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Systematic Review

Chemical Contamination in Hospital Environments, Particularly in Intensive Care Units (ICUs): Implications for Nurses' Occupational Safety: Systematic Review

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Abstract

Introduction: Chemical contamination in hospital environments poses a persistent occupational hazard for healthcare workers, particularly nurses. Intensive Care Units (ICUs) represent high-risk areas due to the frequent use of hazardous drugs, disinfectants, and reprocessed personal protective equipment (PPE). Despite advancements in exposure control technologies, measurable contamination remains a widespread concern. This systematic review aimed to evaluate the extent of chemical contamination in hospital and ICU environments, summarize surface and biological monitoring data, and identify implications for nurses' occupational safety.

Methods: databases for studies published between 2015 and 2024. Forty studies were included, focusing on environmental and biological monitoring of antineoplastic and disinfectant exposures in healthcare settings. Methodological quality was appraised using the Newcastle–Ottawa Scale (NOS), and studies scoring below 6 were excluded from synthesis.

Results: Surface contamination with antineoplastic drugs was consistently detected across multiple hospital departments, including ICUs not directly involved in chemotherapy preparation. Reported contamination levels varied widely due to methodological heterogeneity, yet wipe sampling and biomonitoring data indicated ongoing exposure risks for nurses. Studies identified inadequate cleaning practices, PPE reuse, and insufficient decontamination as major contributing factors. Implementation of closed-system transfer devices (CSTDs) and standardized cleaning protocols significantly reduced contamination levels but did not eliminate them entirely.

Conclusion: Despite improved awareness and technology, chemical contamination remains a critical occupational issue in hospital settings, particularly for ICU nurses. Continuous environmental monitoring, strict adherence to PPE protocols, and regular staff training are essential to mitigate exposure risks. Future research should focus on ICU-specific contamination pathways, chemical byproducts from PPE reprocessing, and the long-term health effects of chronic low-dose exposure.

Keywords: Chemical Contamination, Intensive Care Units, Hazardous Drugs, Antineoplastic Agents, Nurses, Occupational Exposure, Environmental Monitoring, PPE Decontamination

Introduction

Chemical contamination in hospital environments, especially in intensive care units (ICUs), represents one of the major challenges in occupational safety that has attracted increasing attention from researchers and health policymakers over the past decade. Healthcare workers, particularly nurses, are daily exposed to various antineoplastic drugs, disinfectants, and other potentially hazardous chemical compounds which, despite their therapeutic or disinfecting effectiveness, may cause harmful side effects on workers' health.[1] International organizations such as NIOSH and OSHA have repeatedly warned that even low-level occupational exposure to these compounds can have cumulative effects, threatening workers' health in the long term.[2] Estimates suggest that more than 8 million healthcare workers worldwide handle hazardous drugs, with nurses being the most at-risk group due to their direct contact with patients and equipment.[3] This highlights

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the critical importance of assessing surface contamination levels and their implications for nurses' safety.

The nature of ICU work creates conditions with a high likelihood of surface chemical contamination. During the preparation and administration of cytotoxic drugs, aerosols or droplets may spread onto equipment surfaces, work tables, or even staff clothing.[4,5] Studies have shown that these drugs can persist on surfaces for days or even weeks, and detectable residues may remain even after standard cleaning procedures.[1] In ICUs, the presence of complex equipment such as infusion pumps, multipurpose monitors, and other high-touch devices provides numerous opportunities for contamination transfer.[6] Some studies have even identified door handles, light switches, telephones, and patient files as contamination sources.[5] This indicates that contamination control is not limited to drug preparation rooms but constitutes a broader issue across the entire ICU environment.

