Photon Disinfection Technology in the Hospital Environment

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Laurea University of Applied Sciences **Abstract**

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The study's purpose was to increase the awareness of photon disinfection methods for environmental disinfection in hospital settings to prevent and control hospital-acquired infections by providing a clean and safe environment for the patients. An integrative literature review was conducted to analyse the photon disinfection methods and their impact on hospital-acquired infection rates. This integrative literature review was completed for the Research, Development, and Innovation Unit in Laurea University of Applied Sciences to assist future research and development projects. Furthermore, this study focused on infection prevention and control's core competencies and will serve as a relevant context for future students in Learning by Developing Projects in Global Health and Crisis Management studies.

Photon disinfection technology has been known for a long time as an environmental disinfection method. However, due to the golden era of antibiotics, photon disinfection technology was somewhat overlooked. It has recently been reconsidered for disinfecting surfaces in hospital environments due to multiple challenges that the healthcare sectors face worldwide in preventing and controlling the rapid growth of hospital-acquired infections. Hospital-acquired infections increase morbidity and mortality rates worldwide and become a financial, social, and emotional burden to patients and society. Most of the developing countries are severely affected by hospital-acquired infections.

Lack of cleanliness in hospital environments is a significant risk factor for hospital-acquired infections. On top of that, antimicrobial resistance deteriorates the situation. The increased number of hospital-acquired infections led the industrial and medical firms to innovate new healthcare technologies to overcome the issue. Scientists have suggested using light to disinfect the environmental surfaces, called photon disinfection technology. This technology could impact in reducing hospital-acquired infections by inactivating the microorganisms that reside on healthcare environmental surfaces. Unfortunately, this technology has not been utilised adequately in healthcare settings.

The databases used for the data collection were CINAHL, PubMed, ProQuest and ScienceDirect. After the database search from 34 potentially relevant articles, the most 20 relevant articles were selected for the analysis process according to explicit inclusion and exclusion criteria. The quality of the articles was assessed by using STROBE and PRISMA quality assessment tools. Whittemore and Knafl's (2005) strategies and analysis methods were used to enhance rigour in integrative reviews and appropriately conduct this study.

The study results demonstrated that photon disinfection technologies effectively reduce the bioburden of hospital environments and hospital-acquired infection rates. However, in most studies, photon disinfection technologies were implemented as a supplement to manual terminal cleaning with or without chemicals and produced better outcomes. Therefore, it is recommended to implement photon disinfection technology as a supplement to manual terminal cleaning methods to achieve the anticipated reduction in the bioburden of hospital environmental surfaces and hospital-acquired infection rates.

Keywords: Infection prevention and control, photon disinfection, ultraviolet light, blue light, high-intensity narrow-spectrum light, hospital-acquired infection, and healthcare-acquired infection.

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1 Introduction

Photon disinfection technology (PDT) significantly affects bioburden reduction in hospital environments by disinfecting environmental surfaces. Different wavelengths of light are used to inactivate the pathogens which reside on hospital environment surfaces. Scientists and technologists together have innovated photon disinfection products by using different wavelengths of light. Each product has its strengths, limitations and drawbacks in inactivating microorganisms and its impact on environmental safety. (Cabral & Ag 2019.)

PDT is a potential solution in tackling hospital-acquired infections (HAIs), which are severe problems healthcare organisations face today globally. Hospital environmental surfaces are significant risk factors for HAIs, and infection treatments are becoming more challenging due to growing numbers of antimicrobial resistance, which deteriorates the situation. (World Health Organization 2020; Centers for Disease Control and Prevention 2015.) Furthermore, HAIs increase morbidity and mortality rates and increase the financial, social, and emotional burden of patients, relatives, and society (WHO 2020).

Unfortunately, many deaths occur annually due to HAIs worldwide. According to WHO (2019), 700 000 people die annually due to antimicrobial resistance (AMR) worldwide, and according to the European Centre for Disease Prevention and Control (2018), about 33 000 people die in Europe due to HAIs and AMR. In the United States, 1.7 million infections and 99 000 deaths occur annually (Septimus & Moody 2016). According to WHO (2020), developing countries are badly affected by HAIs compared to developed countries. In developing countries, HAIs rates are much higher than the developed countries. Shahida et al. (2016) described that HAIs in Bangladesh might exceed 30% in some hospitals. According to the Finnish health and welfare institute reports (Terveyden ja Hyvinvoinnin Laitos, 2020), about 100 000 HAI cases are reported annually.

Unclean patient room surfaces such as bed rails, bedside tables, call buttons, computer keyboards, and long-term treatment process play a major role in transmitting diseases (CDC 2015; WHO 2020). The increased numbers of morbidity and mortality rates triggered health professionals, the public, healthcare organisations, and decision-makers to find solutions. Therefore, it led the industrial and medical firms to develop new healthcare technologies for disinfecting hospital environmental surfaces. (Su 2016.)

Healthcare technologies have a substantial positive impact on multiple areas of healthcare services. It improves the quality of care provided to patients and increases healthcare services and productivity. (Iandolo, Vito, Fulco & Loia 2018.) Implementing advanced health technologies for infection prevention and control (IPC) in healthcare organisations could

positively impact HAI rates (Reeths & Merkakotiris 2016; Iandolo et al. 2018). Humphreys (2010) stated that PDT could inactivate microorganisms by its light inactivating mechanism and control HAI rates. Cabral and Ag (2019) described that ultraviolet-C (UV-C) light emitted by light-emitting diodes (LEDs), blue light microbial photoinactivation, and its subcategory high-intensity narrow-spectrum light (HINS) as the significant PDTs that used in healthcare settings. Villacís et al. (2019) stated that pulsed-xenon ultraviolet (PX-UV) no-touch disinfection system is a substantial innovation to disinfect environmental surfaces in hospitals.

Reeths and Merkakotiris (2016) described vast amounts of healthcare technology products available in the healthcare market for IPC. However, there is a gap between IPC technologies and the implementation of them in clinical settings. PDTs are very seldom implemented in healthcare settings. Su (2016) enhanced the adherence and the compliance of healthcare professionals towards these novel technologies. This study analyses the primary photon disinfection methods and their impact on bioburden reduction in hospital environments and HAI rates. Furthermore, it aims to increase awareness of photon disinfection methods to disinfect environmental surfaces in hospitals. With the assistance of the compiled information, it might be possible to develop measures to reduce HAI rates by implementing PDTs in hospital environmental disinfection.

The study's main purpose is to analyse the photon disinfection methods and their impact on HAI rates. This integrative literature review (ILR) was completed for the Research, Development, and Innovation Unit at Laurea University of Applied sciences. This study focused on the core competencies of infection prevention and control and will serve as a relevant context for future students in Learning by Developing Projects in Global Health and Crisis Management studies.

2 Prevention and control of hospital-acquired infections

The main focus of this study is to understand the impact of PDT in preventing and controlling HAI rates. HAI is a significant problem that healthcare organisations worldwide are struggling to overcome. It was previously called nosocomial or healthcare-associated infections. The definition for HAIs clearly illustrates that infections occur while the patients are in the treatment process at the hospital, and no incubation is present at the time of admission to the hospital and manifest 48 hours after admission to the hospital. (Monegro, Muppidi & Regunath 2020.)

Furthermore, infections are becoming more antibiotic-resistant than ever, and it could extend the hospital stay and even the potential of becoming life-threatening. On the other

hand, it increases the financial, social, and emotional burden on patients, relatives, and healthcare organisations. (CDC 2009; WHO 2020.) Healthcare setting environments are the core source of many infection outbreaks. Patients and healthcare professionals are at a high risk of being infected in healthcare settings. (Sood & Perl 2016.)

2.1 Definitions for major hospital-acquired infections

According to the CDC (2014), the major HAIs are central line-associated bloodstream infection, catheter-associated urinary tract infections, surgical site infection, ventilator-associated pneumonia (Table 1).

HAI	Definition
Central Line-associated Bloodstream Infection (CLABSI)	Central line-associated bloodstream infections. It mainly occurs due to the prolonged use of bloodstream catheters.
Catheter-associated Urinary Tract Infections (CAUTI)	Urinary catheter-associated infections could involve any part of the urinary system, and it is the most common among HAIs. Prolong use of urinary catheters increases the risk of having CAUTI.
Surgical Site Infection (SSI)	It is an infection that occurs after surgery at the surgical site. There are two types of SSIs: superficial infections involving the skin only. Then, infections under the skin, such as in organs by implanted materials, are considered severe SSIs.
Ventilator-associated Pneumonia (VAP)	It is a lung infection associated with a ventilator. Ventilators are primarily used in ICU settings to support the breathing of patients with breathing difficulties.

Table 1: Definitions for the significant HAIs according to CDC (2014)

2.2 Statistics of hospital-acquired infections

According to WHO (2019), annually 700 000 people die globally, and according to EDDC (2018), 33 000 people die in Europe due to antimicrobial resistance (AMR) and HAIs. Identical or similar types of antimicrobials are used to treat humans and animals, which increases the risk of AMR in humans and animals (WHO 2021). According to ECDC (2020), on any given day, about 80 000 patients are infected at least by one HAI, which means one in every 18 patients in European hospitals is infected with HAIs. According to Septimus and Moody (2016), in the United States, about 15% of patients develop an infection during their stay at hospitals, which means that annually 1.7 million infections and 99 000 deaths occur, increasing healthcare costs services by 10 billion dollars.

HAIs affect millions of people worldwide; lower and mid-income countries are more severely affected (WHO 2020). In developing countries, HAI rates are much higher than in developed countries. The prevalence rates of HAIs in Nigeria in a pediatric hospital are 30.9%, in the United Republic of Tanzania in a general surgery hospital 23%, and in Kenya 19% in a

maternity hospital. (WHO 2009.) Shahida et al. (2016) stated that HAIs risk is estimated to be 2-25 times higher in developing countries than in developed countries. HAIs in Bangladesh may exceed 30% in some hospitals. Studies confirmed the need for urgent practical actions to prevent and control HAIs.

According to the Terveyden ja hyvinvoinnin laitos (2020) annual report, about 100 000 HAI cases are reported in Finland. Most of these infections are associated with various healthcare interventions such as urinary catheters, respiratory ventilators, surgical procedures, corticosteroid treatment and other procedures that weaken the immune system. According to the CDC (2015), uncleanliness of the hospital environment surfaces in the patient rooms, such as bed rails, bedside tables, call buttons, and computer keyboards, may play a role in transmitting diseases, and these elements are considered reservoirs for pathogens. Furthermore, prolonged treatment process in hospitals also increases the risk of HAIs (WHO 2020).

2.3 Healthcare technology reducing infections in healthcare settings

Healthcare technology is a combination of evidence-based knowledge and skills developed in different forms such as devices, medicines, and healthcare-related procedures and systems to increase patients' quality of life by providing better healthcare services (WHO 2020). Healthcare technologies have a substantial positive impact on multiple healthcare services. However, without a proper understanding and appropriate implementation, it could not achieve the anticipated outcome. The healthcare workers' adherence and compliance with the proper use of technology are essential in achieving the goals. (Iandolo et al. 2018.)

According to Reeths and Merkakotiris (2016), healthcare technologies improves the quality of care provided to patients and increases healthcare services and the productivity of the services. On the other hand, some of these healthcare technologies could be impacting reducing HAI rates (Iandolo et al. 2018). AutoDet technology is an excellent example of better healthcare technology. Researchers of the Aalto University of Finland have innovated real-time optical to identify pathogens on environmental surfaces. It can detect biological contamination on environmental surfaces automatically. It is a valuable innovation used in healthcare environments to detect environmental hygiene level. (Aalto University of Finland 2019.) However, innovations of technologies alone cannot improve healthcare services and the quality of patients' lives. It requires successful implementation, including a better understanding of the technology, compliance, and healthcare professionals' adherence. (Iandolo et al. 2018.)

2.3.1 Hospital-acquired infections and infection prevention and control technologies

HAIs is a severe problem that currently, healthcare sectors are facing worldwide. According to statistics, millions of deaths occur annually worldwide, and it becomes a considerable challenge and financial burden to the healthcare sectors to treat HAIs, especially if the *multidrug-resistant organism* (*MDRO*) is the causing agent. (Cabral & Ag 2019.) According to Su (2016), the lack of cleanliness of the hospital environment is a significant risk factor for HAIs. Uncleaned surfaces become reservoirs for pathogens, and it increases the contamination risk. Mostly HAIs are preventable if the right solution is implemented. According to Humphreys (2010), implementing new technologies for keeping the surface clean would increase the healthcare environment's hygiene level.

Furthermore, Cabral and Ag (2019) stated that combining science and technology had taken us a step forward to overcome the problem by using light wavelengths to inactivate the microorganisms and reduce the morbidity and mortality rates. Light therapy is an alternative solution and an effective method to overcome HAIs. It is a vigorous alternative to conventional antimicrobial treatment against *MDROs*.

2.3.2 Photon disinfection measures in infection prevention and control

According to Humphreys (2010), using ultraviolet (UA) robotic technology for cleaning the surface is a valuable technology to disinfect the surface. However, the industrial market has produced various products using different light wavelengths and mechanisms to disinfect the surfaces. For example, one of the significant PDT is UV-C light emitted by LEDs. It positively impacts reducing HAIs by disinfecting surfaces and medical devices without causing any significant damage. It is an effective disinfection method.

According to Maclean, McKenzie, Anderson, Gettinby and MacGregor (2014), ultraviolet (UV) light technology and its germicidal properties have long been known for inactivating microorganisms and reduce contamination. When a microorganism absorbs UV light short wavelength-C, it destroys the DNA and RNA microorganism, leading the microorganism to be inactive. However, only recently antimicrobial properties of visible violet-blue light with a 405 nm light wavelength had been discovered. It has antimicrobial properties against a wide range of microorganisms, although its germicidal efficacy is lower than UV light. Different UV light wavelengths are used to disinfect a wide range of microorganisms and keep the environment cleaner and safer. Blue light microbial photoinactivation and its subcategory HINS-light EDS are mainly used in healthcare environments to disinfect surfaces, impacting reducing HAIs by providing a clean surface. It is an effective sanitisation compared to the usual manual cleaning. (Cabral & Ag 2019.)

2.3.3 Mechanism of photon inactivation

Due to the series of photophysical and photochemical reactions, photodynamic inactivation occurs. Photosensitisers (PS) are triggered by light and get excited and produce reactive oxygen species (ROS), which then oxidise the biomolecules. PS will be in the electronic ground state configuration if the PS is not triggered by light, such as dark circumstances. However, when PS absorbs a photon at a given wavelength, it will be excited and move into a new electronic state. This new electrotonic state of PS will only last for a shorter period, and it will then return to its previous ground state or move to a new excited state called a triplet state, which has a superior lifetime compared to the previous state undergoing a cross-system interaction. The triplet state of PS leads to ROS production; thus, ROS causes permanent oxidative damage to the cells' DNA and RNA. (Cabral & Ag 2019.)

2.3.4 Pulsed xenon ultra-violet light

Pulsed xenon ultra-violet (PX-UV) light is another type of technology that belongs to the UV-C category. It is a non-touch technology. The xenon flash lamp with a non-mercury bulb releases pulses, and each pulse contains the energy of about 505J UV-light within the range of UV-light 200-320 nm, which causes cellular damage to the microorganisms and inactivates its functionality, and as a result, it inhibits the replication of microorganisms. It is an efficient technology to disinfect the floors and high touch surfaces, and it has proven effective in eliminating microorganisms, including *MDROs,* from 95- 99% in healthcare settings. PX-UV is a better technology that has a significant impact on reducing HAI rates. (Villacís et al. 2019; Dippenaar & Smith 2018; Casini et al. 2019.)

2.3.5 Blue light microbial photon inactivation

Blue light therapy uses the visible light wavelength of 400-470 nm. It uses the photodynamic mechanism to inactivate microorganisms. As a result, the microorganism will be inactivated and become incapable of replicating. Its mechanism is oxygen-dependent. Therefore, increasing the quantity of oxygen can achieve ROS's superior action; thus, it requires a less light dose for microorganism's inactivation. Nevertheless, the presence of PS is crucial in inactivating the microorganism. (Cabral & Ag 2019.)

2.3.6 High-intensity narrow-spectrum light environmental decontamination system

High-intensity narrow-spectrum light (HINS-light) environmental decontamination system (EDS) technology is a subcategory of blue light therapy specially designed to disinfect healthcare settings environments. HINS-light EDS uses the blue-light wavelength at 405 nm to inactivate microorganisms. The most significant advantage of this technology is that it is

harmless for humans and can be continuously used in occupied areas to inactivate microorganisms and *MDROs*, thereby it controls HAI rates. (Cabral & Ag 2019.)

