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# Efficacy of photocatalytic processes for hospital environmental disinfection: A systematic review

**Seyed Abolfazl Hosseini[1], Bahador Pourdel[1], Erfan Rajabi[1], Hossein Farash Khayalo[*2,3]**

[1] Student Research Committee, School of Allied Medical Sciences, Iran University of Medical Sciences, Tehran, Iran
[2] Research Center for Environmental Health Technology, Iran University of Medical Sciences, Tehran, Iran
[3] Department of Environmental Health Engineering, School of Public Health, Iran University of Medical Sciences, Tehran, Iran

***Corresponding Author Email: hosseinfarash@gmail.com**

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## Abstract

Healthcare-associated infections (HAIs) and multidrug-resistant organisms threaten patient safety. This systematic review evaluates photocatalytic reactions as continuous, self-disinfecting technologies in hospitals.

Following PRISMA 2020 guidelines, we searched PubMed, Web of Science, Scopus, and Embase. Forty-seven studies were included to assess semiconductor photocatalysts' antimicrobial efficacy against hospital pathogens.

Nearly half (49%) of the studies utilized visible-light-active catalysts (e.g., doped-$TiO_2$). These systems demonstrated high efficacy against superbugs, achieving up to a 4.2 log reduction in Staphylococcus aureus and 99.99% in Methicillin-resistant *Staphylococcus Aureus* (MRSA). Furthermore, field interventions in intensive care units showed that photocatalytic air purifiers reduced airborne contamination by one order of magnitude and significantly lowered infection acquisition rates.

Photocatalytic processes represent a promising adjunctive infection control strategy, providing constant microbial inactivation under ordinary hospital lighting. Future standardized testing of functional stability in clinical environments is required.

**Keywords:** Photocatalytic Processes, Hospital Environmental Disinfection, Healthcare-Associated Infections, Titanium Dioxide, Multidrug-Resistant Organisms.

## Introduction

One of the most severe threats to the health of the entire world is healthcare-associated infections [HAIs] that cause higher mortality rates, extended hospitalization, and high economic costs to healthcare systems (1, 2). Hospital surfaces and indoor air are the most important reservoirs of the spread of dangerous pathogenic organisms, including multidrug-resistant organisms [MDROs] and respiratory viruses, such as SARS-CoV-2 (3, 4). Research has established that pathogens that are carried through airborne particles or indirect contact with contaminated fomites may take hours or days to die (5). As a result, the disinfection of the environment is crucial to interrupt the chain of transmission and keep the patients and healthcare workers safe (6). Today, the most commonly used disinfection methods are based on chemical disinfectants [chlorine compounds, alcohols, and quaternary ammonium compounds] or physical disinfection [ultraviolet-C, UV-C] (7). Although the effectiveness of these approaches has been proven in different studies, they have significant drawbacks (8). The constant application of the chemical agents may result in respiratory and cutaneous irritation of the healthcare workers or corrosion of the medical equipment (9). Moreover, the conventional UV-C tools are not applicable in the standard way because of the shadowing effect, and some places that are not directly facing the light are not properly disinfected (10). In addition, most of these interventions only offer a temporary reduction of microbial load, leaving surfaces vulnerable to being re-contaminated easily once the cleaning process has been completed (11). To counter these difficulties, new disinfection methods founded on Advanced Oxidation Processes [AOPs], especially photocatalysis, have been of great concern (12, 13). A photocatalytic reaction involves the use of a semiconductor [e.g., titanium dioxide, $TiO_2$, or zinc oxide, ZnO], which is activated by light [UV or visible spectrum] and produces Reactive Oxygen Species [ROS], e.g., hydroxyl radical, superoxide anion (14, 15). These free radicals have great oxidation capacity and can damage the walls of the cells, membranes, and genetic material of the microorganisms (16). There is an initial indication that photocatalytic coating or air filters can be used to effectively inactivate viral and bacterial pathogens. Compared to conventional solutions, photocatalytic systems, including self-cleaning surfaces, have the opportunity to be continuously and safely disinfected (17-19).

While previous reviews have covered general disinfection techniques, there is a lack of systematic evidence specifically focusing on the efficacy of photocatalytic processes within real or simulated hospital settings under visible light. Thus, the current study aims to systematically review existing evidence on the effectiveness of these processes in reducing microbial load in hospital air and surfaces, offering evidence-based recommendations for improving infection control procedures.

## Material and Methods

### *Study Design and Protocol*

The systematic review was performed following the Preferred Reporting Items of Systematic Reviews and Meta-Analysis [PRISMA2020] guidelines (20). The main aim was to determine the effectiveness of the photocatalytic process to disinfect hospital conditions.

### *Search Strategy and Data Sources*

The search was done through four large electronic databases: PubMed, Web of Science, Scopus, and Embase. The search strategy was designed based on three main concepts, namely Intervention [photocatalysts], Outcome [disinfection and microbial inactivation], and Setting [hospital and healthcare facilities].

To be sensitive, Medical Subject Headings [MeSH] terms, or Emtree terms, were used together with free-text keywords by use of Boolean operators [AND, OR]. Articles in the English language were searched, and no restrictions concerning the date of publication

