

Review

# Exposure and Health Effects of Bacteria in Healthcare Units: An Overview

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**Abstract:** Healthcare units consist of numerous people circulating daily, such as workers, patients, and companions, and these people are vehicles for the transmission of microorganisms, such as bacteria. Bacteria species may have different allergenic, pathogenic, infectious, or toxic properties that can affect humans. Hospital settings foment the proliferation of bacteria due to characteristics present in the indoor hospital environment. This review article aims to identify the potential health effects caused by bacterial contamination in the context of healthcare units, both in patients and in workers. A search was carried out for articles published in PubMed, Web of Science and Scopus, between 1 January 2000 and 31 October 2021, using the descriptor hospital exposure assessment bacteria. This bibliographic research found a total of 13 articles. Bacteria transmission occurs mainly due to the contact between healthcare workers and patients or through the handling of/contact with contaminated instruments or surfaces. The most common bacterial contaminants are *Escherichia coli*, *Pseudomonas aeruginosa*, *Staphylococcus* spp., *Staphylococcus aureus* and *Micrococcus luteus*, and the principal health effects of these contaminants are hospital-acquired infections and infections in immunocompromised people. A tight control of the disinfection methods is thus required, and its frequency must be increased to remove the microbial contamination of wards, surfaces and equipment. A better understanding of seasonal variations is important to prevent peaks of contamination.

**Keywords:** exposure; health effects; healthcare-associated infections; bacterial contamination; healthcare units; hospital



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## 1. Introduction

Infections associated with healthcare units are a major public health problem that concerns patients, the public, and politicians, since they impact society's development [1]. These infections lead to significant mortality and financial losses for health systems each year. Therefore, the rate of infection associated with healthcare units is not only an indicator of patient safety but also of the global healthcare quality provided in hospitals [2–4]. According to the World Health Organization (WHO), for every 100 hospitalized patients at any given time, 7 in developed countries and 10 in developing countries will acquire at least one healthcare-associated infection [2]. Another survey indicated that 1 in 17 hospitalized patients who received healthcare-associated infections (while being treated for other health issues) died as a result [5].

Healthcare units such as hospitals, maternity centers, blood banks, clinics, medical offices, urgent care centers, or healthcare centers consist of countless people circulating daily, such as workers, patients and their companions, the healthy and the sick. These people are vehicles for transmitting microorganisms, such as bacteria, that can cause infections that are transmitted very easily in this setting due to its population of sick or immunocompromised people [6].

Additionally, bacterial contamination in hospitals is heavily affected by the following important factors: construction characteristics, levels of water and nutrients in the interior environment necessary for the growth and survival of bacteria, people that occupy the space, and the outdoor environment [7]. Medical activities, cleaning procedures and their frequency are crucial factors for the increase in bacterial load [8,9].

Bacterial species have different allergenic, pathogenic, infectious, or toxic properties that can affect humans [10]. Allergenic bacteria, mainly thermophilic bacteria, may generate a hypersensitivity response (hypersensitivity pneumonitis) in the host [10]. A pathogenic bacterium causes disease in a host and is determined by virulence factors, enabling the replication and dissemination of bacteria in the host organism [11,12]. Bacteria infect a host, usually from another host/reservoir, through direct contact, airborne transmission, a vector, or a common vehicle [10]. In addition, bacteria can produce toxins, which trigger a harmful process in the host organism, inhibiting protein synthesis, activating immune responses, and damaging cell membranes [13]. Bacterial cell wall constituents, such as endotoxins and peptidoglycans, are referred to as agents with pro-inflammatory properties causative of respiratory symptoms (asthma, bronchitis and byssinosis) [10].

The transmission of bacteria can be promoted because healthcare workers interact physically with different patients, unaware that they are transmitting potentially pathogenic agents. Additionally, the handling/contact with contaminated instruments or surfaces [14,15] can cause a risk of infection in both workers [16] and patients. In fact, the isolation of microorganisms from the surfaces suggests that some patients acquire bacterial infections in the hospital [17–20].

Hospital-acquired (nosocomial) infections are a concern in terms of patient safety, as they may have a high impact on patient morbidity and mortality [21,22].

Commonly, most bacteria do not cause adverse health effects and can even benefit us and the environment. The problem arises when the concentration of certain potentially pathogenic bacteria is higher than the infective dose, which varies dramatically across pathogen species [23]. The scale of the severity of the effects on human health depends on many factors such as toxicity, exposure time and microbial load, and even one's age and nutritional status [24]. For example, bacteria such as *Acinetobacter baumannii*, *Pseudomonas aeruginosa* and *Stenotrophomonas maltophilia*, which are non-fermenting Gram-negative bacilli, can cause infections and severe health problems. These bacteria have been recognized as multidrug-resistant (MDR) and are associated with higher rates of mortality, increased service costs, and a poorer clinical outcome [25–28]. Additionally, *Burkholderia cepacia* complex (Bcc), which are a non-fermenting Gram-negative bacillus, consist of 20 species that are similar in phenotype and genetically different [29]. During the last two decades, Bcc were considered the most common bacteria in intensive care units, and recognized as a nosocomial pathogen, associated with several outbreaks in immunocompromised patients [28], such as bloodstream infections, pneumonia, urinary tract infections, septic arthritis, and peritonitis [30,31].