3 Purpose, objectives, and research questions of the study

The purpose of this study was to increase the awareness of photon disinfection health technologies in IPC in healthcare settings.

The study objectives are:

1) to analyse photon disinfection methods in environmental disinfection in healthcare settings and their impact on inactivating the microorganisms,

2) to describe the importance of microbiological burden in healthcare settings and its impact on HAI rates and

3) to analyse the barriers and facilitators in implementing photon disinfection methods in clinical settings.

Research questions are:

1) What are the photon disinfection technologies implemented in healthcare environments?

2) What kind of impact do photon disinfection technologies have on the microbial burden of hospital environments?

3) What kind of impact do photon disinfection technologies have in reducing HAI rates?

4) What are the barriers to implementing photon disinfection technologies in hospital environments?

5) How to overcome the barriers and enhance the implementation of photon disinfection technologies in hospital environments?

4 Methods

This ILR study was completed for a Research, Development and Innovation Unit at Laurea University to assist future research and development projects. This study focused on the core competencies of infection prevention and control and will serve as a relevant context for future students in Learning by Developing Projects in Global Health and Crisis Management studies.

The thesis project has started with the thesis topic analysis end of May 2020. With the guidance of the Principal lecturer at the Laurea University of Applied Sciences and thesis supervisor Teija-Kaisa Aholaakko, the author finalised the research topic and the research method at the beginning of August 2020.

The author has been working as a registered nurse in different wards in the Helsinki metropolitan region for the last ten years and has experience working in an infection ward from 2013 to 2015. Nevertheless, the author has treated quite many patients for various infections in the last ten years. In those treated, most of the infections were due to HAIs. In some cases, physicians have prescribed strong antibiotics for a more extended period to treat HAIs; in other cases, physicians had to change the antibiotics due to a lack of response to the previously administered antibiotics. It has been a challenge to healthcare workers to treat infections, and meantime, it is suffering and a burden to the patients. Combining the author's clinical experiences and the thesis supervisor's topic suggestion of photon disinfection as a technology to disinfect the hospital environment motivated the author to conduct the thesis on this specific topic.

In the initial search, it was found that internationally there had been a reasonable amount of research conducted on photon disinfection in disinfecting hospital environments. However, unfortunately, there was not an adequate amount of research conducted on this interest in Finland. It illustrates that this technology has not been adequately implemented in the Finnish healthcare system though it has proven internationally significant in reducing bioburden on environmental surfaces and HAI rates.

Since there was not an adequate amount of systematic literature review conducted in this area of interest in Finland, the author has determined to conduct the research process by using ILR as a research method on photon disinfection in healthcare setting environments to achieve the objectives of this study by finding answers to the research questions. Furthermore, a PICOTT model was used to structure the thesis process. The ILR helped assess the aims and identify the gap between potential and actual health technology implementation in healthcare settings.

The author is a full-time worker and, at present, works at Helsinki University Hospital (HUS). Due to this master's programme, the author has done only 70% of the work from February 2020 until December 2020. Furthermore, the author has used most of the leisure time to write the thesis. The thesis was presented on 16th January 2021 and finalised on 28th May 2021.

4.1 PICOTT model

The PICOTT model is a valuable tool in writing a research thesis. It is essential to have a well-built existing structure as a base to conduct a research process appropriately. In general, it assists the researchers in structuring the thesis process. In this study, the PICOTT model was used to identify the research problem, previously used methods, find new interventions as possible solutions, construct appropriate research questions that need to be answered, and select the appropriate research method to conduct this study. This study results may enhance healthcare personnel's adherence and compliance with PDTs and select PDT measures for environmental services. PICOTT model is provided in table 2.

Problem	Lack of awareness of PDT implemented in healthcare settings as an IPC measure.
Intervention	To investigate the impact, barriers and facilitators of PDT in disinfecting the healthcare environments.
Comparison	Compare traditional practices for environmental disinfection versus PDTs for IPC in healthcare environments.
Outcome	Reduction in microbial burden of hospital environment (= a short-term outcome) and reduction of HAI rates (long-term outcome or patient outcome). Description of barriers and facilitators for the use of PDTs in healthcare environments.
Type of questions	1) What are the PDTs implemented in healthcare environments? 2) What kind of impact do PDTs have on the microbial burden of hospital environments? 3) What kind of impact do PDTs have in reducing HAI rates? 4) What are the barriers to implementing PDTs in hospital environments? 5) How to overcome the barriers and enhance the implementation of PDTs in hospital environments?
Type of study	An ILR

PDT = Photon disinfection technology; IPC = Infection prevention and control; ILR = Intergrative literarture review; HAI = Hospital acquired infections

Table 2: PICOTT model

4.2 Integrative literature review

The primary reason for choosing an ILR was that there was not adequately studied the photon disinfection in hospital environments and its impact in Finland. Therefore, conducting an ILR based on international studies would help conclude the efficacy and effectiveness of photon disinfection in hospital environments and their impact on bioburden reduction and HAI rates. These results may help to design and plan future methods for disinfecting environmental surfaces.

The ILRs are extensive research methods, and they implementing experimental and non-experimental research methods to fully understand the phenomenon of concern. ILRs may consist of data from theoretical and empirical studies. (Whittemore & Knafl 2005.) An ILR is a broad concept, and it has the potential of providing a significant contribution to developing knowledge in a researching topic based on previous research findings. An ILR is a form of research conducted in an integrative way, as it reviews, analyses and synthesises representative literature on a topic. As a result, it generates new frameworks and

perspectives on the topic. Nevertheless, ILR is a sophisticated form of research. Therefore, it requires good research skills and knowledge to succeed in the research process. (Torraco 2005.)

Summarising previous literature on a research topic provides a better understanding of the phenomenon or a health problem called an ILR. It has the potential of creating new knowledge in nursing science, informing research and policy initiatives. Well-done ILR presents the state of the science. Open for diverse methodologies considered as the significant strength of the ILR. Therefore, it can play an essential role in evidence-based practice in the nursing field. (Whittemore & Knafl 2005.) The ILR is an appealing method, and it is the most cited types of reviews across disciplinary fields. Researchers set up a framework and criteria before starting the research process. Most importantly, researchers look for the most recently published literature reviews to be more specific and capture recent information on a topic. (Torraco 2016.) Therefore, the author of this study has determined to limit the literature database search only for the past ten years to acquire the most recent relevant information on the topic.

The ILRs use explicit and systematic methods for analysing data which protects against any bias. However, the primary challenge of ILR is analysing and synthesising the multiple previous sources. Nevertheless, developing strategies for data analysis is essential in updating the methodology of ILR. (Whittemore & Knafl 2005.) Moreover, the primary strength of ILR is that it collects many pieces of literature on a topic and analyses to understand other researchers' perspectives on the topic, such as similarities, issues, deficiencies, errors and inaccuracies, and other related problems. Analysing the previous literature's strengths and weaknesses on a topic and adding the author's notions and knowledge would support constructing new models and perspectives, leading to a new dimension. An ILR can shape the practice and future direction of the research phenomenon. (Torraco 2016.)
Whittemore and Knafl (2005) introduced five stages to conduct research: problem identification stage, literature search, data evaluation stage, data analysis stage, and presentation stage. Figure 1 illustrates the stages of how to conduct the research process.

Figure 1: Stages to conduct an integrative literature review by Whittemore and Knafl (2005), modified by the author

4.2.1 Problem identification stage

It is the first stage in conducting an ILR. In the initial stage of the research process, it is essential to identify the actual problem and the purpose behind addressing the issue. Moreover, the research purpose is an essential concept to collect appropriate data concerning the topic and to avoid other data that are not relevant to the topic. Data extraction is a challenging process because of the existence of a vast number of variables. A clear purpose is essential for facilitating the research process in an ILR because of its complicity. (Whittemore & Knafl, 2005.)

4.2.2 Literature search stage

In the next stage, appropriate search strategies are inevitable to enhance the literature search quality and avoid biases. Otherwise, it may lead to inappropriate and inadequate data collection, which may lead to inaccurate results. Computerised database search is an advanced technology to collect data, but it may provide only 50% of the concerned study due to limitations. Then the traditional way of searching called ancestry searching. It is a comprehensive search for ILR that may provide several primary relevant sources. It is imperative to document all the search process in the method section in an ILR process. This aspect provides a better understating and is transparent to the reader about how the research process has been conducted. (Whittemore & Knafl 2005.)

4.2.3 Data evaluation stage

Evaluating the quality of the primary sources is an essential factor in ILR strategies. Evaluating the primary sources' quality by providing scores for each category based on how it has been handled or performed in the ILR process is an essential factor. This process facilitates the data analysis process by minimising the risk of having inaccurate results. Inappropriate and inadequate data evaluation increases the risk of having inaccurate results. However, evaluating diverse primary sources is challenging. (Whittemore & Knafl 2005.)

4.2.4 Data analysis stage

Data analysis is a broader concept, which has multiple stages. It places data to code, categorise, synthesise, summarise and transform into new valuable information that facilitates drawing conclusions and decision-making. The data analysis's primary objective is to conduct a thorough and unbiased interpretation based on the primary sources' evidence. The data analysing process is the most challenging process amongst any of the stages mentioned above. The primary research methods developed for mixed-methods and qualitative designs are applicable for ILR analysis. Data are analysed one by one to check the similarity and differences to categorise and group them. (Whittemore & Knafl 2005.)

4.2.5 Presentation stage

The author's responsibility is to provide clear evidence and details from the primary sources to support the conclusion. It is crucial from the readers' point of view that the review's conclusion did not exceed the evidence. An ILR provides a comprehensive knowledge of the topic of interest after analysing multiple diverse data. However, the results should be logical to the topic and bring new understanding to the phenomenon of concern, which should be applied in practice, opening future research and policymaking pathways. Nevertheless, it is necessary to mention the methodological limitations and the study's criteria in the presentation. (Whittemore & Knafl 2005.)

4.3 Inclusion and exclusion criteria

It is essential to plan the inclusion and exclusion criteria before the data search. This approach will guide and assist the researchers to find the relevant publications to conduct the research process. Table 3 illustrates the inclusion and exclusion criteria of this study.

Inclusion criteria	**Exclusion criteria**
Original scientific publications limited to the last ten years (2010 – 2020)	Thesis reports, newspaper articles and except original articles
Full text	Abstracts only, conference book proceedings
Peer review research: qualitative, quantitative, mixed methods, systematic literature review, integrative literature reviews	Case reports, narrative literature reviews, commercial advertisements
Reports of technology institutions (National Technology Institution, VTT, e.g.) and Studies in the healthcare environment (hospitals)	Studies in dentistry; elderly care; water processing; direct wound care; food disinfection
Languages English	Other languages than English
Scientific articles related to photon disinfection technology/methods, PDT) (ultraviolet, blue light, blue-violet light and catalytic coating)	Other than PDTs related articles

Table 3: Inclusion and exclusion criteria

4.4 Data search process and review

Scientific research creates new knowledge based on previous literature by combining and interpreting existing knowledge into a beneficial concept. The literature search is the primary base for accumulating the appropriate data for reconstructing previous knowledge into a specific domain. The literature search is the first step and the foundation to conduct a research project. Moreover, the literature search process has a significant impact on the quality of literature reviews. However, in the initial stage of the literature search process, one needs to identify scholarly databases for the literature search and then apply the keywords to obtain relevant articles for the study purpose. (Brocke, Simons, Niehaves, Niehaves & Reimer 2009.)

To enhance the reliability and the validity of the data search in this study, the author has approached the Laurea University of Applied Sciences information specialist's assistance on 24th September 2020 at the campus library and conducted the data search together. Firstly, together decided to limit the search only to four primary databases such as CINAHL, PubMed, ProQuest, and ScienceDirect. However, Google Scholar was recommended by the information specialist if the data is not adequate. The problem was defining the photon disinfection concept because no Medical Subject Headings (MeSH) terms were found. All the references, including excluded sources, were stored in RefWorks. Same search terms used in all the databases to collect data. The data search process illustrated in figure 2.

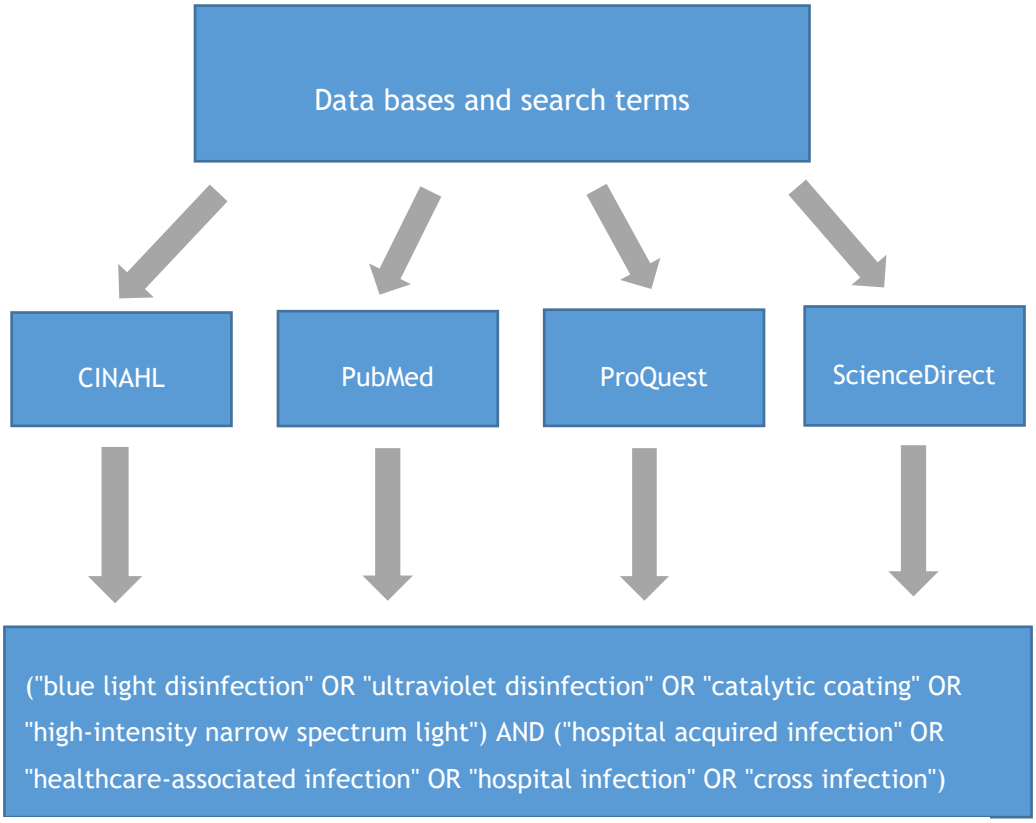

Figure 2: Database search method

Four scholarly databases were used for data collection. Inclusion and exclusion criteria have been set in advance with the guidance thesis supervisor to enhance the reliability and validity of accumulating data. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) was followed to obtain the appropriate data for the study purpose, and the information specialist's guidance has facilitated obtain the relevant articles for the study purpose. The articles' screening process was conducted with the thesis supervisor and selected the most eligible and relevant 20 articles for the study's analysis purposes. PRISMA flow chart of the study demonstrates the data review in figure 3.

All the selected studies conducted between 2010-2020 provided the most recent and updated information about the phenomenon of interest. Countries of chosen articles as follows; USA (10 articles), Canada (1 article), Ecuador (1 article), UK (4 articles), Italy (1 article), Japan (2 articles) and South Africa (1 article).