**Table 1. Comprehensive search strategy across databases**

| Database | Search Strategy |
|---|---|
| **PubMed** | Search: [[["Hospitals"[Mesh]] OR [Hospital[Title/Abstract] OR Hospitals[Title/Abstract] OR "Hospital environment"[Title/Abstract] OR "Hospital setting"[Title/Abstract] OR "Healthcare environment"[Title/Abstract] OR "Healthcare setting"[Title/Abstract] OR "Medical environment"[Title/Abstract] OR "Medical setting"[Title/Abstract] OR "Clinical environment"[Title/Abstract] OR "Clinical setting"[Title/Abstract] OR "Healthcare facility"[Title/Abstract] OR "Healthcare facilities"[Title/Abstract] OR "Medical facility"[Title/Abstract] OR "Medical facilities"[Title/Abstract] OR "Hospital indoor environment"[Title/Abstract] OR "Hospital air"[Title/Abstract] OR "Hospital surfaces"[Title/Abstract] OR "Hospital wards"[Title/Abstract] OR "Hospital rooms"[Title/Abstract] OR "Inpatient care environment"[Title/Abstract]]] AND [["Disinfection"[Mesh]] OR [Disinfection[Title/Abstract] OR Decontamination[Title/Abstract] OR Sterilization[Title/Abstract] OR "Microbial inactivation"[Title/Abstract] OR "Pathogen inactivation"[Title/Abstract] OR "Virus inactivation"[Title/Abstract] OR "Bacterial inactivation"[Title/Abstract] OR "Fungal inactivation"[Title/Abstract] OR "Antimicrobial activity"[Title/Abstract] OR "Antimicrobial effect"[Title/Abstract] OR "Antimicrobial efficacy"[Title/Abstract] OR "Biological decontamination"[Title/Abstract] OR "Environmental disinfection"[Title/Abstract] OR "Surface disinfection"[Title/Abstract] OR "Air disinfection"[Title/Abstract] OR "Infection control"[Title/Abstract] OR "Healthcare disinfection"[Title/Abstract]]]] AND [["zinc germanate" [Supplementary Concept] OR "$Bi_7O_9I_3$" [Supplementary Concept] OR "Bi[2]MoO[6]" [Supplementary Concept]] OR [Photocatalyst[Title/Abstract] OR Photocatalytic[Title/Abstract] OR Photocatalysis[Title/Abstract] OR "Photocatalytic process"[Title/Abstract] OR "Photocatalytic reaction"[Title/Abstract] OR "Photocatalytic oxidation"[Title/Abstract] OR "Advanced oxidation process"[Title/Abstract] OR AOP[Title/Abstract] OR "Photocatalytic disinfection"[Title/Abstract] OR "Light activated catalyst"[Title/Abstract] OR "Light-induced catalysis"[Title/Abstract] OR "Semiconductor photocatalyst"[Title/Abstract] OR "UV activated photocatalyst"[Title/Abstract] OR "Visible light photocatalyst"[Title/Abstract] OR "TiO2 photocatalyst"[Title/Abstract] OR "Titanium dioxide photocatalyst"[Title/Abstract] OR "Nano photocatalyst"[Title/Abstract] OR "Photocatalytic air purification"[Title/Abstract] OR "Photocatalytic surface disinfection"[Title/Abstract]]] Filters: English |
| **Web of Science** | Photocatalyst OR Photocatalytic OR Photocatalysis OR "Photocatalytic process" OR "Photocatalytic reaction" OR "Photocatalytic oxidation" OR "Advanced oxidation process" OR AOP OR "Photocatalytic disinfection" OR "Light activated catalyst" OR "Light-induced catalysis" OR "Semiconductor photocatalyst" OR "UV activated photocatalyst" OR "Visible light photocatalyst" OR "TiO2 photocatalyst" OR "Titanium dioxide photocatalyst" OR "Nano photocatalyst" OR "Photocatalytic air purification" OR "Photocatalytic surface disinfection" [Topic] and Disinfection OR Decontamination OR Sterilization OR "Microbial inactivation" OR "Pathogen inactivation" OR "Virus inactivation" OR "Bacterial inactivation" OR "Fungal inactivation" OR "Antimicrobial activity" OR "Antimicrobial effect" OR "Antimicrobial efficacy" OR "Biological decontamination" OR "Environmental disinfection" OR "Surface disinfection" OR "Air disinfection" OR "Infection control" OR "Healthcare disinfection" [Topic] and Hospital OR Hospitals OR "Hospital environment" OR "Hospital setting" OR "Healthcare environment" OR "Healthcare setting" OR "Medical environment" OR "Medical setting" OR "Clinical environment" OR "Clinical setting" OR "Healthcare facility" OR "Healthcare facilities" OR "Medical facility" OR "Medical facilities" OR "Hospital indoor environment" OR "Hospital air" OR "Hospital surfaces" OR "Hospital wards" OR "Hospital rooms" OR "Inpatient care environment" [Topic] and Review Article [Exclude – Document Types] and Article [Document Types] and English [Languages] |
| **Scopus** | [ TITLE-ABS-KEY [ Photocatalyst OR Photocatalytic OR Photocatalysis OR "Photocatalytic process" OR "Photocatalytic reaction" OR "Photocatalytic oxidation" OR "Advanced oxidation process" OR AOP OR "Photocatalytic disinfection" OR "Light activated catalyst" OR "Light-induced catalysis" OR "Semiconductor photocatalyst" OR "UV activated photocatalyst" OR "Visible light photocatalyst" OR "TiO2 photocatalyst" OR "Titanium dioxide photocatalyst" OR "Nano photocatalyst" OR "Photocatalytic air purification" OR "Photocatalytic surface disinfection" ] AND TITLE-ABS-KEY [ Disinfection OR Decontamination OR Sterilization OR "Microbial inactivation" OR "Pathogen inactivation" OR "Virus inactivation" OR "Bacterial inactivation" OR "Fungal inactivation" OR "Antimicrobial activity" OR "Antimicrobial effect" OR "Antimicrobial efficacy" OR "Biological decontamination" OR "Environmental disinfection" OR "Surface |

| | |
|---|---|
| | disinfection" OR "Air disinfection" OR "Infection control" OR "Healthcare disinfection" ] AND TITLE-ABS-KEY [ Hospital OR Hospitals OR "Hospital environment" OR "Hospital setting" OR "Healthcare environment" OR "Healthcare setting" OR "Medical environment" OR "Medical setting" OR "Clinical environment" OR "Clinical setting" OR "Healthcare facility" OR "Healthcare facilities" OR "Medical facility" OR "Medical facilities" OR "Hospital indoor environment" OR "Hospital air" OR "Hospital surfaces" OR "Hospital wards" OR "Hospital rooms" OR "Inpatient care environment" ] ] AND [ LIMIT-TO [ DOCTYPE , "ar" ] ] AND [ LIMIT-TO [ LANGUAGE , "English" ] ] |
| **Embase** | [photocatalyst:ti,ab,kw OR photocatalytic:ti,ab,kw OR photocatalysis:ti,ab,kw OR 'photocatalytic process':ti,ab,kw OR 'photocatalytic reaction':ti,ab,kw OR 'photocatalytic oxidation':ti,ab,kw OR 'advanced oxidation process':ti,ab,kw OR aop:ti,ab,kw OR 'photocatalytic disinfection':ti,ab,kw OR 'light activated catalyst':ti,ab,kw OR 'light-induced catalysis':ti,ab,kw OR 'semiconductor photocatalyst':ti,ab,kw OR 'uv activated photocatalyst':ti,ab,kw OR 'visible light photocatalyst':ti,ab,kw OR 'tio2 photocatalyst':ti,ab,kw OR 'titanium dioxide photocatalyst':ti,ab,kw OR 'nano photocatalyst':ti,ab,kw OR 'photocatalytic air purification':ti,ab,kw OR 'photocatalytic surface disinfection':ti,ab,kw] AND [disinfection:ti,ab,kw OR decontamination:ti,ab,kw OR sterilization:ti,ab,kw OR 'microbial inactivation':ti,ab,kw OR 'pathogen inactivation':ti,ab,kw OR 'virus inactivation':ti,ab,kw OR 'bacterial inactivation':ti,ab,kw OR 'fungal inactivation':ti,ab,kw OR 'antimicrobial activity':ti,ab,kw OR 'antimicrobial effect':ti,ab,kw OR 'antimicrobial efficacy':ti,ab,kw OR 'biological decontamination':ti,ab,kw OR 'environmental disinfection':ti,ab,kw OR 'surface disinfection':ti,ab,kw OR 'air disinfection':ti,ab,kw OR 'infection control':ti,ab,kw OR 'healthcare disinfection':ti,ab,kw] AND [hospital:ti,ab,kw OR hospitals:ti,ab,kw OR 'hospital environment':ti,ab,kw OR 'hospital setting':ti,ab,kw OR 'healthcare environment':ti,ab,kw OR 'healthcare setting':ti,ab,kw OR 'medical environment':ti,ab,kw OR 'medical setting':ti,ab,kw OR 'clinical environment':ti,ab,kw OR 'clinical setting':ti,ab,kw OR 'healthcare facility':ti,ab,kw OR 'healthcare facilities':ti,ab,kw OR 'medical facility':ti,ab,kw OR 'medical facilities':ti,ab,kw OR 'hospital indoor environment':ti,ab,kw OR 'hospital air':ti,ab,kw OR 'hospital surfaces':ti,ab,kw OR 'hospital wards':ti,ab,kw OR 'hospital rooms':ti,ab,kw OR 'inpatient care environment':ti,ab,kw] |

were used. Table 1 shows the detailed search queries of each database.