For the healthcare sector, the priority is to reduce, prevent and monitor infections to provide a high-quality service with the fewest number of health conditions. Therefore, healthcare units must adopt strategies and systems of epidemiologic surveillance to control infections.

In order to improve public health, this article intends to describe prevalent bacteria and identify their potential health effects in the context of healthcare units, both in patients and in workers. For these, it is important to assess the factors that influence bacterial contamination in this setting. This will ultimately contribute to the prioritization of actions

to establish procedures for evaluating occupational exposure, protocols, and guidelines adaptable to healthcare units, which have an increased risk of the transmission of infections due to prolonged exposure periods and the high density of people.

## 2. Materials and Methods

### 2.1. Systematic Review Registration

The protocol of this systematic review was submitted for registration in PROSPERO (<https://www.crd.york.ac.uk/prospero/>, accessed on 18 December 2021 ) (Registration Number: 291564). Moreover, the Preferred Reporting Items for Systematic Reviews (PRISMA) checklist was completed (Table S1—Supplementary Material).

### 2.2. Search Strategy and Inclusion and Exclusion Criteria

In this study, available data on the exposure assessment of bacteria, including hospitals and healthcare units, published between 1 January 2000 and 31 October 2021, were searched following the Preferred Reporting Items for Systematic Reviews and Meta-Analysis methodology. The databases chosen were PubMed, Web of Science, and Scopus. Searches were carried out in English. The search terms were “Exposure assessment bacteria” and “Hospital” and “Health Care Units”. Articles that did not meet the inclusion criteria and duplicates were excluded from further analysis (Table 1).

**Table 1.** Inclusion and exclusion criteria in the articles selected.

| Inclusion Criteria  | Exclusion Criteria   |
|---|--|
| Articles in the English language  | Articles in other languages (for articles)                                 |
| Articles published from 1 January 2000 to 31 October 2021                           | Articles published before 2000   |
| Articles related to bacteria contamination in healthcare units                      | Articles related to biological samples from patients or workers(exclusive) |
| Articles related to health effects of bacteria on humans                            | Abstract of congress, reviews/state-of-the art, reports                    |
| Articles related exclusively to humans  | Articles related exclusively to animals                                    |
| Bacterial identification to the genera level and if possible, to the species level. |  |

### 2.3. Studies Selection and Data Extraction

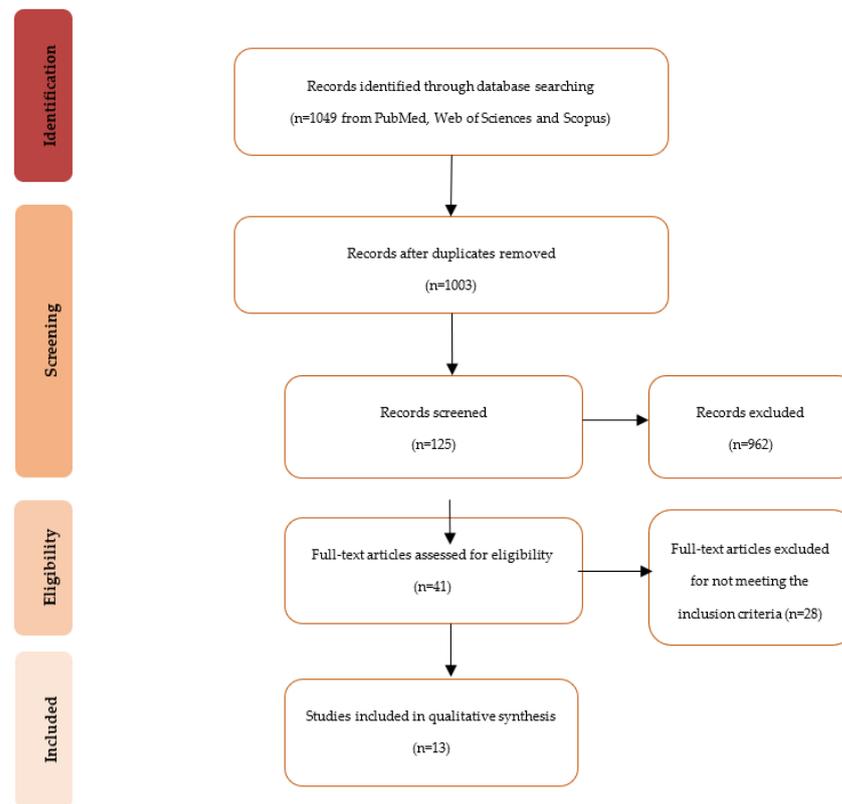
Initially, all titles and abstracts were selected, and then only the full texts of all potentially relevant studies were reviewed, considering the inclusion and exclusion criteria. The following information was manually selected: (1) title, (2) analyzed country, (3) analyzed environment, (4) collected data, (5) results, (6) bacteria found, (7) health effects and (8) affected population.