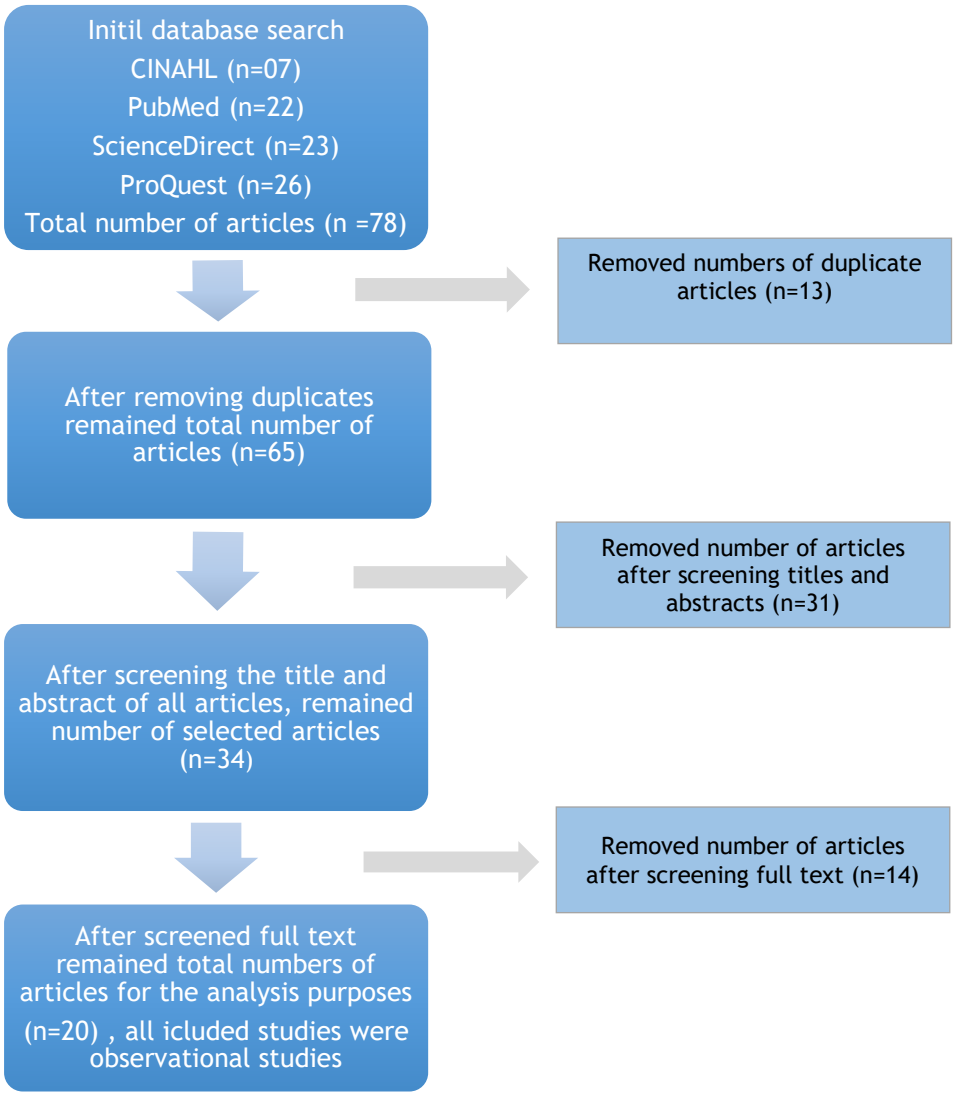

Figure 3: PRISMA flow chart of the data review

4.5 Data quality assessment

Data quality is an essential factor in scientific research. Data are reusable, and there is a high risk of providing inaccurate results if high-quality data is not used to produce new results. Using inaccurate data to produce new results in research could cause significant damages at an organisational level. Therefore, quality check-up strategies are essential to obtain high-quality data for study purposes. (Wuest, Tinscher, Porzel & Thoben 2014.) Data assessment

for its quality is crucial because of its impact on public health interventions (Chen, Hailey, Wang & Yu 2014).

Assessing the data quality of multiple primary sources is challenging and complicated in the ILR (Whittemore & Knafl 2005). The data quality assessment process mainly assesses data collection methods, data capturing and insights, and new knowledge created based on previous research for future use. However, an illustration of methods is essential for future researchers to replicate the study and grasp similarities. (Snyder 2019.)

According to the above statements, researchers of an ILR should carefully assess the primary sources. For that, there is a need to use appropriate tools for the assessment process. In this study, the author has chosen PRISMA and the STrengthening the Reporting of OBservational studies in Epidemiology (STROBE) to evaluate the primary sources' quality. The PRISMA checklist facilitates the reporting in systematic reviews and meta-analysis. It enhances the quality of methodology and the reliability of systematic reviews and meta-analysis. (Moher et al. 2015.) The STROBE was an essential tool for the authors of this study, it facilitated the writing process of articles on epidemiological studies, and it strengthened the reporting factor of observational studies in this ILR (Knottnerus & Tugwell 2008). All the studies selected for further analyses were observational (Figure 4).

The STROBE tool applied in this study (Appendix 2) has 22 sections from its title to findings, and each section assessed for its quality and relevancy for the study purposes. Each section provided scores as follows; X, 1 and 2 according to its relevancy and performance. (X) for hardly/not satisfies assessment criteria, or assessment criteria do not apply, (1) for partly satisfies assessment criteria, and (2) for satisfies assessment criteria. An article could score in total maximum of 44 (100%). Each article's total score converted into a percentage, and the author has decided if any article scores below 70% considered low quality, scoring between 71-85% as moderate and over 86% considered high-quality data. The assessment process conducted individually by the author and the thesis supervisor and then compared the results together. In this combined quality assessment process, only in a few cases were differences in scoring between the author and the thesis supervisor. Then both came to a mutual understanding of scoring by having screened those articles once again. In this study, five articles scored between 71-85%, which is considered moderate quality data, and the rest of the fifteen articles scored over 86%, which considered high-quality data. STROBE table provided as appendix 2.

4.6 Data analysis

Data analysis of ILR require a thorough, unbiased interpretation of primary sources, and this process supports creating new ideas in the research based on the evidence. Unfortunately, in ILRs, strategies for analysis are insufficiently developed. Nevertheless, analysis methods

constructed for mixed-method research and qualitative research can apply to integrative literature analysis. These methods facilitate continually compare the data with one and another on the extracted data. The constant compare approach method allows comparing the extracted data item by item and systematically categorising them into similar groups. Eventually, these coded categories will undergo further analysis and synthesis process. The data analysis process includes data reduction, data display, data comparison, conclusion drawing, and verification. (Whittemore & Knafl 2005.) The data analyses process illustrated in figure 4.

Figure 5: Data analysis process of an integrative literature review from Whittemore and Knafl (2005), modified by the author

After completing the data collection of this study and screening the selected research articles, the author has identified and noted the essential information and documented it in a table format (Appendix 1). The quality of included articles assessed by using the appropriate quality assessment tool (Appendix 2). Both Whittemore and Knalf (2005) and Elo and Kyngäs (2007) analysing methods applied to conduct the data analysing process. In the initial stage of the analysing process, the author of this study repeatedly read all the primary data, identified, and recognised the main meaning units, words, or terms, used as units of analysing answering the study questions. The data reduction was carried out by extracting the identified data and inserting it into a simple data display spreadsheet, facilitating the appraisal and comparison. Finally, the data answers the study questions of this ILR presented in tables 4 and 5.

Moreover, reducing and extracting the text assisted in identifying relationships and similarities within the data in answering the study questions. This process assisted in identifying the primarily implemented PDTs in hospital environments and the impact of PDTs on the hospital environment's microbial burden and the HAI rates. Furthermore, it has facilitated to find out the barriers and enhancements to implementing PDTs in hospitals environments. The results were written and discussed based on the research questions. This entire process was aimed to enhance the appropriate interpretation of the data. The answers to the study questions were drawn after analysing and interpreting similar findings and finally converting them into a general conclusion.

5 Results

The main results of this ILR demonstrated by answering the research questions of the study. The first research question answered by introducing the main PDTs that are used in hospital environments. Then answered the second and third research questions by demonstrating its impact on the microbial burden on the hospital environment and the HAIs rates. These answers were provided with additional tables four and five. Finally, research questions four and five were given a combined answer for barriers and enhancements in implementing the PTDs in hospitals.

5.1 Photon disinfection technologies implemented in healthcare environments

In the analysis process, various types of photon technologies have been discovered. In most studies, photon technology is used as a supplement to traditional manual cleaning, which may or may not include disinfection chemicals.

There are various similar types of UV light devices available for disinfection. In general UV-C emitting devices provides continuous UV-C light from a mercury bulb in either a portable machine or a disinfecting wand. (Nagaraja et al. 2015.) Focused multivector ultraviolet (FMUV) disinfection is a novel technology that has proven its efficiency in reducing the bioburden on hospital environment surfaces. Modular panels of lamps and reflectors of FMUV enclose a target zone, and UV rays emitted from multiple directions successfully eliminate the shadowing on surfaces. Since UV intensity is high, it disinfects the objects rapidly from all sides, and the modular panels block UV rays and prevent leaking outside. It is safe to use the room while the disinfection process is on in an enclosed targeted zone. The foremost significant advantage of this technology is that it does not affect healthcare professionals' daily working routines. (Armellino, Walsh, Petraitis & Kowalski 2019.)

PX-UV device is a no-touch technology designed for automated disinfection in rooms using pulsed UV-C radiation with short cycle times. These devices have a movable section containing a xenon gas flashbulb. In general, the PX-UV devices emit light in high-intensity pulses across a broad wavelength spectrum and includes the peak UV germicidal range of 200 to 320 nm associated with disinfection activity. It has several safety mechanisms to assist and protect the user, including warning signs and a motion sensor to cease operation automatically if the movement is detected. It is convenient to transport, user-friendly, safe, and includes rapid disinfect cycles. The efficacy of no-touch PX-UV depends on the distance between the lamp and the targeted surface for disinfection, and manufacturers recommending high-touch surfaces are within two meters from the central lamp to achieve optimal efficacy. In general, the PX-UV device uses five minutes of disinfection cycles and multiple positions. However, time cycles are adjustable according to the need for targeted area disinfection. This device can be operated only in unoccupied rooms due to the high-

intensity broad-spectrum UV light. The major disadvantage is that the patient must be transferred into another room until complete the targeted room's disinfection. (Casini et al. 2019; Dippenaar & Smith 2018; Villacís et al. 2019.)

The Tru-D SmartUVC uses a sensor to detect direct and reflected UV-C light and has two emitters setting for vegetative (*MRSA* and *VRE*) and sporicidal for *C. difficile* spores. This device calculates the correct dose according to the targeted area's size and the pre-adjusted cycle durations for the targeted site. A wireless handheld device can operate this. The other device is the R-D rapid disinfector system which uses four detached sensors to detect direct UV-C light and has one setting for vegetative and sporicidal. This device is capable of repositioning after two of the four sensors have reached a predefined dose. This device also operated via a wireless handheld, and the data are transferred automatically to a central server by using Wi-Fi. (Wong et al. 2016.)

UV Angel desktop lamps specially designed for disinfecting computer keyboards and specific areas in the patients' rooms; for example, they can be installed over computer keyboards. It provides real-time monitoring of surface use, and the mercury bulb automatically delivers UV light disinfection when the device is not in active mode and turns off automatically when the keyboard is required for use; for example, it detects motion under the lamp as mouse input. This mechanism protects caregivers from the effect of UV radiations. UV Angel desktop lamp is a valuable technology to reduce the bioburden on keyboard surfaces and minimise cross contaminations in hospitals. (Gostine, Gostine, Donohue & Carlstrom 2016.)

The HINS-light EDS ceiling-mounted light provides continuous decontamination. It emits a blue-violet light at 405 nm, which works on safe irradiance though it is bactericidal. It has the capacity of inactivating wide ranges of pathogens, including those that are commonly associated with HAIs. HINS-light EDS's most significant advantage is that it is harmless to patients and staff, and it can be used continuously throughout the day in occupied areas. (Bache et al. 2012; Maclean et al. 2010.)

5.2 The impact of photon disinfection technologies on the microbial burden of hospital environments

Among the selected studies for this ILR, most studies have proven the positive impact of PDTs on bioburden reduction on hospital environment surfaces (Table 4). Using enhanced strategies in terminal disinfection could produce positive outcomes. Suppose previously discharged patients are diagnosed with *MDROs* or *C. difficile* in that case, new admissions to the same room are 10-30% less likely to acquire the same pathogens if the chamber was terminally disinfected using enhanced strategies. Nearly 50% of all hospital environment surfaces are possibly not cleaned during the terminal cleaning process. However, PDT as a supplement to

standard disinfection strategies has proven its effectiveness on bioburden reduction in the hospital environment. (Anderson et al. 2018.)

Beal et al. (2016) deployed a PX-UV device to disinfect the isolation rooms in a clinical haematology ward in their study. The manual cleaning has demonstrated a reduction of 76% *Aerobic* total colony counts, and following the implementation of PX-UV, the *Aerobic* total colony counts reduced further 14%, resulting in over 90% reduction in *Aerobic* total colony counts. Furthermore, there was a 38% reduction in the number of sites where *VRE* was detected in the same study, from 26 of 80 sites following manual cleaning to 16 of 80 sites with additional UV disinfection.

Morikane et al. (2020) evaluated PX-UV devices' effectiveness in controlling the transmission of *MDROs* in a university hospital. By manual cleaning, 81% bacterial reduction was achieved; adding PX-UV disinfection have further increased the bacterial reduction by 59%. In another study, Casini et al. (2019) evaluated the effectiveness of PX-UV in a teaching hospital. The bioburden reduction showed as follows; in the patient rooms, 12%, in ICUs 8%, and ORs 93% with low turnover and 183% in ORs with high turnover. Furthermore, it has demonstrated that 63% positive samples accumulated after standard operating protocol and after PX-UV accumulated only 18% positive samples. The manual cleaning process has shown a considerably high bioburden reduction on surfaces; however, adding PX-UV to manual cleaning has increased bioburden reduction efficiency.

In addition to the authors introduced above, Dippenaar and Smith (2018) evaluated the impact of PX-UV compared to standard care in a neonatal and paediatric hospital surface. Pre-cleaning surface bioburden on control period from colony-forming units (CFU) 244 significantly improved to CFU 44 in the PX-UV period, and the post-cleaning surface bioburden on control period from CFU 300 significantly improved to CFU 6 in the PX-UV period. A constant higher amount of bioburden discovered on the refrigerator door handle. 90% of surface bioburden reduction was achieved from the control period CFU 544 to the corresponding PX-UV period CFU 50.

Green et al. (2017) evaluated the effect of PX-UV on environmental surface bioburden, HAI rates, and *MDROs* acquisition in burn intensive care units (BICU). Researchers assessed the HAIs and *MDROs* acquisitions one year before and three-month periods before, during, and after PX-UV. Samples showed that the bioburden level was very high in bathroom hoppers, bedside monitors, and door handles before the PX-UV. After implementing PX-UV, bioburden decreased in total samples 48% vs 31%, as did surface growth alone 51% vs 33%. The bioburden of high touch surfaces remained high. Anyhow implementing PX-UV have reduced the bioburden on high touch surfaces dramatically. Furthermore, in this study, a total number of

379 colonies identified from air and surfaces, and most of those represented skin commensals without identified *MDROs*.

In tertiary care conducted a study on *C. difficile* infection in isolation rooms. Pre and post bleach cleaning positive rates of *C. difficile* reduced from 27.8% to 13.9%, and meanwhile, pre-and post-PX-UV disinfection rates reduced from 31% to 11.3%. Furthermore, it illustrated that PX-UV disinfection effectively reduces *C. difficile* contamination from high-touch surfaces. (Kitagawa et al. 2020.)

In another study in a general hospital, Villacís et al. (2019) evaluated the effectiveness of PX-UV disinfection on bacterial reduction on environmental surfaces. From 124 surfaces showed CFU 3569 after manual terminal cleaning and dropped to CFU 889 after PX-UV disinfection. In the patient rooms, 76% and ORs 87% microbial reduction on surfaces was achieved. As a result, a total of 75% microbial reduction was achieved after PX-UV disinfection in addition to manual terminal cleaning. Furthermore, in the same study, the polymerase chain reaction (PCR) amplification in four rooms identified *serine carbapenemases* (*blaKPC, blaIMP, blaVIM,* and *blaNDM*), and data obtained for in-vitro testing for *MDROs* showed a high bacterial efficacy level in all four pathogens. There was an 8-log reduction found in all cases after 5 minutes of PX-UV disinfection on the surfaces.

In a different study, PX-UV disinfection was implemented in an ICU of a community hospital, but on non-ICU floors, the device was used only in *C. difficile* occupied areas. In the ICU, 56% reduction in *MRSA* burden, 87% in *VRE* burden, and 45% reduction in *C. difficile burden* were observed. A significant reduction in non-ICU floors showed only in *C. difficile* at 40% but in *VRE* 37%, and however, *MRSA* increased by 52%. (Vianna, Dale, Jr, Simmons, Stibich & Licitra 2016.)

A similar study conducted in four veterans' affairs facilities, and two of those facilities, PX-UV devices, added to standard manual terminal cleaning and represented the intervention sites. In contrast, two other facilities served as control sites with standard manual cleaning. An overall *MRSA* reduction observed from CFU 16.9 to 2.7(84.1%) in PX-UV rooms and from CFU 31.8 to 17.4 (45.1%) manually terminal cleaned rooms. *Aerobic bacteria colonies* (*ABC*) reduced PX-UV rooms from CFU 397 to 98 (75.3%) and manual terminal cleaning only from CFU 151 to 111(26.5%). As a result, the overall count reduction was 75.7% for PX-UV disinfection and 30.6% for manual cleaning. (Zeber et al. 2018.) These results indicate that manual cleaning alone was not effective in bioburden reduction; instead, PX-UV addition to manual cleaning produced a better outcome on bioburden reduction.

