Healthcare PPE Selection Guidance Research Gaps Identified Through Literature Review

BY

MARINA V TECUANHUEY
B.A., University of Illinois Chicago, 2021

THESIS

Submitted as partial fulfillment of the requirements
for the degree of Master of Science in Public Health Sciences
in the Graduate College of the
University of Illinois Chicago, 2024

Chicago, IL

Defense Committee:

Margaret Sietsema, Chair and Advisor
Tessa Bonney, Environmental and Occupational Health Sciences
Susan Buchanan, Environmental and Occupational Health Sciences

This thesis is dedicated to my husband, Francisco Bautista, whose unwavering support, encouragement, and reassurance have been a constant source of inspiration and have played a vital role in my success.

ACKNOWLEDGMENTS

I want to thank my thesis committee—Margaret Sietsema (PhD, CIH), Tessa Bonney (PhD, CIH), and Susan Buchanan (MD, MPH)—for their invaluable support and guidance.

Special thanks to Rosie Hanneke, Head Librarian of Information Services and Research for the Library of Health Sciences at the University of Illinois Chicago, for her assistance throughout the literature search process.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

FIGURE PAGE

NOMENCLATURE

AGP	Aerosol-generating procedure
CINAHL	Cumulative Index to Nursing and Allied Health
CO_2	Carbon dioxide
CPR	Cardiopulmonary Resuscitation
FFR	Filtering facepiece respirator
HCW	Healthcare worker
HICPAC	Healthcare Infection Control Practices Advisory Committee
N_2O	Nitrous oxide
OPC	Optical particle counter
OPS	Optical particle sizer
PPE	Personal protective equipment
TB	Tuberculosis

SUMMARY

The *2007 Guideline for Isolation Precautions: Preventing Transmission of Infectious Agents in Healthcare Settings*, published by the Healthcare Infection Control and Prevention Advisory Committee, is a crucial document used to inform infection control practices in healthcare settings. From this guideline come the widely recognized transmission-based precautions, which are used to prevent the spread of infectious diseases, including the spread of infectious aerosols. Transmission-based precautions are important because they inform personal protective equipment recommendations for healthcare workers in different scenarios.

Since the 2007 guidelines were published, there has been substantial research into the dynamics of aerosol generation and transmission. A literature review was conducted to better understand how the scientific evidence that informed the 2007 guidance aligns with current evidence. The search involved identifying literature relevant to aerosol transmission and its implications for healthcare workers in patient care. The search results were then filtered against specific inclusion and exclusion criteria. The literature that met the criteria was synthesized.

The key findings from this literature review highlight the complexities of aerosol dispersion, healthcare workers' exposure to patient-produced aerosols, and the classification of medical procedures as aerosol-generating. Based on the findings from this review, the recommendations put forth by the 2007 guidance document may need to be revisited to better align with the current evidence regarding the transmission of infectious aerosols.

1. INTRODUCTION

1.1 Background

The Healthcare Infection Control Practices Advisory Committee (HICPAC)—a federal advisory committee established in 1991—provides the Centers for Disease Control and Prevention and the Department of Health and Human Services with advice and guidance regarding infection control practices (Hospital Infection Control Practices Advisory Committee, 1996). This includes, “strategies for surveillance, prevention, and [management] of healthcare-associated infections, antimicrobial resistance, and related events” (HICPAC, 2023b). The committee is comprised of clinicians who contribute their infection control expertise to create guidelines and recommendations for healthcare settings.

One of HICPAC’s most influential guidance documents, the *2007 Guideline for Isolation Precautions: Preventing Transmission of Infectious Agents in Healthcare Settings*, focuses primarily on the interactions between patients and healthcare workers (HCWs). This guidance document is intended for all persons responsible for developing, implementing, and evaluating infection control programs for healthcare settings (HICPAC, 2023a). Although it has been over a decade since the original document was published, it has been updated since then, most recently in July 2023. The updates are meant to address changes and concerns regarding the transmission of infectious agents to keep patients and HCWs safe; however, the fundamental guidance most recognized by healthcare leaders—standard and transmission-based precautions—has remained unchanged.

1.2 HICPAC Standard and Transmission-Based Precautions

Standard and transmission-based precautions are two tiers of infection prevention practices. The first tier, standard precautions, includes principles of infection prevention that HCWs should apply to all patient-related activities. These principles include proper hand hygiene, use of personal protective equipment (PPE) such as gloves, gown, and/or mask depending on the anticipated exposure and other measures that may protect against potential exposure to infectious agents. Transmission-based precautions are the second tier of precautions that are applied to supplement standard precautions as they are applied to patient interactions when there is a known or suspected infectious pathogen. These precautions are supplemental to standard precautions and require targeted efforts to reduce transmission.

There are three categories of transmission-based precautions: contact precautions, droplet precautions, and airborne precautions. The infection prevention practices for each of these categories are based on confirmed or suspected transmission mechanisms of the infectious agent (as shown in Table I). The recommendations associated with contact precautions pertain to infectious agents spread through direct or indirect contact with a patient or their environment (e.g., assessing a patient's vital signs, cleaning equipment after patient use, etc.). Droplet precautions are measures taken to prevent the spread of infectious agents through close contact with respiratory secretions—generally within 6 ft of the patient (e.g., a patient sneezing on a provider). Airborne precautions are put in place when pathogens can remain infectious while suspended in the air over long distances (e.g., infectious aerosols produced by a patient can travel to other patient rooms).

Apart from droplet and airborne transmission, additional precautions are necessary when medical procedures are found to produce aerosols. These procedures, known as aerosol-generating procedures (AGPs), can create aerosols mechanically or induce the patient to produce them through sneezing or coughing. The procedures that the 2007 HIPAC guidelines acknowledge as AGPs are bronchoscopy, endotracheal intubation, cardiopulmonary resuscitation (CPR), and open suctioning of the respiratory tract. This review centers on the precautions associated with the transmission of infectious aerosols (i.e., AGPs and droplet and airborne transmission).

TABLE I
TRANSMISSION OF INFECTIOUS AGENTS PER HICPAC

Transmission	Mechanism of Transmission
Contact	Infectious agents spread through direct or indirect contact with a patient or their environment
Droplet	Infectious agents spread through close distance (<6 ft) or mucous membrane contact with respiratory secretions
Airborne	Infectious agents can travel long distances (≥6 ft) while remaining infectious over time
Aerosol-generating procedure	Procedures that can generate aerosols mechanically or induce the patient to produce them through sneezing or coughing

1.3 Potential Limitations of Current Guidelines

The 2007 HICPAC guidelines build upon the isolation and infection prevention documents summarized in the *1996 Guideline for Isolation Precautions in Healthcare Centers*. According to HICPAC (2023a), the studies used to support the current guidelines are based on evidence derived from quasi-experimental design studies. The precautions associated with aerosol transmission, specifically droplet and airborne transmission, were informed by epidemiological studies of disease outbreaks, experimental studies, and information on aerosol dynamics. The studies used to inform these procedures were published between 1946 and 2004. The literature used to inform procedures where aerosol generation was observed was published from 1996 to 2003. It is crucial that the HICPAC guidelines reflect current knowledge and promote evidence-based practice, especially regarding PPE, due to the risk of infectious aerosols to HCWs.