### *Eligibility Criteria*

The selection of the studies was done according to the PICOS framework [Population, Intervention, Comparison, Outcome, and Study design]. Table 2 outlines the specific inclusion and exclusion criteria that will be used during the screening process.

### *Study Selection and Data Extraction*

Following the importing of search results into the citation management software and eliminating the duplicates, two reviewers were then independent of each other and used the titles and abstracts to filter through the results against the Table 2 eligibility criteria. Potentially relevant articles were reviewed in full-text. The disputes were solved by a consensus or consultation with a third reviewer. A standardized form was used to extract data: study characteristics, the type of catalyst, light source, target pathogen, and disinfection efficiency.

**Table 2. Inclusion and Exclusion Criteria**

| Criterion | Inclusion Criteria | Exclusion Criteria |
|---|---|---|
| **Study Type** | Original research articles providing empirical, experimental, or field data. | Review articles, systematic reviews, meta-analyses, letters, editorials, book chapters, and modeling studies without microbial testing. |
| **Intervention** | Photocatalytic processes [semiconductors like $TiO_2$, ZnO, etc., activated by UV or visible light] utilized for disinfection. | Disinfection methods without a photocatalytic component [e.g., UV irradiation alone, chlorination, ozonation, or adsorption without photo-reaction]. |
| **Setting** | Hospital environments [including air and surfaces] or laboratory studies explicitly targeting hospital pathogens. | General water treatment [rivers, dams], industrial wastewater [non-medical], or hospital wastewater treatment. |

| | | |
|---|---|---|
| **Outcome** | Reported efficacy of disinfection [reduction or elimination of bacteria, viruses, fungi, and spores]. | Studies investigating only physicochemical properties of the catalyst [e.g., dye degradation or pharmaceutical removal] without microbial testing. |
| **Language** | Full-text articles published in English. | Articles published in languages other than English, even if the abstract is in English. |

### *Quality Assessment*

The quality of the methodology of the included studies was independently evaluated with the help of the modified version of the Joanna Briggs Institute (JBI) Critical Appraisal Checklist of Quasi-Experimental Studies. The five criteria were chosen to assess the reliability of the findings: [1] the research objectives were clearly stated; [2] the study included proper experimental controls [e.g. dark controls or non-coated surfaces]; [3] the photocatalytic materials were characterized in detail; [4] the outcome measurements were reliable [e.g. standard colony-forming unit assays]; and [5] the research used proper statistical analysis. Each criterion was given a score of Yes [1 point], No [0 points], or Unclear [0 points]. The scores of 4-5 represented High Quality, and the scores of less than 3 represented Low Quality. Table 3 contains the detailed quality assessment results of every study. Due to the high heterogeneity of the included studies regarding light intensity, catalyst dosage, and experimental setups, a quantitative meta-analysis was not feasible. Therefore, a narrative synthesis of the findings was performed, categorizing studies by catalyst type, light source, and target pathogen, consistent with the PRISMA guidelines.

**Table 3. Quality assessment of the included studies based on the modified JBI Critical Appraisal Checklist.**

| Author Name | Year | Clear Objective | Experimental Controls | Material Characterization | Outcome Measurement | Statistical Analysis | Total Score | Quality Level | References |
|---|---|---|---|---|---|---|---|---|---|
| Nigel S. Leyland et al. | 2016 | Yes | Yes | Yes | Yes | Yes | 5/5 | High | (21) |
| Guohong Li et al. | 2011 | Yes | Yes | Yes | Yes | Yes | 5/5 | High | (22) |
| Jun Li et al. | 2019 | Yes | Yes | Yes | Yes | Yes | 5/5 | High | (23) |
| Yuanzhe Li et al. | 2022 | Yes | Yes | Yes | Yes | Yes | 5/5 | High | (24) |
| Rupy Kaur Matharu et al. | 2020 | Yes | Yes | Yes | Yes | Yes | 5/5 | High | (25) |
| Elham F. Mohamed et al. | 2020 | Yes | Yes | Yes | Yes | Unclear | 4/5 | High | (26) |
| Alaa Kamo et al. | 2024 | Yes | Yes | Yes | Yes | Yes | 5/5 | High | (27) |
| Ionela Cristina Nica et al. | 2016 | Yes | Yes | Yes | Yes | Yes | 5/5 | High | (28) |
| Gi Byoung Hwang et al. | 2025 | Yes | Yes | Yes | Yes | Yes | 5/5 | High | (29) |
| S. Petti et al. | 2016 | Yes | Yes | Yes | Yes | Yes | 5/5 | High | (30) |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Pham et al. | 2014 | Yes | Yes | Yes | Yes | Unclear | 4/5 | High | (31) |
| Reid et al. | 2018 | Yes | Yes | No | Yes | Yes | 4/5 | High | (32) |
| Rtimi et al. | 2016 | Yes | Yes | Yes | Yes | Yes | 5/5 | High | (33) |
| Shintani et al. | 2006 | Yes | Yes | Unclear | Yes | Yes | 4/5 | Medium | (34) |
| Sousa et al. | 2013 | Yes | Yes | Yes | Yes | Yes | 5/5 | High | (35) |
| Sunada et al. | 1998 | Yes | Yes | Yes | Yes | Unclear | 4/5 | Medium | (36) |
| Khaiboullina et al. | 2021 | Yes | Yes | Yes | Yes | Yes | 5/5 | High | (37) |
| Synnott et al. | 2013 | Yes | Yes | Yes | Yes | Yes | 5/5 | High | (38) |
| Thurston et al. | 2016 | Yes | Yes | Yes | Yes | Yes | 5/5 | High | (39) |
| Tseng et al. | 2016 | Yes | Yes | Yes | Yes | Yes | 5/5 | High | (40) |
| Yang et al. | 2018 | Yes | Yes | Yes | Yes | Yes | 5/5 | High | (41) |
| Yoshizawa et al. | 2020 | Yes | Yes | Unclear | Yes | Yes | 4/5 | High | (42) |
| Zuccheri et al. | 2013 | Yes | Yes | Yes | Yes | Unclear | 4/5 | High | (43) |
| Szczawiński, J et al. | 2011 | Yes | Yes | Yes | Yes | Yes | 5/5 | High | (44) |
| Alhussein, A et al. | 2017 | Yes | Yes | Yes | Yes | Yes | 5/5 | High | (45) |
| Balikhin, I. L et al. | 2016 | Yes | Yes | Yes | Yes | Yes | 5/5 | High | (46) |
| Bonetta, S et al. | 2013 | Yes | Yes | Unclear | Yes | Yes | 4/5 | High | (47) |
| Chotigawin, R et al. | 2010 | Yes | Yes | Yes | Yes | Yes | 5/5 | High | (48) |
| Chung, C. J et al. | 2008 | Yes | Yes | Yes | Yes | Yes | 5/5 | High | (49) |
| de Jong, B et al. | 2018 | Yes | Yes | No | Yes | Yes | 4/5 | High | (50) |
| Deshmukh, S. P et al. | 2021 | Yes | Yes | Yes | Yes | Yes | 5/5 | High | (51) |
| Desoubeaux, G et al. | 2014 | Yes | Yes | No | Yes | Yes | 4/5 | High | (52) |
| Dholiya, K et al. | 2021 | Yes | Yes | Yes | Yes | Unclear | 4/5 | High | (53) |
| Dunnill, C. W et al. | 2009 | Yes | Yes | Yes | Yes | Yes | 5/5 | High | (54) |
| Dunnill, C.W et al. | 2010 | Yes | Yes | Yes | Yes | Yes | 5/5 | High | (55) |
| Dunnill, C.W et al. | 2011 | Yes | Yes | Yes | Yes | Yes | 5/5 | High | (56) |
| Foster, H.A et al. | 2012 | Yes | Yes | Yes | Yes | Yes | 5/5 | High | (57) |
| Gharaibeh, A et al. | 2021 | Yes | Yes | Unclear | Yes | Yes | 4/5 | High | (58) |
| Ikram, M et al. | 2022 | Yes | Yes | Yes | Yes | Yes | 5/5 | High | (59) |
| Jafri, A. A et al. | 2011 | Yes | Yes | No | Yes | Yes | 4/5 | High | (60) |
| Khani, A et al. | 2017 | Yes | Yes | Yes | Yes | Yes | 5/5 | High | (61) |
| Khwanmuang, P et al. | 2017 | Yes | Yes | Yes | Yes | Yes | 5/5 | High | (62) |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Kim, J-H et al. | 2006 | Yes | Yes | Unclear | Yes | Yes | 4/5 | Medium | (63) |
| Kim, M.H et al. | 2018 | Yes | Yes | No | Yes | Yes | 4/5 | High | (64) |
| Koklic, T et al. | 2018 | Yes | Yes | Yes | Yes | Yes | 5/5 | High | (65) |
| Kowal, K et al. | 2014 | Yes | Yes | Yes | Yes | Yes | 5/5 | High | (66) |
| Krumdieck, S. P et al. | 2019 | Yes | Yes | Yes | Yes | Yes | 5/5 | High | (67) |

