation.

(Mandatory)

No staff, patients, or visitors should be permitted to be in rooms being treated with continuous UV light decontamination.

(Category B recommendation)

Risk assessments should be in place to assess UV exposure of individuals in the vicinity (staff, patients, visitors).

(Category C recommendation)

Methods of protection from UV radiation may include:

- use of alternative, safer light source that achieves the same result
- use of filters, screens and curtains, remote viewing, remote controls, and time delays
- providing workers with training on best-practice for using devices
- organise work in a way that minimises exposure and restricts access to hazardous areas
- provide staff with personal protective equipment (PPE)
- use of safety signage

(Category C recommendation)

Are there any practical or logistical considerations associated with using UV light decontamination systems?

In use UV light systems must be maintained in good working order with a system of programmed maintenance, supported by the manufacturer and including quality assurance, in place with documented evidence.

(Category B recommendations)

UV light systems should not be used to replace routine cleaning.

(Category B recommendation)

The time for both standard terminal cleaning and UV decontamination treatment should be factored into room turnaround time.

(Category B recommendation)

Manufacturer's instructions should be followed when deciding UV decontamination treatment cycle and placement of device.

(Category B recommendation)

Effort should be made to ensure that UV devices are in direct line of exposure of surfaces being decontaminated to ensure efficacy.

(Category B recommendation)

What costs are associated with using UV light decontamination systems?

Setting/organisation-specific cost analysis should be undertaken before purchasing a UV light decontamination system.

(Category B recommendation)

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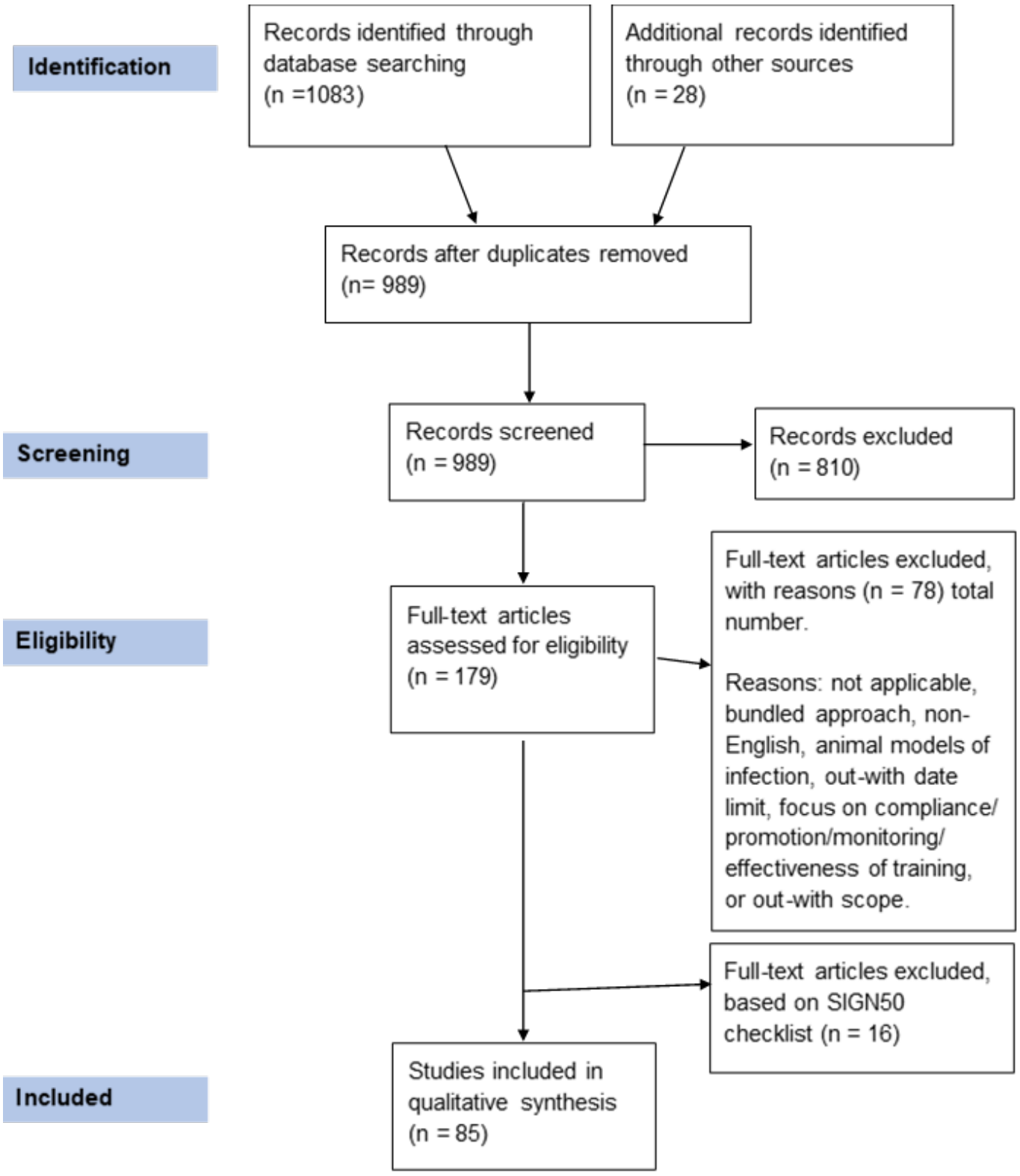
Appendices

Appendix 1: Grades of recommendation

Grade	Descriptor	Levels of evidence
Mandatory	'Recommendations' that are directives from government policy, regulations or legislation	N/A
Category A	Based on high to moderate quality evidence	SIGN level 1++, 1+, 2++, 2+, AGREE strongly recommend
Category B	Based on low to moderate quality of evidence which suggest net clinical benefits over harm	SIGN level 2+, 3, 4, AGREE recommend
Category C	Expert opinion, these may be formed by the NIPC groups when there is no robust professional or scientific literature available to inform guidance.	SIGN level 4, or opinion of NIPC group
No recommendation	Insufficient evidence to recommend one way or another	N/A

Appendix 2: PRISMA Flow Diagram[86]



Appendix 3: Considered Judgement Forms

Objective 1: What is the actual or proposed mechanism of action of UV light decontamination systems?

1. Volume of Evidence - Quantity of evidence on this topic and quality of method
Nine pieces of evidence were identified that are relevant to this research question; 3 pieces of expert opinion, 4 before and after studies, 1 in vitro observational study, and 1 narrative review.
2. Applicability – in Scotland
A single before and after study that were identified as relevant to this research question was undertaken in the United Kingdom. The remaining studies and pieces of expert opinion were undertaken or written for health and care settings of the United States.
3. Generalisability - How reasonable it is to generalise from the available evidence
Identified evidence is reasonably generalisable based on wavelength of UV light used.
4. Consistency - Degree of consistency demonstrated by the available evidence
The method of DNA and RNA deactivation by UV light decontamination systems was consistently reported across the relevant evidence.
5. Potential Impact of the intervention
6. Other factors to consider while assessing the evidence base

7. Evidence Statement – synthesis of the evidence relating to this question	**Evidence level**
Evidence identified that addressed the actual or proposed mechanisms of action of UV light decontamination systems included five before and after studies, [3, 7, 10-12] one *in vitro* observational study, [13] one narrative literature review, [14] and three pieces of expert opinion.[15-17] In accordance with	

7. Evidence Statement – synthesis of the evidence relating to this question	Evidence level
the SIGN methodology, seven of these are considered level 3 evidence (six before and after studies[3, 7, 9-12] and one *in vitro* studies[13]) and four are considered level 4 evidence (one narrative review[14] and three expert opinions[15-17]). UV light can sever the molecular bonds in DNA and RNA when used at specific wavelengths, thereby destroying micro-organisms. DNA and RNA are particularly vulnerable to UV light at 254 nanometres (nm) because DNA absorbs UV light maximally in this region, resulting in the formation of lethal photoproducts.[11-13, 15, 18] UV light decontamination devices are often described as germicidal, meaning that they are capable of destroying microorganisms, particularly organisms that are pathogenic.[16] UV 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 rays, will not be destroyed.[7] The dose required for inactivation of microorganisms may vary depending on the microorganisms and the system used.[3, 7, 14, 17] Within the evidence identified for this review, UV light dose administered was often not reported, when reported dose ranged from 450 to 22,000 microwatt per square centimetre ($\mu W/cm^2$) and 0.9 to 1 joules per square centimetre (J/cm^2) for UV-C devices and 0.29 to 2.59×10^8 J/cm^2 for UV-A devices.[3, 6, 13, 19-22]	

8. Recommendation -	Grade of Recommendation
Note: Recommendations are not applicable to this objective. The below statements are summaries of the evidence relating to this objective. UV light severs molecular bonds in DNA and RNA rendering it inactive. UV light cannot destroy organisms when they are not in the direct line of exposure.	