1.4 **Infectious Aerosol Transmission**

In healthcare settings, there is a concern about the release of infectious agents into the air through patient-produced aerosols—generated during coughing and breathing (Lindsley et al., 2012; Tang et al., 2006)—and aerosols generated during medical procedures. This is particularly relevant in the context of infectious respiratory diseases, such as influenza, SARS-CoV-2, and tuberculosis (TB). Factors such as proximity to an infected person, duration of exposure, and pathogen-specific characteristics like virulence and infectivity can increase the risk of transmission (Bischoff et al., 2013; Rule et al., 2018; Tang et al., 2006; Yip et al., 2019; Zhang et al., 2020). However, there is a limited understanding of how infectious aerosols disperse and transmit disease. This is important because HCWs are at an inherent occupational risk of exposure to infectious agents while performing patient care. It is crucial to understand the dynamics of aerosol transmission and the risk infectious aerosols pose to HCWs to implement effective preventive measures to protect them.

While some of the infection prevention practices associated with each of the precautions include engineering controls such as isolation rooms, PPE is the primary measure used to protect HCWs. Therefore, it is crucial to have adequate PPE to reduce the opportunity for pathogen transmission. Determining the appropriate PPE for each task and exposure scenario varies by hospital, as the HICPAC guidance document is meant to inform, not enforce, infection prevention and control practices.

The HICPAC (2023a) guidelines outline PPE recommendations, which are based on patients' disease status and the corresponding precautions in place (as shown in Table II). The PPE recommendations for AGPs include the use of gloves, gowns, masks, and eye protection or face shields, as per standard precautions. When performing AGPs on patients with suspected or confirmed respiratory infections, HCWs should wear a fit-tested respirator in place of a mask. In accordance with droplet precautions, HCWs should wear, at minimum, a procedure or surgical mask and gloves for close contact with infectious patients. In case of airborne precautions, HCWs should wear gloves and a fit-tested N95 filtering facepiece respirator (FFR) or a respirator with a higher protection factor, such as a Powered Air Purifying Respirator, depending on the disease-specific recommendations. For both droplet and airborne precautions, HCWs should also wear eye protection, such as goggles or a face shield, and a gown if there is a potential for contamination from respiratory secretions or other body fluids being sprayed or splashed.

TABLE II
PRECAUTIONS FOR AEROSOL TRANSMISSION

Precautions	PPE	Additional Measures
During AGPs	Gown + protection of eyes, nose and mouth	Use of respirator if aerosols likely to contain respiratory virus (e.g., TB, SARS, avian or pandemic influenza virus)
Droplet	Surgical or procedure mask	Eye protection + gown if there is potential for respiratory secretions or other body fluids being sprayed or splashed
Airborne	Fit-tested N95 filtering facepiece respirator (FFR) or respirator with higher protection factor	Eye protection + gown if there is potential for respiratory secretions or other body fluids being sprayed or splashed; use of isolation Room

1.5 Aims of the Literature Review

This literature review identifies evidence-based data regarding the characteristics, generation, and dispersion of infectious aerosols. It investigates the impact of these aerosols on HCWs and the implications for infection control measures. To achieve this, the review includes a thorough examination of relevant literature that explains the scientific basis for aerosol-related hazards. This literature has broader applicability across various infectious diseases and healthcare settings. The scope of this review does not include literature on the epidemiology of disease-specific characteristics, such as virulence and infectious dose.

The aims of this literature review were:

1) to characterize the literature for infectious aerosol hazards in healthcare and their relevance and appropriateness to PPE, and

2) to describe the alignment of the literature with existing guidelines.

2. METHODS

To address the first aim of this thesis, a literature review was conducted on infectious disease hazards in healthcare, specifically related to aerosol disease transmission. The review included PubMed, Scopus, and the Cumulative Index to Nursing and Allied Health (CINAHL) databases. The search process focused on the relevance and suitability of the literature to PPE. This involved identifying materials that addressed infectious aerosol hazards encountered by HCWs, which could inform evidence-based guidance for providers performing patient care activities.

The search process was initiated by compiling general search terms to locate pertinent literature. The terms included were specifically related to healthcare providers typically engaged in patient care, infectious diseases, generation and dispersion of aerosols, and occupational exposure. The literature derived from the amalgamation of these terms was expected to provide a nuanced understanding of the potential infectious aerosol exposures to HCWs by patients.

Through several consultations with the Head Librarian at the UIC Library of Health Sciences, the search terms were refined and categorized. Eventually, five distinct concepts were identified:1) healthcare providers, 2) infectious disease hazards, 3) modes of disease transmission, 4) characteristics related to transmission, and 5) occupation-related factors. The search terms corresponding to each concept were amalgamated into a single search string. This unified search string was then applied across various databases, incorporating the appropriate controlled vocabulary terms to optimize the quality of results obtained.

Although the structure of this literature review closely follows the methodology of a systematic literature review, it does not meet the criteria to be classified as such. The task of identifying relevant literature across multiple disciplines proved to be challenging, as it was difficult to capture all the necessary terminologies needed to uncover literature across various fields of study. The diverse nature of the literature made it difficult to narrow the scope of the search while simultaneously retaining pertinent studies. The review deviated from the established systematic review methodology during the screening process and literature synthesis stages. Title and abstract screening were performed followed by full-text screening to thoroughly evaluate and select pertinent literature. The search process, including search strategies, progress, and inclusion/exclusion criteria, is outlined in the subsequent sections.

2.1 Search Strategy

The literature search strategy for this review involved identifying relevant keywords and grouping them by search concepts before applying Boolean operators, search modifiers, and database-specific controlled vocabulary and search field tags.

Boolean operators connect or manipulate keywords in a search query, helping to identify results that contain a particular combination of search terms (Hock, 2016). In this literature search, the operator "OR" was used to indicate that any of the keywords within a group were acceptable. Conversely, the operator "AND" indicated that a particular group of keywords must be present.

In addition to these operators, the logic of each search iteration was enhanced using search modifiers. Keywords and phrases were enclosed in quotation marks to ensure exact matches in search results. Asterisks were added at the end of keywords or phrases to include results in their plural form. The keywords and phrases for each search concept were grouped with parentheses to ensure the proper execution of Boolean operators.

When performing search iterations, various databases were used. The PubMed database is a service of the National Library of Medicine (NLM) that provides access to a wide range of medical literature. A preliminary search was conducted using PubMed to determine the relevancy of search results. In subsequent searches, additional databases—Scopus and CINAHL—were used to search for relevant literature as the search criteria (i.e., keywords and phrases) were refined. The Scopus and CINAHL databases were chosen for their expansive coverage of multidisciplinary science and nursing and allied health literature, respectively. The combined use of these databases allowed for comprehensive coverage and inclusion of the diverse literature.

Database-specific controlled vocabulary terms and search field tags were applied to the keywords and phrases used in each search. Controlled vocabulary terms, such as Medical Subject Headings (MeSH) in PubMed and Major Headings (MH) in CINAHL, are standardized terms or phrases that retrieve articles indexed with particular headings. Search field tags (e.g., [tiab]) were used to direct the databases to search for literature with the keywords or phrases in the title, abstract, or article tags. Including these elements enhanced the search efficiency and improved the results' accuracy and reliability. The search results were not limited to a specified date range. A detailed record of the search process, including the databases searched and modifications made, was maintained to ensure transparency.