## Results

### 1. Overview of Included Studies

The systematic search and selection process is illustrated in the PRISMA flow diagram (Figure 1). Initially, a total of 327 records were identified through database searching. After removing duplicates and screening titles/abstracts based on the eligibility criteria, 76 full-text articles were assessed. Ultimately, 47 studies met all inclusion criteria and were selected for the final review. The detailed features of each of the included studies, such as the type of photocatalyst used, light source, target pathogens, and important findings, are summarized in Table 4. These articles, published between 1998 and 2025, assessed the effectiveness of photocatalytic processes for disinfecting a hospital environment and managing the pathogens present. The literature included in the study consists of both laboratory experiments under control and field interventions that are carried out in Intensive Care Unit [ICU] and operating rooms that span a range of different technologies, including thin-film nanocoatings and photocatalytic air purification systems.

### 2. Efficiency by Photocatalyst Type

*Titanium Dioxide [$TiO_2$]-based Catalysts:*

TiO2 was used as the main semiconductor in the majority of the studies. It was found that pure TiO2 nanoparticles [e.g., P25] are efficient at UV irradiation, which reduces the number of bacteria (47), but the structural changes were necessary to increase the applicability in practice. The addition of metals like copper [Cu] and non-metals like fluorine [F] led to the development of strong antimicrobial behavior at visual wavelengths and a 4.2 log reduction of Staphylococcus aureus (21). In addition, the antibacterial activity of silver-doped nanocomposites [Ag@ TiO2] was better than that of pure TiO2 because of the plasmonic property of silver (22, 51). Equally, Ti-Nb-Ta-Zr alloy films doped with copper were shown to have the ability to kill Escherichia coli in 75 minutes in hospital visible light (45). In addition to metallic doping, co-doping with nitrogen [N] and sulfur [S] also had a great effect on the responsiveness of the catalyst to the typical hospital white light (54, 55).

*Zinc Oxide [ZnO]-based Catalysts:*

Zinc oxide became a very good alternative. Research showed that ZnO nanoparticles irradiated with blue LED had the potential to effectively decrease the population of Acinetobacter baumannii and Klebsiella pneumoniae through membrane disruption (41). Also, Red Phosphorus/ZnO composites [RP/ZnO] demonstrated a higher removal rate of Gram-positive and Gram-negative bacteria at the solar and LED light sources (23). Additional ZnO improvements [e.g., doping with rare-earth elements, such as Lanthanum] led to a reduction rate in E. coli over 85 percent (24).

*Novel Composites and Materials:*

New materials like Tungsten oxide [$WO_3$] embedded into polymeric fibers proved to be effective in eliminating 96 percent of viruses and 83.7 percent of bacteria in ambient light (25). G-C3N4 [graphitic carbon nitride] nanosheets also demonstrated a 50 percent reduction in bacteria in the presence of low radiation doses under visible light (39). Moreover, the $SnO_2$ quantum dots doped with Vanadium exhibited large inhibition areas with hospital-associated pathogens (59).

## 3. Influence of Light Source

The arrangement of the light sources used in the photocatalytic activation is summarized in Figure 2. Although UV irradiation [UVA/UVC] was one of the standard reference techniques, a significant share of the reviewed studies [about 49 percent] were devoted to the activation of visible, solar, or indoor light. As can be seen in the figure, this trend will represent a technological change, towards more energy-saving and safer disinfection systems that can be used continuously in occupied hospital zones. The spectral range of the light source was the key factor in the disinfection kinetics. The highest rates of microbial inactivation were always observed when UV irradiation [in particular, UVC and UVA] was used, especially in such devices as AirLyse and TIOKRAFT (46, 52). Nonetheless, major improvements were observed in catalysts that are active in visible light. The use of peroxotitanium showed good antiviral activity [2.4 log reduction] even in regular fluorescent light (42). In addition, some copper-based composites [CuO/ $TiO_2$] retained antibacterial activity under dark conditions because of the constant release of copper ions (57).

## 4. Efficacy against target pathogens

Figure 3 shows the incidence of target microorganisms across the selected studies. As illustrated, Escherichia coli and Staphylococcus aureus were the most frequent model pathogens since they were employed in 28 and 20 studies, respectively. This focus is one of the signs of their status as common Gram-negative and Gram-positive bacteria indicators in infection control guidelines. Also, there is a significant number of studies that addressed multidrug-resistant organisms, including MRSA and A. baumannii, which indicates the clinical relevance of the investigated photocatalysts.

### *Multidrug-Resistant [MDR] Bacteria:*

Photocatalytic systems were discovered to be highly effective in the case of superbugs. Ag-$TiO_2$ nanocomposites placed on polyurethane surfaces were useful in the prevention of seven antibiotic-resistant hospital strains (62). Ag- $TiO_2$ particularly worked against Methicillin-resistant S. aureus [MRSA] in white light, as it decreased it by 99.99 percent (56). However, the resistance of photocatalytic oxidation to colistin-resistant A. baumannii strains was more than that of susceptible strains, which implied possible tolerance mechanisms (40).