Objective 2: What are the different types of UV light decontamination systems?

1. **Volume of Evidence** - Quantity of evidence on this topic and quality of method
Sixty four pieces of evidence were identified that were relevant to this research question; one guidance document, three systematic literature reviews, four cohort studies, one single case study, thirty two before and after studies, five observational studies, nine in vitro studies, two case reports, two narrative reviews, and five pieces of expert opinion.
2. Applicability – in Scotland
Seven pieces of evidence identified as relevant to this research question were written for or undertaken within the United Kingdom (1 guideline document, 4 before and after, 1 observational, 1 expert opinion). Nine pieces of evidence were completed in vitro and so may be applicable to NHS Scotland health and care settings, along with two expert opinion pieces from international organisations. The remaining pieces of evidence were written for or undertaken in the United States, South Africa, Taiwan, Italy, Brazil, and The Netherlands.
3. Generalisability - How reasonable it is to generalise from the available evidence
The identified evidence was reasonably generalisable.

4. Consistency - Degree of consistency demonstrated by the available evidence
Different types of UV decontamination devices were reported consistently across the identified evidence.
5. Potential Impact of the intervention
6. Other factors to consider while assessing the evidence base
While there was a large amount of evidence available relevant to this research question, the majority of it related to general UV-C or PX-UV. Evidence regarding UV-A, UV-B, far/upper room-UV, hand-held UV devices was limited.

7. Evidence Statement – synthesis of the evidence relating to this question	**Evidence level**
Evidence that addressed the different types of UV light decontamination systems available included one guidance document,[23] three systematic literature reviews,[24-26] four cohort studies,[9, 27-29] one single case study,[30] thirty two before and after studies,[2-4, 7, 8, 11, 20, 31-53] five observational studies,[6, 19, 54-56] nine *in vitro* studies,[13, 21, 22, 57-62] two case reports,[63, 64] two narrative reviews,[14, 65] and five pieces of expert opinion.[15, 17, 66-69] In accordance with SIGN methodology, three are considered level 1 evidence (three systematic literature reviews[24-26]), fifty one are considered level 3 evidence (five cohort studies,[9, 27-29, 53] one single case study,[30] thirty one before and after studies,[2-4, 7, 8, 11, 20, 31-52] five observational studies,[6, 19, 54-56] nine *in vitro* studies[13, 21, 22, 57-62]), and nine are considered level 4 evidence (two case reports,[63, 64] two narrative reviews,[14, 65] five expert opinions[17, 66-69]). The guidance document included in this section was assessed using the AGREE tool as Recommended.[23] There are several different types of UV decontamination systems that are presented across the evidence included in this review, often referred to as ultraviolet germicidal irradiation (UVGI) devices/systems. These include UV-A, UV-C, far-UV, and pulsed-xenon ultraviolet (PX-UV) systems.[15] The main difference between these systems is the wavelength of light emitted, letters following UV (e.g. -A, -B, -C) can be used to indicate these wavelengths. UV light falls within the spectrum of 100 to 400 nm, between 315 and 400nm is designated UV-A, between 280 and 315nm	

7. Evidence Statement – synthesis of the evidence relating to this question	Evidence level
is UV-B and between 100 and 280nm is UV-C (peak at 254nm).[66] Far-UV systems also emit light within the UV-C range, with a peak around 222nm.[15, 18] Hand-held UV devices emitting UV-C light are also mentioned within the literature.[18, 31] PX-UV systems emit a broad spectrum of light that is filtered to produce mainly UV-C wavelengths.[14, 15] Different wavelengths of UV light emitted may impact upon the germicidal efficacy of the device.[15] UV-C devices have the ability to deliver UV doses that have been shown to be effective against vegetative bacteria and spores, between the wavelengths of 100 and 280 nm, and are described within the literature as being germicidal.[15, 65-67, 70, 71] Devices are available that emit specific or broad wavelengths of UV light.[15] Low-pressure mercury lamps emit UV at a peak of 254nm, in a continuous manner, and are used within these systems.[15, 65, 66, 68] UV-C systems are investigated in 34 studies included in this review; two systematic literature reviews,[24, 25] one single case study,[30] eighteen before and after studies,[3, 4, 8, 11, 20, 31-43] five observational studies,[6, 19, 54-56] four *in vitro* studies,[13, 21, 57, 58] and 2 case reports. [63, 64] Three pieces of expert opinion and one guidance document also covered UV-C light devices.[23, 66-68] PX-UV devices emit broad spectrum light (200-320nm), filtered to leave mainly UV-C wavelengths, in short pulses, in contrast to continuous UV-C devices.[14, 65] PX-UV devices also remove the need for mercury lamps. These systems were investigated in 18 studies included in this review; two systematic literature reviews,[25, 26] five cohort studies,[9, 27-29, 53] ten before and after studies,[2, 44-52] and four *in vitro* experimental studies.[59-62] One guidance document specifically covering PX-UV was also included in this review.[23] There was a much smaller evidence base identified for UV-A (315-400nm) (two *in vitro* studies)[21, 22] and far-UV devices (280-315nm) (one before and after study).[18]	

7. Evidence Statement – synthesis of the evidence relating to this question	Evidence level
UV-B (280-315nm) and UV-A (315-400nm) light are not described as being germicidal by the International Commission on Non-Ionising Radiation Protection (ICNIRP), instead the risk they present for sunburn, skin cancer, cataracts, and skin aging are mentioned.[66, 68] These risks are also noted by the United States Food and Drug Administration (US FDA).[15] The germicidal efficacy of UV-A is assessed by Heilingloh *et al.* and Livingston *et al.* and is discussed in more detail under the objective 'What is the scientific evidence for the effectiveness of UV light for decontamination'.[21, 22] Expert opinion from the US Centers for Disease Control and Prevention (CDC) and the ICNIRP also detail the use of upper-room UVGI devices.[17, 68, 69] These devices are installed permanently in rooms, pointing upwards to create a "disinfection zone" away from occupants of the room. Unlike other devices, it is reported that upper-room UV systems can be used when people remain in the room.[69] The CDC also mention in-duct UVGI systems, however, the majority of studies covering these devices bundle the efficacy of air filters and UV disinfection so were not included in this review.[69]	
8. Recommendation -	**Grade of Recommendation**
Note: Recommendations are not applicable to this objective. The below statements are summaries of the evidence relating to this objective. UV-C devices emit light within the wavelengths of 100 to 280nm, with a peak at 254nm. Pulsed-xenon ultraviolet devices emit broad spectrum light that is filtered to mainly UV-C light, and do not require mercury lamps. UV-A devices emit light within the wavelengths of 315 and 400nm. UV-B/Far-UV devices emit light within the wavelengths of 280 and 315nm.	