Gostine et al. (2016) evaluated an automated UV-C device's efficacy to eliminate the bioburden on hospital computer keyboards in an intensive care unit (ICU). The baseline samples showed a 193 (95.1%) bacteria positive median of CFU 120 associated per keyboard.

Out of 193 samples, 25 (12.3%) had *gram-negative species*. After implementing the UV-C device, out of 218 samples, 205 (94%) were sterile, 13 were bacterial positive, and in one of the six samples, one CFUs was found. In total, 99% bacterial reduction was demonstrated in the study, comparing median pre and post CFU 120 and CFU 0, respectively. Furthermore, the keyboards associated with bacteria were *Staphylococcus*, *Streptococcus*, *Enterococcus*, *Pseudomonas Pasteurella Klebsiella, Acinetobacters*, and *Enterobacters* associated with HAIs.

According to Wong et al. (2015), in a general hospital, the UV-C emitting devices to reduce *MRSA, VRE*, and *C. difficile* evaluated in isolation rooms. After manual cleaning in high touch surfaces, the number of CFUs decreased from 88.0 to 19.6, and after UV-C disinfection, it further reduced to CFU 1.3. However, the microbial bioburden on the floor increased from CFU 241.4 CFU to 591 after manual terminal cleaning, but after UV-C disinfection, it reduced to CFU 8.8. Though manual cleaning positively reduces the bioburden on high touch surfaces, it increased the bioburden on the floor for an unknown reason. Nevertheless, implementing UV-C has positively decreased the bioburden both on high touch surfaces and the floors.

Armellino et al. (2019) completed a 3-phase non-randomised observational study and evaluated the FMUV system's performance in disinfecting patient care equipment inside and outside the OR without chemical disinfection. The manual-chemical disinfection reduced the active microbial burden on sampled objects in-between cases CFU 79.4%, ranging from 52.8%-90.9%. Without chemical disinfection, FMUV effectively reduced the microbial burden by 92%-97.7% before the first and in-between cases combined and 96.3%-99.6% on objects outside the OR. A high CFU was found in the baseline condition before the FMUV disinfection on all the targeted objects. However, after implementing FMUV, overall average reductions of 97.8% was achieved.

Bache et al. (2012) evaluated the HINS-light EDS efficacy in the inpatient and outpatient settings. In the burn unit, the bioburden reduced between 27% and 75% after using HINS-light EDS. In the outpatient clinic, the bacterial contamination on the surfaces reduced by 61% during patient care. Results demonstrate that HINS-light EDS effectively reduced the bioburden on surfaces in both settings. Later, Bache et al. (2018) evaluated the impact of prolonged HINS-light EDS treatment and irradiance in reducing hospital environments' microbial burden. During the HINS-light EDS use, mean values of microbial reductions on the surfaces were between 22% and 86%. There was an increase in the microbial level between 78% and 309% when the HINS-light EDS was ceased. No correlation found between bacterial kill and irradiance levels. Nevertheless, there was a strong correlation found between bacterial kill and exposure time. Using HINS-light EDS in a patient room showed microbial burden reduction after two days 53%, after four days 69%, and after seven days of use 86%.

Maclean et al. (2010) conducted a similar study on HINS-light EDS's impact in a burn unit isolation room. A 90% reduction in environmental surface bacterial level was achieved while the room is unoccupied in using HINS-light EDS, and when the room occupied by an *MRSA*

infected patient, from 56% to 86% bacterial level reduction observed. This 86% reduction achieved as a result of extended use of HINS EDS. In an on and off situation, 62% environment surface bacterial reduction was achieved. However, when the HINS-light EDS switched off for two days, the bacterial contamination level returns to an average contamination level. Furthermore, the same study illustrated that the HINS-light EDS treatment significantly impacts bacterial reductions on *Staphylococci*, including *Staphylococcus aureus MRSA*. Microbial reduction illustrated in table 4.

Author	Disinfected methods	Hospital environment	Microbes disinfected	Reduction of Microbes (in different units)
Beal et al. 2016	Manual cleaning PX- UV	Single patient rooms (Haematology ward)	*Aerobic total colony counts* *VRE* *Aerobic total colony counts* *VRE*	76% Sites from 80 to 26 90% Sites from 80 to 16
Morikane et al. 2020	Manual cleaning PX- UV	Single rooms and multiple beds rooms (ICU)	*MRSA* and *two-drug resistant Acinetobacter baumannii*	81% Further by 59%
Casini et al. 2019	PX-UV	Patient rooms (single occupancy) ICU isolation rooms ORs	*GNR* and *C. difficile*	12% 8% 93% lower turnover; 183% high turnover
Dippenaar and Smith 2018	Control period to corresponding PX-UV period Pre-cleaning in the control period to PX-UV period Post cleaning in the control period to PX-UV period	Neonatal and paediatric hospital expressed human milk feed preparation areas	*GNR and GPR*	From 544 to 50 CFU Total 90% reduction From 244 to 44 CFU From 300 to 6 CFU
Green et al. 2017	After PX-UV	BICU patient rooms an ORs	*C. difficile, ESBL, MDR Pseudomonas aeruginosa, MRSA, Stenotrophomonas maltophilia, MDRO* (Not specified), *MDR GNR* (not specified)	Environmental samples with any growth from 48% to 31% Surface growth alone from 51% to 33%

Kitagawa et al. 2020	Bleach PX-UV	Isolation rooms	*C. difficile*	From 27.8% to 13.9% From 31% to 11.3%
Villacís et al. 2019	Post manual cleaning After PX-UV Patient rooms ORs	Patient rooms and ORs	*Serine carbapenemase resistance genes blaKPC, blaIMP, blaVIM,* and *blaNDM*	3569 CFU 889 CFU 76% 87% In total, 75%
Vianna et al. 2016	PX- UV	ICU Non-ICU units	*MRSA* *VRE* and *C. difficile* *C. difficile* *VRE* *MRSA*	56% 87% 45% 40% 37% increased by 52%
Zeber et al. 2018	Pre & post manual cleaning Pre & post-PX-UV Pre & post manual cleaning Pre & post PX-UV Manual cleaning PX-UV	Patient rooms in veteran affairs facilities	*MRSA* *MRSA* *ABC* *ABC* *MRSA & ABC* *MRSA & ABC*	From 31.8 to 17.4 (45.1%) CFU From 16.9 to 2.7 (84.1%) CFU 151 to 111 CFU (26.5%) 397 to 98 (75.3%) CFU 30.6% 75.7%
Gostine et al. 2016	Baseline UV-C	Computer keyboards of medical and surgical ICUs	*Staphylococcus, Streptococcus, Enterococcus, Pseudomonas, Pasteurella, Klebsiella, Acinetobacter, Enterobacter* and *GNR*	193 in 203 samples (95.1%) bacteria were positive. Median of 120 CFU per keyboard 205 in 218 samples (94%) sterile In total 99%
Wong et al. 2016	Manual cleaning UV-C Manual cleaning UV-C	Single patient rooms (on high touch surfaces) Single patient rooms (on the floor)	*MRSA, VRE & C. difficile*	From 88 to 19.6 CFU From 19.6 to 1.3 CFU From 241.4 to 591 CFU From 591 to 8.8
Armellino et al. 2019	Manual chemical cleaning FMUV FMUV	Inside OR Inside OR Outside OR	Not specified	79.4% 94.8% 97.8%

Bache et al. 2012	HINS-light EDS	In a burn unit inpatient (isolation rooms and multiple beds rooms) Outpatient settings	Not specified	From 27% to 75% 61%
Bache et al. 2018	During the HINS-light EDS When ceased HINS-light EDS	Burn unit isolation rooms	Not specified	From 22% to 86% (after 7 days) From 78% to 309% (increased)
Maclean et al. 2010	During HINS-light EDS During HINS-light EDS On & off situation HINS-light EDS	Burn unit isolation rooms When the room is unoccupied The room is occupied with *MRSA* patient	*Staphylococcus aureus* and *MRSA*	90% From 56% to 86% 62%

VRE = vancomycin-resistant enterococci; *C. difficile* = Clostridium difficile; *ESBL* = extended spectrum beta-lactamase; *ABC* = Aerobic bacteria colonies; *MDR* = Multi drug resistance; *MDRO* = Multi drug resistance organisms; *GNR* = gram-negative rods; *GPR* = gram-positive rods; *MRSA* = methicillin-resistant Staphylococcus aureus; *2DRA* = two-drug resistant *Acinetobacter baumannii*

Table 4: Impact of photon disinfection technologies on microbial reduction

5.3 The impact of photon disinfection technologies in HAI rates

Anderson et al. (2018) did a pragmatic, multicentre, cluster-randomised, crossover trial in nine hospitals to evaluate the effectiveness of four different strategies for terminal room disinfections on acquiring *MDROs* and *C. difficile*. The findings did not significantly differ the incidence of *C. difficile* with or without UV-C disinfection. *MRSA* incidence was not significantly lower in UV and bleach groups and bleach with UV groups. Using bleach decreased *VRE* incidence by 57%, and adding UV-C to bleach has shown a 64% decrease in *VRE* incidence. It shows that *VRE* incidence was not significantly lower in the UV group but significantly lower in bleach groups. *C. difficile* incidence among exposed patients did not change after adding UV to cleaning with bleach 30.4 vs 31.6 per 10 000 exposure days.

The study conducted by Brite et al. (2018) evaluated the UV's effectiveness on *VRE* and *C. difficile* in a bone marrow transplant unit in a cancer tertiary cancer centre. In this study, 265 admissions were recorded in the pre-intervention (baseline) period, and among that, 21 identified *C. difficile* positive with an overall 8% prevalence rate, and *VRE* prevalence rate was 17% at the time of admission. In the post-intervention period (UV period), 439 admissions were recorded, and among that, 31 identified *C. difficile* positive with a prevalence rate of 7%, and *VRE* prevalence rate was 13% at the time of admission. Adding a UV disinfection

system into routine manual cleaning did not affect *VRE* and *C. difficile* rates among stem cell transplant (SCT) recipients.

Sampathkumar et al. (2019), in a tertiary care hospital, demonstrated a reduction in *C. difficile* rates in intervention units from 21.3 to 11.2 per 10 000 patient days after the PX-UV disinfection in addition to the bleach and terminal cleaning. However, there was a slight rise in control units in *C. difficile* rates from 26.1 to 28.7 per 10 000 patient days after bleach and terminal cleaning. As an additional finding, the intervention units showed a reduction in *VRE* acquisition. In the Morikane et al. (2020) study, a statistically significant reduction was shown in *MRSA* from 13.8 to 9.9 per 10 000 patient days by 29% and two-drug resistant *Acinetobacter baumannii* (*2DRA*) from 48.5 to 18.1 by 63%, respectively.

In the study of Vianna et al. (2016), there were 36 fewer infections in the whole facility and 16 infections fewer in ICU reported during the intervention period than the baseline data. Similarly, Green et al. (2017) stated that in their study, a prolonged interval noticed without healthcare-associated *C. difficile* infection after implementing the PX-UV disinfection and however, there was no significant impact of UV on HAI found.

Nagaraja et al. (2015) conducted a study in a community hospital referral centre for highly immunocompromised patients. Including ICU and non-ICU for paediatrics and adults demonstrated a 22% reduction in hospital-acquired *C. difficile* during UV-C use than pre-UV-C use. In the adult, ICUs showed a 70% reduction in *C. difficile*. However, during UV-C, community-acquired *C. difficile* increased by 18%. For some unknown reason, the community-acquired *C. difficile* infection rate increased though UV-C has effectively reduced the hospital-acquired *C. difficile* infection rates.

Schaffzin et al. (2020) evaluated UV-C's impact on HAIs rates in a pediatric quaternary referral facility. In the study, a 16.2 % reduction in HAIs achieved following the UV-C robot implementation in the patient rooms following patients discharge in transmission-based precautions for *MDRO* or *C. difficile*. This program achieved disinfection averages of 85.7% of isolation and 87.7% priority rooms in 6 months. (Schaffzin et al.2020.) PDTs' impact on HAI rates Illustrated in table 5.

Author	Disinfected methods	Hospital environment	Reduction of HAI rates (in different units)
Anderson et al. 2018	With or without UV-C UV-C group Bleach group	Single patient rooms (nine hospitals)	No significant difference in *C. difficile* incidence The incidence of *MRSA* and *VRE* were not significantly lower The incidence of *MRSA* was not significantly lower. *VRE* was significantly decreased by 57%

	Bleach and UV-C group		The incidence of *MRSA* was not significantly lower. But *VRE* was significantly decreased by 64% *C. difficile* 30.4 vs 31.6 per 10 000 exposure days
Brite et al. 2018	Manual cleaning PX -UV	Bone marrow transplant (BMT) unit	*C. difficile* prevelnce rate at the time of admission preintervention 8% post intervention 7% *VRE* prevalence rate at the time of pre-intervention 17% and post-intervention 13% No significant reduction by using UV
Sampathkumar et al. 2019	Bleach and terminal manual cleaning (control unit) PX-UV in addition to bleach and terminal manual cleaning (intervention units)	Haematology and bone marrow transplant units and one medical-surgical unit	*C. difficile* from 26.1 to 28.7 per 10 000 patient days *C. difficile* from 21.3 to 11.2 per 10 000 patient days Reduction showed in *VRE* incidence
Morikane et al. 2020	PX - UV	Single rooms and multiple beds rooms (ICU)	*MRSA* from 13.8 to 9.9 per 10 000 patient days by 29% *2DRA* reduced from 48.5 to 18.1 by 63%
Vianna et al. 2016	PX- UV	ICU ICU & Non-ICU units	16 fewer infections 36 fewer infections in the whole facility
Green et al. 2017	PX- UV	BICU patient rooms and ORs	No significant impact on HAI found A prolonged interval without *C. difficile*
Nagaraja et al. 2015	UV-C	Referral centre for highly immunocompromised patients. Including ICU and non- ICU for paediatrics and adults.	Hospital-acquired *C. difficile* 22% reduced Community-acquired *C. difficile* 18% increased
Schaffzin et al. 2020	UV-C	Pediatric quaternary referral facility Isolation room and priority rooms	16.2% reduction in HAIs

Table 5: Impact of photon disinfection technology on HAI rates

5.4 Barriers and enhancements in implementing photon disinfection technologies in hospitals

This study focuses on the PDT methods and their impact on the microorganism, the importance of microbiological burden and its impact on HAI rates, and barriers and enhancements in implementing PDT in clinical settings. In the analysing process of this study, few barriers and enhancement factors confronted in implementing the PDTs in hospitals.

According to Armellino et al. (2019), using chemicals for disinfection minimises the bioburden on the hospital environment surfaces and makes them visibly clean. However, evidence indicates that these visibly clean hospital environmental surfaces may have a higher residual contamination level, and these visibly clean surfaces become a barrier to investigating the bioburden level on surfaces. As a result, it prevents the implementation of advanced technologies such as photon disinfection systems and proving its effectiveness in hospitals in reducing the bioburden on surfaces. Furthermore, UV intensity will decrease if the target surface's distance is far from the central lamp. Harmful UV rays, shadowing effects, and prolonged disinfection time are considered barriers to implementing PDTs in hospital settings. FMUV is a valuable advanced technology to overcome most of these barriers. Because FMUV disinfection occurs in a targeted enclosed zone, its modular panels protect from UV rays leaking outside the enclosed zone.

Though UV-C light technology has proven its effectiveness in reducing hospital bioburden on hospital surfaces, the effect is temporary, and the microorganisms start to grow within a couple of hours after the disinfection process. Furthermore, UV-C technology is considered costly, time-consuming, restricted for use in an unoccupied sealed room, requires an operator, and needs to train the operator to use the device. Moreover, it is complicated in a busy ward to remove the patient from the room until the UV-C process is carried out. (Bache et al. 2012; Bache et al. 2018.) The HINS-light EDS light is a ceiling-mounted lamp that uses a visible light wavelength at 405 nm; it is safe for humans and can be used in occupied rooms throughout the day. (McClean et al. 2010; Bache et al. 2012; Bache et al. 2018.) However, blue light could interfere with circadian rhythm and affect the sleeping process due to the photosensitive retinal ganglion cells (pRGCs) having a maximum absorption of 480 nm. HINS-light EDS uses 405 nm violet light, and it is far below 480 nm blue-violet light but still has an impact on reducing wide ranges of bacteria. Nevertheless, HINS-light EDS may have a minor effect on the pRGCs, interfering with the sleeping process. (Bache et al. 2012; Bache et al. 2018.)