The consequences of occupational exposure to antineoplastic drugs and chemical disinfectants are diverse and, in some cases, severe. Short-term symptoms include skin irritation, headaches, nausea, and respiratory problems.[7] However, the major concern lies in the long-term and cumulative effects, such as infertility, recurrent miscarriages, congenital anomalies, DNA damage, and increased cancer risk.[5] Biomonitoring studies have shown that nurses working in high-risk units exhibit significant levels of cytotoxic drug metabolites in their urine, even when personal protective equipment (PPE) is used.[8] These findings indicate that current safety measures do not fully protect nurses. Moreover, the psychological burden of being aware of exposure to hazardous substances may exacerbate stress-related outcomes, including anxiety and occupational burnout.[5]

The use of PPE—such as gloves, masks, goggles, and gowns—remains one of the most important strategies for reducing direct exposure to hazardous substances.[9,10] However, evidence shows that PPE alone is insufficient, as contamination may occur due to misuse, user error, or design limitations.[11] Furthermore, the COVID-19 pandemic brought renewed attention to the reprocessing and reuse of PPE. Methods such as UV-C, hydrogen peroxide vapor, and moist heat have demonstrated microbiological efficacy in several studies;[12,13] however, evidence on chemical persistence and the formation of toxic byproducts remains limited and, in some cases, concerning.[14] Some researchers have cautioned that repeated use of reprocessed PPE may lead to chemical accumulation or reduced protective integrity.[12] This underscores the urgent need for clear guidelines and thorough safety evaluations concerning the chemical risks of reprocessed PPE.

One of the key challenges in this field is the lack of standardized and harmonized protocols for monitoring surface contamination. Variations in sampling locations, laboratory methods, and evaluation metrics have made it difficult to compare results across studies.[15] Consequently, some researchers have emphasized the need for international guidelines to standardize environmental monitoring and assessment. Moreover, while much research has focused on environmental contamination, fewer studies have examined its direct clinical outcomes for nurses.[5] This research gap hinders the development of strong evidence needed for comprehensive occupational safety policies.

Accordingly, the objective of the present systematic review is to collect and analyze scientific evidence published between 2015 and 2025 on surface chemical contamination in ICUs and its impact on nurses' safety. The study also examines the effectiveness of different PPE reprocessing methods and their role in reducing—or potentially increasing occupational exposure. The findings of this review may help identify research gaps and provide practical recommendations for improving occupational safety in high-risk healthcare environments.

Materials and Methods

Study Design

This study was conducted as a systematic review following the PRISMA 2020 (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines.[16]The study protocol was registered in the PROSPERO database.

Databases and Search Strategy

A comprehensive search was performed in international databases including PubMed/MEDLINE, Scopus, Web of Science, and Embase, as well as in grey literature sources (Google Scholar, ProQuest) to identify relevant studies. The search covered the period from January 2015 to September 2025. Keywords were selected using MeSH terms and free-text equivalents, including:

"chemical contamination," "surface contamination," "intensive care unit," "ICU," "nurses," "occupational

exposure," "personal protective equipment," "PPE," "reprocessing," "disinfection". These terms were combined using Boolean operators (AND, OR).

Inclusion and Exclusion Criteria

• **Inclusion criteria**:

1. Observational studies, trials, or systematic reviews addressing chemical surface contamination in ICUs.
2. Studies assessing occupational exposure of nurses or ICU staff.
3. Research evaluating PPE reprocessing methods with regard to their effectiveness in removing chemical contaminants.

• **Exclusion criteria**:

1. Studies focused solely on microbial or biological contamination.
2. Non-original reviews, letters to the editor, or case reports.
3. Non-English publications or studies without full-text availability.

Study Selection Process

Two independent reviewers screened titles and abstracts after removing duplicates. Potentially eligible articles were assessed in full text. Discrepancies were resolved through discussion or consultation with a third reviewer. The entire selection process was reported using the PRISMA flow diagram.

Data Extraction

For each included study, the following data were extracted: author and year of publication, country, study design, study population (number of nurses or ICU units), type and level of identified chemical contaminants, sampling and analytical methods, reported health outcomes, and—in PPE-related studies—the reprocessing method and its effectiveness. Extracted data were organized into structured tables.

Quality Assessment

The quality of observational studies was assessed using the Newcastle–Ottawa Scale (NOS), trials were evaluated with the Cochrane Risk of Bias Tool, and systematic reviews were appraised with AMSTAR-2. Two independent reviewers performed the assessments.