7. Evidence Statement – synthesis of the evidence relating to this question	Evidence level
Upper-room UV decontamination devices are installed permanently and create a “disinfection zone” away from occupants of the room.	

Objective 3: When should UV light decontamination systems be used in health and care settings?

1. Volume of Evidence - Quantity of evidence on this topic and quality of method
Ten pieces of evidence were identified that were relevant to this research question: one guidance document, three cohort studies, and six before and after studies.
2. Applicability – in Scotland
A single guideline document produced for the United Kingdom was identified as relevant to this research question. A single before and after study was completed in South Africa. All remaining pieces of evidence were undertaken within the United States (3 cohort studies, 5 before and after studies).
3. Generalisability - How reasonable it is to generalise from the available evidence
While the majority of the evidence identified as relevant to this research question was written for or undertaken in non-UK health and care settings, however due to the consistency of the identified evidence they can be generalised to settings within NHS Scotland.
4. Consistency - Degree of consistency demonstrated by the available evidence
The use of UV decontamination devices only following standard cleaning procedures is consistently presented across the identified evidence.
5. Potential Impact of the intervention
Inappropriate timing of use of UV light decontamination devices within health and care settings may result in inadequate environmental cleaning or harm to patients, staff, or visitors.

6. Other factors to consider while assessing the evidence base

7. Evidence Statement – synthesis of the evidence relating to this question	Evidence level
The evidence identified that addresses when UV light decontamination systems should be used included one guidance document,[23] three cohort studies,[27, 28, 49] and six before and after studies.[8, 31, 32, 40, 48, 53] In accordance with SIGN methodology, nine of these studies are considered level 3 evidence (three cohort studies[27, 28, 49] and six before and after studies[8, 31, 32, 40, 48, 53]). The included guidance document was assessed as AGREE Recommend.[23] In their guideline document, Beswick *et al*. state that there are a number of indicators that may trigger the use of a UV decontamination device, including availability of staff to undertake decontamination activities, and risk assessment based on the pathogenicity of potentially present organisms.[23] Outbreak situations are suggested as a possible indicator for the implementation of UV decontamination systems.[23] These indicators should be decided on and implemented via risk assessment by individual organisations and facilities. Across the literature it is clear that UV decontamination is recommended most commonly as an adjunct to standard manual cleaning with sodium hypochlorite solutions or other regular detergents and cleaning solutions.[8, 23, 27, 28, 31, 32, 40, 48, 49, 53] Due to possible decreased efficacy of UV decontamination devices when used on soiled surfaces, and the requirement for rooms to be cleared of staff, patients, and visitors when using certain devices, UV decontamination can often only be implemented as a terminal cleaning measure. Ultimately, the efficacy of devices should be confirmed before use within the health and care environment. Details on scientific efficacy of UV decontamination devices is included in this review under the objective 'What is the scientific evidence for effectiveness of UV light for decontamination?'.	

8. Recommendation -	Grade of Recommendation
UV decontamination devices should only be used as an adjunct to standard cleaning.	Category B recommendation

Objective 4: What is the procedure for using UV light decontamination systems?

1. Volume of Evidence - Quantity of evidence on this topic and quality of method

Thirty pieces of evidence were identified that were relevant to this research question: one guidance document, three cohort studies, eighteen before and after studies, six *in vitro* studies, one narrative review, and one expert opinion.

2. Applicability – in Scotland

One guideline document and two before and after studies were written for or undertaken within the United Kingdom. Further before and after studies were completed in the United States, South Africa, Canada, Italy, and Taiwan. Additionally, three cohort studies completed in the United States, seven in vitro studies, one international expert opinion, and one narrative review were identified as relevant to this research question.

3. Generalisability - How reasonable it is to generalise from the available evidence

The evidence identified as relevant to this research question was reasonably generalisable.

4. Consistency - Degree of consistency demonstrated by the available evidence

Findings across the relevant evidence was broadly consistent.

5. Potential Impact of the intervention

Following the correct procedures for use of UV light decontamination systems will allow for effective use of these devices and the prevention of potential harm to patients, staff, and visitors.

6. Other factors to consider while assessing the evidence base
Procedures for effective use of UV light decontamination systems may vary within different health and care settings.

7. Evidence Statement – synthesis of the evidence relating to this question	Evidence level
Evidence regarding the procedure to be followed when using UV light decontamination systems consists of one guidance document,[23] three cohort studies,[27-29] eighteen before and after studies,[2-4, 6, 11, 12, 18, 31, 32, 34-36, 38, 39, 42, 44, 47, 65, 72] six *in vitro* studies,[13, 21, 22, 58, 59, 62] one narrative reviews,[14] and one expert opinion.[66] In accordance with SIGN methodology, twenty seven are considered level 3 evidence (three cohort studies,[27-29] eighteen before and after studies,[2-4, 6, 11, 12, 18, 31, 32, 34-36, 38, 39, 42, 44, 47, 72] six *in vitro* studies[13, 21, 22, 58, 59, 62]) and three were considered level 4 evidence (two narrative reviews[14, 65] and one expert opinion[66]). The included guidance document was assessed as AGREE Recommend.[23] Standard facility cleaning procedures should be undertaken prior to the UV device entering the space requiring decontamination. Varma *et al*. and Nerandzic *et al*. noted that while using a hand-held UV-C device, their operators wear personal protective equipment (PPE).[18, 36] This requirement was not reported for automated devices, where operators leave the room while devices are in use, however, if required/recommended by the manufacturer, relevant PPE should be donned prior to use of the UV device. Safe limits for UV radiation (180-400nm) exposure were published by the ICNIRP in 2004 and state that over an 8 hour period, exposure of unprotected eyes and skin should not exceed 30 Joules per meter squared (Jm^{-2}).[66] Since UV-C light travels in a straight line, it is important the surfaces to be disinfected using UV light systems are in direct line of sight of the devices to ensure optimal exposure.[14, 23] In order to achieve this, there may be a requirement to open drawers and cabinets, and place high touch items (such as remotes, call buttons, and blood pressure cuffs) in positions of exposure.[4, 27, 31, 34] A number of papers indicate that a number of decontamination cycles in different positions, or different lengths of cycle, are required to achieve this.[6, 14, 27, 28, 31, 35, 65] The number of UV cycles is determined by the size of the room requiring decontamination.[3, 32, 58] Lowman *et al*. states that there should be a maximum of 2.5 meter radium from the centre of the UV device per cycle, however this may differ between UV devices.[32] Manufacturer's instruction should be followed when determining number of,	

7. Evidence Statement – synthesis of the evidence relating to this question	Evidence level
or length of, cycles required in a given space. Efficacy of UV decontamination devices could also be impacted by the distance surfaces are from the light source, this is further discussed under the objective 'Are there any practical and logistical considerations associated with using UV light decontamination systems?'. Prior to decontamination using continuous UV-C and PX-UV, rooms should be cleared of people, including patients, staff, and operators. For this reason devices are often automatic, commencing a UV decontamination cycle after a set time without movement in the room, or remotely operated, and can be turned on from outside the room being treated.[3, 11, 12, 32, 35, 42, 47, 72] Operators should set up the UV device, ensuring correct placement, then leave the room before activating the device, closing the door securely. Signage indicating the use of a UV device within the room is recommended to ensure no one enters during the UV treatment cycle. Some devices are fitted with motion sensors that facilitate automatic shut off when motion is detected.[3, 11, 12, 23, 29, 35, 38, 39, 42, 47, 58, 72] UV decontamination cycle times vary between devices and the size of the room being treated, however, in the studies included in this review, cycles times ranged between 3 and 7 minutes.[2, 28, 31, 35, 42] Nottingham *et al*. stated that the UV device used in their study used cycle times of 20 minutes in small rooms (20m^2) and 55 minutes in large rooms (56.6m^2).[6] Anderson *et al*. reported cycles times when using 12,000 micro-watt per square centimetre (µWs/cm^2) as 25 minutes, and 45 minutes when using 22,000 µWs/cm^2.[4] Mahida *et al*. reported time taken for disinfection between 27 and 49 minutes with a dose of 12,000 µWs/cm^2, and 23 and 93 minutes with a dose of 22,000 µWs/cm^2, depending on size of the room being treated.[3] For *in vitro* studies, exposure time was as little as 20 seconds and as long as 40 minutes.[13, 21, 58-60, 62] Furthermore, Livingston *et al.* ran the UV-A device tested in their *in vitro* study for 4, 8, or 12 hours.[22] Across the literature it was indicated that UV-C and PX-UV devices automatically shut off following the set cycle time or when an adequate reflective dose of UV light has been emitted. Following use, devices should be decontaminated following manufacturer's instructions, portable devices should be returned to their storage area, and rooms should be set up for the next incoming patient.	