### 2.4. Quality Assessment

In each study, we assessed the bacterial results, type of bacteria found, and health effects in order to eliminate the risk of bias and ensure that each study was complying with the inclusion criteria focused on bacterial contamination, health effects and the fact that the study was performed in a clinical environment.

## 3. Results

Figure 1 illustrates the process used to identify and select the articles for analysis. The primary search on the databases returned 1049 studies from which 1003 abstracts were screened, and 125 full texts were assessed for eligibility. After considering the inclusion and exclusion criteria, we were able to select 44 articles. This review is centered on 13 articles about the context of exposure assessment bacteria in hospital and healthcare units.



**Figure 1.** PRISMA-based selection of articles.

### 3.1. Characteristics of the Selected Studies

The selected articles (13) were studied in terms of reference values of bacteria and health effects that could be caused by bacteria. The obtained data can be found in Table 2. These studies were conducted in several countries such as Italy, Poland, The United States of America, Korea, Pakistan, Greece, Uganda, Iran, Brazil, and Tehran. For the assessment of bacteria, more than half of the studies used air samples (7 out of 13), others used settle plates and swab methods, and some did not disclose the method used to assess bacteria.

#### 3.1.1. Reference Values for Bacteria

Regarding the reference values for bacteria, the median level of colony forming units (CFU) in the wards of hospital 1 was 129.87 (87.46–268.97) CFU/m<sup>3</sup> and, for hospital 2, was 297.97 (217.66–431.85) CFU/m<sup>3</sup> [32], both part of a teaching hospital in Tehran. A study conducted in a Brazilian hospital reported median bacterial loads of 345.25 CFU/m<sup>3</sup> in the post-surgical restroom and 566 CFU/m<sup>3</sup> in operating theatres [33]. Another study in a hospital from Poland reported a median bacterial load of 347.4 CFU/m<sup>3</sup> (257.1–436.3 CFU/m<sup>3</sup>) [34]. In a university hospital from Greece, the highest mean total microbial load (689 CFU/m<sup>3</sup>) and the highest Gram-negative bacteria load (4.16 CFU/m<sup>3</sup>) were observed in the intensive medicine ward [35]. A study dedicated to hospitals in the USA observed a mean bacterial load of 720 CFU/m<sup>3</sup> [36]. Some of the analyzed articles did not quantify the bacterial contamination found (5 out of 13).

#### 3.1.2. Seasonal Variation

Peak values of airborne bacteria occurred in November and May, and the lowest values were recorded between December and February [34], not specifying the month. Park et al. [36] concluded that winter was shown to have a lower bacterial concentration (mean) 230 CFU/m<sup>3</sup> (14 samples), while summer had the highest, 970 CFU/m<sup>3</sup> (25 samples). Considering the effect of the time of day, studies suggested that the concentrations in the morning (9 h) ranged between 267.1–505.6 CFU/m<sup>3</sup> and in the afternoon (13 h),

213.6–410.9 CFU/m<sup>3</sup> [34]. In another hospital the main concentration of bacteria was found during service hours (8 h–18 h) with an average of 930 CFU/m<sup>3</sup> [36].

In the waiting rooms of primary healthcare units and hospital wards [37], mesophilic bacteria were the highest at 297 CFU/m<sup>3</sup> in autumn. Airborne *Staphylococci* peaked at 96 CFU/m<sup>3</sup> in winter (cardiology ward and intensive care room). The concentration of airborne actinomycetes was 231 CFU/m<sup>3</sup> in winter (children's ward).

### 3.1.3. Prevalent Bacteria

Several studies reported the variability of prevalent bacteria in hospital settings. For example, a gynecology theatre from a hospital in Italy [38] presented the highest bacterial load of  $261.3 \pm 131.3$  CFU/dm<sup>2</sup>/h, with a prevalence of *Pseudomonas* spp. (25.8%), and the ophthalmology theatre had the highest concentration of microbial pathogens (38.9%), being 22% of *Pseudomonas* species and 18.7% of *Bacillus* spp. [38]. In other hospital wards and operating theatres [39], the bacterial concentration ranged from  $1.27 \times 10^4$  to  $17.83 \times 10^4$  CFU/dm<sup>2</sup>/h.

In an Italian hospital [40], the group of workers with the highest number of infections by *H. pylori* were physicians (16 out of 47) and nurses (18 out of 45). Both groups worked in the endoscopy unit; nurses (30 out of 75) worked in direct contact with patients but did not work in the endoscopy unit.