UV light is harmful to humans and possibly could cause serious health problems. Most UV devices are designed with motion sensors that shut off if any movement is detected inside the room. Furthermore, able to move the device closer to the targeted area for disinfection. There were not any materials damages reported during the use of the PX-UV light. This technology does not require room ventilation changes and does not leave any residue after the treatment process (Casini et al. 2019). Kitagawa et al. (2020) illustrated that UV disinfection might not be very useful on *C. difficile* contaminated surfaces, such as behind an over-bed table. Manual cleaning would be a better option in disinfecting these types of surfaces. PX-UV is user-friendly and easy to use, which includes rapid cycle times for disinfection. Moreover, unlike other UV devices, it does not contain mercury bulbs and safe to use (Beal et al. 2016).

The automated Angel UV-C lamps can be installed over computer keyboards. It functions independently and does not require any effort from the staff or other maintenances. It is an effective technology in bioburden reduction. (Gostine et al. 2016.) However, Schaffzin et al. (2020) stated that there would be a need for multiple devices or multiple cycles of one device to disinfect the rooms' surfaces. Comparing to manual or HINS lights disinfection systems, UV devices are more expensive and requires extra environmental department staffing, and need to provide specialised training to operate the devices, which would increase the budget. Though UV technologies are considered more expensive than traditional manual cleaning or other PDTs, it effectively reduces the bioburden on surfaces and HAIs rates. This process considerably minimises the healthcare costs in treating HAIs, which is considered a cost-saving measure in the long run. (Sampathkumar et al. 2019; Schaffzin et al. 2020.) Staff perception plays an essential role in implementing UV disinfection in the hospital. If the staff considers that the UV disinfection systems delay the patients flow, it may affect implementing UV disinfection systems in hospitals. Therefore, educating the staff about the benefits of photon disinfection is necessary. Moreover, good training programmes dedicated to environmental service staff with clear goals and strong data support could increase UV disinfection effectiveness and improve outcomes. (Schaffzin et al. 2020.)

6 Discussion

In this study, results were discussed based on the study's research questions, and that facilitated to conduct of the discussion systematically. Firstly the study results were reported, then illustrated the studies supporting and contraindicating the study´s topic and findings. Moreover, the positive and negative results of the study were given proper and fair reasoning in this discussion session. Then finally, the recommendation was given to support the PDTs implementation in hospitals settings. However, there seems to be a very confusing and not standard manner in reporting results of primary PDT studies. One of the discussion aims was to describe the importance of the study results and their relevance in practical lives. The study was conducted as part of a Laurea (UAS) research and development project in IPC studies, and the study's primary purpose was to increase the awareness of PDTs in IPC in healthcare settings.

6.1 Reliability and validity

According to Moher et al. (2015), researchers of an ILR should carefully assess the primary sources. Therefore it is essential that to use appropriate tools for the assessment process. In this study, appropriate tools were used to enhance the reliability and validity of ILR. In the initial stage, a PICOTT model (Eriksen et al.2018) was used to structure the thesis process, and it assisted in focusing on the study's actual problem and conducting the study

appropriately to achieve the purpose. A comprehensive inclusion and exclusion criteria were created before the database search, and it facilitated to conduct of the database search systematically. The combined database search with the Laurea University of Applied Sciences information specialist has validated conducting an appropriate database search and, thus, able to accumulate a reasonable amount of various range of PDTs related articles relevant to the topic.

In this data search process, four authorised primary databases were used for the data collection, bringing more value to the data search's reliability and validity. The PRISMA flow chart (PRISMA 2015) facilitated to conduct of the data collection process systematically. A combined abstract and full-text screening process conducted with the thesis supervisor has facilitated collecting the most relevant 20 articles for analysing purposes. All selected 20 articles were assessed by the STROBE quality assessment tool (Knottnerus & Tugwell 2008.) for the quality of the articles. Both tools enhanced the quality of the selected data for the study purpose. Whittemore and Knafl (2005) five prior stages to conduct research and the data analysis process of an ILR were used as base models to conduct the research process and analyse the results of this study.

Since the analysed articles were from various parts of the world, it provides a broader view of photo disinfection methods and other countries' perspectives. All the included articles for the study purpose were moderate or high-quality data (Appendix 2). Unfortunately, in the database search, there were no articles found from Finland. It indicates that a lack of interest has shown in Finland to study the photon disinfection system's effect, which has a vast impact on reducing the bioburden on the hospitals' surfaces and HAIs rates.

An adequate number of articles were selected for the analysis purpose of this ILR, which provides a broader view and comprehensive knowledge of the topic. A comprehensive inclusion and exclusion criteria were used to select the articles. Most importantly, the data search was limited to 2010-2020, which facilitated to be updated with the latest information on PDTs in hospital environments. Case reports, narratives, literature reviews and commercial advertisements excluded to obtain high-quality data. However, only the English language articles were included in this study which may lead to publication bias. Publication bias may have excluded some evidence that may have enhanced the reliability of this study.

In this ILR, various PDTs have been analysed, which provides a comprehensive understanding of different types of PDTs such as UV-C, PX-UV and HINS-light. The majority of the analysed studies illustrated the PX-UV's effectiveness, which uses UV-C light to eliminate microorganisms on environmental surfaces. Only a few studies demonstrated that UV-C's limited effectiveness against microorganisms. Only three studies were found, which enhanced the use of HINS-light EDS in the patient rooms. However, all these three studies have

demonstrated HINS's bioburden reduction capability against most pathogens. Except for a few studies, most of the studies were conducted on a larger scale. The studies conducted on a smaller scale were derived from a small number of samples from the environmental surfaces with limited study duration. Although those results indicate the photon disinfection's effectiveness, still samples were relatively small to generalise the results. The primary studies used various tools for measuring the bioburden on surfaces and used a unique way to interpret their results. However, misinterpreting the primary results were avoided cautiously and interpreted all results into a general concept.

6.2 Discussion of the main results

The bioburden of hospital environmental surfaces is a major factor that increases the risk of HAI rates, and PDTs is a better solution to overcome the problem by reducing the microbiological burden on hospital environments, directly impacting the reduction of HAI rates. The spreading of *MDROs* could cause severe consequences for the whole society unless the right solutions are implemented. Bacterial resistance against antibiotics is increasing; therefore, antibiotics become ineffective in treating infection. Prolonged use of the same antibiotics for treating infections and using the same antibiotics for treating humans and animals increases antibiotic resistance. (WHO 2020; CDC 2015.)

According to Bache et al. (2012), bacteria can survive on surfaces from weeks to months, and hospital environments are the reservoirs for pathogens, and they play a massive role in cross-contaminations. Several studies indicated the outcomes of the indirect transmission of the microorganisms through a contaminated hospital environment. High-touch surfaces such as bed controls, chair arm, patient tables and door handles are recognised as super reservoirs and at high risk of spreading pathogens. Armellino et al. (2019) stated that high touch surfaces' bioburden was not adequately studied in hospital environments. Residual pathogens increase the cross-contamination risk, and there is a high risk of being contaminated with residual pathogens from unknown sources inside the OR in the daily working routine. Visibly clean areas in OR may contain 47% pathogen residual, and only 25% of the surface are being cleaned according to the disinfection guidelines. Since ORs are a core place for transmitting diseases, the surfaces of the ORs, objects and surgical instruments should be disinfected and sterilised appropriately. These results emphasise the importance of implementing enhanced strategies for central services in hospital settings to improve sterile fields and other environmental surfaces.

According to Gostine et al. (2016), acquiring an infection is increased up to 250% by a patient if the previous patient occupied the same room with a positive bacterial culture unless the room was disinfected appropriately. In the analysis process, PDTs have demonstrated their efficiency in bioburden reduction on hospital surfaces. For example, in the Villacís et al.

(2019) study, the samples were taken from multiple places from a clinical setting such as internal medicine, ICU, operating rooms, neonatology, obstetric centre, and microbiology laboratory units after manual cleaning and PX-UV implementation. Overall, the results demonstrated a 75% bioburden reduction on surfaces after PX-UV implementation as a supplement to manual cleaning.

Increasing infection rates could increase morbidity and mortality rates. Furthermore, it would increase the financial, social, and psychological burden of the patients and relatives. As a result, it weakens the individual's productivity for the country's development. This whole process has a direct impact on the country's economy. (CDC 2009; WHO 2020.) Therefore, there was a need to find better solutions to overcome HAIs. The concept of photon disinfection is not new, and it was known for long for inactivating microorganisms. Decades ago, it had been in use for treating infectious diseases in the medical world. However, due to the golden era of antibiotics, it has been forgotten. (Maclean et al. 2014.) Hospital environmental surfaces play a major role in transmitting the diseases, and the deterioration of antibiotics in infectious treatments led the medical world to reconsider using photon disinfection methods for reducing the hospitals' bioburden on environmental surfaces. Scientists and technologies have developed novel photon disinfection devices with advanced technologies to reduce the bioburden of the hospital environment surfaces. (WHO 2020; Cabral & Ag 2019; Iandolo et al. 2018.)

Nevertherless, Casini et al. (2019) stated that manual cleaning with or without chemicals remains necessary for disinfecting hospitals environment surfaces. However, it cannot single-handedly disinfect the surfaces appropriately to achieve the optimal target of bioburden reduction on the surfaces. It continued saying that terminal manual disinfection is inadequate, and 50% or more hospital surfaces remain uncleaned untouched during the manual terminal cleaning disinfection. Unless these surfaces are appropriately disinfected, the risk of contamination remains high and may lead to severe consequences. Moreover, visibly clean areas even after chemical disinfection contain a high level of pathological residual. It is a barrier to investigating the surfaces' hygiene level and implementing the right solution to reduce the bioburden. (Armellino et al. (2019.)

However, PDT has been introduced in many countries to overcome these issues. In the analysis process, various types of germicidal UV-C devices and HINS-light EDS were identified for the surface disinfection, which effectively reduces the HAIs rates by eliminating various pathogens. (Casini et al. 2019.) However, the majority of these PDTs were used in addition to manual cleaning with or without chemicals. The Cabral and Ag (2019) study demonstrated photon disinfection methods and their impact on bioburden reduction on environmental surfaces, impacting HAI rates, disadvantages and drawbacks.

FMUV is an effective disinfection technology that has proven its efficacy in ORs bioburden reduction. The most significant advantage of the technology is that the modular panels of the system enclose the targeted zone, limiting the UV rays to remain within the enclosed area. The lamps emit the UV rays rapidly from multiple directions, and UV intensity remains high and homogenous, which supports eliminating the shadowing on surfaces from all sides of the objects in a rapid phase. Since the disinfection process active in an enclosed zone in the rest of the room could carry out the daily working activities. This technology is reported suitable for use in ORs for disinfecting surfaces of objects, instruments and floors. (Armellino et al. 2019.) HINS-light EDS emits blue-violet light wavelength at 405 nm, which is safe for humans, and meantime, it is highly germicidal. Since the irradiance is safe for humans, it can be used in occupied areas throughout the day in any hospital setting. This possibility is enhancing continuous decontamination. (Cabral & Ag 2019; Bache et al. 2018.)

Various types of UV-C light technologies have been discovered in this study. The majority of the primary studies have evaluated the PX-UV devices' effectiveness in reducing the bioburden of environmental surfaces, and meantime, only a few of the primary studies have demonstrated the impact of PX-UV on HAI rates. PX-UV is a no-touch, portable device with a flashbulb using UV-C radiation with short cycle times and uses a light wavelength between 200-320 nm. UV-C is very highly germicidal than HINS- light EDS, but unfortunately, these lights' wavelength between 200-320 nm could cause severe damage to human health. Therefore, these devices should be used only in unoccupied sealed rooms, and almost all the PX-UV devices include safety mechanism to prevent possible harm that could cause to humans, for example, auto ceased if any movement detected inside the targeted room. The other disadvantage is that if the targeted object distance is greater than two meters from the central bulb, it could decrease the disinfecting efficacy. The manufacturers advise the users to place the device within two meters from the targeted surface to achieve optimal efficacy. (Casini et al. 2019; Dippenaar & Smith 2018; Villacís et al. 2019.)

Tru-D SmartUVC and R-D Rapid Disinfector system are similar advanced technologies used to disinfect environmental surfaces. Both of these technologies use UV-C light for disinfection. UV Angel desktop lamps are specially designed to disinfect computer keyboards and specific areas in the patients' rooms. Installation over the computer keyboards would facilitate the disinfection process by eliminating microorganisms on the keyboards' surface. As a result, it prevents cross-contamination and reduces HAI rates. It is safe to use since it provides real-time monitoring of surface use and automatically delivers mercury bulb UV light disinfection when the device is not in use. (Gostine 2016; Wong et al. 2016.)

In the findings, Brite et al. (2018) demonstrated that implementing UV-C disinfection in addition to routine manual cleaning was not effective in reducing hospital-acquired *VRE* and *C. difficile* among SCT recipients. However, Beal et al. (2016) stated that manual cleaning

effectively reduced the bioburden on high touchpoints and continued saying that the UV efficacy against *VRE* is limited, but more extended periods of UV emission could increase the effectiveness against *VRE*. Anderson et al. (2018) also presented similar findings, such as UV-C were not efficient against *C. difficile* and *MRSA*, and using bleach alone is effective in *VRE* reduction. However, UV-C disinfection, in addition to bleach, was much more effective in reducing *VRE* incidence. These few findings clearly illustrate that UV-C effectiveness against *MDROs* and *C. difficile* are limited. However, more extended time of use of UV-C and UV-C in addition to bleach could produce positive results in reducing pathogens such as *VRE*. Moreover, it should not underestimate the effectiveness of manual cleaning in bioburden reduction.

Morikane et al. (2020) stated that implementing UV-C disinfection as a supplement to manual cleaning controls *C. difficile* and *MDROs*. Similarly, Green et al. (2017) demonstrated that the UV-C effectively reduced *MDROs*, especially *gram-negative rods* (*GNR*). Wong et al. (2016) stated that UV-C devices, in addition to manual cleaning, effectively reduces patient room contamination with *MRSA*, *VRE*, and *C. difficile*. Nagaraja et al. (2015) demonstrated a reduction in hospital-acquired *C. difficile* during UV-C use than pre-UV-C use, specifically in ICUs. However, during UV-C, community-acquired *C. difficile* increased by a small percentage. This rise of *C. difficile* in community-acquired infection may be due to the advanced and sensitive technologies used to diagnose, which resulted in high community-acquired *C. difficile* rates. Similarly, Vianna et al. (2016) demonstrated that *C. difficile* infections were significantly decreased after implementing UV-C and Schaffzin et al. (2020) added that UV-C disinfection reduces HAI rates significantly.

Moreover, most of the findings illustrated that UV-C disinfection, in addition to manual cleaning, effectively reduced bioburden hospital surfaces. (Armelio et al. 2019; Casini et al. 2019; Dippeaar & Smith 2018; Kitagawa et al. 2020; Zeber et al. 2018; Villacís et al. 2019; Gostine et al. 2016.) Furthermore, Vianna et al. (2016) demonstrated a direct correlation between the UV-C disinfection on all facility-wide *C. difficile* and decreased post incidence infection rates. For example, a significant reduction in non-ICU floors showed in *C. difficile* and *VRE;* however, *MRSA* rates dramatically increased, which may be due to the environmental pathogen transmission. In the analysis process majority of the findings demonstrated the positive impact of the UV-C disinfection systems on bioburden reduction on hospital environment surfaces and HAIs rates. However, according to a few findings, UV-C was ineffective against *MDROs* and *C. difficile* and *VRE*. (Brite et al. 2018; Beal et al. 2016; Anderson et al. 2018.)

In general, UV devices are expensive, and it would increase the environmental service budget dramatically. However, implementing UV disinfection in hospitals is a cost-saving measure because it may reduce HAIs rates in the long run. Nevertheless, there are some limitations

regarding these devices; for example, these devices can use only in unoccupied closed areas such as in single rooms and ORs. (Green et al. 2017; Brite et al. 2018.) Keyboards are among the most used devices in hospitals, and it increases the bioburden on keyboard surfaces and the risk of cross-contamination. The UV angle lamp is an excellent solution for disinfecting keyboards, which could significantly minimise cross-contamination and HAI rates. This automated device uses low exposure and is designed to disinfect only targeted areas only when the keyboards not in function. (Armellino et al. 2019.)

Furthermore, there could be surfaces that the UV-C cannot be effective in disinfecting, but the manual nonbleach or bleach could effectively disinfect those surfaces appropriately, for example, *C. difficile* contaminated surfaces behind the bed where the UV-C rays cannot reach. (Kitagawa et al. 2020.) Enhanced effective UV disinfection programs such as providing better training to a dedicated team with clear goals could increase photon technology's efficacy to achieve the optimal effect. Arranging education programmes for healthcare staff is essential to understand the importance of PDT and its benefits to avoid negative perceptions. (Schaffzin et al. 2020.)