8. Recommendation -	Grade of Recommendation
UV decontamination devices should be used in accordance with manufacturer's instructions.	Category B recommendation
If manufacturer's instructions indicate, personal protective equipment should be worn while using UV decontamination devices.	Category B recommendation
Prior to UV light decontamination treatment, where indicated by UV type, the room should be adequately prepared e.g. opening drawers and cabinets, and placing high touch items in direct line of sight if the device.	Category B recommendation
Manufacturer's instructions should be followed when determining number of, or length of, cycles required in a given space.	Category B recommendation
No staff, patients, or visitors should be permitted to be in rooms being treated with continuous UV light decontamination and safety/no entry signage must be displayed with the device is in use.	Category B recommendation
Operators should leave the room, securing the area prior to activation of continuous Uv light decontamination device.	Category B recommendation
Manufacturer's instructions must be followed to ensure appropriate UV light cycle time is delivered.	Category B recommendation

Objective 5: What is the current guidance or legislation regarding the use of UV light decontamination of the healthcare environment?

1. Volume of Evidence - Quantity of evidence on this topic and quality of method
Four pieces of evidence were identified that were relevant to this research question: one British Standard, two pieces of UK Government legislation, and one guidance document.
2. Applicability – in Scotland
All of the evidence relevant to this research question was written to be applied within the United Kingdom. Three of these are mandatory pieces of legislation.
3. Generalisability - How reasonable it is to generalise from the available evidence
Three of the four included pieces of evidence are mandatory within the United Kingdom.
4. Consistency - Degree of consistency demonstrated by the available evidence
None of the included pieces of evidence relevant for this research question were contradictory.
5. Potential Impact of the intervention
6. Other factors to consider while assessing the evidence base

7. Evidence Statement – synthesis of the evidence relating to this question	**Evidence level**
One British Standard,[73] two pieces of UK Government legislation,[74, 75] and one guidance document[23] were identified that cover the use of UV light decontamination systems in health and care settings. Three of these are mandatory pieces of legislation[73-75] and the guidance document was assessed as AGREE Strongly Recommend.[23] The British Standard BS 8628 relates to the method of determining disinfection efficacy of UV devices used in human health settings, that claim microbial inactivation of vegetative bacteria, bacterial spores, yeasts, fungal spores, viruses, and bacteriophages.[73] It should	

7. Evidence Statement – synthesis of the evidence relating to this question	Evidence level
be noted that hand-held devices and air and water disinfection devices are excluded from this standard.[73] Both the Health and Safety at Work etc Act 1974 and the Control of Artificial Optical Radiation at Work Regulations 2010 are applicable to the use of UV decontamination devices.[74, 75] Employers are required to remove or reduce risk to workers health and safety as far as is reasonably practicable.[74] UV light decontamination systems are identified as a hazard in the Control of Artificial Optical Radiation at Work Regulations 2010 and methods for removing or reducing the risk of these devices are covered under the objective 'What are the safety considerations associated with using UV light decontamination systems?'.[75] High quality guidance on the use of UV light decontamination devices in health and care settings is limited. Beswick *et al.* published guidance covering the use of automated room decontamination systems, including UV light decontamination systems.[23] Within these guidelines, recommendations and good practice points for indications for use, procedure, and practical considerations are provided. This document was produced by a Healthcare Infection Society Working Party made up of Infection Prevention and Control (IPC) experts and professionals from the UK, making the recommendations provided applicable to Scottish health and care settings.[23]	
8. Recommendation -	**Grade of Recommendation**
Employers are required to remove or reduce risk to workers health and safety when using UV decontamination systems, as far as is reasonably practicable.	Mandatory

Objective 6: What is the scientific evidence for effectiveness of UV light decontamination of the healthcare environment?

1. Volume of Evidence - Quantity of evidence on this topic and quality of method
Twenty one pieces of evidence were identified that were relevant to this research question: three systematic literature reviews with meta-analyses, three cohort studies, seven before and after studies, one in situ observational study, and seven *in vitro* studies.
2. Applicability – in Scotland
Only one of the papers identified as relevant to this research question was undertaken within the United Kingdom (1 before and after study). The majority of the remaining studies were undertaken in the United States (3 cohort studies, 4 before and after studies), with before and after studies also being completed in Canada and Brazil. One South African in situ observational study was also included. The three included systematic reviews present apers from the United States, Canada, and Japan. Seven in vitro studies were also identified as relevant to this research question.
3. Generalisability - How reasonable it is to generalise from the available evidence
Evidence presented across the included studies varies greatly in methodology with differing room size and configurations, UV decontamination devices, treatment times, and protocols. Therefore, ability to generalise the findings of the included evidence is limited.
4. Consistency - Degree of consistency demonstrated by the available evidence
As above, the methodologies of evidence relevant to this research question varies greatly.
5. Potential Impact of the intervention **6. Other factors to consider while assessing the evidence base**
Evidence relevant to this objective was limited due to a number of studies lacking a suitable control/comparison group that was comparable to current NHSScotland cleaning methods. Additionally, a great deal of available evidence assesses UV light decontamination systems in bundled approached of a number of IPC methods.

7. Evidence Statement – synthesis of the evidence relating to this question	Evidence level
As mentioned under the objective covering legislation and guidance, the British Standard BS 8628 relates to the disinfection efficacy of UV devices used in health settings that claim microbial inactivation of vegetative bacteria, bacterial spores, yeasts, fungal spores, viruses, and bacteriophages.[73] Any devices (other than those excluded from this Standard) used within Scottish health and care settings should have been tested using the methods of this Standard and have proven disinfection capability before use.[73] There is a great deal of evidence relating to the efficacy of UV decontamination devices, however the majority of this is of low quality. Evidence for this objective was informed by three systematic literature reviews with meta-analyses,[24-26] three cohort studies,[27-29] nine before and after studies,[3, 8, 20, 42, 46, 49, 50, 52, 76] one in situ observational study,[19] and seven *in vitro* studies.[6, 13, 21, 22, 59, 60, 62] The outcome measure used to demonstrate effectiveness of UV decontamination is either a reduction in environmental contamination (experimental or real-life) and/or incidence of hospital associated infections (HAIs). Assessing reduction in incidence of HAIs provides evidence of the impact of interventions at a patient level, it also allows analysis to focus on targeted patient groups, often those that are vulnerable to HAIs. However, this outcome measure often allows for confounding factors, including the implementation of other interventions within the same study period which may also impact on HAI rates. These studies typically fail to specify HAI routes of transmission, further limiting analysis of the impact interventions may be having. Reduction in environmental contamination is often measured using reduction in colony forming units (CFU) or plaque forming units (PFU) of target pathogens. Using this as an outcome measure allows for assessment of specific areas within the care environment, such as high touch surfaces. These studies also prove the presence of HAI pathogens on surfaces and can support the need for robust cleaning methods, sometimes targeted to specific pathogens. However, this outcome measure does not capture the infectivity of organisms found within the environment and is limited by not linking to real time infection rates. Additionally, these studies are typically setting specific so may not be applicable to all health and care settings, or all variations of treatment areas. Ten studies assessed	