2.1.1 **Initial Terms**

To initiate the search, only two search concepts were used, Health Provider and Infectious Disease Hazard. A list of healthcare provider roles and possible infectious disease hazards was created (listed in Table III). Synonyms and variations of the keywords were included to ensure a comprehensive list of terms. The keywords from this list were then organized and grouped into the concepts: Health Provider and Infectious Disease Hazard.

2.1.2 **Refinement of Terms**

All the keywords in Table III were used in the preliminary literature search.

TABLE III
DEVELOPING SEARCH PARAMETERS

Search Concept	Keywords
Health Provider	CNA, Healthcare Provider*, Healthcare worker*, Nurse*, Physician assistant*, Medical assistant*, Doctor*, Healthcare personnel, Hospital worker*
Infectious Disease Hazard	Infectious agent*, Aerosol*, Aerosol generating procedure*, Bloodborne pathogen*, Bloodborne, Contact, Transmission-based precaution*, Infectious disease*, Blood, Bodily fluids, Secretions, Contact, Airborne, Droplet, Needlestick

Though most of these keywords were used in subsequent searches, changes were made throughout the refinement process, which involved the following steps:

1) Adding new search concepts and related keywords. For example, creating the “Occupation-related” concept and including keywords such as “workplace” and “occupational” to promote search results that were specific to infectious disease hazards in the workplace.
2) Grouping keywords into new concepts. For example, aerosol-related keywords from the “Infectious disease hazard” concept were separated into the “Transmission” concept to capture search results that included at least one keyword from concepts to better characterize aerosol-related infectious disease hazards.
3) Removing keywords that were deemed irrelevant. For example, removing broad infection prevention terms, such as “universal precaution,” “standard precaution,” and “infection prevention,” to further narrow search results.

Boolean operators and search modifiers (shown in Table IV), controlled vocabulary terms (shown in Table V), and search field tags (shown in Table VI) were applied to the keywords used in each search iteration—terms varied by the database.

The Boolean operator "OR" was placed between keywords—within concepts—to broaden the search scope, and the operator "AND" was placed between concepts to narrow search results and find articles containing at least one specified term from each concept. To improve the accuracy of search results, the search terms for each concept were enclosed in parentheses. This ensured the databases recognized the keywords and phrases within each concept as a cohesive unit, allowing for a more focused search approach. As per the recommendation of the Head Librarian, quotation marks were placed around each keyword and used to locate literature containing the exact word or phrase, while an asterisk was used to identify literature with plural forms of a word or phrase.

When searching in PubMed, keywords identified as MeSH terms in the NLM's MeSH Browser were tagged as such. Keywords from each search concept were reviewed and tagged accordingly. All non-MeSH keywords were tagged with "[tiab]" which directed PubMed to look for the tagged search terms within the title or abstract of articles. In CINAHL, subject headings operated much like MeSH terms. All keywords were reviewed, and the appropriate controlled vocabulary terms were applied to those identified as CINAHL Subject Headings within the database.

The remaining keywords in CINAHL were tagged with "AB( ) OR TI( )" to search for the keywords within articles' titles or abstracts. The search field tag used in Scopus, "TITLE-ABS-KEY," was applied to all keywords in the search. This narrowed the search to include articles with the tagged keyword in the title, abstract, or author keywords. By applying controlled

TABLE IV

BOOLEAN OPERATORS AND SEARCH MODIFIERS USED IN SEARCH

		Placement	Example
Boolean operator	OR	Between keywords within a search concept to broaden search results	Healthcare personnel OR Healthcare provider
	AND	Between search concepts to narrow down results so that at least one keyword from each concept is included	Healthcare Provider AND Disease
Search Modifiers	( )	Around keywords and groups of keywords to separate search concepts	(Healthcare personnel OR Healthcare provider…) AND (Disease OR Virus…)
	“ ”	Around keywords to search for a specific phrase	“Patient-to-professional”
	*	At the end of keywords to capture plural forms or distinct endings of the word	Physician*

TABLE V

CONTROLLED VOCABULARY USED IN LITERATURE SEARCH

Controlled Vocabulary Terms by Database		Application of Controlled Vocabulary Terms to Keywords[a]
PubMed	“MeSH heading”[MeSH]	Health Personnel Communicable diseases Infection Control Aerosols Respiratory Aerosols and Droplets Infectious disease transmission, patient-to-professional
CINAHL	MH “Subject heading+”	Health Personnel Communicable diseases Infection Disease* Secretions Aerosols Infectious disease transmission, patient-to-professional
Scopus	None	N/A

[a] Not all of the keywords listed were used in each search iteration.

TABLE VI
SEARCH FIELDS USED IN LITERATURE SEARCH

Search Fields by Database	
PubMed	(Keyword)[tiab]
CINAHL	AB(Keyword) OR TI(Keyword)
Scopus	TITLE-ABS-KEY(Keyword)

vocabulary terms and search field tags across each search, the retrieved results were more accurate and comprehensive.

To assess the quality of the results obtained using these terms, a search was carried out on PubMed and initial search results were briefly reviewed. A search string was created by using Boolean operators and search modifiers to combine the keywords and concepts that would yield the most accurate and relevant results. This preliminary search was considered Search 0.

2.1.2.1 **Search 0: Scoping Search**

The preliminary PubMed search yielded over 100,000 results (shown in Table VII). However, upon reviewing the titles and abstracts of the first one hundred results, it was evident that much of the literature was irrelevant and the search needed further refinement. The resulting articles' focus areas included community surveillance, vaccine efficacy, administrative practices in healthcare settings, and non-healthcare occupations—outside the scope of infectious aerosol hazards to HCWs.

In the subsequent phase of the search process, an iterative approach was used to improve search terms, enhancing the precision of the search parameters and results. In addition to

TABLE VII
PROGRESSION OF LITERATURE SEARCH – SEARCH 0

Search Parameters		Results by Database		
Search Concept	Keywords	PubMed	Scopus	CINAHL
Health provider	CNA, Healthcare Provider*, Healthcare worker*, Nurse*, Physician assistant*, Medical assistant*, Doctor*, Healthcare personnel, Hospital worker*	149,895	N/A	N/A
Infectious Disease Hazard	Infectious agent*, Aerosol*, Aerosol generating procedure*, Bloodborne pathogen*, Bloodborne, Contact, Transmission-based precaution*, Infectious disease*, Blood, Bodily fluids, Secretions, Contact, Airborne, Droplet, Needlestick			

PubMed, the Scopus and CINAHL databases were used to identify relevant literature in all subsequent searches.

2.1.2.2 **Search 1: Expanded Databases and Modified Search Parameters**

In the first search iteration using all three databases (shown in Table VIII), the “Health provider” search concept was amplified to include all variations of the keywords used in Search 0. For example, in Search 0 the “Health provider” concept included the keyword “CNA,” so to further expand results related to this term in Search 1, the variation “certified nursing assistant” was added. This was repeated where applicable. Additionally, other provider roles that may be exposed to infectious aerosols during patient interactions were included, such as “primary care provider,” “physician,” and “nursing assistant.” This was done to prevent the exclusion of relevant search results as keywords were searched in the title, abstract, and tags.

To improve search results, modifications were made to refine the related concepts.