In terms of prevalent bacteria found in the air, the most mentioned was *Escherichia coli*, found in patients on a ward [34] in a Pakistan hospital [41] and in operating beds in Uganda [38]. Additionally, *Pseudomonas aeruginosa* was reported in the air of a hospital ward [34] in a Tehran teaching hospital [32], and in patients from a Pakistan hospital [41], in the gynecology theatre, main operating theatre, and on the instrument trolley. *Pseudomonas* spp. showed a higher prevalence, even though the species were not specified [38]. *S. aureus* were another common bacteria species found in patients from a Pakistan hospital [41], on the door handles of a Ugandan operating theatre [38], and in several wards in a Tehran hospital [32]. *Staphylococcus* spp. was detected in the air from a university hospital in Greece [35], in a Ugandan operating theatre [38] and in primary healthcare units and hospital wards in Poland [37]. *Micrococcus luteus* was found in the female surgery and male surgery wards in an Iranian hospital [39] and in a Brazilian hospital [33]. Other bacteria were mentioned, such as *H. pylori* [40], *Staphylococcus epidermidis*, *Micrococcus*, *Streptococcus*, *Flavobacterium* spp., *Acinetobacter calcoaceticus*, *Pantoea agglomerans*, *Enterobacter* spp., *Klebsiella oxytoca*, *Branhamella catarrhalis* and *Neisseria flavescens*, *Arthrobacter* spp., *Brevibacterium* spp [34], *Clostridium difficile* [42], Gram-negative bacilli (XDR-GNB) [43], *Haemophilus influenzae* [41], *Bacillus* spp. [38], *Staphylococcus epidermidis*, *Streptococcus* spp., *Diphtheroid* spp., *Micrococcus roseus*, *Bacillus subtilis*. [39], mesophilic bacteria, airborne actinomycetes, *S. saprophyticus*, *S. warneri* [37], *S. haemolyticus* and *S. hominis* [33], *Acinetobacter lwoffii*, *Salmonella typhimurium* and *Klebsiella pneumoniae* [32].

### 3.1.4. Health Effects

Regarding health effects, the most prevalent bacteria-associated effects were hospital-acquired infections caused by Gram-positive bacteria and antibiotic-resistant Gram-negative bacteria [34,43], followed by nosocomial diarrhea caused by *Clostridium difficile* [42,44], nosocomial infections, and infections in immunocompromised people [33,37]. The other infections reported were bloodstream infections [33]; osteoarticular infections [41]; respiratory and infection diseases [36]; allergenic properties [34]; chronic active gastritis; gastric and duodenal ulcers [40]; osteomyelitis [41]; bacteremia; infections of skin, bones and joints; endocarditis; and central venous catheter infection [33].

**Table 2.** Information obtained from the articles selected.

|        | Title   | Country       | Analyzed Environment | Collected Data  | Results   | Bacteria Found   | Health Effects   | Affected Population | References |
|--------|---|---------------|----------------------|---|---|--|--|---------------------|------------|
| PubMed | Does Hospital Work Constitute a Risk Factor for Helicobacter Pylori Infection?    | Italy         | Hospital             | A questionnaire was completed by participants before collection of fecal specimens.                               | 249 workers tested positive for <i>H. pylori</i> : 16 out of 47 physicians (endoscopy unit); 18 out of 45 nurses (endoscopy unit); 5 out of 30 physicians (only contact with patients); 30 out of 75 nurses (only contact with patients); 9 out of 52 healthcare personnel (no patient contact).  | <i>H. pylori</i>   | Helicobacter pylori infection likely represents the most common bacterial infection of the human species, with a prevalence of 25–50% in developed countries and up to 90% in developing countries. A vast body of evidence now indicates that <i>H. pylori</i> is the principal etiological agent of chronic active gastritis, as well as gastric and duodenal ulcers, and represents a major risk factor for the development of gastric cancer.  | Workers             | [40]       |
| PubMed | Variability of Airborne Microflora in a Hospital Ward Within a Period of One Year | Poland        | Hospital (ward)      | Air samples   | Concentrations of airborne bacteria: 257.1–436.3 CFU/m <sup>3</sup> , peak values—November and May, lowest values—December to February; Gram-positive cocci: 31.4–46.4% of the total count and 37.2–49.6% of the respirable fraction; Gram-negative bacteria: 11.8–27.5% of the total count and 5.6–30.2% of the respirable fraction.             | <i>Staphylococcus epidermidis</i> , <i>Micrococcus</i> , <i>Streptococcus Flavobacterium</i> spp., <i>emphAcinetobacter calcoaceticus</i> , <i>Pantoea agglomerans</i> , <i>Escherichia coli</i> , <i>Enterobacter</i> spp., <i>Klebsiella oxytoca</i> , <i>Pseudomonas aeruginosa</i> , <i>Branhamella catarrhalis</i> and <i>Neisseria flavescens</i> , <i>Arthrobacter</i> spp., <i>Brevibacterium</i> spp. | The risk of exposure to <i>Staphylococci</i> was diminished by the fact that the isolated strains were coagulase-negative and unlikely to cause infections. Gram-negative bacteria found in the air of the hospital ward could be a source of adverse endotoxin, and <i>Acinetobacter</i> strains may be a potential cause of hospital infections transmitted by air. Some of the Gram-positive isolates belonging to corynebacteria and actinomycetes ( <i>Arthrobacter</i> spp., <i>Brevibacterium</i> spp., <i>Streptomyces albus</i> ) show allergenic properties. | Patients            | [34]       |
| PubMed | Clostridium Difficile Infection in Hospitalized Children in the United States     | United States | Hospital             | Data were obtained from the triennial Healthcare Cost and Utilization Project Kids' Inpatient Database (HCUP-KID) | <i>Clostridium difficile</i> infections increased from 3.565 in 1997 to 7.779 in 2006; <i>Clostridium difficile</i> infections had an increased risk of death with an adjusted odds ratio (95% confidence interval); 1.20 (1.01–1.43), colectomy; 1.36 (1.04–1.79), longer length of stay; 4.34 (3.97–4.83) and higher charges; 2.12 (1.98–2.26). | <i>Clostridium difficile</i>   | <i>Clostridium difficile</i> is a Gram-positive, spore-forming, anaerobic bacillus that can colonize the gastrointestinal tract and can lead to <i>C. difficile</i> infection (CDI). CDI has a wide variation of severity, ranging from asymptomatic colonization to severe diarrhea, pseudomembranous colitis, toxic megacolon, bowel perforation, and death.   | Patients (children) | [42]       |