7. Evidence Statement – synthesis of the evidence relating to this question	Evidence level
HAI rates,[24-29, 49, 50, 52, 76] and fourteen assessed environmental contamination,[3, 8, 19, 20, 42, 46, 77] including seven *in vitro* studies undertaken in laboratories or experimental settings.[6, 13, 21, 22, 59, 60, 62] **HAI Rates** The studies that assessed the impact of implementation of UV decontamination devices on HAI rates included three systematic reviews with meta-analysis,[24-26] three cohort studies,[27-29] and three before and after studies.[49, 50, 52] Three systematic literature reviews with meta analyses found significant decreases in *C. difficile* infection (OR = 0.43, 95% CI 0.25 - 0.74, I^2 = 0%[24]; pRR 0.6, 95% CI 0.49-0.84[25]; IRR 0.73, 95% CI 0.57–0.94, I^2 = 72%, P = 0.01)[26] when using UV light decontamination devices (both UV-C and PX-UV) in addition to standard cleaning with sodium hypochlorite solutions. One of these found that UV decontamination was also associated with reduction in environmental contamination with *C. difficile*(OR 0.79, 95% CI 0.53-1.19, I^2=0%).[24] Additionally, Dong *et al.*, found UV light decontamination treatment resulted in significant reduction of MRSA infections (IRR: 0.79, 95% CI 0.64–0.98, I^2 = 35%, P = 0.03).[26] Two papers analysed the impact of UV decontamination on VRE infections, with one finding a significant reduction (pRR 0.42, 95% CI 0.28-0.65)[25] and the other finding an insignificant reduction (IRR: 0.80, 95% CI 0.63–1.01, I^2 = 60%, P = 0.06).[26] Of the 20 papers pooled for meta-analysis across these studies, 5 did not meet the criteria for inclusion in this review and were therefore not included as stand-alone studies. Two of the included cohort studies assessed the impact of UV light decontamination on hospital-associated *C. difficile* infection (CDI), reductions were found in both when compared to standard cleaning only, however significance was only reported by Samathkumar *et al.* (p=0.034).[27, 29] Sampathkumar also reported significant reductions in rate of CDIs per 10,000 patient days in the study units from 21.3 to 11.2 (p=0.03).[27] Brite *et al.* assessed the impact of a PX-UV decontamination device on the rate of toxigenic *C. difficile* (TCD) in a bone marrow transplant unit. They found no significant change compared to standard cleaning alone (p=0.5).[28] Two of these also assessed the impact of UV decontamination on the rates of VRE.[27, 28] Sampathkumar *et al.* found a significant reduction in rate of VRE per 10,000 patient days from 25.6	

7. Evidence Statement – synthesis of the evidence relating to this question	Evidence level
to 12.3(p=0.02).[27] Brite *et al.* found no significant change in the rate of VRE infections between their pre- and post-intervention periods (p=0.4).[28] Three of the included before and after studies used rates of hospital associated infections (HAIs) as their outcome measure and used PX-UV devices. In three of these studies a significant reduction in CDI was reported.[49, 50, 52] Significant reductions in MRSA, VRE and MDR gram negative bacteria infections were also seen across these before and after studies.[49, 50, 52] All of these before and after studies have similar limitations. All were undertaken within the United States meaning their applicability to Scottish health and care settings may be limited.[49, 50, 52, 76] They were all undertaken in specific areas of the facilities (ICU, paediatric, and contact precaution rooms) meaning their findings may not be applicable across all areas of health and care settings.[49, 50, 52, 76] The use of antibiotics and other medications, that would have assisted in reducing rates of HAIs, was not addressed by any of these studies. Other environmental cleaning initiatives were reported within the baseline or intervention period of two of these studies.[49, 50] Additionally, authors of two studies were employed by the manufacturer of the UV light decontamination device assessed within the studies.[49, 52] **Environmental Contamination** Studies that assessed environmental contamination included one cohort study,[77] five before and after studies,[3, 8, 20, 42, 46] and one observational study.[19] The included cohort study assessed the impact of UV decontamination on MRSA, finding that 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.[77] Five before and after studies used reduction in environmental contamination as an outcome measure. Four assessed UV-C devices, and one assessed a PX-UV device. Two of these studies reported complete removal of bacterial contamination.[3, 20] Dos Santos *et al*. also reported log 4 reduction of *C. albicans*.[20] Significant reductions in microbial colony counts, heterotrophic plate	

7. Evidence Statement – synthesis of the evidence relating to this question	Evidence level
counts, aerobic and anaerobic bioaerosols were reported by three studies.[20, 42, 46] A non-significant reduction of MRSA was reported by Mustapha *et al*.[8] Mahida *et al.* investigated the difference in efficacy in direct line of sight and in shaded areas of the room. They reported reductions of 99.97% of organisms when in direct sight of UV light and reductions of between 90 and 99.99% reductions in shaded areas.[3] One *in situ* observational study was identified that assessed the efficacy of UV decontamination devices. When challenged on agar plates there was a >90% mean kill rate for MRSA, extended-spectrum beta-lactamase (ESBL)-producing *Klebsiella pneumoniae*, carbapenem-resistant *K. pneumoniae*, VRE, multi-drug-resistant (MDR) *A. baumannii*, and *Candida auris*.[19] Environmental swabbing in this study found 92% reduction after cleaning with sodium hypochlorite, was increased to 100% after UV treatment.[19] This study was undertaken in a single centre in South Africa, limiting the applicability and generalisability of its findings. Further evidence of reduction of bioburden was provided by the findings of the seven included *in vitro* studies.[6, 13, 21, 22, 59, 60, 62] Three of these assessed the direct exposure of test organisms to UV-C light, resulting in complete inactivation of SARS-CoV-2 after 9 minutes,[21] ≥4 log reductions of *A. baumannii* after 20 minutes,[6, 13] and >2 log reduction of *E. faecalis* and *S. aureus* after 20 minutes.[6] When applied for 55 minutes ≥4 log reductions were reported for *A. baumannii, E. faecalis*, and *S. aureus*.[6] One study assessed the indirect exposure of test organisms to UV-C light and found that after a 55 minute treatment time, ≥4 log reduction was observed for *A. baumannii* and >2 log reductions were observed for *E. faecalis* and *S. aureus*.[6] Three studies assessed direct exposure of test organisms to PX-UV light, resulting in >5 log reductions in MRSA, VRE, carbapenemase-producing *K. pneumoniae*, ESBL-producing *E. coli*, and MDRA,[59] >4 log reduction in SARS-CoV-2,[60] and 99.5% and 98.5% reductions in *C. auris* and *C. parapsilosis*, respectively.[62] Two studies assessed the direct exposure of test organisms to UV-A light, and reported <2 log reductions for MRSA, a non-enveloped virus bacteriophage (MS-2), *C. auris* and an enveloped virus	