### *Viruses:*

The virucidal property of photocatalysis was recently verified by investigations. The $TiO_2$ nanoparticles under UV-C were effective at inactivating the Human Coronavirus NL63, and the effect was increased in high humidity conditions [Khaiboullina et al., 2021]. It was also reported to have antiviral activity against Bacteriophage T4 and Dengue virus [DENV2] (25, 58).

### *Fungi and Spores:*

Greater amounts of energy were needed to decontaminate fungi. As an example, the conidia of Aspergillus fumigatus were reduced to 95% with the AirLyse device, taking 18 minutes of UVC/photocatalytic exposure (52).

### *Field and Real-World Applications*

The results of the studies that were carried out in clinical settings were mixed yet promising. Air purifiers with photocatalysts installed in operating theaters and ICUs minimized the airborne contamination by one order of magnitude (46, 60). $TiO_2$ coating of high-contact surfaces in ICUs had a significant impact in reducing the rate of MRSA infection acquisition (64). On the contrary, a conducted study on the wall coverings in an ICU also revealed that the application was safe, but the effect was largely influenced by the intensity of light, with less influence in darker locations (32, 50).

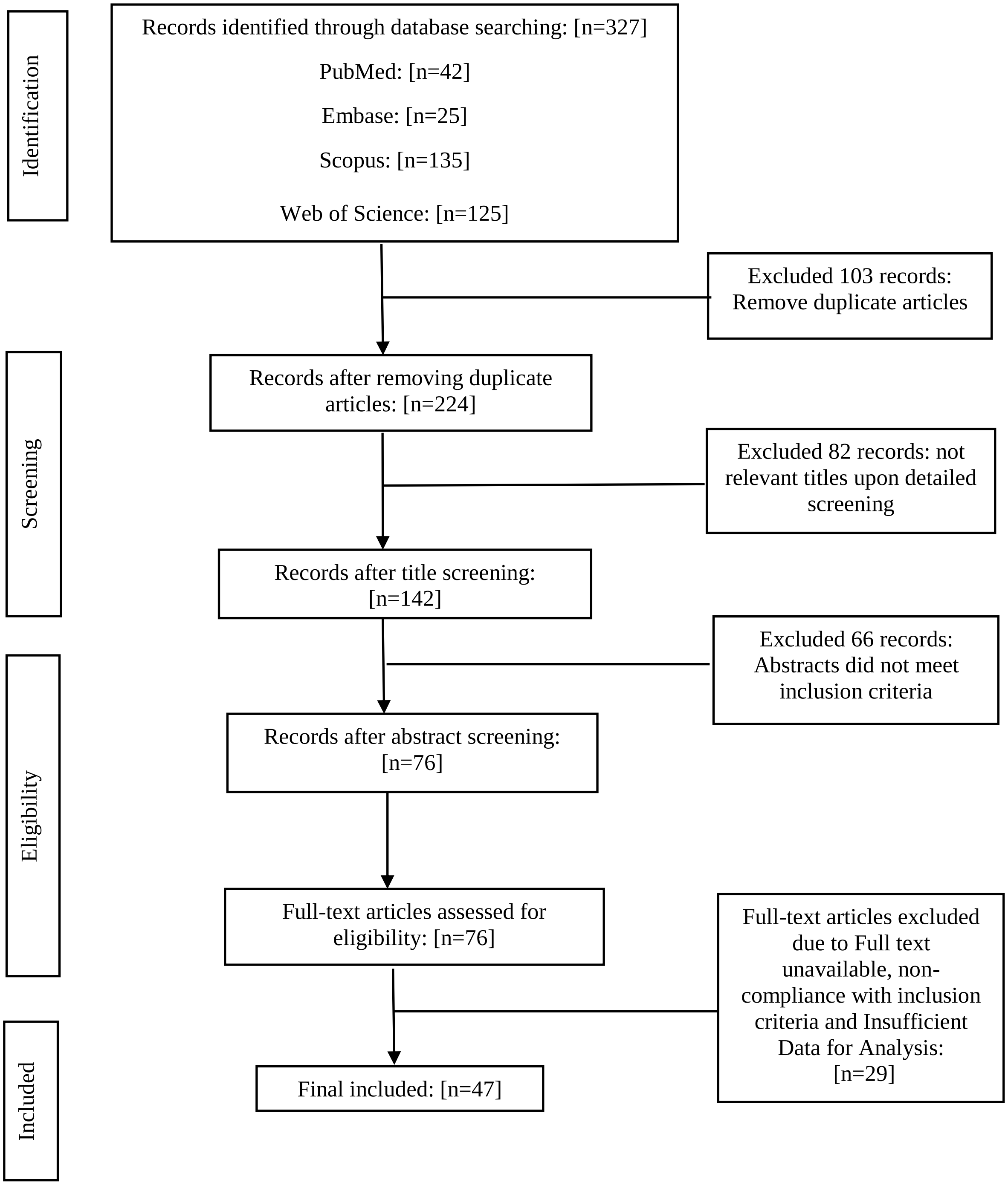

**Figure 1. PRISMA diagram for searching resources**

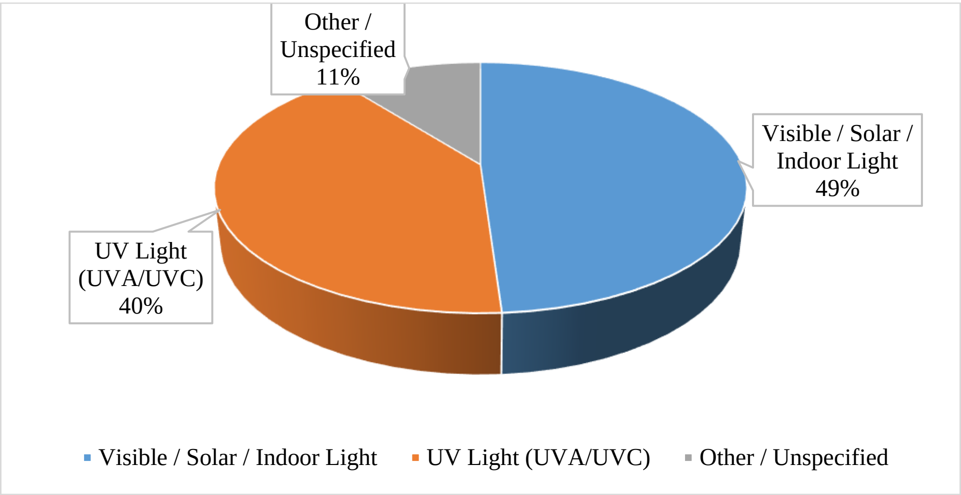

**Figure 2. Distribution of light sources for photocatalytic activation, showing a shift toward visible and indoor lighting (~49%) over traditional UV-based approaches.**