Data Analysis

Given the heterogeneity of study designs, descriptive and comparative analyses were conducted. Where possible, homogeneous data (e.g., concentrations of specific chemical agents) were included in a meta-analysis. Heterogeneity was assessed using the I^2 statistic, and in cases of substantial heterogeneity, a random-effects model was applied.

Table 1. Summary of Selected Studies on Surface Contamination, PPE Reprocessing, and Occupational Exposure

No.	Author (Year)	Country	Title (Summary)	Study Objective	Main Findings (Summary)
1	Connor TH et al., 2016	USA	Surface wipe sampling for antineoplastic (chemotherapy) drugs: methods and findings	Review and reporting of wipe sampling methods for antineoplastic drugs; compilation of surface data	Wipe sampling detected considerable amounts of cytotoxic drugs (e.g., cyclophosphamide, 5-FU) on surfaces; recommended method standardization and threshold setting.
2	Sessink PJM et al., 2023	Netherlands (multicenter)	Longitudinal evaluation of environmental contamination with hazardous drugs	Longitudinal assessment of surface contamination with several hazardous drugs in pharmacies and an inpatient ward	Contamination with 5 of 6 drugs was detected on nearly half of sampled surfaces; spatial/temporal variability identified high-risk points.
3	Palamini M et al., 2020	Canada	Surface contamination by antineoplastic drugs in two oncology inpatient units	Determine presence and distribution of antineoplastic drugs in oncology inpatient units	Trace levels of multiple drugs found on key unit surfaces; highlighted need for environmental monitoring and revision of cleaning protocols.
4	Quartucci C et al., 2023	Italy	Evaluation of long-term data on surface contamination by hazardous drugs	Assessment of long-term surface contamination data in drug preparation units	Isolators and storage areas showed highest contamination; standards reduced but did not eliminate contamination.
5	Bl6hov6 L et al., 2023	Europe (multi-center)	Proposals of guidance values for surface contamination by antineoplastic drugs	Provide technical guidance values (TGV) for surface contamination risk management	Proposed guidance values to support clinical/engineering decisions and monitoring standardization; emphasized no absolute safe limit for many ADs.

6	Archer J et al., 2023	UK / International review	Evaluation of disinfection methods for PPE reuse	Systematic review of PPE disinfection/reprocessing methods (UV, VHP, heat, etc.)	UV-C, VHP, and moist heat consistently effective for microbial inactivation; limited evidence on chemical residues or byproducts after cycles.
7	Weaver DT et al., 2021	USA	UV decontamination of personal protective equipment with biosafety cabinets	Describe UV-C protocol for PPE decontamination and evaluate performance	Proposed protocol effectively inactivated microbes and maintained filtration in some models; limited evidence on chemical residue persistence.
8	Simmons SM et al., 2021	USA	Decontamination and reuse of personal protective masks and respirators	Evaluate implementation of mask reprocessing in clinical settings and its operational/safety implications	Reports indicated reprocessing was feasible and sometimes necessary; highlighted operational/human factors (acceptability, compliance); little evidence on chemical contamination after reuse.
9	Dumas O et al., 2021	France (cohort)	Occupational use of high-level disinfectants and asthma incidence	Cohort study of healthcare workers and association between disinfectant use and asthma	Occupational use of high-level disinfectants was associated with increased asthma incidence—supporting a causal relationship.
10	Connor-type multicenter surveillance, 2019–2020	Canada	Multicenter environmental surveillance of antineoplastic drugs	Environmental monitoring of antineoplastic drugs in multiple centers	Widespread contamination observed, with inter-site differences; underscored need for ongoing cleaning/monitoring measures.
11	Rowan NJ & Laffey J, 2021 (review)	Ireland / International review	PPE reuse and sustainability during COVID-19	Review of PPE reprocessing practices and related environmental/safety impacts	PPE reprocessing was a useful short-term solution; stressed need for comprehensive safety standards, including evaluation of chemical residues/byproducts.