HINS-light EDS is harmless and safe to use in an occupied clinical environment (Bache et al. 2018; MacClean et al. 2010). HINS-light EDS has proven its effectiveness in bioburden reduction on hospital environment surfaces. Maclean et al. (2010) illustrated that HINS-light EDS effectively reduces various types of bacteria, but *MRSA* is more susceptible to HINS-light EDS. When HINS-light EDS switched off, then there was a rise up detected in bacterial growth. The bactericidal effect of blue light increases with treatment time. Therefore, continues HINS-light EDS use could bring better outcomes. Since it can be used continuously, it will not affect the daily routine work of the staff. However, HINS-light EDS is not a replacement for a manual cleaning process. (Bache et al. 2012.)

Moreover, it is a better technology to use in different hospital settings, and it effectively disinfects all kinds of surfaces. Once the HINS-light EDS is placed on the ceiling, do not require an operator to handle it. It does not require any other expenses for maintenance, and there are almost no disadvantages reported against this technology's use. However, HINS-light EDS may have a slight effect on the pRGCs and their associated physiological effects, interfering with sleep onset. (Bache et al. 2012; Bache et al. 2018.)

6.3 Recommendations

Aholaakko (2020) created a baseline model to facilitate general aseptic practices to maintain a higher hygiene level in the hospital environment. It is a model for nursing practice, and therefore, it may be useful to implement and test this model in daily routine work at the general level in health care. However, in this ILR, most studies have proven the PTDs' efficiency on bioburden reduction in hospitals environment surfaces such as in the patient

rooms and the ORs. Thus, testing these novel PDTs into this Aholaakko's baseline model would improve the implementation of disinfection methods in hospital environments, which would provide better outcomes by providing highly disinfected surfaces for medical practices (figure 5).

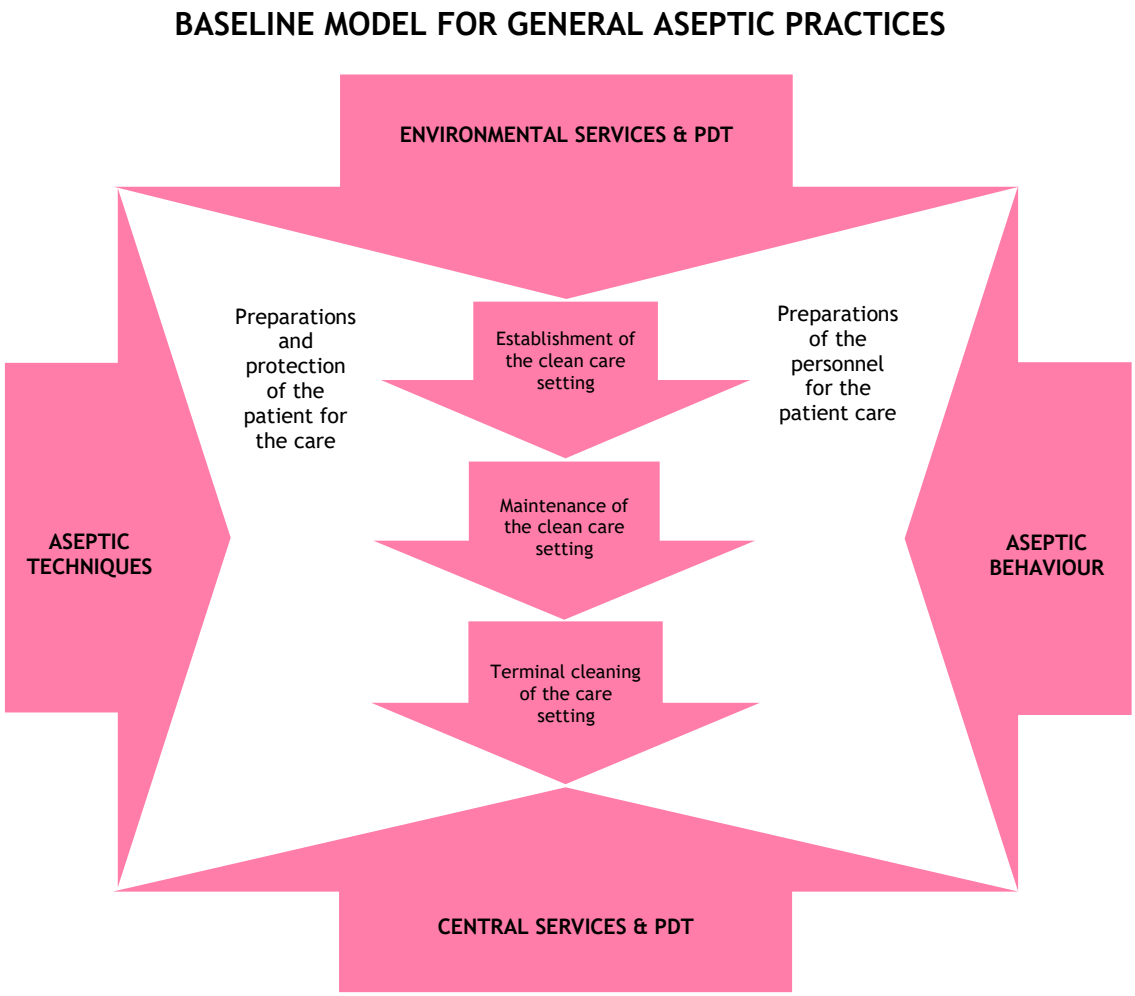

Figure 6: Aholaakko© (2020) baseline model for general aseptic practices, modified by Aholaakko© and Mohamed 2021

6.4 Ethical considerations

This ILR was not limited to a particular clinical setting or a patient ward. Therefore, it was not required to acquire permission from an ethical board. The Principal Lecturer and thesis supervisor Teija-Kaisa Aholaakko accepted the thesis plan granted permission to conduct the thesis. The study process is transparent for the reader, and the assessment process conducted in an unbiased way. Ethics maintained according to ALLEA and TENK guidelines as well as Laurea (UAS) ethical guidance. For example, a documented signed agreement between the author of this report and the supervisor constructed according to TENK's guidelines (Finnish

national board on research integrity TENK 2020.) to publish this thesis in peer-reviewed journals. All the references documented and copyright and authorship are respected. There were no conflicts of interests, and in this study, no funding sources were used.

7 Conclusion

1) HAIs is a severe problem that healthcare organizations are struggling to overcome. Hospital environmental surfaces play a significant role in spreading microorganisms. Inadequate cleanliness in hospital environments becomes a super reservoir for microorganisms. Evidence shows that even hospitals' visibly clean areas contain a high contamination level, increasing the cross-contaminations and HAIs rates. Furthermore, it increases morbidity and mortality rates which negatively impact the financial and emotional burden. Studies demonstrated that using enhanced strategies for disinfecting environmental surfaces in clinical settings reduces the bioburden level and lowering HAIs rates by providing a clean and safe environment to the patients and staff.

2) Manual cleaning disinfection methods alone with or without chemicals cannot achieve the anticipated bioburden reduction targets on hospitals' environmental surfaces. Therefore, scientists and technologists have reintroduced PDTs to disinfect environmental surfaces. PDTs are capable of reducing HAIs by inactivating the microorganisms that reside on hospitals surfaces. In PDTs different wavelengths of lights are used to inactivate the microorganisms. The primary purpose of producing PDTs is to respond to the healthcare industry's needs to reduce hospital surfaces' bioburden. In this study, various types of PDTs such as UV-C, PX-UV and HINS were analysed, and it demonstrated that PDTs are a robust alternative solution to conventional antimicrobial treatment for different types of HAIs. These technologies have proved their efficiency and efficacy in reducing bioburden on hospital surfaces, and as a result, it reduces HAI rates when implemented as a supplement to the manual cleaning process. Therefore, manual cleaning with or without chemicals remains essential in maintaining hospital environmental hygiene.

3) In this study's analysis process, different barriers and facilitators confronted in implementing PDTs in clinical settings. Health professionals' negative perceptions about PTDs are significant barriers to implementing these technologies in clinical settings. A proper understanding of the technology among healthcare professionals is required. Educating the importance and the advantages of PDTs and providing good training programmes for healthcare professionals would enhance the adherence and compliance of healthcare workers. Furthermore, it could facilitate decision-making and selecting the appropriate technology for the targeted clinical settings. This whole process would facilitate overcoming the barriers in implementing PDTs in clinical settings. In general, UV-C devices are expensive

but very efficient against pathogens, and HINS EDS-lights are economical but have a similar effect against the inactivation of microorganisms like UV-C devices. Moreover, these PDTs could minimise the infections treatment processes' expenses and reduce morbidity and mortality rates in the long run. This study's results emphasise the worthiness of investing in PDTs in hospital environments.

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Figures

Tables

Appendices

Appendix 1: Research table

Reference	Aim	Methods design and data collection	Data analysis	Results	Validity and reliability; Serendipitous findings
Anderson et al. 2018. Enhanced terminal room disinfection and acquisition and infection caused by multidrug-resistant organisms and Clostridium difficile (the Benefits of Enhanced Terminal Room Disinfection study): a cluster-randomised, multicentre, crossover study. USA.	To assess the effects of four different disinfection strategies on the acquisition of multidrug-resistant organisms and *C .difficile* in the patient rooms	(1) A pragmatic, cluster-randomised, crossover trial at nine hospitals. Patient rooms with infection or colonisation with a target organism were discharged and terminally disinfected with one of four strategies: reference, UV, bleach, bleach, and UV-C. (2) The next patient admitted to the targeted room was considered exposed. (3)Every strategy was used at each hospital in four consecutive 7-month periods.	An observational study. Power calculations carried out based on a review of 4 years of surveillance data from study hospitals and published literature. All power calculations were done with a two-sided significance level of 0·05. The power analysis was done using simulation and was based on a Poisson regression model with hospital-level incidence rate as the outcome and disinfection strategy and hospital as the covariates.	The incidence of target organisms among exposed patients was significantly lower after adding UV to standard cleaning strategies 33·9 cases per 10 000 exposure days. The primary outcome was not statistically lower with bleach 41·6 cases per 10 000 exposure days than bleach and UV 45·6 cases per 10 000 exposure days. Then, *C. difficile* infection among exposed patients was not changed after adding UV to cleaning with bleach 30·4 cases vs 31·6 cases per 10 000 exposure days.	A large study. Could be the first to demonstrate a decrease in acquisition and infection with epidemiologically essential pathogens following enhanced room disinfection strategies. First, it relied on clinical cultures obtained during standard care, which might have introduced ascertainment bias. Clinicians probably changed their culturing practices during the study. Did not screen seed patients with a history of infection or

					colonisation or exposed patients on exit from the seed rooms. They did not capture all acquisitions and might have failed to exclude a patient with community-onset colonisation denominators might have included extra exposure days.
Armellino et al. 2019. Assessment of focused multivector ultraviolet disinfection with shadowless delivery using 5-point multisided sampling of patient care equipment without manual-chemical disinfection. USA.	The study aimed to evaluate an FMUV system's performance by employing shadowless delivery with a 90-second disinfection cycle for patient care equipment inside and outside the operating room (OR) suite without manual-chemical disinfection.	A 5-point multisided sampling protocol was utilized to measure the microbial burden on objects inside and outside the OR environment in a 3-phase nonrandomized observational study. Surface sampling was performed pre-and post-disinfection in-between cases (IBCs) to assess manual-chemical disinfection performance. FMUV system performance was separately assessed pre-and post-disinfection before the first case and IBCs. Additionally, visibly clean high-touch objects were sampled outside the OR, and the microbial burden reductions after FMUV disinfection were quantified without manual-chemical	A 3-phase nonrandomized observational study. The Wilcoxon signed-rank test was applied to the differences between the number of total CFUs per equipment before and after FMUV disinfection, as per similar studies.11 Statistical significance was achieved when a 2-sided P value was <.05. No statistical comparison was performed between phase 1 chemical cleaning results and the phase 2 FMUV results because phase 1 was observational and not intended to compare the methods directly.	Manual-chemical disinfection reduced the active microbial burden on sampled objects IBCs by 52.8%-90.9%. FMUV reduced the active microbial burden by 92%-97.7% before the first case and IBCs combined, and 96.3%-99.6% on objects outside the OR without chemical disinfection.	Too few samples were taken in phase 1 and 3 to achieve statistical significance for individual pieces of equipment using the Wilcoxon signed-rank test. Then no speciation of sampled microbes was performed, and no direct statistical comparison was made between phase 1 and phase 2 results, as this was not

		disinfection. The study was conducted at a teaching hospital with 24 ORs and 524 beds, a second hospital with 23 ORs and 806 beds, and a community hospital with 7 ORs and 219 beds. A total of 3,420 microbiological samples were taken over 1 week from 104 surgical cases and equipment outside the OR environment.			the study's objective. No conclusions can be drawn regarding the impact the measured reductions may have on SSI rates.
Bache et al. 2018. Universal decontamination of hospital surfaces in an occupied inpatient room with a continuous 405 nm light source. UK.	To ascertain the correlation between bacterial kill achieved on sampled surface sites around the burns unit and irradiance levels of the 405 nm light and exposure time.	The study took place in a burn's inpatient unit 13-bed adult burns ward. Seventy samples were taken from surfaces within an occupied side room in the burns unit before, during, and after a seven-day use of the HINS light EDS. A different patient occupied the isolation room during each of the three studies. The same protocol was repeated: (i) before-use samples were collected from selected sites around the room; (ii) the HINS-light EDS was switched on for seven consecutive days, during which time between one and three sets of during-use samples were collected; and (iii) after-use samples were taken two or three days after the HINS-light EDS exposure had been discontinued.	An observational study. Following the enumeration of bacterial CFU, the mean CFU per plate for each study was calculated. Percentage reduction in the bacterial count during use and percentage increase after use were also calculated. Further analysis was performed on log-transformed counts using Minitab V16. Analysis of variance (ANOVA) and Dunnett's post-hoc comparisons were done to examine for significant differences between before-use and each of the during-use periods for each study and between after-use and the final during-use period for each study. $P < 0.05$ was considered statistically	A decrease of between 22% and 86% in the mean number of surface bacteria was shown during the HINS-light EDS use. When the light ceased to be used, increases of between 78% and 309% occurred. There was no correlation between bacterial kill and irradiance levels at each sampling site but a strong correlation between bacterial kill and exposure time.	The sample size was too small to generalize the findings.

			significant. The 70 contact-plate sample sites were grouped into 18 sample areas. The mean percentage reduction achieved following seven days' use of the HINS-light EDS was calculated for each area. A scatter graph was produced to determine the relationship between irradiance and mean percentage reduction after seven days' exposure to each area. Pearson's correlation coefficients demonstrated the significance of any interaction between irradiance and the bacterial kill percentage.		
Bache et al. 2012. Clinical studies of the High-Intensity Narrow-Spectrum light Environmental Decontamination System (HINS-light EDS), for	To investigate and compare the HINS-light EDS efficacy in bacterial reductions in inpatient and outpatient settings in the burn unit.	A 13-bed burn unit arranged as six single isolation rooms, one three-bed high dependency bay, one four-bed open bay and an outpatient clinic area. Environmental samples were collected from inpatient isolation rooms and the outpatient clinic in the burn unit. Over 1000 samples were taken. Between forty and fifty sites on frequently touched surfaces were identified around each room being studied, and bacterial samples were collected by directly pressing the contact	Comparisons were made between the bacterial contamination levels observed with and without the use of the HINS-light EDS. Statistical software (Minitab version 15) was used, and a log transformation was found to normalise data and equalise variances when analysing CFU data. For the inpatient studies, analysis of variance (ANOVA) and Tukey pair-wise comparisons were	Inpatient studies following HINS-light EDS use reduction between 27% and 75%. There was more variation when samples were taken at times of increased activity in the room. Outpatient studies demonstrated a 61% efficacy in reducing bacterial contamination on surfaces throughout the room during a clinic.	The inpatient rooms' study was limited in that it only examined the effect of the HINS-light EDS for a relatively short period of between 8 h and 14 h a day on two consecutive days. A large number of samples taken.

continuous disinfection in the burn unit inpatient and outpatient settings. UK.		agar plates onto the sampling site, with samples being taken from the same sites each time.	undertaken. The CFU counts per plate were compared between the three periods, pre-HINS, HINS and post-HINS. A 95% confidence interval (CI) was calculated for the differences obtained between the means of the three sampling periods. The CFU count differences before the clinic and after the clinic were compared with and without using the HINS light EDS for the outpatient studies. Results were displayed using mean values, and statistical testing was carried out at the 5% significance level.		
Beal et al. 2016. First UK trial of Xenex PX-UV, an automated ultraviolet room decontamination device in a clinical haematology and bone marrow transplantation unit. UK.	To investigate the device's microbiological efficacy when deployed for terminal decontamination of isolation rooms within a clinical haematology unit.	The device was deployed in isolation rooms in a clinical haematology unit. Contact plates were applied to common touchpoints to determine aerobic total colony counts (TCCs), and samples collected using Polywipe sponges for detection of *VRE*,	An observational study. Quantitative data (TCCs) were summarized using boxe whisker plots, and a chi-squared test was performed to compare the percentage of *VRE*-positive samples before and after PX-UV disinfection. 5% was considered statistically significant.	There was a 76% reduction in the TCCs following manual cleaning, with an additional 14% reduction following UV disinfection. Overall reduction of 90% in TCCs. There was a 38% reduction in the number of sites where *VRE* was detected, from 26 of 80 sites following manual cleaning to 16 of 80 sites with additional UV disinfection.	It was performed in one institution, and sampling was performed in a small number of rooms. A limited number of touchpoints were sampled in the rooms, which may not accurately reflect the actual contamination level.