Table 2. Cont.

|                | Title   | Country       | Analyzed Environment | Collected Data  | Results  | Bacteria Found  | Health Effects  | Affected Population | References |
|----------------|---|---------------|----------------------|---|--|---|---|---------------------|------------|
| PubMed         | Trends in Clostridium Difficile Infection and Risk Factors for Hospital Acquisition of Clostridium Difficile Among Children With Cancer           | United States | Hospital             |   |  |   | Clostridium difficile infection (CDI) is the most common cause of nosocomial diarrhea and can lead to a range of complications from colitis to toxic megacolon, bowel perforation, and death. CDI is a significant cause of nosocomial and antibiotic-associated diarrhea in adults, with increasing frequency and severity.  | Patients (children) | [44]       |
| PubMed         | Assessment of the Levels of Airborne Bacteria, Gram-Negative Bacteria, and Fungi in Hospital Lobbies  | Korea         | Hospital Lobbies     | Air samples   | Mean level of airborne bacteria:<br>7.2 × 10 <sup>2</sup> CFU/m <sup>3</sup> ; service hours (08 h–18 h): 9.3 × 10 <sup>2</sup> CFU/m <sup>3</sup> (mean); after service hours (18 h–24 h): 4.4 × 10 <sup>2</sup> CFU/m <sup>3</sup> ; winter: 2.3 × 10 <sup>2</sup> CFU/m <sup>3</sup> (mean); summer: 9.7 × 10 <sup>2</sup> CFU/m <sup>3</sup> (mean); Gram-negative bacteria mean: 1.7 × 10 <sup>2</sup> CFU/m <sup>3</sup> . |   |   | All occupants       | [36]       |
| PubMed         | Risk Factors and Outcomes of Infections Caused by Extremely Drug-Resistant Gram-Negative Bacilli in Patients Hospitalized in Intensive Care Units | United States | ICUs                 | A matched case-control (1:2) study was conducted from February 2007 to January 2010 in 16 ICUs.       | An immunocompromised state (OR = 1.55, <i>p</i> = 0.047) and exposure to amikacin (OR = 13.81, <i>p</i> < 0.001), levofloxacin (OR = 2.05, <i>p</i> = 0.005), or trimethoprim-sulfamethoxazole (OR = 3.42, <i>p</i> = 0.009) were factors associated with XDR-GNB HAIs.  | Extremely drug-resistant Gram-negative bacilli (XDR-GNB)  | Antibiotic-resistant, Gram-negative bacilli (GNB) are increasingly common causes of healthcare-associated infections (HAIs) in intensive care units (ICUs) and are associated with higher mortality rates, longer hospitalizations, and increased healthcare expenditures. Effective treatment for extremely drug-resistant (XDR) GNB infections is challenging because of limited therapeutic options. | Patients            | [43]       |
| Web of Science | <i>Staph Aureus</i> as the most common cause of osteoarticular infection in Dost-1 Mayo Hospital, Lahore  | Pakistan      | Hospital             | Patients were followed up in OPD for 24 weeks post operatively to assess the outcome of the procedure | Causative organism (200 patients): <i>Staph Aureus</i> in 96% of the patients, <i>Haemophilus influenzae</i> 1.2%, <i>Escherichia Coli</i> was 2% and <i>Pseudomonas Aeruginosa</i> was 0.8%.  | <i>Staph Aureus</i> , <i>Haemophilus influenzae</i> , <i>Escherichia Coli</i> , <i>Pseudomonas Aeruginosa</i> | <i>Staph Aureus</i> was the organism which caused osteoarticular infection in 96% of patients.  | Patients            | [41]       |

Table 2. Cont.