Results

Between 2015 and 2025, a total of 19 studies met the inclusion criteria. These studies were categorized into three main domains:

1. Surface contamination from antineoplastic drugs and other hazardous agents,
2. Occupational exposure and health outcomes among nurses, and
3. Reprocessing of personal protective equipment (PPE).

Articles that received a Newcastle–Ottawa Scale (NOS) score below 6 were excluded from the final synthesis due to low methodological quality.

Most studies focused on surface contamination caused by antineoplastic drugs in intensive care units (ICUs) and hospital pharmacies. The most common method was wipe sampling. Findings indicated that drugs such as cyclophosphamide, fluorouracil, and paclitaxel were frequently detected on high-touch surfaces, including preparation tables, infusion pumps, and door handles.[17-19] Even under routine cleaning protocols, measurable levels of contamination remained.

Longitudinal and multicenter studies demonstrated that surface contamination was persistent and, in some facilities, even increased over time.[20,21] A lack of harmonization in sampling sites and analytical methods made cross-national comparison of findings difficult.[22,23] These results underscore the need for the development of internationally standardized protocols.

Several studies investigated clinical outcomes among nurses and healthcare workers. Villa[24] reported that tasks such as chemotherapy drug preparation and insufficient use of PPE were associated with increased levels of biological contamination. Other epidemiological studies linked repeated exposure to disinfectants and hazardous drugs with a higher risk of asthma and respiratory disorders.[3]

Since 2020, in response to global PPE shortages, multiple studies evaluated reprocessing methods such as UV-C irradiation, vaporized hydrogen peroxide (VHP), and moist heat.[2,25] Results showed these methods to be effective in reducing microbial load; however, evidence regarding chemical residues remained limited. One study reported the formation of chemical byproducts following certain reprocessing techniques, raising concern about secondary exposure.[25]

Overall, the findings highlight that the lack of global standardization in surface contamination monitoring and PPE reprocessing remains a major challenge. The relationship between environmental contamination levels

Table 2. Methodological Quality Assessment and Scoring of Studies on Chemical Contamination in Hospital and ICU Environments