Brite et al. 2018. Effectiveness of ultraviolet disinfection in reducing hospital acquired Clostridium difficile and vancomycin-resistant Enterococcus on a bone marrow transplant unit. USA.	To determine the effectiveness of UV environmental disinfection system on rates of hospital-acquired *VRE* and *C. difficile*.	Using active surveillance and an interrupted time-series design, hospital-acquired *VRE* and *C. difficile* on a BMT unit were examined before and after implementing terminal disinfection with UV on all rooms regardless of the isolation status of patients. The primary outcomes were hospital-based acquisition measured through (1) active surveillance: admission, weekly, and discharge screening for *VRE* and toxigenic *C. difficile* (TCD) and (2) clinical surveillance: incidence of *VRE* and *C. difficile* on the unit.	An observational study. During the 20-month study period, 579 patients had 704 admissions to the BMT unit, and 2,160 surveillance tests were performed. Comparison of unit-level patient characteristics was assessed using the x2 or Fisher exact test for categorical variables and the t-test for continuous variables. The incidence rate was calculated as many new acquisitions over the total number of patient days at risk. First, mean monthly rates were assessed using a t-test. A power analysis was performed to determine the number of time points needed assuming a baseline average incidence of 12 cases per 1,000 patient days (SD, 5) for *VRE* acquisition and 10 cases per 1,000 patient days (SD, 5) for *C. difficile* acquisition.	No change in level or trend in the incidence of *VRE* IRR, 0.96; 95% CI, 0.81–1.14; level IRR, 1.34; 95% CI, 0.37–1.18 or *C. difficile* (trend IRR, 1.08; 95% CI, 0.89–1.31; level IRR, 0.51; 95% CI, 0.13–2.11) was observed after the intervention.	This study is the first to incorporate active surveillance and detect actual nosocomial infections in the healthcare setting. Most importantly, extrapolation of findings to non-transplant settings should be done with caution.
Casini et al. 2019. Evaluation of an Ultraviolet C (UVC) Light-Emitting	To evaluate the effectiveness on the field of an ultraviolet C (UVC) light-emitting device in reducing the	Sampling was performed in different critical areas: 5 patient rooms, 2 ICU isolation rooms, and 9 OT. Sampled a total of 345 high-touch surfaces—135 after healthcare activity, 125 after SOP, 85 after application of SOP and	A prospective open-labelled cross-over study was conducted in an 1158-bed teaching hospital with a follow-up of four months. Applied the Wilcoxon matched-pairs signed-rank	Effective in reducing microbial contamination, showing only 18% of positive samples after treatment compared to 63% after SOP, and 12% increased reduction of	The number of surfaces sampled after pulsed-UV exposure was not high due to the difficulty of applying ORs'

Device for Disinfection of High Touch Surfaces in Hospital Critical Areas. Italy.	bacterial environmental burden and the presence of pathogens when compared to the current standard operating protocol (SOP).	Pulsed-UVC treatment. 20 samples were collected after Pulsed-UVC disinfection applied without performing SOP.	test to analyse the results obtained in the patient rooms and ICUs, while for OTs low turnover and OTs high turnover, the analysis was conducted with the Mann–Whitney test. Statistical significance was inferred from $p < 0.05$. Statistical analysis was performed using Prism 8.	positive samples in the patient rooms, 8% in ICUs, 93% in ORs with low turnover, and 183% in ORs with high turnover.	treatment, where surgical activity scheduling cannot be delayed. Moreover, only isolated single rooms in the ICU were included in the study since the treatment was not applicable in multi-bedrooms.
Dippenaar & Smith. 2018. Impact of pulsed xenon ultraviolet disinfection on surface contaminatio n in a hospital facility's expressed human milk feed preparation area. South Africa.	To evaluate a PX-UVD effect compared to standard care on surface CFU/cm2 within neonatal and paediatric EHM feed preparation areas.	The impact of a PX-UVD on surface CFU/cm2 in feed preparation areas was evaluated following its implementation as standard care. Identified 6 high-risk feed preparation areas. Pre and post-conventional cleaning neutralizing rinse swabs were collected fortnightly over a 16-week control period before introducing the PX-UVD and compared to a matching set of samples for the PX-UVD period.	A quasi-experimental study was conducted. Total surface bioburden was calculated as the sum of the viable colony count of the 6 counter surfaces in the pre and post-cleaning phases. Statistical analyses were performed using the NCSS statistical analysis package (NCSS 11 Statistical Software (2016). Numerical data were log-transformed to achieve normality. A multi-variance ANOVA analysis was applied to the log sample data to determine statistical relevance and trend analysis. The log data was back transformed, and the observed geometric mean	A 90% reduction in total surface bioburden was noted from the control period 544 CFU compared to the corresponding PX-UVD period 50 CFU. Sub-analysis of both the Pre-clean Control: Pre-clean PX-UVD counts and the Post-clean Control: Post-clean PX-UVD counts noted significant improvements ($p < 0.001$). A statistically significant improvement was noted between pre-and post-cleaning total surface bioburden following exposure to the PX-UVD ($p = 0.0004$).	A relatively small study and limited study duration, and the lack of variability in performing a single-institution study. Did not evaluate the potential long term cumulative suppressive effects following the introduction of the PXUVD and its impact on both environmental and potentially pathogenic organisms, nor the potential

			differences represented as risk ratios.		impact of a lower surface bioburden and its effect on nosocomial infection rates.
Gostine et al. 2016. Evaluating ultraviolet-C lamps' effectiveness for reducing keyboard contaminatio n in the intensive care unit: A longitudinal analysis. USA.	To investigate the efficacy of an automated UV-C device to eliminate bioburden on hospital computer keyboards	This study took place in the medical ICU (15 beds) and surgical ICU (15 beds) of the presence resurrection medical centre, a 360-bed, acute care, academic medical centre. Baseline cultures were obtained from keyboards in ICU. The lamps were tested at varying cycle lengths to determine the shortest effective cycles. Delay after use and before cycle initiation was varied to minimize cycle interruptions. Finally, 218 post installation samples were analyzed.	An observational study. Used descriptive statistics to describe the baseline and post UV light installation keyboard cultures. Because the culture results were non-normally distributed, median values for the total colony counts were compared. The x2 2-sided test of zero difference was used to compare the sterility rate between the 2 sets of cultures by treating the keyboard culture results as binary (i.e., keyboards were either sterile or contaminated). A 2-sided significance level of .05 was used for statistical significance.	Of 203 baseline samples, 193 were positive for bacteria, with a median of 120 colony forming units (CFU) per keyboard. There were numerous bacteria linked to HAIs, including. Of the 193 keyboards, 25 had gram-negative species. Of 218 post installation samples, 205 were sterile. Of the 13 that showed bacterial growth, 6 produced a single CFU. Comparison of pre-and post-UV decontamination median CFU values (120 and 0, respectively) revealed a >99% reduction in bacteria.	This study was conducted scientifically with an adequate number of samples and by using appropriate statistical analysis.
Green et al. 2017. Pulsed -xenon ultraviolet light disinfection in a burn unit: Impact on	To evaluate the surface and microbial air contamination in inpatient rooms and ORs before and after use of PPX-UVD. The secondary	PPX-UVD used for 3 months after standard cleaning of patient and ORs. Settle and touch plates in the patient rooms and ORs were obtained after a standard cleaning, pre-and-post-PPX-UVD. HAI and MDRO acquisition evaluated 1year before and for 3 month periods before, during, and after PPX-UVD.	A pre-and post-intervention quasi-experimental study. Basic descriptive statistics were used to summarize the findings. Categorical variables were compared by chi-squared testing or Fisher's exact test where appropriate. Statistical	After the PPX-UVD, environmental samples with any growth decreased (48% vs 31%), as did the mean colony count/sample (2.8 pre- vs 1.6 post). The 379 colonies primarily represented skin commensals without	Relatively short period for the intervention, which significantly limits the ability to exclude an effect on HAI and incident *MDRO*

environmental bioburden, multidrug-resistant organism acquisition and healthcare associated infections. USA.	aim was an assessment of NHSN defined HAI rates, MDRO acquisition, and clinical bioburden.	110 touch and settle plates (33 pre- and 30 post-PPX-UVD) obtained after a standard cleaning, pre-and-post-PPX-UVD.	significance was set at $p<0.05$ (two-tailed).	identified *MDRO*. Following PPXUVD, no changes in device-associated infections, overall *MDRO*, or MDR GNR were seen, though a prolonged interval without healthcare-associated *C. difficile* infection was observed. PPX-UVD in a BICU reduced overall environmental bioburden without a statistically significant impact on HAI or *MDRO*.	acquisition or demonstrate statistical significance for reductions in unique events like HAI.
Kitagawa et al. 2020. Effectiveness of pulsed xenon ultraviolet disinfection for Clostridioides (Clostridium) difficile surface contamination in a Japanese hospital. Japan.	To evaluate the effectiveness of manual bleach cleaning and pulsed xenon UV (PX-UV) disinfection in addition to nonbleach cleaning on *C. difficile* contamination of high-touch surfaces in a Japanese hospital.	The environmental surfaces of 20 *C. difficile* isolation rooms were sampled immediately after patients with *C. difficile* were discharged or transferred to another room. 286 samples were collected (bleach cleaning, 144 samples; PX-UV disinfection, 142 samples). The rooms selected for inclusion in the study were identified using medical records by infection prevention and control staff. The inclusion criteria were as follows: (1) single occupancy room and (2) room occupied for at least 48 hours by a patient with *C. difficile* were defined as the presence of diarrhoea and a positive toxin test using C. DIFF QUIK CHEK COMPLETE (Techlab,	An observational study. The Wilcoxon matched-pairs signed-rank test was used to determine the differences in *C. difficile* CFU counts before and after manual bleach cleaning and before and after PX-UV disinfection in addition to nonbleach cleaning. The McNemar test was used to determine the differences in the number of *C. difficile*-positive samples before and after manual bleach cleaning. Then before and after PX-UV disinfection. Differences in baseline *C. difficile* CFU between the bleach cleaning and PX-UV disinfection	Before cleaning, the positive rates of *C. difficile* were 27.8% and 31.0% in bleach cleaning and PX-UV disinfection, respectively. Both bleach cleaning and PX-UV disinfection significantly reduced overall *C. difficile*-positive samples (P = .018 and P = .002, respectively) and *C. difficile* colony-forming unit counts (P = .002 and P = .001, respectively). In addition to manual nonbleach cleaning, PX-UV disinfection effectively reduces *C. difficile* contamination from high-	It was not a noninferiority test, and the quasi-experimental study was conducted in only 1 Japanese hospital. Therefore, the number of sampled surfaces was relatively small. This study's findings were consistent with a previous report on PX-UV disinfection in

		Blacksburg, VA) for stools, or a *C. difficile* strain isolated from a stool culture. Contact precautions were implemented when caring for these patients.	groups were analyzed with a 2-sample Wilcoxon rank-sum test. Between-group comparisons of the CFU changes before and after cleaning were evaluated using covariance analysis (ANCOVA) with adjustments for precleaning CFU. The data were analyzed using JMP version 13.0 (SASInstitute Inc., Cary, NC, USA), and $P < .05$ was considered to indicate statistical significance.	touch surfaces in a Japanese hospital.	the United States.
Maclean, et al. 2010. Environmental decontamination of a hospital isolation room using high-intensity narrow-spectrum light. UK.	To assess the effectiveness of a HINS-light environmental decontamination system (HINS-light EDS) to reduce environmental bacterial contamination, specifically staphylococcal organisms, on surfaces at various sites within a hospital isolation room.	The evaluation studies reported here investigated the effect of HINS-light EDS treatment on environmental bacterial levels on selected contact surfaces within the isolation room under three scenarios: (A) in an unoccupied room; (B) in an occupied room with HINS-light EDS operated intermittently over an extended period; and (C) in an occupied room with and without HINS-light EDS in operation (on/off intervention). (i) 30 samples collected before the HINS-light EDS was switched on ('pre-HINS'); (ii) 30 samples collected after a 24 h period with the HINS-light EDS on ('HINS'); and (iii) 30 samples	An observational study. Previous exploratory analyses had indicated that sample sizes of 100 bacterial counts from different locations within wards would have 90% statistical power to detect a 40% reduction in mean counts at the 5% significance level and that the log transformation of the data was appropriate. Statistical analyses were undertaken using general linear modelling (GLM) and other statistical procedures in the Minitab proprietary statistical software package version 9.1. For each study, total BPA and presumptive S.	When the room was unoccupied, use of HINS-light EDS resulted in a 90% reduction of bacterial surface levels, and when an *MRSA*-infected burns patient occupied the room, reductions between 56% and 86% were achieved, with the highest reduction (86%) measured following an extended period of HINS-light EDS operation. In an on/off intervention study, bacterial surface levels were reduced by 62% by HINS-light EDS treatment and returned to normal contamination levels two days after the system was	The findings reflect consistency across the three different studies and are robust according to various statistical analyses. Because of the studies conducted under routine infection control procedures, the HINS-light EDS findings are externally valid and indicate that HINS-light EDS can significantly

		collected 24 h after the HINS-light EDS was switched off ('post-HINS').	aureus count data were analysed for significant differences between pre-HINS, HINS and post-HINS phases at the 5% significance level using a two-factor model account of sampling site variation. Data were transformed before analysis, and estimates were obtained of the difference in counts between phases and the associated 95% confidence interval (CI) and the percentage increase or decrease in mean counts between phases.	switched off. These *staphylococci reductions, including Staphylococcus aureus and methicillin-resistant S. aureus*, were more significant than the reductions achieved by HINS-light EDS treatment standard infection control and cleaning activities alone.	contribute to bacterial decontamination in clinical environments.
Morikane, et al. 2020. Clinical and microbiologi cal effect of pulsed xenon ultraviolet disinfection to reduce multidrug-resistant organisms in the intensive care unit in a Japanese hospital: a before-after study.	To evaluate disinfection effectiveness by portable pulsed xenon ultraviolet (PX-UV) devices in controlling transmission of *MDROs* in a non-US healthcare setting.	All patients admitted in the intensive care unit in a 629-bed tertiary referral hospital in Japan from August 2016 to February 2019 were enrolled. During the study period, PX-UV disinfection was added to manual terminal cleaning after every patient transfer/ discharge. For microbiological evaluation, surfaces were selected for sampling by contact plates before/after manual cleaning and after PX-UV. After overnight incubation, colonies on the plates were counted. In total, 128 sites were sampled.	An observational study. Poisson regression model analysis was used to estimate *MRSA* and *2DRA* infection incidence, expressed as the number of acquisitions per 10,000 patient days. The statistical analysis assumed that the pre-intervention period was the baseline, which means the event (acquisition of *MRSA* or 2DRA) occurs in a probability calculated by using the data in the preintervention period. A ShapiroWilk test was conducted to determine the	The incidence of newly acquired *MRSA* declined significantly from 13.8 to 9.9 per 10,000 patient days and newly acquired drug-resistant Acinetobacter 48.5 to 18.1. The percent reduction of the microbiological burden by manual cleaning was 81%, but PX-UV achieved a further 59% reduction.	Since only one ICU in the hospital was not able to have a non-intervention arm in this study. The microbiological effect of PX-UV was evaluated by comparing the number of colonies from sampling the same frequently touched surface and different sites adjacent to