TABLE VIII
PROGRESSION OF LITERATURE SEARCH – SEARCH 1

Search Parameters		Results by Database		
Search Concept	Keywords	PubMed	Scopus	CINAHL
Health provider	Certified nursing assistant*, CNAs, Doctor*, Health personnel, Healthcare provider*, Health care provider*, Healthcare worker*, Health care worker*, Healthcare personnel, Health care personnel, HCP, HCPs, Hospital worker*, Medical assistant*, Nurse*, Nursing assistant*, Physician assistant*, Physician*, Primary care provider*	11,304	12,634	1,020
Infectious Disease Hazard	Aerosol-generating procedure*, Aerosol*, AGP, AGPs, Airborne*, Biological exposure*, Bodily fluid*, Communicable diseases, Droplet*, Infection prevention, Infection*, Infectious agent*, Infectious disease*, Pathogen*, Secretion*, Standard precaution*, Transmission-based precaution*, Universal precaution*			
Occupation-related	Workplace*, Occupational			

Because this literature review focused on infectious disease hazards in healthcare related to aerosols, the keywords pertaining to disease transmission by mode of contact (i.e., touch) were removed, including “contact,” “bloodborne pathogen,” “bloodborne,” “blood,” and “needlestick.” The concept “Occupation-related” was added to limit results related to occupational exposures and hazards.

During the search across PubMed, Scopus, and CINAHL, approximately 25,000 total results were obtained. Much of the literature generated was not relevant to the search. In contrast to the previous search, the literature retrieved from all of the databases was more often related to infectious disease hazards encountered by HCWs in general. This could be due to the addition of the "Occupation-related" search concept. However, due to the lack of literature regarding infectious aerosols or patient-to-provider transmission, it was determined that the search parameters required further refinement.

2.1.2.3 **Search 2: Further Modifications to Search Concepts and Keywords**

In an effort to produce more relevant literature, an additional search concept was created in the ensuing search iteration (shown in Table IX). Keywords from the "Infectious Disease Hazard" search concept were separated into two categories to better identify literature specific to transmission and infectious disease hazards. The new search concept, “Transmission,” included aerosol-related terms pertaining to modes of transmission, such as droplet and airborne, as well as terms that related to the characteristics and production of infectious particles.

Keywords associated with infection control measures, such as “infection prevention,” “standard precaution,” “transmission-based precaution,” and “universal precaution,” were removed from the search. These search terms were originally intended to expand the search

TABLE IX
PROGRESSION OF LITERATURE SEARCH – SEARCH 2

Search Parameters		Results by Database		
Search Concept	Keywords	PubMed	Scopus	CINAHL
Health provider	Certified nursing assistant*, CNAs, Doctor*, Health personnel, Healthcare provider*, Health care provider*, Healthcare worker*, Health care worker*, Healthcare personnel, Health care personnel, HCP, HCPs, Hospital worker*, Medical assistant*, Nurse*, Nursing assistant*, Physician assistant*, Physician*, Primary care provider*	457	704	40
Infectious disease hazard	Communicable disease*, Infectious agent*, Infection*, Pathogen*, Biological exposure*, Infectious disease*, Secretion*, Bodily fluid*			
Transmission	Aerosol*, Aerosol-generating procedure*, AGP, AGPs, Droplet*, Airborne			
Occupation-related	Workplace*, Occupational			

results; however, because the terms are broadly applicable within the realm of infection prevention, they did not yield pertinent literature and, consequently, were deemed irrelevant.

In the second search, the keywords pertaining to the search concepts "Health provider" and "Occupation-related" remained unchanged. The compiled results from this search iteration produced over 1,000 articles. After scanning the titles and abstracts of the first fifty results, less than 20% were deemed relevant to this search. It was determined that further refinement of search criteria and an additional search would be needed to filter out irrelevant literature.

2.1.2.4 **Search 3: Final Refinement**

In the third search, adjustments were made to the search criteria to further narrow the results (as shown in Table X). Keywords related to aerosol particle production and characteristics were separated into the new concept of "Characteristics of transmission." The search concept of "Transmission" was limited to predefined modes of infectious aerosol transmission, such as droplet and airborne. Separating characteristics of transmission from specific modes of transmission allowed for a more structured search of the literature.

To enhance the precision of search results regarding occupational exposure and risks to HCWs from infectious aerosols produced by patients, relevant search results from Search 2 were evaluated. Results tagged with occupation-related terms, including MeSH and MH terms in PubMed and CINAHL respectively, were assessed. Only three articles were included in this assessment as subsequent results did not contain new occupation-related terms. New terms were incorporated into the search to obtain more comprehensive results.

The keywords pertaining to the search concepts "Health provider" and "Infectious disease hazard" remained unchanged. No further modifications to search criteria were deemed

TABLE X
PROGRESSION OF LITERATURE SEARCH – SEARCH 3

Search Parameters		Results by Database		
Search Concept	Keywords	PubMed	Scopus	CINAHL
Health provider	Certified nursing assistant*, CNAs, Doctor*, Health personnel, Healthcare provider*, Health care provider*, Healthcare worker*, Health care worker*, Healthcare personnel, Health care personnel, HCP, HCPs, Hospital worker*, Medical assistant*, Nurse*, Nursing assistant*, Physician assistant*, Physician*, Primary care provider*	145	298	20
Infectious disease hazard	Communicable diseases*, Infection Control, Infectious agent*, Infection*, Pathogen*, Biological exposure*, Infectious disease*, Secretion*, Bodily fluid*, Disease*, Virus*			
Transmission	Airborne, Droplet*			
Characteristics of transmission	Aerosol*, Aerosols, Respiratory Aerosols and Droplets, Aerosol-generating procedure*, AGP, AGPs			
Occupation-related	Infectious disease transmission, patient-to-professional, Workplace*, Patient-to-professional, Occupational, Work-related, Work environment*, Occupation*			

necessary. The final search iteration applied across all databases yielded 463 results, with 136 duplicates removed, leaving 327 for title and abstract screening.

2.2 **Title and Abstract Screening**

The search results from PubMed, Scopus, and CINAHL were imported into Covidence online software (Melbourne, Australia). After the duplicates were removed, 325 articles remained. The selection process included screening titles and abstracts before reviewing full texts in Covidence. Two reviewers independently performed the screening before convening to resolve conflicts. The reviewers addressed approximately 70 conflicts. A third reviewer was available if the two reviewers could not resolve a screening conflict. Screening criteria (article inclusion and exclusion criteria) were developed and applied to identify relevant articles.

2.2.1 **Inclusion Criteria**

When screening titles and abstracts, inclusion criteria encompassed articles addressing the hazards associated with aerosol (i.e., droplet and airborne) transmission, including aerosol-generating procedures, of infectious agents from patients to HCWs in hospital settings. The inclusion criteria comprised articles published in peer-reviewed journals and systematic reviews in the English language. All research study types were considered, including observational studies, experimental studies, and reviews. Priority was given to articles specifically addressing the health and safety implications for HCWs exposed to aerosolized infectious agents during routine care or medical procedures. The selected articles were required to provide insights into the hazards associated with aerosol transmission, including potential risks and modes of exposure from the HCW's perspective. The inclusion criteria did not impose geographical restrictions, and studies from various global regions were considered. Articles discussing various infectious agents, such as bacteria, viruses, or other pathogens, that can be transmitted through aerosols from patients to HCWs were also included.