|                | Title  | Country | Analyzed Environment                    | Collected Data                                    | Results  | Bacteria Found  | Health Effects | Affected Population | References |
|----------------|--|---------|---|---|--|---|----------------|---------------------|------------|
| Pubmed         | Air Contamination in Different Departments of a Tertiary Hospital. Assessment of Microbial Load and of Antimicrobial Susceptibility              | Greece  | University hospital                     | Air samples                                       | The highest mean total microbial load was observed in the IMW (689/m <sup>3</sup> ), followed by the SW (596 CFU/m <sup>3</sup> ), the NU (509 CFU/m <sup>3</sup> ) and, finally, the ICU (353 CFU/m <sup>3</sup> ). The load of GN, the highest load, was observed in the IMW (4.16 CFU/m <sup>3</sup> ), followed by the ICU (1.14 CFU/m <sup>3</sup> ), the SW (0.83 CFU/m <sup>3</sup> ), and the NU (0.81 CFU/m <sup>3</sup> ). | In total, 101 samples were collected, from which 158 Gram-positive (GP) and 44 Gram-negative (GN) strains were isolated. The majority of GP isolates were <i>Staphylococcus</i> spp. (n = 100). The highest total microbial load was reported in the IMW (p = 0.005), while the highest <i>Staphylococcus</i> load was observed in the ICU (p = 0.018). |                | All occupants       | [35]       |
| PubMed         | Contamination of Microbial Pathogens and Their Antimicrobial Pattern in Operating Theatres of Peri-Urban Eastern Uganda: A Cross-Sectional Study | Uganda  | Operating theatre                       | 109 samples (n = 31 air samples and n = 78 swabs) | Gynecology theatre—261.3 ± 131.3 CFU/dm <sup>2</sup> /h ( <i>Pseudomonas</i> spp.—25.8%); main OT—69.5 ± 78.7–38.9% microbial pathogens ( <i>Pseudomonas</i> spp.—22%; <i>Bacillus</i> spp.—18.7%); operating bed ( <i>E. coli</i> —77.8%), instrument trolley ( <i>Pseudomonas</i> spp.—28.6%), door handles (100% of <i>S. aureus</i> )  | <i>Pseudomonas</i> spp., <i>coagulase negative staphylococcus</i> , <i>Bacillus</i> spp., <i>E. coli</i> , <i>Staphylococcus aureus</i>   |                | Patients            | [38]       |
| Web of Science | Assessment of bioaerosol particle characteristics at different hospital wards and operating theatres: A case study in Tehran                     | Iran    | Hospital (CCU, GICU, ICU, NICU, OT, NS) | Passive sampling method (252 plates)              | Concentration of bacterial: 127 to 1783 CFU-m-2 h-1; <i>Micrococcus luteus</i> : NS (41.5%), WS (72.3%), MS (70.0%), ICU (66.2%); <i>Staphylococcus epidermidis</i> : GICU (46.6%), NICU (50.0%); CCU: <i>Streptococcus</i> spp. (53.8%), <i>Micrococcus luteus</i> (46.2%).   | <i>Micrococcus luteus</i> , <i>Staphylococcus epidermidis</i> , <i>Streptococcus</i> spp., <i>Diphtheroid</i> spp., <i>Micrococcus roseus</i> , <i>Bacillus subtilis</i> .  |                | All occupants       | [39]       |

Table 2. Cont.

|                | Title  | Country | Analyzed Environment                        | Collected Data                             | Results  | Bacteria Found   | Health Effects   | Affected Population | References |
|----------------|--|---------|---|--|--|--|--|---------------------|------------|
| PubMed         | Assessment of Microbiological Aerosol Concentration in Selected Healthcare Facilities in Southern Poland | Poland  | Primary healthcare units and hospital wards | Air samples                                | Mesophilic bacteria ranged 5 CFU/m <sup>3</sup> in winter (No. IV)–297 CFU/m <sup>3</sup> in autumn (No. V); airborne Staphylococci ranged 1 CFU/m <sup>3</sup> in spring–96 CFU/m <sup>3</sup> in winter (both No. IX); airborne actinomycetes ranged 7 CFU/m <sup>3</sup> in spring and autumn (No. IV)–231 CFU/m <sup>3</sup> in winter (No. VII); 55 isolates strains of <i>Staphylococcus</i> spp.: <i>S. saprophyticus</i> 25% (14), <i>S. warneri</i> 24% (13). | <i>Mesophilic Bacteria</i> , <i>Airborne staphylococci</i> , <i>Airborne actinomycetes</i> , <i>Staphylococcus</i> spp., <i>S. saprophyticus</i> , <i>S. warneri</i>   | Nosocomial infections and infections in immunocompromised people.  | All occupants       | [37]       |
| web of Science | Potentially pathogenic bacteria isolated from neglected air and surfaces in hospitals                    | Brazil  | Hospital                                    | Air samples, surfaces and uniforms samples | The highest microbial load was found in the PSRR (566 CFU/m <sup>3</sup> , Hospital B) and the lowest in the ORT (124.5 CFU/m <sup>3</sup> , Hospital B).  | In the aerial microbiota of the sampled areas of both hospitals, <i>M. luteus</i> , <i>S. haemolyticus</i> and <i>S. hominis</i> spp. <i>hominis</i> were the prevalent microorganisms, with a percentage greater than 30%. On the surfaces and uniforms, there was a prevalence of <i>M. luteus</i> (40%) and <i>S. hominis</i> spp <i>hominis</i> (20%). | <i>S. hominis</i> subsp. <i>hominis</i> is reported as a potential pathogen isolated in generalized infections. <i>M. luteus</i> , found in several sampled environments, is described as the causative agent in endocarditis and central venous catheter infection. Some microorganisms, isolated in low percentages in this study, are described in some cases of nosocomial infections, as is the case of <i>E. ludwigii</i> , reported as an agent causing an outbreak of bloodstream infection. <i>Bacillus cereus</i> causes bacteremia, infection of skin, bones and joints; <i>S. lugdunensis</i> causes bacteremia. <i>S. warneri</i> causes endocarditis and <i>S. cohnii</i> subsp. <i>urealyticus</i> causes bacteremia. | All occupants       | [33]       |