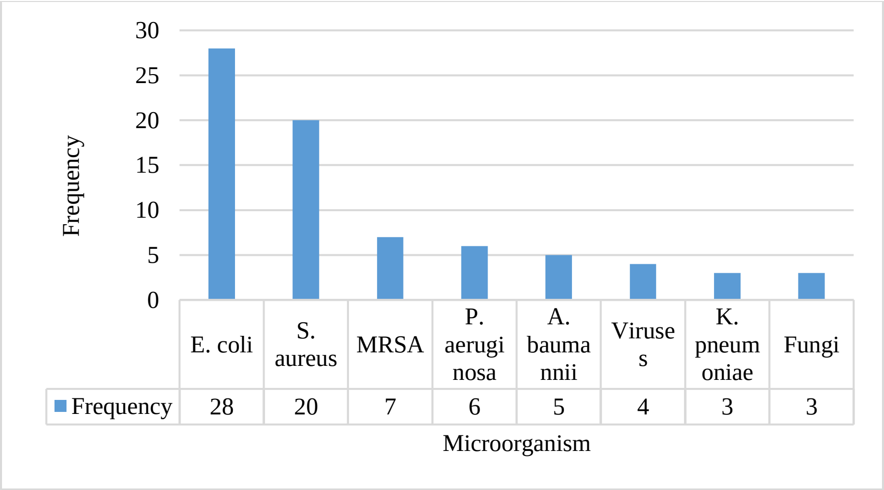

**Figure 3. Frequency of target microorganisms in reviewed studies, with E. coli and S. aureus being the most common, reflecting their role as indicators of hospital-acquired infections.**

## Discussion

### 1. Mechanisms of Action and Synergistic Effects

The results of this review indicate that the combination of semiconductor photocatalysts with noble [Ag, Au] or transition [Cu] metals improves the efficiency of disinfection in two main ways: [1] the electron trapping capabilities of photocatalysts delay the recombination of electron-holes and [2] the biological synergism. In Ag/$TiO_2$ composites, as an example, silver nanoparticles not only enhance light absorption but also penetrate bacterial cell walls and interfere with DNA, so they complement the

Reactive Oxygen Species [ROS] production by $TiO_2$ (22, 51). Moreover, copper-doped composites are characterized by a dark killing effect, in which the release of the Cu 2+ ion persists to prevent bacterial growth in the dark, which is an important attribute in the hospital setting with fluctuating light conditions (57).

## 2. Clinical Implications for Infection Control

Photocatalytic technology can be used as a powerful, specific supplement to conventional cleaning procedures. The information shows that self-disinfection of surfaces may decrease the bioburden between cleaning intervals, thus breaking the chain of infection transmission (32, 53). The resulting drop in the rate of hospital-acquired pneumonia and the acquisition of MRSA in the units using these coatings highlights the possibility of the technology to reduce morbidity and healthcare expenses (64). Also, photocatalytic air filtration has been demonstrated to be effective in removing bioaerosols, which inhibits the spreading of airborne pathogens, including tuberculosis and respiratory viruses, and is stable in performance over a period of time (60, 63).

## 3. Role of Environmental and Operational Parameters

One of the issues that has been found is that efficacy depends on environmental variables. Relative humidity [RH] fulfills two functions: when it is very low, it inhibits the formation of hydroxyl radicals, but when it is high [around 60 per cent], it maximizes bacterial and viral inactivation (31, 37). The strength of light and the spectrum are also important. The use of UV lamps is restricted by the considerations of safety, though they have high efficiency. Conversely, the creation of third-generation catalysts [e.g., N-doped or S-doped $TiO_2$], which can be activated by normal LED and fluorescent lamps, has enabled the implementation of this technology safely into existing hospital systems (42, 54). Along with such clinical advantages, the actual use of the photocatalytic technology requires a thorough balance between safety and cost. Although photocatalysis is a low-maintenance system, in contrast to the conventional chemical disinfectants, the installation costs of special lighting [e.g., UV-LEDs] and coating can be high at the beginning. Additionally, the possibility of toxicity of free nanoparticles, especially when they are separated on surfaces through mechanical abrasion, is a safety issue. Thus, there is a strong necessity to develop strong fixation methods and biocompatibility tests to safeguard patients in critical hospital settings. However, studies utilizing stable coating techniques, such as those embedding catalysts into polymeric fibers or utilizing HIPIMS deposition, have reported durable adhesion and minimal nanoparticle release, suggesting that safety risks can be mitigated through proper engineering.

## 4. Durability and Stability of Coatings

Advanced coating techniques are used in addressing concerns about nanoparticle detachment and environmental safety. The research that employed sonochemical coating or thermal spraying showed that the films are stable and have bactericidal activity despite repeated washing (65, 66). Moreover, the High-Power Impulse Magnetron Sputtering [HIPIMS] type of deposition generates dense-structured films with high adhesion, which leads to more rapid bacterial inactivation than conventional DC magnetron sputtering (33).

## 5. Limitations and Future Perspectives

There are some limitations of this systematic review. First, because of the high heterogeneity of study designs, which included the light intensity and dosage of catalysts to be tested and the types of microbial strains that were tested, the quantitative meta-analysis was not possible. Second, the study limited itself to peer-reviewed articles written in English, which might have caused a language bias and omitted possible relevant data in grey literature. Also, the majority of the studies included were in vitro, and although field studies were also incorporated, the conditions within hospitals vary, and this makes it difficult to make a direct comparison.

Although positive results are achieved, there are still some limitations. The inherent resistance to certain strains, e.g., colistin-resistant bacteria, implies that photocatalysis cannot be considered a one-size-fits-all solution but, instead, a multimodal approach (40). In addition, the efficacy in the real world might be lower than the laboratory measurements because organic matter and proteins in the hospital setting might foul the catalyst surface (34). Future studies must aim at developing international guidelines to test these surfaces in real situations and develop hybrid reactors to address the shadowing effects (44, 58).

## Conclusion

This systematic review establishes that photocatalytic oxidation reactions, especially those that involve metal-doped and semiconductor materials, are an effective and promising approach towards the decrease of the microbial load in hospitals. The review points to one of the key technological advances in visible-light-active catalysts, which facilitates the safe and sustained disinfection of air and high-touch surfaces in occupied clinical environments. Although these technologies have proven to be strongly effective in the treatment of multidrug-resistant organisms [including MRSA] and viruses, it has been shown that they should be used as a complementary measure that would enhance the standard cleaning procedures, but not as an alternative. Although the advantages are evident, there are problems associated with the real-life implementation concerning the environmental variables and coating durability. Therefore, the next generation of research should focus on long-term field research, standard testing protocols to test the real-world conditions of the hospital, and strict evaluation of the safety of nanoparticles to enable their extensive clinical application.

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The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Author Contributions

All authors contributed to the study conception and design. Investigation, data curation, and writing of the original draft were performed by Seyed Abolfazl Hosseini. Methodology, validation, and resources were handled by Bahador Pourdel. Formal analysis, visualization, software, and supervision were conducted by Erfan Rajabi. Conceptualization, supervision, writing (review & editing), and project administration were performed by Hossein Farash Khayalo. All authors read and approved the final manuscript.

## Data Availability

All data generated or analyzed during this study are included in this published article.