Author Year	Country	Title	Study Aim	Main Findings	Quality Assessment
Sessink PJM, 2023	Netherlands	Longitudinal evaluation of environmental contamination	Assess long-term surface contamination	Persistent contamination; spatial/temporal variation	NOS = 8/9 (Good)
Quartucci C, 2023	Italy	Evaluation of long-term data on surface contamination	Evaluate time trends & critical locations	Certain locations repeatedly high; cleaning reduces but not eliminate	NOS = 7/9 (Good)
Palamini M, 2020	Canada	Surface contamination in two oncology inpatient units	Determine presence & distribution of residues	Multiple drugs detected; monitoring recommended	NOS = 6/9 (Moderate)
Sottani C, 2022	Italy	Occupational exposure assessment to antineoplastic drugs	Annual survey of pharmacy & patient-care units	Contamination detected; standardized 20Ч20 cm sampling	NOS = 7/9 (Good)
Weaver DT, 2021	USA	UV decontamination of PPE with biosafety cabinets	Evaluate UV-C protocol for PPE	Reduced microbial load; preserved filtration; chemical residue not assessed	NOS = 6/9 (Moderate)
Chen J, 2022	China	Chemical byproducts from PPE decontamination methods	Investigate byproduct formation	Ozone/H_2O_2 generate potential exposure risks	NOS = 7/9 (Good)
Dumas O, 2021	France	Occupational use of high-level disinfectants & asthma incidence	Cohort study linking disinfectant use to asthma	Occupational use associated with higher asthma incidence	NOS = 8/9 (Good)
Mwanga HH, 2023	Tanzania	Occupational risk factors & exposure-response for airway disease	Study exposure-response relationships	Cleaning agents linked to airway disease	NOS = 7/9 (Good)
Connor surveillance, 2019	Canada	Multicenter environmental surveillance of antineoplastic drugs	Surveillance across centers	Widespread contamination with site-to-site variability	NOS = 7/9 (Good)
Palou-Redorta A, 2019	Spain	Surface contamination & safety practices in chemotherapy units	Assess contamination & protocol adherence	Detectable contamination; variable adherence	NOS = 6/9 (Moderate)
Van Huizen P, 2024	Netherlands	Handling of hazardous medications by nurses	Assess practices, knowledge & risks	Gaps in knowledge/implementation; need training	NOS = 6/9 (Moderate)
Villa A, 2023	Canada	Factors associated with internal contamination of nurses	Identify factors via biomonitoring	Certain tasks & inadequate controls linked to measurable contamination	NOS = 7/9 (Good)
Kharbat A, 2021	USA	PPE decontamination to overcome PPE shortage in rural hospitals	Describe N95 FFR decontamination service	VHP enabled reuse of >12,000 N95s; feasible operationally	NOS = 7/9 (Good)
Eisenhardt L, 2017	Germany	Closed-system transfer devices and contamination reduction	Evaluate CSTD effectiveness	CSTDs reduced surface contamination in compounding areas	NOS = 8/9 (Good)
Chen, 2020	USA	Surface contamination with cyclophosphamide	Measure cyclophosphamide residues	Detected on various surfaces; exposure concerns	NOS = 7/9 (Good)
van den Berg R, 2025	Europe	Surface wipe sampling proficiency study	Evaluate lab performance	Variability; need for standardization	NOS = 6/9 (Moderate)
Nygren O, 2020	Sweden	Trends in environmental contamination with antineoplastic drugs	National monitoring of AD contamination	Persistent contamination; policy implications	NOS = 8/9 (Good)
Yoshida J, 2015	Japan	Surface contamination with cytotoxic drugs in Japanese hospitals	Assess contamination in multiple hospitals	Detectable contamination; monitoring recommended	NOS = 7/9 (Good)
Kiffmeyer TK, 2018	Germany	Antineoplastic drug residues in German hospitals	National monitoring program	Residues across multiple hospitals; calls for harmonized monitoring	NOS = 8/9 (Good)
Vuma S, 2018	South Africa	Antineoplastic contamination in South African hospitals	Assess contamination in LMIC settings	Contamination found; limited control measures	NOS = 6/9 (Moderate)
Bobin-Dubigeon C, 2019	France	Risk assessment of exposure to cytotoxic drugs	Quantitative risk assessment	Identified key exposure pathways & mitigation strategies	NOS = 7/9 (Good)

Bartel S, 2019	USA	Airborne and surface contamination from chemotherapy compounding	Compare airborne vs surface contamination	Both present; engineering controls needed	NOS = 7/9 (Good)
Ziegler E, 2017	USA	Effectiveness of closed-system transfer devices in reducing contamination	Evaluate CSTD impact	CSTDs effective; supports adoption	NOS = 8/9 (Good)
Breede H, 2024	Netherlands	Antineoplastic contamination on PPE post-decontamination	Assess residual ADs on PPE	Residual ADs detected after some decontamination cycles	NOS = 6/9 (Moderate)
Carrez L, 2022	Belgium	Reprocessing of surgical masks and gowns	Investigate chemical safety	Residue risks highlighted; monitoring recommended	NOS = 6/9 (Moderate)
Ramirez A, 2020	Mexico	Occupational exposure to hazardous drugs in Latin American hospitals	Survey contamination & practices	Detectable contamination; gaps in adherence	NOS = 6/9 (Moderate)
Kato Y, 2021	Japan	Longitudinal monitoring of cytotoxic drug contamination in ICUs	Monitor contamination over time	Persistent contamination; high-risk locations identified	NOS = 7/9 (Good)
Breton MC, 2016	Canada	Occupational exposure assessment during antineoplastic drug handling	Measure exposure & recommend controls	Exposure metrics measured; suggested engineering controls	NOS = 7/9 (Good)

and nurses' health outcomes has not yet been comprehensively addressed, with most evidence being indirect.

Discussion

The findings of the included studies indicate that surface chemical contamination in intensive care units and other hospital settings remains a consistent concern, although the reported levels of contamination and the effectiveness of control measures varied across studies.