2.2.2 **Exclusion Criteria**

To maintain consistency during title and abstract screening, exclusion criteria were developed to omit extraneous articles from the review. Articles exclusively focused on aerosol mitigation strategies (i.e., engineering controls), SARS-CoV-2 restrictions, contact or fomite transmission, PPE effectiveness, and institution or provider knowledge of PPE, including selection, donning/doffing practices, and adherence were considered irrelevant. Furthermore, studies that primarily focused on populations other than HCWs, such as community settings and households, were excluded. Studies specific to aerosol exposure in dental clinics were not considered. Articles that did not specifically address aerosolized transmission of infectious agents from patients to HCWs were also excluded. Additionally, studies that did not emphasize the occupational health and safety aspects of HCWs were excluded. Finally, articles published in languages other than English, as well as non-peer-reviewed publications such as editorials, opinion pieces, letters to the editor, and conference abstracts, were excluded during the screening process.

2.3 **Full-Text Review**

Upon completion of the title and abstract screening, 59 articles were included in the full-text review. The review was performed in Covidence by an independent reviewer, Marina Tecuanhuey. If needed, a second reviewer was available for consultation. In this final phase of the search process, the content of the studies was examined in greater detail. Previously developed screening criteria (see sections 2.3.1 and 2.3.2, below) were refined and applied to ensure the inclusion of relevant studies in the literature review. Because there are no standardized data collection methods for aerosol particles, screening criteria were not dictated by the study methodology. Despite undergoing title and abstract screening, several articles from the full-text review did not qualify for this literature review. The reasons for excluding studies were documented.

2.3.1 **Inclusion Criteria**

When performing the full-text screening, inclusion criteria were applied to achieve a comprehensive understanding of infectious aerosol hazards in healthcare. Articles were included when they investigated or related to aerosol transmission within the scope of healthcare settings. The study of particle characteristics (e.g., size, concentration, dispersion) and the risks (e.g., potential exposure) associated with routine care, medical procedures, or HCW interactions with infectious patients were of particular interest. When discussing potential risks to HCWs, studies that examined aerosolizing procedures and directly measured aerosol production and dispersion were included despite varying methodologies.

Although intervention studies were excluded, studies comparing aerosol generation in standard procedures to those involving interventions were included. This inclusion aimed to investigate aerosol generation in typical scenarios of interest within this review. Additionally, studies that used human subjects or simulations in addition to modeling were included. Peer-reviewed literature reviews were considered relevant as they synthesize knowledge of existing related research. Select reviews were included that outlined the current evidence on the transmission of infectious aerosols.

2.3.2 **Exclusion Criteria**

During the full-text review, studies were excluded if they lacked evidence related to aerosol particles that could contribute to an understanding of dispersion and generation dynamics. This included studies that exclusively focused on the effectiveness of PPE or other interventions used to mitigate the spread of aerosols, such as room ventilation or physical barriers, were excluded. This was done because the purpose of the review was not to evaluate the efficacy of the measures used to prevent disease transmission to HCWs, such as PPE. Instead, the review aimed to evaluate the evidence used to inform PPE recommendations in healthcare settings.

Solely in vitro or animal studies without direct relevance to human HCWs were excluded. Studies that relied solely on modeling to quantify the risk of aerosol dispersion were not included in the review due to the variations in assumptions and uncertainties used in the approaches. Literature that assessed the risk of disease transmission to HCWs related to infection control practices, such as inadequate ventilation, environmental quality, vaccination, and PPE knowledge and adherence, were also excluded. Additionally, narrative reviews, letters to the editor, opinion pieces, and book sections were not considered.

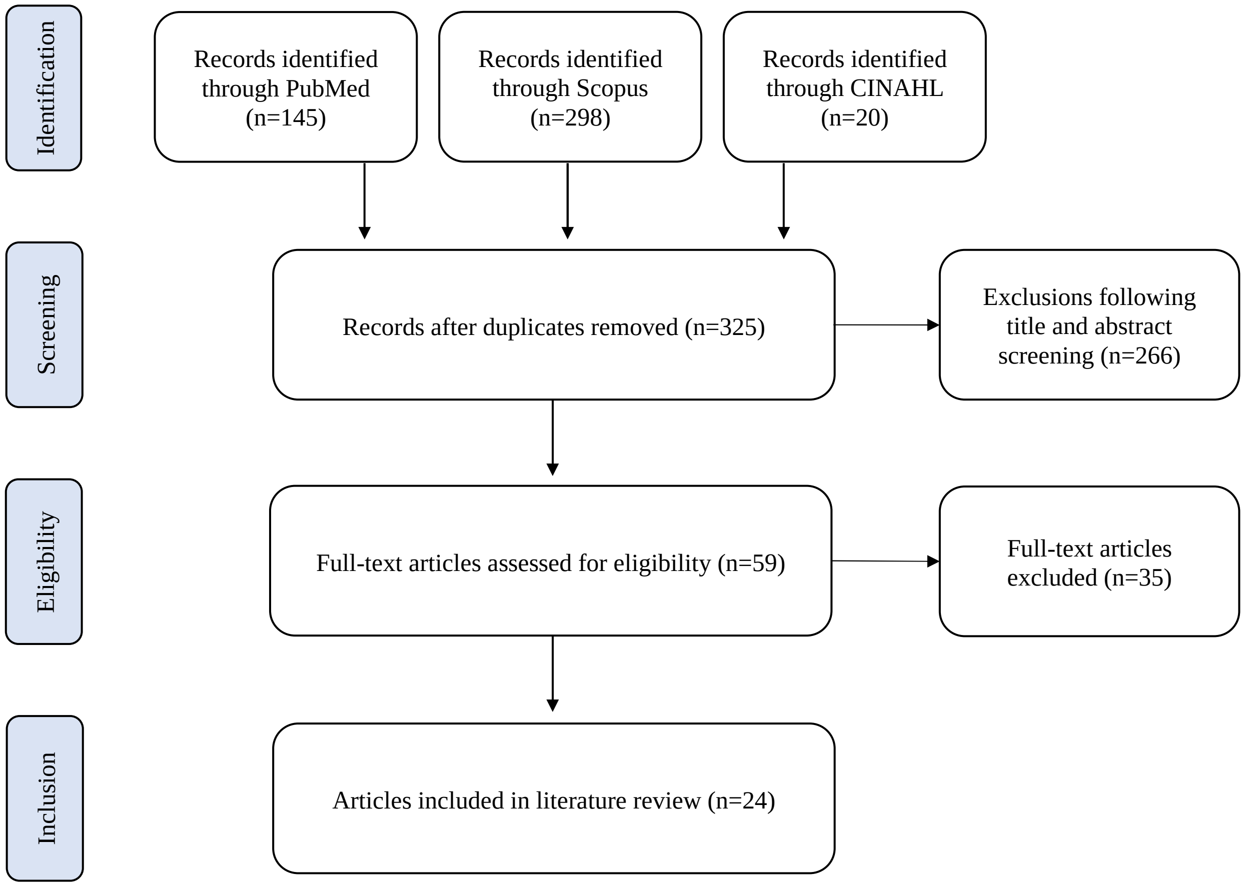
The studies excluded from this review have been documented, providing a comprehensive summary of reasons for exclusion (for details, refer to Table XIII, Appendix). These reasons have been categorized according to study design, intervention, outcome, and population/setting. While some studies initially met certain inclusion screening criteria, they were ultimately excluded based on the predefined exclusion criteria.