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**Table 4. Summary of the characteristics and main findings of the 47 included studies regarding photocatalytic disinfection in hospital environments.**

| **No.** | **Author Name** | **Year** | **Country** | **Study Environment** | **Photocatalyst Type** | **Light Source** | **Target Microbes** | **Main Result** | **References** |
|---|---|---|---|---|---|---|---|---|---|
| **1** | Nigel S. Leyland et al. | 2016 | Ireland | Float glass substrates | F, Cu-doped $TiO_2$ | Visible light [T5, 1000 lux] | S. aureus [MRSA] | Log10 reduction of 4.2 [visible] & 1.8 [dark] | (21) |
| **2** | Guohong Li et al. | 2011 | China | Silk fibroin fabric [SFF] | $TiO_2$ & $TiO_2$@Ag NPs | UV lamp [254 nm] | E. coli, S. aureus, P. aeruginosa | Excellent anti-bacterial zone & MO degradation | (22) |
| **3** | Jun Li et al. | 2019 | China | Thin film on Ti plates | Red Phosphorus [RP]/ZnO | Solar [Xenon] & LED | S. aureus, E. coli, MRSA | >99.9% reduction [Solar], effective under LED | (23) |
| **4** | Yuanzhe Li et al. | 2022 | Singapore | Polyurea coatings | RE-doped nano-ZnO [La, Ce...] | UV light | E. coli, P. aeruginosa | La-doped ZnO showed highest rate [>85%] | (24) |
| **5** | Rupy Kaur Matharu et al. | 2020 | UK | Polymeric fibres [PMMA] | Tungsten oxide [$WO_3$] | Visible light [Ambient] | E. coli, S. aureus, Virus [T4] | 2% $WO_3$ killed 83.7% bacteria & 96% virus | (25) |
| **6** | Elham F. Mohamed et al. | 2020 | Egypt | Air filter [Tissue sheet] | Ag/$TiO_2$ | UV lamp | Airborne microorganisms | 100% removal after 300 min | (26) |
| **7** | Alaa Kamo et al. | 2024 | Turkey | Aqueous suspension | Mg-doped ZTO [Mg1.5@ZTO] | Visible light | E. coli, S. aureus | 99.76% [E. coli] & 96.96% [S. aureus] kill in 1h | (27) |
| **8** | Ionela Cristina Nica et al. | 2016 | Romania | Polyester [PES] textiles | Fe-N co-doped $TiO_2$ | Visible, UV, Solar | P. aeruginosa, E. coli | Active against P. aeruginosa [15 min]; E. coli [24h] | (28) |
| **9** | Gi Byoung Hwang et al. | 2025 | UK | Polymer [Keyboard cover] | Crystal violet + 1.2 nm Au | Low-intensity Visible | S. aureus | 5.3 log reduction in 6h [hospital light] | (29) |
| **10** | S. Petti et al. | 2016 | Italy | PVC surfaces | Nano-$TiO_2$ in PVC | Full-spectrum lamp | MRSA | 93% reduction [1.16 log] in 3h | (30) |
| **11** | Pham et al. | 2014 | South Korea | Indoor air [Lab model] | Ag-$TiO_2$/GF | Visible light | Staphylococcus | %75efficiency with 7.5% Ag; best at 60% humidity | (31) |
| **12** | Reid et al. | 2018 | UK | Hospital ward | $TiO_2$ + Ag zeolite [MVX] | Normal illumination | Bioburden ,S. aureus | Reduced bioburden and hygiene failures in hospital | (32) |
| **13** | Rtimi et al. | 2016 | Switzerland | Lab scale [Films] | $TiO_2$ [HIPIMS sputtered] | Solar simulated 400<]nm] | E. coli | HIPIMS films were 3x faster in inactivation than DCMS | (33) |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **14** | Shintani et al. | 2006 | Japan | Healthcare facility | $TiO_2$ membrane | UV lamp [253.7 nm] | Airborne/Surface microbes | Effective on airborne microbes, not surface ones | (34) |
| **15** | Sousa et al. | 2013 | Portugal | Lab scale [Paint] | $TiO_2$ [P25] paint | UV-A [365 nm] | E. coli [Resistant strains] | Effective against multi-drug resistant strains | (35) |
| **16** | Sunada et al. | 1998 | Japan | Lab scale | $TiO_2$ thin film | Black-light [UV-A] | E. coli ,Endotoxin | Bactericidal and degraded endotoxins [detoxification] | (36) |
| **17** | Khaiboullina et al. | 2021 | USA | Lab scale | $TiO_2$ Nanoparticles | UV-C [254 nm] | Human Coronavirus NL63 | Enhanced virus inactivation; effective in humidity | (37) |
| **18** | Synnott et al. | 2013 | Ireland | Lab scale | ZnS nanomaterials | Indoor light [60W bulb] | S. aureus ,E. coli | %88reduction in 5h under indoor light | (38) |
| **19** | Thurston et al. | 2016 | USA | Lab scale | $g\text{-}C_3N_4$ [Graphitic carbon nitride] | Visible radiation | E. coli ,S. aureus | %50 reduction with 0.31J dose; non-toxic in dark | (39) |
| **20** | Tseng et al. | 2016 | Taiwan | Lab scale | $TiO_2$ [P-25] | UV-A [365 nm] | A. baumannii | Colistin-resistant strains were more resistant to PCO | (40) |
| **21** | Yang et al. | 2018 | Taiwan | Lab scale [Glass tubes] | ZnO nanoparticles [ZnO-NPs] | Blue light LED [462 nm] | A. baumannii, K. pneumoniae | Significant reduction of bacteria via membrane disruption | (41) |
| **22** | Yoshizawa et al. | 2020 | Japan | Lab scale [ISO 18071] | Peroxotitanium/Anatase $TiO_2$ | Visible light [Fluorescent] | Bovine Coronavirus [BCoV] | Effective antiviral activity [>2.4 log reduction] under indoor light | (42) |
| **23** | Zuccheri et al. | 2013 | Italy | Lab scale [Painted wood] | $TiO_2$ [Aeroxide P25] paint | Fluorescent light | S. aureus, P. aeruginosa, E. coli | Significant bacterial reduction with 2% $TiO_2$ under fluorescent light | (43) |
| **24** | Szczawiński, J et al. | 2011 | Poland | Laboratory [In vitro on ceramic tiles] | $TiO_2$ [coated by RF diode sputtering, APCVD, or SPD] | UV-C [253.7 nm] | Staphylococcus aureus | $TiO_2$ coated tiles showed significantly higher bactericidal effect than uncoated tiles; APCVD method was most effective. | (44) |
| **25** | Alhussein, A et al. | 2017 | France | Laboratory [Glass substrates] | Ti-Nb-Ta-Zr [TNTZ] "Gum Metal" films doped with Copper [Cu] | Indoor Visible Light [Actinic hospital light] | Escherichia coli [K12] | 8.3 at. % Cu-doped films achieved fastest bacterial inactivation [75 min] under visible light. | (45) |