7. Evidence Statement – synthesis of the evidence relating to this question	Evidence level
bacteriophage (Phi X174) after 24 hours exposure.[22] The second paper reported 1 log reduction of SARS-CoV-2 after 9 minutes of exposure.[21] The US FDA also mention UV-A light within a published expert opinion, stating that this wavelengths, along with UV-B, is “expected to be less effective than UV-C radiation”, specifically when used to inactivate SARS-CoV-2.[15] The impact of distance on the efficacy of UV light decontamination devices was assessed by one *in vitro* study, without other variables also being changed. After 5 minutes of PX-UV treatment at 1 meter distance, *C. auris* and *C. parapsilosis* were reduced by 99.5% and 98.5%, respectively. After the same treatment time, but with the device 2 meters from inoculated glass slides, reductions of 90.2% and 15.7%, respectively, were reported.[62] Significance was not reported within this study. It should be noted that across these *in vitro* studies the wavelengths and doses of UV light test organisms were exposed to varied, and often was not reported. *In vitro* studies are inherently limited in their methodologies which impacts on their applicability to health and care settings. Four of the included studies focussed on one or a small number of pathogens to assess efficacy of UV light decontamination devices.[13, 21, 22, 62]. Furthermore, test surfaces (steel, aluminium, glass, plastic, paper) may not reflect surfaces present within the health and care environment that could be contaminated with potentially pathogenic organisms.[1, 6, 13, 22, 62] Additionally, the use of seeded agar plates can impact both the level of bioburden assessed and may not reflect hard surfaces commonly found in health and care settings and targeted by environmental cleaning procedures.[59] Sample sizes across the included studies are small which limits their generalisability in practice. Finally, in a number of the included studies, manufacturers are involved in funding of studies or employ authors. 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, the majority of this evidence was considered level 3 evidence (3 cohort studies[27-29], 9 before and after studies[3, 8, 20, 42, 46, 49, 50, 52, 76], 1 *in situ* observational study[19], 7 *in vitro* studies[6, 13, 21, 22, 59, 60, 62]). As systematic literature reviews with meta-analyses Kato *et al*., Marra *et al*., and Dong *et al*. are considered level 1+ evidence. The	

7. Evidence Statement – synthesis of the evidence relating to this question	Evidence level
methodologies of the included studies are variable, assessing a number of different devices that work with different doses, treatment times, and wavelengths of UV light. For this reason, their generalisability is limited. Additionally, the *in situ* studies were undertaking in various health and care settings, in a number of countries. Sample sizes across the included literature were also small, limiting how robust their findings were. These limitations impact greatly on the ability to make recommendations on efficacy. Although available evidence is limited and of low quality, there is consistency across the evidence showing UV light decontamination as an effective method against a number of challenge organisms. Four clinical studies demonstrated reduction in rates of common hospital associated infections,[27-29, 77] with three of these reporting these as significant.[27, 29, 77] Ten clinical studies reported reduction in bioburden,[3, 8, 19, 20, 42, 46, 49, 50, 52, 76] with six reporting these reductions as significant,[20, 42, 46, 49, 50, 52] and all seven of the included *in vitro* studies reported reductions in the test organisms following exposure to UV light decontamination devices.[6, 13, 21, 22, 59, 60, 62]	
8. Recommendation -	**Grade of Recommendation**
Manufacturer's instructions for use must be followed to ensure all surfaces are adequately decontaminated. UV decontamination systems are effective at reducing environmental bio burden when used in addition to standard cleaning practices. There is insufficient evidence available to provide recommendations on specific UV decontamination treatment dose and cycle time or specific models of device.	Category B recommendation Category B recommendation Category B recommendation

Objective 7: Are UV light decontamination systems currently in use in UK health and care settings? If not, are these systems used internationally?

1. Volume of Evidence - Quantity of evidence on this topic and quality of method
Eight pieces of evidence were identified that were relevant to this research question: one British Standard, one guideline document, four before and after studies, one observational study, and one expert opinion. Two UK guideline documents were also identified that provide recommendations on cleaning within health and care settings, however, these did not include mention of UV decontamination systems.
2. Applicability – in Scotland
All of the identified evidence was written for or undertaken in the United Kingdom.
3. Generalisability - How reasonable it is to generalise from the available evidence
While there is a limited volume of evidence, the use of UV decontamination devices within UK health and care settings can be reasonably generalised from that relevant to this research question.
4. Consistency - Degree of consistency demonstrated by the available evidence
Reporting use of UV decontamination devices was consistent in the limited evidence that was identified as relevant to this research question.
5. Potential Impact of the intervention **6. Other factors to consider while assessing the evidence base**

7. Evidence Statement – synthesis of the evidence relating to this question	Evidence level
The routine use of UV light systems for the decontamination of the health and care environment is not currently recommended in NHSScotland. There is no mention of UV light decontamination systems in the NHS Scotland National Cleaning Services Specification, or the National Patient Safety Agency (NPSA) Revised Healthcare Cleaning Manual.[78, 79] Four before and after studies,[2, 3, 33, 45] one observational study,[55] and one guideline document[23] included in this review were undertaken within or written for UK health and care settings. This evidence suggests that UV light decontamination systems are used or have the potential to be used to some extent within UK health and care settings. In accordance with SIGN methodology, five are considered level 3 evidence (four before and after studies[2, 3, 33, 45] and one observational study[55]) and the guidance document was assessed as AGREE Strongly Recommend.[23] Additionally, the Scientific Advisory Group for Emergencies - Environmental and Modelling Group (SAGE EMG) published a summary paper that outlined the use of UV disinfection systems for the control of COVID-19.[67] There is also a British Standard (BSI 2628) that relates to the use of UV disinfection systems in a number of settings, including health and care.[73] These further support the use of UV decontamination systems within UK health and care settings.	
8. Recommendation -	**Grade of Recommendation**
Note: Recommendations are not applicable to this research question.	

Objective 8: What are the safety considerations associated with using UV light decontamination systems in health and care settings?

1. Volume of Evidence - Quantity of evidence on this topic and quality of method
Thirty one pieces of evidence were identified that were relevant to this research question: two pieces of legislation, one guidance document, one randomised control trial, two cohort studies, one single case study, sixteen before and after studies, one observational study, one *in vitro* study, one case report, and five pieces of expert opinion.
2. Applicability – in Scotland
Two pieces of legislation, one guideline document, one before and after study, one observational study, and two expert opinions were written for or undertaken in the United Kingdom. Two additional expert opinion pieces were included from an international organisation. The majority of the remaining pieces of evidence were written for and undertaken in the United States (2 cohort studies, one single case study, nine before and after studies, and one expert opinion). Additional before and after studies were completed in South Africa, Taiwan, Italy, Canada, and The Netherlands. One in vitro study and one Indian case report were also relevant to this research question.
3. Generalisability - How reasonable it is to generalise from the available evidence
Evidence identified as relevant to this research question was reasonably generalisable.
4. Consistency - Degree of consistency demonstrated by the available evidence
Evidence is consistent across the included papers.
5. Potential Impact of the intervention
If potential safety considerations of using UV light decontamination systems are not taken into account there is risk of harm to patients, staff, or visitors.
6. Other factors to consider while assessing the evidence base

7. Evidence Statement – synthesis of the evidence relating to this question	Evidence level
Two pieces of legislation,[74, 75] one guidance document,[23] one randomised control trial,[80] two cohort studies,[29, 43]one single case study,[81] sixteen before and after studies,[3, 4, 11, 12, 18, 32, 35, 36, 38, 39, 42, 44, 46, 47, 53, 72] one observational study,[55] one *in vitro* study,[58] one case report,[63] and five expert opinion pieces[17, 66, 67, 71, 82] contributed towards evidence on safety considerations that should be made when using UV light decontamination systems. In accordance with SIGN methodology, the randomised control trial was considered level 1 evidence,[80] twenty one were considered as level 3 evidence (two cohort studies,[29, 43] one single case study,[81] sixteen before and after studies,[3, 4, 11, 12, 18, 32, 35, 36, 38, 39, 42, 44, 46, 47, 53, 72] one observational study,[55] one *in vitro* study[58]), and six were considered level 4 evidence.[17, 63, 66, 67, 71, 82] The guidance document was assessed as AGREE Strongly Recommend and the legislation is considered mandatory. Under the Health and Safety at Work Act 1974, suppliers of UV devices have the responsibility to provide devices that are safe for use.[74] Furthermore, employers are expected to remove or reduce risk of staff injury as far as is reasonably practicable. UV decontamination devices are also covered by the Control of Artificial Optical Radiation at Work Regulations (AOR) 2010.[75] These regulations state that employers are required to protect the eyes and skin of workers from exposure to potentially harmful radiation, including from ultraviolet sources. The suggested methods for this include: • use of an alternative, safer light source that achieves the same result; • use of filters, screens and curtains, remote viewing, remote controls, and time delays; • providing workers with training on best-practice for using devices; • organise work in a way that minimises exposure and restricts access to hazardous areas; • provide staff with personal protective equipment (PPE); • use of safety signage.[75, 82]	