3. RESULTS

The literature identified for this review collectively reveals the multifaceted nature of infectious aerosol hazards encountered by HCWs in the workplace. While varying in methodology, the studies identified through the search process support the aims of this review. The researchers discuss how infectious agents can be transmitted through aerosols, identifying key risk factors and modes of transmission. A comprehensive exploration of these hazards aims to inform the relevance and appropriateness of current PPE strategies. The selected literature delves into the nuances of aerosol hazards encountered by HCWs during routine care and medical procedures, contributing to a better understanding of the occupational health and safety implications.

This literature review included 24 articles (Figure 1) which were categorized into two distinct categories. The first category, “Characteristics of Aerosol Dispersion” describes the properties and behaviors of aerosols, including those produced by patients in healthcare environments. This includes factors such as particle size, travel distance, persistence in the air, and the potential risk they pose to HCWs. This literature offers valuable insights into the dynamics of aerosol transmission, highlighting potential hazards to HCWs. The second category, “Aerosols Generating Procedures," synthesizes the findings related to the identification of diverse medical procedures that generate aerosols and associated risk levels. This section aims to describe the current state of knowledge and consensus, highlighting areas of agreement or disagreement and their implications for infection control, particularly in relation to PPE in healthcare settings.

Figure 1. Literature search results and screening process



3.1 **Characteristics of Aerosol Dispersion**

In the review of literature focused on aerosol dispersion, nine articles were analyzed (as shown in Table XI and summarized in the text, below). These articles discuss the potential risks of infectious aerosols to HCWs. The articles reviewed include four reviews, four observational studies, and one experimental study. Several researchers have measured aerosol particle concentrations in hospital rooms, some of which focused on defined particles (e.g., those generated by influenza-positive patients) and others that focused on non-specific aerosols (e.g., particles dispersed by cough, generally).

3.1.1 **Characterizing Aerosol Dispersion**

Aerosol dispersion plays a key role in the transmission dynamics of infectious diseases. By characterizing how infectious particles move through the air, researchers can gain insights into the potential routes and distances over which transmission can occur. It is important to know how infectious aerosols move and spread to best protect HCWs. This section contains literature related to aerosol dispersion specific to the risk they present to HCWs. This includes four review articles and one experiment.

In Bahl et al. (2022), researchers analyzed evidence from ten studies on the horizontal distance traveled by respiratory aerosols classified as droplets. Through this review, the researchers aimed to examine the evidence supporting the current spatial separation of 1 m (about 3 ft) for droplet precautions as per the issued guidelines, including CDC. Ten studies were included in the review, and of those, eight "discussed a horizontal trajectory greater than 2 m (about 6 feet) for a range of droplet sizes of less than 60 µm" (Bahl et al., 2022). The findings from five studies were based on modeling, and the other five experimental studies used a combination of modeling and human or only human subjects. The authors conclude that although

TABLE XI
LITERATURE RELATED TO THE CHARACTERISTICS OF AEROSOL DISPERSION

Author (Year)	Type of Study	Relevant finding(s)
Bahl et al. (2022)	Review	The studies reviewed confirmed that large aerosols (classified as droplets) spread at distances greater than 1 to 2 meters.
Bischoff et al. (2013)	Observational	Based on air sampling conducted in patients' rooms positive for influenza, it was determined that patients produced small influenza virus-carrying particles during routine, non-AGPs. HCWs could be exposed to infectious aerosols from patients beyond current recommended spatial separation for droplet transmission.
Lindsley et al. (2012)	Experiment	Based on simulated cough and breathing in a simulated medical examination room, it was determined that aerosolized particles produced by a patient's cough can travel rapidly and disperse throughout the room—potentially exposing HCWs to infectious aerosols.
Rhee et al. (2022)	Review	The studies reviewed discount the existing dichotomy between droplet and airborne transmission; rather, respiratory particles are produced in a continuous range.
Rule et al. (2018)	Observational	Based on sampling conducted in patient areas during influenza season, it was determined that HCWs might encounter increased concentrations of influenza virus when near patients; furthermore, the data supports HCWs' exposure to influenza via aerosols.
Tang et al. (2006)	Review	The reviewed studies describe the sources of infectious agents and the mechanics of aerosol transmission. This includes changes in particle size such as the evaporation of large aerosols into droplet nuclei, which can cause infection over longer distances.
Yan et al. (2021)	Observational	The negative pressure rooms of intubated and non-intubated positive SARS-CoV-2 patients were sampled. Despite the lack of AGPs, there were detectable viral aerosols were generated.

TABLE XI (continued)
LITERATURE RELATED TO THE CHARACTERISTICS OF AEROSOL DISPERSION

Author (Year)	Type of Study	Relevant finding(s)
Yip et al. (2019)	Observational	Based on sampling conducting in rooms of patients positive for influenza, viral RNA was detected in a HCW's breathing zone after providing routine care. Viral RNA of all specified sizes was found at each sample location.
Zhang & Duchaine (2020)	Review	The studies used in the review discount the distinction between droplet and airborne transmission. The risk of infection is more complex than the dispersal of infectious aerosols. Other factors, such as viral load, infectivity, and virus specificity, must be considered.

the studies used different methodologies, the evidence from this review confirms that the current spatial separation limit prescribed for droplet precautions is not based on current scientific evidence. Researchers note that droplet size is not fixed and may change due to evaporation, so what may start as a droplet can eventually become an airborne particle. Based on this review, airborne and droplet spread of disease should not be characterized as mutually exclusive modes of transmission. Furthermore, recommendations based on the current 1-meter spatial separation rule, including respiratory protection, should be revisited as the risk of infection extends beyond the current range.

In a review by Rhee et al. (2022), researchers provide a current understanding of respiratory pathogen transmission and the implications for infection control. The review included literature regarding the role of small aerosols in transmitting respiratory viruses, risk factors for transmission, and proposed strategies to prevent transmission in healthcare facilities. For the purposes of this review, the findings related to respiratory pathogen transmission were of particular interest. A major finding was that the conventional infection control dichotomy of droplet and airborne transmission is not supported by current evidence and requires revision. Additionally, researchers discussed that the AGP framework reinforces the distinction between droplet and airborne transmission. Although heightened preventive measures are often implemented during AGPs due to the perception that there is an increased risk of transmission through aerosolized particles, researchers found that in recent studies minimal, if any, aerosol generation was documented during various procedures. This, in combination with the lack of consensus regarding procedures considered aerosol generating, underscores the flaws of the HICPAC guidelines.

Based on their findings, Rhee et al. suggest shifting towards aerosol-based transmission since infectious particles are produced in a continuous range of sizes, rather than categorizing transmission as droplet or airborne. Ultimately, researchers emphasized the importance of considering factors beyond aerosol transmission when assessing pathogen transmission risks to HCWs, including viral load and proximity to infected patients, exposure duration, symptoms, and activities that increase respiratory emissions.