Japan.			skewness of the CFU data to analyse the CFU data.		each other. If there were significant differences in contamination between sites on the same surface, the result might not accurately reflect the effect of cleaning and PX-UV.
Nagaraja, et al. 2015. Clostridium difficile infections before and during use of ultraviolet disinfection. USA.	To evaluate *C. difficile* infection cases in greater detail to understand the effect of UVD.	With 525 *C. difficile* cases (including hospital-acquired and community-acquired cases) throughout the study: 251 cases occurred during the UVD period, and 274 cases occurred during the pre-UVD period. *C. difficile* rates (HA and community-acquired [CA]), *C. difficile* patient length of stay, room occupancy, and the number of days between a *C. difficile* case in a room and an HA *C. difficile* case in the same room were studied for the first year of UVD compared with the 1-year period pre-UVD.	Pre- and post-intervention quasi-experimental study. The number of patients days with *C. difficile* as a proportion of all patient days on a unit is referred to as colonization pressure; colonization pressure is an independent risk factor for acquiring *C. difficile*.	Compared with pre-UVD, during UVD, HA *C. difficile* was 22% less. There was a 70% decrease for the adult ICUs, where the percentage of room discharges with UVD was more significant. During UVD, CA *C. difficile* increased by 18%, and the length of stay of all *C. difficile* cases was lower because of the greater proportion of CA *C. difficile*. No significant difference was found in days to HA *C. difficile* in rooms with a prior *C. difficile* occupant.	The number of *C. difficile* patients increased by the percentage of hospitals using the more sensitive tests have increased from 10% to 70% over the last 3 years. Preintervention, Intervention design, which cannot exclude confounding variables that affect *C. difficile* acquisition. The change to a new environmental services company 6 months before

					UVD started may have impacted *C. difficile* rates.
Sampathkumar et al. 2019. A trial of pulsed xenon ultraviolet disinfection to reduce Clostridioides difficile infection. USA.	As part of a quality improvement project aimed at reducing *C. difficile*. An intervention was designed to test whether the addition of ultraviolet (UV) disinfection step after terminal cleaning would help reduce *C. difficile* rates in a real-world situation.	3 similar units as control units. Intervention units 2 haematology and bone marrow transplant units and one medical-surgical unit. UV disinfection was added after patient discharge and terminal cleaning in the intervention units.	A quasi-experimental design using 3 units as intervention units for the intervention. The primary endpoint was the rate of healthcare −associated *C. difficile*. These *C. difficile* were diagnosed by a polymerase chain reaction test, were classified as healthcare−associated infections, and were attributed to the unit if *C. difficile* was diagnosed >3 days after admission. Incidence rates were expressed as the number of healthcare−associated *C. difficile* per 10,000 patient days. Data were analyzed using a negative binomial regression model in Stata 12 (StataCorp LLC, College Station, TX).	At baseline, *C. difficile* rates in the intervention and control arms were similar. During the 6 months of UV disinfection, the *C. difficile* rate in the intervention units decreased to 11.2 per 10,000 patient days, compared with 28.7 per 10,000 patient days in the control units. Also, the intervention units saw a reduction in *VRE*.	Validity and reliability not assessed. Depending on baseline *C. difficile* rates and performance on other healthcare−associated infection metrics, UV disinfection has the potential to be a cost-saving measure.
Schaffzin, et al. 2020. Maximizing efficiency in a high occupancy setting to	To evaluate UV disinfection's effectiveness following patients' discharge in TBP	A pediatric quaternary referral facility with 449 beds spanning 21 units. Following the discharge of patients in TBP and assessed its effect on HAI rates. Efficiency was increased by granting	A quasi-experimental study with an intervention of a two-robot program to UV-disinfect rooms. Run charts were generated to measure changes in HAI rates. Preliminary median rates	The program achieved 6-month disinfection averages of 85.7% of isolation and 87.7% priority rooms. The environmental team used a dedicated UV disinfection team, and setting isolation	Unable to conclude directly that UV disinfection implementation caused a reduction in HAI

utilize ultraviolet disinfection for isolation rooms. USA.	for MDROs and *C.difficile*.	environmental services' personnel oversight, increasing coverage, and modifying shift-based goals. An isolation room housed a patient in any type of TBP. A priority room was an isolation room in TBP for multidrug-resistant organisms or C. difficile infection. Percent rooms disinfected and HAI rates were calculated monthly.	were established based on 8 points, beginning with January 2015 for HA- *C. difficile*, July 2015 (July 2015-Feb 2016) for all HAIs, and January 2016 for percent HAI-*MDR-GNR*.	room per shift goals improved coverage. HAI rates decreased by 16.2% following program implementation.	rate. Unable to extract complete retrospective data to the start of the study and are left to assume coverage was lower than when we were able to measure more reliably.
Vianna et al. 2016. Impact of pulsed xenon ultraviolet light on hospital-acquired infection rates in a community hospital. USA.	To describe the feasibility and impact of implementing a no-touch PX-UV disinfection system within the ICU and non-ICU setting of an acute care hospital in an attempt to identify significant changes in the rates of MDROs and *C.difficile*	80-bed psychiatric care unit. The device was implemented in the ICU to use the pulsed xenon ultraviolet system to disinfect all discharges and transfers after standard cleaning and before the room's occupation by the next patient. For all non-ICU discharges and transfers, the pulsed xenon ultraviolet system was only used for *C. difficile* rooms. Infection data were collected for methicillin-resistant Staphylococcus aureus, *C.difficile*, and *VRE*.	The intervention period was compared with the baseline using a 2-sample Wilcoxon rank-sum test. Infection rates (incidence divided by patient days) for the PXUV intervention were compared with infection rates before implementation. Because the data were not normally distributed, a 2-sample Wilcoxon rank-sum test indicated the significance of changes occurring (Stata Corp, College Station, TX).	In non-ICU areas, a significant reduction was found for *C. difficile*. There was a non-significant decrease in *VRE* and a significant increase in methicillin-resistant S aureus. In the ICU, all infections were reduced, but only *VRE* was significant. It may be because of the increased role that environment plays in the transmission of this pathogen. Overall, there were 36 fewer infections in the whole facility and 16 fewer infections in the ICU during the intervention period than expected based on baseline data.	Using historical comparison data rather than an experimental design, effecting potential statistically significant conclusions within the ICU area. Because of the study design's nature, confounders, such as hand hygiene compliance, manual environmental cleaning quality, antimicrobial stewardship, and colonization

					pressure, were not controlled and could have influenced the outcome.
Villacís, et al. 2019. Efficacy of pulsed-xenon ultraviolet light for disinfection of high-touch surfaces in an Ecuadorian hospital. Ecuador.	The purpose of this study was: 1) to evaluate the effectiveness of pulsed-xenon ultraviolet light (PX-UV) disinfection for the reduction of bacteria on environmental surfaces of Hospital and 2) to evaluate the in-vitro efficacy against multi-drug resistance microorganisms	During the study, 146 surfaces from 17 rooms were sampled in a secondary 329-bed public medical centre. Microbiological samples of high-touch surfaces were taken after terminal manual cleaning and after pulsed xenon ultraviolet disinfection. Cleaning staff were blinded to the study purpose and told to clean, following their usual protocols. For positive cultures, PCR identification for *carbapenemase-resistance genes (blaKPC, blaIMP, blaVIM, and blaNDM)* were analyzed and confirmed by sequencing.	An observational quality-improvement study is looking at cleaning and disinfection of patient areas. The total number of CFU were obtained, and statistical analyses were conducted using Wilcoxon Rank Sum tests to evaluate the difference in CFU between terminal manual cleaning and after pulsed xenon ultraviolet disinfection.	After manual disinfection of 124 surfaces showed a total of 3569 CFU dropped to 889 CFU in 80 surfaces after pulsed xenon disinfection. Overall, the surface and environmental contamination were reduced by 75% after PX-UV compared to manual cleaning and disinfection. There were statistically significant decreases in CFU counts of high touch surfaces in OR 87% and patient rooms 76%. Four rooms presented *serine carbapenemases blaKPC, and metallo beta-lactamases blaNDM, blaVIM, blaIMP*. Confirmed by PCR and sequencing. In all cases, the in-vitro testing with endemic strains found that after five minutes of pulsed xenon ultraviolet exposure, an 8-log reduction was achieved.	This study was conducted at a single hospital site, and the rooms sampled may not be representative of other hospitals in Ecuador. Samples size was, and this study was not designed to assess the impact of HAIs.
Wong et al. 2016.	A prospective observational	Six surfaces in rooms previously occupied by patients with *MRSA*,	Observational study. Standard descriptive	Sixty-one rooms and 360 surfaces were assessed.	This study is a single-centre

Postdischarge decontamination of MRSA, VRE, and Clostridium difficile isolation rooms using 2 commercially available automated ultraviolet-C–emitting devices. Canada.	study at a tertiary care the hospital that used 2 commercial UVC devices to evaluate the incremental the benefit of UVC decontamination in *MRSA*, *VRE* & *C. difficile*.	*VRE*, or *C. difficile* were cultured before and after cleaning and after UVC disinfection. In a parallel laboratory study, *MRSA* and *VRE* suspended in trypticase soy broth were inoculated onto stainless steel carriers in triplicate, placed in challenging room areas, subjected to UVC and subcultured to detect growth. Standard descriptive statistics were performed. The McNemar the test was used to determine the difference in the proportion of paired plates positive with any ARO before and after manual cleaning and UVC disinfection.	statistics were performed. The McNemar test was used to determine the difference in the proportion of paired plates positive with any ARO before and after manual cleaning and UVC disinfection. The McNemar test was used to determine the difference in the proportion of rooms positive with any ARO before and after manual cleaning and UVC disinfection. A t-test with Welch correction was used to determine the difference between mean aerobic colony counts before and after manual cleaning and UVC disinfection. Regression analysis was used to compare the 2 UVC machines in the laboratory carrier study with the final model based on minimized Akaike information criterion and model fit. (Akaike information criterion selects the best quality model by assessing goodness of fit while including a penalty to discourage overfitting by increasing the number of parameters.) A post hoc power analysis indicated	*MRSA* was found in 34.4% before cleaning, *VRE* was found in 29.5%, and *C. difficile* was found in 31.8% of rooms. Cleaning reduced *MRSA*-, *VRE*-, and *C. difficile* contaminated rooms to 27.9%, 29.5%, and 22.7%, respectively (not statistically significant). UVC disinfection further reduced *MRSA*, *VRE*, and *C. difficile* -contaminated rooms to 3.3%, 4.9%, and 0%, respectively. Surface colony counts (excluding floors) decreased from 88.0 to 19.6 CFU after manual cleaning; UVC disinfection further reduced it to 1.3 CFU.	study, and the results may not reflect other hospital experiences where cleaning and decontamination processes may be different. Furthermore, the study is limited because it does not assess the impact of UVC on reducing health-acquired infections.

			that the overall sample size was large enough to yield a power of 99% at α = 0.05. Statistical analyses were performed with R Studio (Version 0.98.953; RStudio, Boston, MA).		
Zeber, et al. 2018. Effect of pulsed xenon ultraviolet room disinfection devices on microbial counts for methicillin-resistant Staphylococcus aureus and aerobic bacterial colonies. USA.	Compare PX-UV technology's adoption into standard terminal room cleaning protocols in 2 facilities with manual cleaning to reduce bacteria frequently associated with HAI.	70 samples collected. Environmental samples were collected before and after terminal room cleaning: 2 facilities incorporated PX-UV disinfection into their cleaning protocols, and 2 practised manual disinfection only. Specimens from 5 high-touch surfaces were collected from rooms harbouring *MRSA* or *ABC*.	An observational study. Unadjusted mean pre- and post-disinfection colony count for *MRSA* and *ABC* were calculated along with reduction percentages, per room surface and overall total. Multivariable models were run to adjust before cleaning differences because plate counts were not equivalent at baseline and not normally distributed. A negative binomial (Poisson) regression was used to determine PX-UV disinfection's association versus manual cleaning to microbial counts. Contact plates resulting in confluent growth were designated as too numerous to count for reporting purposes. Too numerous to count plates and any plates with a colony count of ≥250 for *MRSA* were assigned a value of 250	Overall, PX-UV reduced *MRSA* and *ABC* counts by 75.3% and 84.1%, respectively, versus 25%-30% at control sites. Adjusting for baseline counts, manually cleaned rooms had significantly higher residual levels than PX-UV sites. Combined analyses revealed an incident rate ratio of 5.32, with bed rails, tray tables, and toilet handrails showing statistically superior PX-UV disinfection.	The availability of terminal rooms for specimen collection and PX-UV disinfection was not predictable and often subject to discharge timing (weekends or evenings) or nursing priorities to admit the next patient, affecting the sampling frame and size. This fact has significant implications for the widespread use of PX-UV devices or other promising innovative technology: the potential impact of daily clinical priorities.

			colonies for statistical analysis.		

Appendix 2: STROBE table

References	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	Scores max=44
Anderson et al. 2017	2	2	2	2	2	X	2	2	2	2	2	2	1	2	2	2	2	2	2	2	2	1	40/44 = 90,90%
Armellino et al. 2019	2	2	2	2	2	X	1	2	2	2	2	2	X	2	2	2	1	2	2	2	1	X	35/44 = 79.54%
Bache et al. 2018	2	2	2	2	2	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	43/44 = 97,72%
Bache et al. 2012	2	2	2	2	2	X	2	2	2	2	2	2	2	1	2	2	1	2	2	2	2	2	40/44 = 90,90%
Beal et al. 2016	2	2	2	2	2	X	2	2	2	2	2	2	1	2	2	2	X	2	2	2	2	2	39/44 = 88,63%
Brite et al. 2018	2	2	2	2	2	2	2	2	2	2	2	2	1	2	2	2	2	2	2	2	2	2	43/44 = 97,72%
Casini et al. 2019	2	2	2	2	2	X	2	2	1	2	2	2	X	2	2	2	2	2	2	2	2	2	39/44 = 88,63%
Dippenaar, & Smith 2018	2	2	2	2	2	X	2	2	2	2	2	2	X	2	2	2	2	2	2	2	2	2	40/44 = 90,90%
Gostine et al.2016	2	2	2	X	2	X	2	2	1	2	2	2	X	2	2	2	2	2	X	2	1	X	32/44 = 72,72%
Green et al. 2017	2	2	2	2	2	X	2	2	2	2	2	2	X	2	2	2	2	2	2	2	2	2	40/44 = 90,90%
Kitagawa, Mori et al. 2020	2	2	2	2	2	X	2	2	1	2	2	2	X	2	2	2	1	2	2	1	1	X	34/44 = 77,27%
Maclean et al. 2010	2	2	2	2	2	X	2	2	2	2	2	2	X	2	2	2	2	2	1	2	2	2	39/44 = 88,63%
Morikane et al. 2020	2	2	2	2	2	1	2	2	1	2	2	2	X	2	2	2	2	2	2	2	2	2	40/44 = 90,90%
Nagaraja et al. 2015	2	2	2	2	2	1	2	2	1	2	2	2	X	2	2	2	2	2	2	2	2	X	38/44 = 86,36%
Sampathkumar et al.2019	2	2	2	2	2	1	2	2	2	2	2	2	X	2	2	2	2	2	X	2	2	X	37/44 = 84,09%
Schaffzin et al. 2020	2	2	2	2	2	X	2	2	2	2	2	2	X	2	2	2	2	2	2	2	2	X	38/44 = 86,36%
Vianna et al.2016	2	2	2	2	2	X	2	2	2	2	2	2	X	2	2	2	2	2	2	2	2	X	38/44 = 86,36%
Villacís et al. 2019	2	2	2	2	2	X	2	2	X	2	2	2	X	2	2	2	X	2	2	2	2	2	36/44 = 81,81%
Wong et al. 2016	2	2	2	2	2	X	2	2	2	2	2	2	X	2	2	2	2	2	2	2	2	X	38/44 = 86,36%
Zeber et al. 2018	2	2	2	2	2	X	2	2	2	2	2	2	X	2	2	2	2	2	2	2	2	X	38/44 = 86,36%

1. Study title and abstract is defined
2. The background of the study is explained
3. Objectives are stated
4. Study design is presented
5. Study settings are described
6. Participants eligibility criteria are presented
7. Variables are defined
8. Data sources/measurement are described
9. Bias is defined
10. Study size is explained
11. Quantitative variables are explained
12. Statistical methods are described
13. Number of the participants is reported and explained
14. Descriptive data is presented
15. Outcome data is reported
16. Main results are reported
17. Other analyses are reported
18. Key results are summarised
19. Study limitations are discussed
20. Interpretation is presented
21. Generalisability is discussed
22. Funding is reported

Scores: 2 Satisfies assessment criterion 1 Partly satisfies assessment criterion X Hardly or not satisfies assessment criterion, or assessment criteria do not apply