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| **26** | Balikhin, I. L et al. | 2016 | Russia | Field Study [Hospital: ICU, Surgery, Mycology Lab] | Nanocrystalline $TiO_2$ on porous glass [TIOKRAFT device] | UV-A [315–400 nm] | E. coli, Staphylococcus spp., Fungi [Molds/Yeasts] | Reduced airborne microbiological contamination in hospital facilities by approx. 1 order of magnitude [10-fold]. | (46) |
| **27** | Bonetta, S et al. | 2013 | Italy | Laboratory [Petri dishes & ceramic tiles] | $TiO_2$ [P25 powder] | UV-A [350–380 nm] | E. coli, S. aureus, P. putida, L. innocua | Significant photoactivated bactericidal effect observed for all strains; S. aureus reduced significantly after 60 min. | (47) |
| **28** | Chotigawin, R et al. | 2010 | Thailand | Laboratory [HVAC / HEPA filter simulation] | $TiO_2$ [Degussa P-25] coated on HEPA filter | UV-A | S. epidermidis, B. subtilis, A. niger, P. citrinum | 60–80% inactivation of retained microorganisms; S. epidermidis reached 100% inactivation. | (48) |
| **29** | Chung, C. J et al. | 2008 | Taiwan | Laboratory [Medical grade stainless steel AISI 304] | $TiO_2$ [Anatase] prepared by Arc Ion Plating [AIP] | UV [Photocatalysis implied by JIS Z2801] | Staphylococcus aureus, Escherichia coli | Antimicrobial activity [R] was 3.0 for S. aureus and 2.5 for E. coli, exceeding JIS standards. | (49) |
| **30** | de Jong, B et al. | 2018 | Netherlands | Field Study [Hospital Intensive Care Unit - ICU] | $TiO_2$ coating on environmental surfaces [walls/objects] | Ambient Hospital Light | S. aureus, Enterobacteriaceae, Total CFU | Mean colony count ratio [post/pre] was 0.86; S. aureus specific ratio was 0.71 [trend towards reduction]. | (50) |
| **31** | Deshmukh, S. P et al. | 2021 | India | Laboratory [Antibacterial Paint] | Ag@ $TiO_2$ Nanocomposites [3 wt% Ag] | Visible Light | Escherichia coli, Staphylococcus aureus | 3 wt % Ag@ $TiO_2$ paint showed highest antibacterial activity; more effective against E. coli than S. aureus. | (51) |
| **32** | Desoubeaux, G et al. | 2014 | France | Laboratory / Experimental Room [Hospital mimic] | $TiO_2$ photocatalysis + UVC device [AirLyse] | UVC + Photocatalysis | Aspergillus fumigatus [Conidia] | 95% reduction of airborne conidia in 18 min; below detection threshold in 29 min. | (52) |
| **33** | Dholiya, K et al. | 2021 | Sweden | Laboratory [In vitro] | Modified Nano $TiO_2$ coating [Ecobactix] | Light [Photocatalysis activated] | E. coli, S. aureus, P. aeruginosa | Coating inhibited growth and colonization of all | (53) |

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| | | | | | | | | three bacterial types on solid surfaces. | |
| **34** | Dunnill, C. W et al. | 2009 | UK | Laboratory [Glass thin films] | Sulfur-doped $TiO_2$ [S-$TiO_2$] | White Light [Hospital lighting] | Escherichia coli | S-doped films were effective at killing E. coli under standard hospital white light conditions. | (54) |
| **35** | Dunnill, C.W et al. | 2010 | UK | Laboratory [Glass thin films] | N-doped $TiO_2$ and S-doped $TiO_2$ | White Light [Hospital lighting] | Escherichia coli | Both N-doped and S-doped films killed bacteria under white light; N-doped performed slightly better. | (55) |
| **36** | Dunnill, C.W et al. | 2011 | UK | Laboratory [Glass thin films] | Nanoparticulate Silver [Ag] on $TiO_2$ | White Light [Hospital lighting] & UVA | MRSA, Escherichia coli | 99.99% reduction in MRSA and 99.996% in E. coli under hospital lighting [Synergistic effect]. | (56) |
| **37** | Foster, H.A et al. | 2012 | UK | Laboratory [Glass slides] | Dual layer CuO / $TiO_2$ | UVA and Fluorescent Light | MRSA, VRE, E. coli, A. baumannii, K. pneumoniae | >5 log kill under UVA [4-6h]; Enhanced activity observed in dark and under fluorescent light due to Cu. | (57) |
| **38** | Gharaibeh, A et al. | 2021 | USA | Laboratory & Field [Test hospital room] | Photocatalytic Reactor [$TiO_2$ based] | UV [contained in reactor] | S. aureus, C. difficile, Dengue virus [DENV2] | Significant reduction in surface contamination of S. aureus and C. difficile in test room; reduced viral infectivity. | (58) |
| **39** | Ikram, M et al. | 2022 | Pakistan | Laboratory [Nanomaterial synthesis] | $V_2O_5$/Chitosan co-doped $SnO_2$Quantum Dots | Visible Light | S. aureus, E. coli | Significant bactericidal inhibition zones observed; CS/$SnO_2$ showed high activity for hospital dye/bacteria degradation. | (59) |
| **40** | Jafri, A. A et al. | 2011 | UK | Field Study [Randomised Controlled Trial in Orthopaedic Ward] | Portable UV/ $TiO_2$ air purifier [ActivTek 300] | UV [internal to device] | Airborne bacteria [Total Colony Count] | 55% mean reduction in airborne bacterial colony counts when device was on vs Off [$p<0.01$]. | (60) |

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| **41** | Khani, A et al. | 2017 | Iran | Laboratory [Cotton fabric] | CuO/ $TiO_2$ / PEG Nanocomposite | Dark Condition [testing chemical/metal ion effect] | E. coli, S. aureus | High antibacterial efficiency in dark [due to Cu ions]; CuO / $TiO_2$ [1:1] composite was most effective. | (61) |
| **42** | Khwanmuang, P et al. | 2017 | Thailand | Laboratory [Polyurethane coating] | Ag-$TiO_2$ /Polyurethane [PU] Nanocomposite | Visible Light | E. coli, S. aureus, K. pneumoniae, P. aeruginosa, A. baumannii | Superior antimicrobial activity against all 7 antibiotic-resistant hospital strains tested. | (62) |
| **43** | Kim, J-H et al. | 2006 | Korea | Field Study [Hospital installation] | Thin-film $TiO_2$ on ceramic filters | UV [in device] | Floating germs [Bioaerosols] | Powerful sterilization of floating germs in hospital air; maintained performance over 7 months. | (63) |
| **44** | Kim, M.H et al. | 2018 | Korea | Field Study [Prospective Cohort in Medical ICU] | $TiO_2$ -based photocatalyst on high-touch surfaces/walls | Indoor Ambient Light | MRSA [acquisition rate], VRE, A. baumannii | Significant decrease in MRSA acquisition rate [Hazard Ratio 0.37] after coating; reduced hospital-acquired pneumonia. | (64) |
| **45** | Koklic, T et al. | 2018 | Slovenia | Laboratory [Surfaces] | Copper-doped $TiO_2$ nanotubes | Low intensity UVA [30 $W/cm^2$] | MRSA, E. coli [ESBL] | Inactivation of $10^3$ microbes/$cm^2$ in 24h; stable deposition resistant to washing. | (65) |
| **46** | Kowal, K et al. | 2014 | Poland / Ireland | Laboratory [Textiles] | Nano-$TiO_2$ [P25] sonochemically coated on PET | UV [Standard for P25] | E. coli, MRSA, Candida albicans | Confirmed biocidal activity against hospital pathogens; coating durable after washing at $40^{C}$. | (66) |
| **47** | Krumdieck, S. P et al. | 2019 | New Zealand | Laboratory [Stainless steel coating] | Nanostructured $TiO_2$ [Anatase-Rutile-Carbon] | Visible Light | Escherichia coli | >3 log reduction [99.9%] in viable bacteria after 4 hours of visible light exposure. | (67) |