Connor et al.[1] showed that residues of antineoplastic drugs persist on surfaces despite routine cleaning protocols, making "zero contamination" difficult to achieve. Similarly, Vermette[17] in Canada reported cyclophosphamide and fluorouracil residues in over 60% of surface samples. Quartucci (2023) also confirmed that such contamination can persist over time.[3] Similarly, Walton et al. (2025) identified antineoplastic drug residues on multiple surfaces in patient care areas, including nursing counters, intravenous poles and pumps, patient tables, door handles, and floors, highlighting the potential for ongoing exposure among healthcare workers.[26] These findings emphasize the importance of standardized cleaning protocols and regular environmental monitoring. Regarding occupational exposure, biological monitoring studies have demonstrated the potential for systemic uptake of antineoplastic drugs among healthcare workers. In the multicenter European MASHA-2 project, Korczowska et al. (2023) identified antineoplastic drug residues in urine samples collected from healthcare workers, including nurses, indicating that occupational exposure may occur despite established protective measures.[27] In addition, Sottani et al. (2012) reported widespread environmental contamination in four Italian healthcare settings, although antineoplastic drugs were not detected in the collected urine samples.[28] These findings highlight the importance of combining environmental monitoring with biological surveillance when evaluating occupational exposure. Furthermore, Walton et al. (2025) reported that the use of PPE and closed-system drug-transfer devices (CSTDs) was inconsistently documented across the reviewed studies, limiting the assessment of their effectiveness in preventing contamination.[26] In terms of health outcomes, Dumas et al. (2021) investigated the association between occupational use of high-level disinfectants and asthma incidence among female nurses, highlighting the importance of evaluating chemical exposures associated with healthcare cleaning and disinfection practices.[29] Dang et al. (2022), in a systematic review and meta-analysis of 34 studies, found a significantly increased risk of asthma among hospital workers exposed to cleaning and disinfecting products (RR = 1.35, 95% CI: 1.09–1.68).[30] Together, these findings suggest that occupational exposure to disinfectants represents an additional respiratory health concern for healthcare workers. However, the possibility of additive or synergistic health effects resulting from simultaneous exposure to cytotoxic drugs and disinfectants has not been sufficiently established and requires further investigation.

The issue of PPE reprocessing gained prominence

after 2020 in response to global shortages of disposable respirators. Schumm et al. (2021), in a systematic review of 42 studies, evaluated different methods for reprocessing N95 respirators, including ultraviolet germicidal irradiation and vaporized hydrogen peroxide. Their findings indicated that several methods could achieve effective microbial decontamination while maintaining filtration performance and facial fit under specific experimental conditions.[31] However, these findings primarily concern microbiological decontamination and respirator performance. They do not establish the effectiveness of these methods in removing cytotoxic drug residues from contaminated PPE. Therefore, the chemical safety of reprocessing PPE previously exposed to antineoplastic drugs remains uncertain and warrants further investigation. A geographical comparison also revealed important differences in the distribution of available evidence. Walton et al. (2025) reported that most studies investigating antineoplastic drug contamination in patient care areas were conducted in North America and Europe, indicating a geographical concentration of the available research.[26] Similarly, the European MASHA-2 project provided evidence of environmental and occupational contamination across multiple European healthcare settings.[27] However, the limited representation of low- and middle-income countries restricts the generalizability of current findings. Differences in healthcare infrastructure, availability of protective equipment, staff training, and implementation of occupational safety policies may influence contamination control and occupational exposure in different healthcare systems.

Overall, the reviewed studies consistently indicate that antineoplastic drug contamination can occur on multiple hospital surfaces and that healthcare workers, particularly nurses, may remain at risk of occupational exposure. Although preventive measures, including standardized cleaning protocols, appropriate PPE, educational interventions, and CSTDs, may help reduce contamination, their effectiveness depends on consistent implementation and monitoring. Furthermore, evidence regarding PPE reprocessing primarily addresses microbial decontamination rather than the removal of hazardous chemical residues. These findings highlight the need for comprehensive occupational safety strategies and further research into the effectiveness of contamination control measures in hospital environments.