7. Evidence Statement – synthesis of the evidence relating to this question	Evidence level
One of the main safety considerations for using UV decontamination devices is the risk of radiation injuries following exposure, specifically eye and skin damage when exposed to UV radiation for extended periods of time, or from improperly fitted or maintained devices.[23, 63, 66, 82] UV radiation is absorbed by all components of living organisms, with peak absorption by DNA at approximately 260nm.[71] Woods *et al*. undertook an observational study assessing the effects of a 222nm emitting UV decontamination device on healthy skin.[55] This study was conducted with a very small sample size of only four participants, however it did find that even at low doses UV light from the device had the potential to cause erythema (redness) and DNA damage (cyclobutene pyrimidine dimerization).[55] Vaidya *et al*. published a case report detailing the condition of nine operating theatre personnel with intense tearing of the eyes and erythematous rash on exposed body parts, which developed between 2 and 4 hours following a work shift.[63] UV light radiation was concluded as the cause for these symptoms after it was discovered that germicidal lamps were accidentally switched on, exposing operating theatre personnel to 8 hours of UV radiation. This was possible due to the placement of UV device switches being located near the regular light switches. This risk is addressed by the CDC when they recommend that switches should be in restricted areas or lockable switches should be used to prevent this.[17] The ICNIRP published expert opinion recommendations in 2004 providing limits for exposure to UV radiation (180-400nm), over an 8-hour period. For unprotected skin and eyes this limit was $30Jm^{-2}$.[66] Barriers between operators and UV light sources are reported to be protective against the risk of radiation. SAGE EMG stated in their summary paper that UV-C light is inhibited by double-glazed glass, and rarely passes through single-glazed panes.[67] In order to ensure safety, staff should exit rooms being treated prior to activating UV decontamination devices.[67] This is supported by a number of experimental studies included in this review that state operators leave the room before activating UV devices, or that devices are only used in empty rooms.[3, 11, 12, 32, 35, 42, 44, 72] While it is known that UV light does not usually penetrate glass, this should be confirmed by use of a light meter on the	

7. Evidence Statement – synthesis of the evidence relating to this question	Evidence level
outside of glass between operators and the rooms being treated.[23] The ICNIRP recommend that UV measurements are undertaken for risk assessment, not during every use.[66] Another safety feature fitted to minimise the risk of UV radiation exposure is motion activated shut off. Devices can include sensors that detect movement within a room being treated, triggering the device to immediately end its cycle, rather than complete the pre-set treatment time or reach acceptable reflected dose.[3, 11, 12, 23, 29, 35, 38, 39, 42, 43, 47, 58, 72] Beswick *et al*. recommend that any personnel that will be using UV decontamination devices should receive training, particularly from the manufacturer of the device.[23] The CDC also note that staff should be trained in using UV devices.[17] It is stated by SAGE EMG that UV-C and upper-room GUVI disinfection systems can have significant safety considerations and they should only be used by trained staff "*with appropriate risk assessment and controls in place*."[67] These statements are supported by experimental studies included in this review that include mention of staff training before implementation of a UV decontamination device.[4, 12, 43, 80, 81] The need for PPE is mentioned by Varma *et al*. and Nerandzic *et al*., where is it stated that when using a hand-held UV device, operators wore protective goggles and gloves.[18, 36] In these studies, operators were not in the line of direct exposure from the UV devices and so the risk of exposure related injuries may have been reduced, however, the use of PPE further reduced this risk.[18, 36] The ICNIRP (2004) recommend that engineering measures are preferred to PPE.[66] These engineering controls include glass and plastic shielding cabinets, curtains and barriers. Even separation by distance is mentioned as a method of protection from exposure.[66] The CDC note that warning signage should be in place where UVGI devices are used.[17] The CDC also highlight the risk of untrained personnel accessing UV device power supplies and either turning on or off unintentionally. In response to this it is recommended that having switches in restricted areas or using lockable switches could prevent this.[17] A safety risk that is often identified when discussing UV decontamination devices is the production of ozone gas by UV lamps. Beswick *et al*. mention that there have been anecdotal reports of ozone	

7. Evidence Statement – synthesis of the evidence relating to this question	Evidence level
production by UV decontamination devices.[23] The ICNIRP note that some UVC lamps marketed for home use emit ozone "which is irritating to breathing passages (nose, throat and lungs), particularly for those who have respiratory sensitivity such as asthma or allergies."[66] Casini *et al*. noted that the PX-UV device used in their study did not produce ozone to levels above short-term exposure limits set by the Occupational Safety and Health Administration (OSHA) (USA).[47] This limit is stated to be 0.1 parts per million per 8 hours (0.1ppm/8h).[47] One health and safety factor that should be considered prior to the use of UV decontamination systems is the size and weight of the devices. Many of these devices are portable and are expected to be moved between rooms and within rooms between treatment cycles. The weight and size of the devices should be considered before implementation since additional health and safety measures may be required to ensure safe use by all cleaning personnel. Devices used in the included studies that contained information on weight and size both weighed 68kg[29, 53], apart from the larger robotic device used by Russo *et al.* that weighed 140-180kg.[38] However, this device was equipped to self-manoeuvre between treatment positions, rooms, and storage facilities. Some devices are able to be moved on wheels to aid in transportation from storage to and between rooms being treated.[4, 11, 39, 43, 46]	
8. Recommendation -	**Grade of Recommendation**
Employers must remove or reduce risk of staff injury as far as is reasonably practicable.	Mandatory
Employers are required to protect the eyes and skin of workers from UV radiation.	Mandatory
No staff, patients, or visitors should be permitted to be in rooms being treated with continuous UV light decontamination.	Category B recommendation
Risk assessments should be in place to assess UV exposure of individuals in the vicinity (patients, staff, visitors).	Category C recommendation

7. Evidence Statement – synthesis of the evidence relating to this question	Evidence level
Methods of protection from UV radiation may include: • Use of alternative, safer light source that achieves the same result • Use of filters, screens and curtains, remote viewing, remote controls, and time delays • Providing workers with training on best-practice for using devices • Organise work in a way that minimises exposure and restricts access to hazardous areas • Provide staff with personal protective equipment (PPE) • Use safety signage	Category C recommendation

Objective 9: What are the practical and logistical considerations associated with using UV decontamination systems in health and care settings?

1. **Volume of Evidence** - Quantity of evidence on this topic and quality of method
Twenty seven pieces of evidence were identified as relevant to this research question: four cohort studies, one single case study, eleven before and after studies, two observational studies, five *in vitro* studies, two narrative literature reviews, and two pieces of expert opinion.
2. Applicability – in Scotland
Only one expert opinion written for the United Kingdom was identified as relevant to this research question. Three cohort studies, one single case study, one before and after study, one observational study, and one expert opinion were written for and undertaken in the United States. Further studies were undertaken in Taiwan, Canada, and South Africa. Additionally, five in vitro studies and two narrative reviews were identified as relevant to this research question.
3. Generalisability - How reasonable it is to generalise from the available evidence
The findings of the included studies are reasonably generalisable.