In Lindsley et al. (2012), optical particle counters (OPCs) monitored aerosol particle concentrations at various locations in a room to capture the dispersion of a cough. Although the primary focus of this study was to evaluate the effectiveness of PPE, such as surgical masks and FFRs, in protecting HCWs from cough aerosols, a substantial aspect of the study that pertains to this literature review is the simulation of HCW exposure to aerosols generated by a coughing patient. The results showed that aerosol particles traveled forward in the direction of the cough before quickly dispersing throughout the room. A major limitation of this study is that it was conducted in an environmentally controlled chamber and did not include any human subjects, as cough and breathing simulators were used. Observing the dispersion of human cough aerosol particles would better reflect the variation in aerosol counts and size. Nonetheless, this simulation demonstrates that HCWs in front or close to a coughing patient are likely to have higher average exposure levels to cough aerosols; furthermore, after several minutes, cough particles disperse throughout the room and can potentially reach HCW regardless of location.

A review by Tang et al. (2006) discussed the factors involved in the aerosol transmission of infections in healthcare facilities. Short-range transmission occurs when air flows between individuals and can infect one another. According to the researchers, “infectious agents that can cause infection at long range can also cause infection at short range, as well as [through] direct contact" (Tang, 2006). Infectious diseases transmitted by aerosols cannot be neatly categorized as transmitted via short or long-range aerosols.

Infectious agents can spread through sneezing or coughing, which produce large droplet-like aerosols that can then be inhaled. These aerosols can evaporate and become smaller over time. The movement of these particles is primarily influenced by their size and the environment, including airflow. The droplet size changes with time, and the infectious dose, the quantity of a pathogen required to cause infection, is often unknown and varies by person. Aerosol transmission is a complex process that occurs along a continuum rather than in a predictable manner.

Zhang and Duchaine (2020) reviewed the available literature to identify key concepts and knowledge gaps related to airborne transmission. Based on their findings, the researchers proposed a revised model for SARS-CoV-2 transmission in the context of low-risk healthcare settings. Relevant findings included those related to droplet and airborne transmission and AGPs.

The researchers determined that the evidence demonstrates that respiratory droplets may travel further than 1 – 2 m due to factors such as ventilation, forceful ejection (e.g., sneezing/coughing), and environment. During travel, smaller droplets can evaporate and form aerosols capable of carrying infectious agents. The researchers determined that the transmission of infectious aerosols cannot be classified as droplet or airborne, as they exist on a continuum. Moreover, the risk of airborne infection is not just due to the dispersion of aerosols, but also infectivity, virus specificity, and a patient's viral load. There is currently no consensus on which medical procedures qualify as AGPs, as many are associated with uncertain risks of aerosolization.

Overall, the findings from the articles characterizing aerosol dispersion are in agreement and indicate that the current spatial separation guidelines that characterize infectious pathogens transmitted through aerosols as droplet or airborne transmission are not supported by current scientific evidence.

3.1.2 **Infectious Aerosol Dispersion by Patients in Healthcare Settings**

Understanding how infectious aerosols disperse in healthcare settings is of paramount importance in assessing the potential transmission risks to HCWs. This section presents literature related to aerosol dispersion in patient care settings, including four observational studies.

In Bischoff et al. (2013), the purpose of the study was to understand how the influenza virus is transmitted by examining the spatial distribution of aerosols generated by symptomatic patients in a healthcare setting. Three 6-stage cascade impactors were used to collect air samples to detect particles carrying the influenza virus. The samplers were placed at head-level distances from the patient at ≤0.305 m, 0.914 m, and 1.829 m. Researchers measured aerosols emitted by patients (n=61) with influenza during routine care over 20 minutes. Sampling was performed in real-life environments and no AGPs were performed. In this study, AGPs included bronchoscopy, sputum induction, intubation and extubation, autopsies, opening suctioning of airways, and CPR.

The results collected from the cascade impactor were categorized as <4.7 µm and ≥4.7 µm. A decrease in viral load was noted as aerosol dispersion patterns changed, with an increase in small particles as the distance from the patient's head increased. Infectious amounts of the virus were detected up to 1.829 m (6 feet) from patients during non-AGP patient care activities, indicating potential exposure of HCWs exceeding suggested exposure zones.

In Rule et al. (2018), researchers sought to understand frontline HCWs' exposure to influenza in the emergency department. This study was performed during influenza season.

Healthcare workers (n=30) wore personal bioaerosol samplers to measure influenza near their breathing zones. Following personal sampling, HCWs completed a questionnaire to assess the frequency and type of interactions (i.e., patient care or AGPs) with infected patients. Additionally, room bioaerosol samples and surface samples were collected in waiting areas, screening rooms, a triage area, and an observation unit.

Over the course of six weeks, a total of 125 HCW personal bioaerosol samples and 98 room bioaerosol samples were collected. Influenza viral RNA was detected in 42% of the personal bioaerosol samplers collected and in 43% of the room bioaerosol samplers with a greater concentration of viral RNA found in personal samplers. Based on the detection of viral RNA in the room air samples, the observation area had the highest level of contamination. Influenza was detected in 47% of surface samples collected from patient care areas. Additionally, viral RNA was detected in 10 out of 25 personal bioaerosol samplers worn by HCWs who performed AGPs. The HCWs from whom the 10 samplers with viral RNA were detected were nurses. The AGPs performed by nurses included intubations, airway suctioning, administration of nebulizers, and nasopharyngeal aspirations. It was unclear which procedure(s) were responsible for the detection of viral RNA in the personal bioaerosol samplers.

This study established a positive correlation between the frequency of virus detection in personal samples and the frequency of contact with individuals exhibiting influenza symptoms; furthermore, when HCWs come into close contact with patients, they may come across higher concentrations of the influenza virus. CNAs and nurses, who had the most patient contacts per shift, were at a higher risk of exposure. Additionally, the detection of viral RNA in air and surface samples collected around the emergency department demonstrates that viral contamination exists outside of direct patient contact or proximal encounters. Although the samples collected could not be assessed by particle size, based on the data, there is evidence that HCWs in emergency rooms are likely to be exposed to influenza through aerosols.

Yan et al. (2021) conducted a study measuring the aerosolization of viral RNA from patients positive with SARS-CoV-2 (n=13). Three of these patients were intubated; however, the procedure was performed prior to sampling and no endotracheal intubations (potential AGP) occurred during data collection. All patients were in private, negative-pressure rooms, and air samplers were placed 1 and 4 m away from patients' upper airways. If either sampler tested positive for viral RNA, air from patient rooms was considered positive.

While air from one non-intubated patient room had detectable viral RNA, all the rooms with intubated patients were positive. Furthermore, higher airborne concentrations were found closer to intubated patients, with greater levels at 1 m than at 4 m. Even though the SARS-CoV-2 patients were in a negative-pressure room and intubated patients were mechanically ventilated through an endotracheal tube on a closed circuit with in-line suctions, viral RNA was detected in the air. While the study does not provide direct evidence that airborne viral RNA can cause viral transmission, in the context of this study, the findings suggest that virus-laden particles can enter the air in enclosed spaces even with all necessary precautions in place.

The aim of the study by Yip et al. (2019) was to determine the distribution of viral RNA in the air emitted by patients with confirmed influenza (n=16). The study was conducted in an acute care hospital where filter cassettes were used to detect the presence of viral RNA from the breathing zones of seven nurses engaging in patient care. Bioaerosol samplers were used to collect air samples from within patients' rooms and in the outside corridor.