In conclusion, although there is a broad scientific consensus on the seriousness of surface contamination and occupational exposure, the most effective strategies for risk control remain under debate. Future research should employ longitudinal designs and adopt standardized monitoring methods to better elucidate the relationship between environmental contamination, biological exposure, and health outcomes. Such evidence is essential to inform policy-making and the development of global safety standards.

Strengths and Limitations

One of the main strengths of this systematic review is the use of a broad timeframe (2015–2025), which allowed the analysis of recent trends and comparisons of changes in nurses' occupational exposure and management of surface chemical contamination. The geographical diversity of included studies (Europe, North America, Asia, Africa, and Latin America) also provided a more comprehensive understanding of structural and operational differences across healthcare systems. Furthermore, by integrating evidence on both environmental contamination and reprocessing of personal protective equipment (PPE), this review offered a multilayered perspective on occupational risks and safety measures affecting nurses.

However, several important limitations should be acknowledged. First, heterogeneity in study designs and monitoring methods made direct comparisons challenging. For instance, some studies relied solely on wipe sampling, while others combined environmental and biological assessments. Second, most studies focused on environmental contamination, with limited evidence directly linking contamination levels to clinical outcomes in nurses. Third, regarding PPE reprocessing, the majority of studies concentrated on microbiological efficacy, while data on chemical safety and the potential generation of harmful byproducts remained scarce.

Another limitation relates to publication bias. Studies that found no contamination or exposure may have been less likely to be published, meaning that this review may be disproportionately influenced by positive findings. Additionally, the reporting quality of several included studies was suboptimal, providing insufficient data for meta-analysis or robust quantitative synthesis.

Finally, this review included only English and Persian publications, which may have excluded relevant evidence published in other languages, potentially

limiting the generalizability of findings.

Conclusion and Practical Implications

This systematic review demonstrates that surface contamination by antineoplastic drugs and disinfectants in hospital environments—particularly in intensive care units—remains a serious occupational threat for nurses. Evidence shows that even in facilities where cleaning protocols and PPE are implemented, measurable levels of environmental contamination and biological exposure persist. Current strategies appear insufficient and require revision and reinforcement.

In the field of PPE reprocessing, methods such as UV-C, vaporized hydrogen peroxide (VHP), and moist heat were shown to be microbiologically effective; however, the chemical safety of these approaches remains uncertain, with some studies reporting the presence of chemical byproducts post-reprocessing. Therefore, the use of such methods should be approached cautiously, with strict monitoring and standardized protocols.

The findings underscore the urgent need for standardization of monitoring methods. The absence of harmonized international protocols for sampling sites, analytical methods, and reporting metrics makes global comparison difficult. Establishing international guidelines could significantly enhance the quality of evidence and support evidence-based policymaking.

From a policy perspective, ensuring nurses' safety requires a multilayered approach that includes:

1. Regular environmental and biological monitoring to assess contamination levels and occupational exposure.

2. Implementation of novel technologies such as closed-system transfer devices (CSTD) and isolator equipment.

3. Continuous training programs for nurses and healthcare staff on safe handling of cytotoxic drugs and disinfectants.

4. Rigorous review and regulation of PPE reprocessing protocols, addressing both microbiological and chemical safety.

5. Strengthening of international collaboration for the development and adoption of global safety standards.

Finally, identified research gaps suggest that future studies should employ prospective designs to establish quantitative links between environmental contamination, biological uptake, and clinical outcomes in nurses. Such evidence will provide a stronger foundation for policymaking and investment in occupational safety programs.

In summary, the present review emphasizes that nurses' safety in high-risk environments cannot rely solely on individual protective equipment, but must be supported by a comprehensive management system and evidence-based policy framework. Only through such integrated efforts can occupational exposure risks be effectively reduced, ensuring the sustained health and safety of nurses—the backbone of intensive care delivery.

Conflict of Interest

The authors declare no conflicts of interest.

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