Table 2. Cont.

|        | Title  | Country | Analyzed Environment                     | Collected Data | Results  | Bacteria Found  | Health Effects | Affected Population | References |
|--------|--|---------|--|----------------|--|---|----------------|---------------------|------------|
| Pubmed | Assessment of Bacterial Pathogens and their Antibiotic Resistance in the Air of Different Wards of Selected Teaching Hospitals in Tehran | Tehran  | Wards of selected two teaching hospitals | Air samples    | The median level of colonies in the wards of hospital 1 was 129.87 (87.46–268.97) CFU/m <sup>3</sup> and 297.97 (217.66–431.85) CFU/m <sup>3</sup> for hospital 2. | <i>Staphylococcus aureus</i> was identified in most wards of the tow hospital. <i>Acinetobacterlwoffii</i> and <i>Salmonella typhimurii</i> were the most abundant and least Gram-negative bacteria in hospital 1, respectively. In hospital 2, <i>Pseudomonas aerungos</i> and <i>Klebsiella pneumonia</i> were the most abundant Gram-negative bacteria in the sampling stations. |                | All occupants       | [32]       |

#### 4. Discussion

Numerous studies presented divergent points of view on how bacterial contamination can be observed in different locations within hospital facilities, how seasonal variations affect the concentration, and even how data regarding the most prevalent genera that can be found in healthcare environments and staff due to occupational activities.

In the first presented study [34], concentrations of airborne bacteria reached a peak in November (436.3 CFU/m<sup>3</sup>), and the lowest value was identified in December (257.1 CFU/m<sup>3</sup>). However, the authors did not explain the decrease between these two months or between the other months of the year that were assessed. Another study, conducted in Portugal [45], described that most of the departments analyzed presented a high level of bacterial concentration (ranging from 12 to 170 CFU/m<sup>3</sup>) and concluded that the indoor bacterial concentration was not influenced by outdoor concentration but by indoor air. A higher bacterial concentration was identified in the mornings (267.1–505.6 CFU/m<sup>3</sup>), and even though the authors did not provide an explanation, we hypothesize that this could be due to increased human activity from visitors or workers [36,46].

In another analyzed study [37], winter and autumn had the highest concentration levels of bacteria with the increased bioburden associated with the waiting room in autumn and children's ward in the winter. A possible explanation for the higher load in the waiting room can be attributed to an increase in the number of occupants (200 per day or more). The same hypothesis is suggested in the children's ward, with the additional factor of the increased number of infections in children during the wintertime. The fact that the rooms in that ward are small, and that more than one parent can accompany the child, is another factor that increases the concentration of bacteria such as airborne actinomycetes, which were the most prevalent in the children's ward [37].

The data from Portuguese studies revealed that *Staphylococcus epidermidis* [45] and *Micrococcus* spp. [45–47] were the most prevalent bacteria identified. However, *S. epidermidis* is not considered to be a relevant risk of exposure due to its lower infections rates [34]. On the other hand, *Acinetobacter* (species not identified) was found in two studies [32,34] as a prevalent genus in a university hospital from Ethiopia, justifying its persistence due to its great survival ability in the indoor environment [47], which can be a potential cause for hospital infections transmitted via the air [48]. Another relevant microorganism is *Pantoea agglomerans*, which is able to infect hospitalized individuals, particularly immunodeficient patients, through contaminated medical instruments [49].

A bacteria genus described in several studies considered of great interest is *Staphylococcus* spp., which was identified at the highest concentration in a cardiology ward/intensive care room (hospital 5). Once the strains were analyzed, *S. saprophyticus* was the most predominant, followed by *S. warneri*, being reported as an important opportunistic pathogen and associated with healthcare-acquired infections [37]. Cabo Verde et al. [45] also found *S. warneri* to be a prevalent species in the hospital, but no data were reported regarding *S. saprophyticus* in contrast to the findings of Sivagnanasundaram et al. [50]. *S. saprophyticus* can infect an individual's blood through catheters, surgical prostheses, pneumonia, urinary tract infections and more [51–53]; therefore, this species is of particular relevance. Moreover, *Staphylococcus aureus* is one of the most relevant nosocomial pathogens, described as one of the main pathogenic bacteria that cause osteomyelitis (including in children)[54–59] septic arthritis [60–63], and prosthetic joint infections [64–67]. *S. aureus* is a commensal bacterium and a human pathogen; about 30% of all humans are colonized with *S. aureus* [68]. Osteoarticular infections can occur by the direct inoculation of microorganisms into tissues due to penetrating or open trauma [69]. In limited settings, infections complicate as many as 44% of open fractures [69]. Trauma-related osteoarticular infections among patients with punctures wounds seeking medical care varied from 2–60% depending on the type of the injury [70–72]. *S. aureus* was also prevalent in the studies by Matinyi et al. [38] and Thomas et al. [73], being detected on door handles, which could be considered a possible source of nosocomial infection [38]. Additionally, *Staphylococcus epidermidis*, as well as *Micrococcus luteus* and *Bacillus subtilis*, were common in the studies by Sivagnanasundaram et al. [50],