4. Consistency - Degree of consistency demonstrated by the available evidence
There is some variation in the findings of the included studies, particularly in treatment time.
5. Potential Impact of the intervention
Failing to take into account the practical and logistical considerations of using UV light decontamination systems may impact upon the efficacy of decontamination, workload of cleaning personnel, and safety of patients, staff, or visitors.
6. Other factors to consider while assessing the evidence base

7. Evidence Statement – synthesis of the evidence relating to this question	**Evidence level**
Four cohort studies,[27-29, 83] one single case study,[30] eleven before and after studies,[31, 35, 42] two observational studies,[19, 56] five *in vitro* studies,[13, 21, 58, 59, 62] two narrative literature reviews,[14, 85] and two expert opinions[17, 67] informed the evidence base for practical and logistical considerations that should be made when using UV light decontamination systems. In accordance with SIGN methodology, twenty four were considered level 3 evidence (Four cohort studies,[27-29, 83] one single case study,[30] eleven before and after studies,[31, 35, 42] three observational studies,[19, 56, 84] five *in vitro* studies,[13, 21, 58, 59, 62]), and four were considered level 4 evidence (two narrative literature reviews,[14, 85] and two expert opinions[17, 67]). All room decontamination technologies have advantages and disadvantages. UV decontamination systems operation time may be an issue for some settings, particularly where patient turnover is high. Cycle times vary between devices and the size of the room being treated, however, in the studies included in this review, cycle times ranged between 3 and 7 minutes.[28, 31, 35, 42] For *in vitro* studies, exposure time was as little as 20 seconds and as long as 40 minutes.[1, 13, 21, 58, 59, 62] UV decontamination was reported to add between 15 and 60 minutes to the total room cleaning time, depending on the size of the room and number of cycles required.[2, 27, 29, 83] Total room turnaround time was reported to be between 56 and 156 minutes when UV decontamination was added to standard terminal cleaning, compared to between 44 and 69 minutes with only standard terminal cleaning.[3, 30, 56] As mentioned within the sections on procedure for using UV decontamination devices and scientific efficacy of UV decontamination devices, the use of UV decontamination	

7. Evidence Statement – synthesis of the evidence relating to this question	Evidence level
systems does not remove the need for manual cleaning, and so timings for using UV decontamination devices should be added to the time taken for these procedures. 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.[4] Jinadatha *et al*. 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.[5] Due to this, and the requirement for rooms to be cleared of staff, patients, and visitors when using certain devices, UV decontamination can often only be implemented as a terminal cleaning measure. As mentioned within the section covering safety considerations, barriers between operators and UV light sources are reported to be protective against the risk of radiation.[67] However, this means that UV devices are only effective for surfaces in their direct line-of-sight. For this reason many manufacturers recommend multiple cycle times in different locations within the room. Boyce *et al*. 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.[85] Kitagawa *et al*. found that PX-UV decontamination is not effective against bacteria that is shielded from direct exposure.[59] However, in an in situ experimental study Nottingham *et al*. found that the use of a UV-C device at a reflective dose 12,000 µWs/cm2, resulted in similar reductions in bacterial contamination on agar plates in positions of both direct and indirect exposure.[6] 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.[3, 14] 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.[3, 7, 17] Efficacy of UV decontamination devices could also be impacted by the distance surfaces are from the light source. Maslo *et al*. investigated the efficacy of UV light decontamination at different	

7. Evidence Statement – synthesis of the evidence relating to this question	Evidence level
distances and found that greater reductions were achieved at shorter distances.[62] However, a number of studies found no significant difference in reduction of microorganisms at different distances.[6, 8, 19] Ultimately manufacturer's instructions should be followed for positioning and cycle time of any UV decontamination device. Another consideration that should be made before implementing UV decontamination devices is the ongoing maintenance requirements. The CDC state that UVGI lamps need to be replaced every 1-2 years and replacement schedules should be agreed with the device manufacturers.[17] 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.[14]	
8. Recommendation -	**Grade of Recommendation**
In use UV light systems must be maintained in good working order with a system of programmed maintenance, supported by the manufacturer and including quality assurance, in place with documented evidence.	Category B recommendation
UV light systems should not be used to replace routine cleaning.	Category B recommendation
The time for both standard terminal cleaning and UV decontamination treatment should be factored into room turnaround time.	Category B recommendation
Manufacturer's instructions should be followed when deciding UV decontamination treatment cycle and placement of device.	Category B recommendation
Effort should be made to ensure that UV devices are in direct line of exposure of surfaces being decontaminated to ensure efficacy.	Category B recommendation

Objective 10: What costs are associated with using UV light decontamination systems in health and care settings?

1. Volume of Evidence - Quantity of evidence on this topic and quality of method
Five pieces of evidence were identified that were relevant to this research question: one guidance document, two cohort studies, one before and after study, and one expert opinion.
2. Applicability – in Scotland
One piece of evidence (a guideline document) that was relevant to this research question was directly applicable to the Scottish health and care setting. The remaining four pieces of evidence were studies undertaken in or expert opinion written for health and care settings in the United States.
3. Generalisability - How reasonable it is to generalise from the available evidence
The evidence identified that is relevant to this research question is not easily generalisable. Each included paper presented evidence from differing situations (purchase, rental, etc), providing a broad range of cost considerations.
4. Consistency - Degree of consistency demonstrated by the available evidence
There is a wide range of costs presented across the identified evidence.
5. Potential Impact of the intervention
Cost of UV light decontamination systems could be a barrier to use withing health and care settings.
6. Other factors to consider while assessing the evidence base
The evidence available relating to cost of UV light decontamination systems is limited and often confounding factors associated with savings are not accounted for.

7. Evidence Statement – synthesis of the evidence relating to this question	Evidence level
One guidance document,[23] two cohort studies,[29, 49] one before and after study,[53] and one expert opinion[17] included in this review addressed the cost of using UV light decontamination systems. In accordance with SIGN methodology, three are considered level 3 evidence (two cohort studies,[29, 49] one before and after study[53]), the expert opinion was considered level 4,[17] and the guidance document was assessed as AGREE Strongly Recommend.[23] Assessments of cost of implementing UV decontamination systems are limited due to the varying cost of devices and ongoing maintenance, facility/location specific specifications, and often do not account for additional costs associated with implementing UV decontamination systems such as staff training and cost of labour. In their 2022 guidelines, Beswick *et al*. stated that purchasing an automated decontamination device outright can cost in excess of £50,000.[23] While there are limited consumables related to UV decontamination devices, additional service contracts covering risk assessment, training of staff, and maintenance would increase this cost further.[23] As is mentioned above, the cycle time of devices vary and the potential economic impact of this in terms of staffing and labour costs should also be considered when choosing a UV decontamination device. The CDC stated in 2021 that the cost to install a system suitable for a 500 ft^2 room (two or three UV fixtures) is approximately $1,500 to $2,000.[17] There are often options for long-term hire or loan, rental, or rental with the option to purchase at the end of a set period available to spread the cost of these devices.[17] Ghantoji *et al*. stated that the PX-UV device used in their study costs $3000 per month and can disinfect more than 30 rooms per day.[53] This equates to a per-room cost of approximately $3 (excluding labour). Levin *et al*. reported that leasing two PX-UV devices for their study cost less than $5,000 a month.[29] Potential savings from reduction in healthcare associated infection can also be considered when choosing to implement a UV decontamination system however there is little direct evidence to demonstrate this. While Miller *et al*. estimated that implementation of PX-UV disinfection resulted in savings of approximately $300,000 associated with reduction in HAI cases over the course of their 15 month intervention period, this study did not account for potential confounders that may have	

7. Evidence Statement – synthesis of the evidence relating to this question	Evidence level
impacted the observed reduction in HAI rates, including compliance with IPC measures and the criteria for defining HAI cases.[49]	
8. Recommendation -	**Grade of Recommendation**
Setting/organisation-specific cost analysis should be undertaken before purchasing a UV light decontamination system.	Category B recommendation