Bielawska-Drózd et al. [74], and Bolookat et al. [39]. The reason for these results could be related to the presence of these bacteria in the skin, mucous membranes, hair of human beings and animals [75–78].

Considering health effects, the identification of *Clostridium difficile*, a Gram-positive, anaerobic, spore-forming bacillus, must be considered, as it is the principal agent of pseudomembranous colitis in humans [79]. In the hospital setting, *C. difficile* infection is the main cause of healthcare-associated diarrhea [80]. Symptoms arise when *C. difficile* spores germinate in the intestine, and the bacteria start to produce toxins, Toxin A (TcdA) and Toxin B (TcdB), causing the inflammation of the large intestine [81]. The clinical presentation can range from mild diarrhea to lethal toxic megacolon [81]. Nonetheless, the ingestion of *C. difficile* spores does not always lead to the development of symptomatic disease, since this bacterium can be silently present in the intestine without manifesting any symptoms, denominated as asymptomatic *C. difficile* colonization [82]. However, the patients with this condition act as a reservoir for further transmissions [83,84], and they can progress to the infection themselves, especially if they are affected by an underlying illness [85]. The infection is transmitted by spores that are environmentally resistant [86].

Another microorganism of interest is *H. pylori*, which is associated with occupational exposure among endoscopy personnel [87]. The study by Mastromarino et al. [40] aimed to determine if different staff groups of healthcare workers, either with or without direct patient contact, were at equal risk of acquiring *H. pylori* infection. The authors concluded that direct contact with patients is an important factor for becoming infected, as opposed to simply working in the endoscopy unit. Another study highlighted [87] that 24% (9 out of 37) of gastrointestinal endoscopy personnel, and 47% (33 out of 70) of workers in a hospital who care for disabled individuals, tested positive for *H. pylori*. In this case, direct contact with patients and working in a hospital where disabled individuals reside was associated with *H. pylori* infections, but the exposure to gastrointestinal secretions of the patients was not [87]. This study supports the previous study's idea that direct contact with patients is a factor to take into consideration.

Among Gram-negative bacteria, the most frequently identified pathogens are *Escherichia coli*, *Klebsiella pneumoniae*, *Pseudomonas aeruginosa*, and *Acinetobacter baumannii*. *E. coli* was described to be prevalent in operating beds due to fecal contamination and the lack of efficiency in the cleaning process [88,89]. *Pseudomonas* spp., one of the most significant genera of nosocomial pathogens, was the most prevalent bacteria in all operating theatres in the Matinyi et al. study [38], and was identified in other studies [73,90] that referred to antiseptic solutions as a possible source of this contamination [56,57,91,92]. Other bacteria, *Bacillus* spp., can be related to dusty environments, the type commonly found in Uganda [38]. This contamination might occur in indoor areas if the windows are open for natural ventilation and could then be transferred to the operating theatres [73]. Furthermore, *A. baumannii* was associated with a vast number of infections, such as those of the bloodstream, respiratory tract, surgical sites, and urinary tract [93]. Transmission between patients in hospital settings is difficult to prevent because of the bacterium's capacity to persist in the environment, particularly in intensive care units [93]. These Gram-negative pathogens are associated with the etiology of numerous and severe hospital-acquired infections in humans and have the capacity to resist antimicrobial agents, which has become an increasingly relevant problem [94]. Currently, antimicrobial-resistant Gram-negative bacteria are expanding worldwide and are considered a significant threat to human health [3].

## 5. Conclusions

The bacterial contamination of healthcare units was found to be diverse and causative of several hazardous health effects. The reported contamination in this setting was divergent depending mostly on the sampling site. Nevertheless, *Pseudomonas* spp. and *Staphylococcus* spp., two of the greatest nosocomial pathogens, were the most prevalent bacteria identified in healthcare units. Hospital-acquired infection caused by Gram-positive

bacteria and antibiotic-resistance, Gram-negative bacteria were the most frequent and relevant associated health effects. The necessity for tight control in the cleaning process was made clear in order to improve disinfection efficiency in wards, surfaces, equipment, and uniforms and prevent direct contact transmission. A better understanding of seasonal variations is essential, allowing hospitals to avoid contamination peaks.

**Supplementary Materials:** The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/app12041958/s1>, Table S1: PRISMA Checklist (Adopted from Moher et al. 2009 \*).

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