The study found that 37.5% of patients emitted viral RNA into the air. The researchers found viral RNA in particles of all sizes, and most of these particles were emitted within 0.5 to

1.0 m from the patient's head. Viral RNA was recovered from the breathing zone of one nurse. However, the researchers pointed out that the detection of viral RNA in air is not a definitive indication of risk potential after exposure.

The findings from these articles demonstrate that patients can release potentially infectious aerosols that can reach HCWs beyond the defined spatial separation boundaries set by droplet and airborne precautions. Therefore, it is imperative to take appropriate measures to minimize the spread of aerosols and protect HCWs from potential infections.

3.2 Aerosols Generated During Medical Procedures

In the review of literature focused on aerosols generated during medical procedures, fifteen articles were analyzed (as shown in Table XII and summarized in the text, below). HCWs frequently come into close contact with patients during various medical procedures. If a patient is infected, this proximity increases their chance of exposure to infectious aerosols that are expelled through coughing, sneezing, or even regular breathing. The risk is even greater during aerosol-generating procedures, where respiratory secretions can become a direct source of transmission.

3.2.1 Surgical Procedures

The use of surgical instruments during medical procedures can potentially generate aerosols. However, the exact level of risk associated with these AGPs remains uncertain. Moreover, the lack of agreement over which procedures classify as aerosol-generating procedures further complicates the matter. This lack of clarity regarding which procedures pose risks to HCWs emphasizes the need for a more defined understanding and categorization of AGPs to ensure the safety of HCWs in healthcare settings. This section examines literature

TABLE XII
LITERATURE RELATED TO AEROSOLS GENERATED DURING MEDICAL PROCEDURES

Author (Year)	Type of Study	Relevant finding(s)
Berges et al. (2021)	Experimental	During simulated tracheostomy surgery and care, open suctioning and nebulization were shown to increase respirable aerosol particles.
Brown & Chan. (2020)	Review	Based on a review of the available studies, it is not possible to definitely state whether chest compressions generate aerosols. While there is evidence to suggest chest compressions are AGPs, the quality of available studies is low.
Campiti et al. (2021)	Observational	The data collected during MT insertion suggest that aerosols do not increase during the procedure above the induction of anesthesia; therefore, this procedure should not be considered high risk to providers.
Christian et al. (2004)	Case report	Based on the case report, the transmission of SARS-CoV from an infected patient to providers may have occurred due to the generation of aerosols during chest compressions and ventilation using a bag-valve mask.
Dharmarajan et al. (2020)	Experimental	The aerosols generated during simulated endonasal surgery were associated with drilling. The use of the cutting and coarse diamond burr generated small aerosols ($\leq$3.30 µm). Unlike the coarse diamond burr, the cutting burr generated larger particles and more surgical residue.
Dhillon et al. (2021)	Observational	The data collected during intubation and extubation demonstrate that the procedures generate aerosols. Particles produced during tracheal intubation and extubation ranged from 0.05 to 4 µm. In both intubation and extubation, positive pressure bag and mask ventilation generated the largest particle count. The particles produced were small and remained suspended in the air, spreading throughout the operating theatre.

TABLE XIII (continued)
LITERATURE RELATED TO AEROSOLS GENERATED DURING MEDICAL PROCEDURES

Author (Year)	Type of Study	Relevant finding(s)
Guderian et al. (2021)	Experimental	Of the surgical interventions simulated in this study (i.e., mechanical stress with a passive instrument, carbon dioxide [CO_2] laser treatment, drilling, and bipolar electrocoagulation), large aerosols were produced by laser treatment and drilling, while electrocoagulation produced the most particle and aerosol formation.
Harding et al. (2020)	Review	Based on a review of the evidence of AGPs, (i.e., intubation, tracheotomy, CPR and manual ventilation, bronchoscopy and airway suctioning, noninvasive ventilation, high-flow nasal canulae and oxygen masks, nebulizer treatment, nasopharyngeal swabbing and collection of sputum, and endoscopy and transesophageal echocardiography intubation), the quality of evidence for all procedures—except for intubation—is very low. It cannot be definitively determined which procedures increase the risk of transmission to HCWs.
Ip et al. (2007)	Experimental	Following the simulation of airflow with different air supply rates to simple, nonbreathing, and Venturi-type oxygen masks, visible exhaled airflow was observed from all mask types.
Loth et al. (2021)	Experimental	By simulating aerosol exposure during surgical tracheotomy and visualizing the airflow produced, it was determined that aerosol distribution during the procedure is possible but varies by condition (i.e., closed versus open airway plus expiration or coughing). Compared to the other conditions tested, the speed of aerosol propagation was higher when the procedure was simulated with an open airway and cough, exposing the surgeon's facial area during exhalation.

TABLE XIV (continued)
LITERATURE RELATED TO AEROSOLS GENERATED DURING MEDICAL PROCEDURES

Author (Year)	Type of Study	Relevant finding(s)
Millar & Moorhouse (2023)	Observational	Particle counts collected during administration of continuous flow nitrous oxide reflect minimal aerosol generation. This procedure is of low risk to providers.
Murr et al. (2021)	Observational	During endonasal surgery in a standard operating room, drilling and microdebrider use lead to an increase in airborne particle concentrations.
Thamboo et al. (2020)	Review	Evidence indicates that various surgical instruments used in otolaryngology procedures generate aerosols. Additionally, evidence supports endotracheal procedures like suctioning and tracheotomies as AGPs.
Ye et al. (2021)	Experimental	Most aerosols produced during orbital repair were in the small size range of 0.3 to 0.374 μm. Spikes in aerosol concentrations occurred during electrocautery and drilling.
Zheng et al. (2021)	Observational	During laryngology procedures, CO_2 laser use was associated with the greatest increase in aerosolized particles. Direct laryngoscopy with general endotracheal anesthesia was associated with small increases in particle concentration.

related to potential surgical AGPs and includes five experimental studies, two observational studies, and one review article.

In Berges et al. (2021), researchers measured the generation of aerosol particles during a tracheostomy procedure in swine. Procedures were performed using cold instrumentation or electrocautery while recording events like skin incision, tracheal incision, tracheostomy tube insertion, and tracheostomy tube securement. In addition to the tracheostomy procedure, an electrocautery simulation was performed using an ex vivo trachea specimen. During the surgical procedures, an OPC was used to measure the aerosol concentration. The OPC was placed at the approximate height of the surgeon's head and at various horizontal distances from the procedure site. The objective was to evaluate the generation and concentration of aerosols in relation to HCWs during the procedure, including the surgeon, anesthesiologist, and operating room staff.

In the swine tracheostomy, electrocautery produced more aerosol particles than cold instrumentation during the period between the skin and tracheal incision. Electrocautery of ex vivo tracheal tissue resulted in increased aerosol particle generation, with the highest concentrations observed in areas near the anesthesia location and left and right sides of the surgeon. This study's findings support tracheostomy as an AGP.

In Campiti et al. (2021), an optical particle sizer (OPS) was used to measure aerosol generation during myringotomy and tympanostomy tube (MT) insertion. The OPS was positioned near the external auditory canal and was used to measure the number concentration of aerosols during live surgery on pediatric patients (n=9). A baseline measurement was obtained over 60 seconds. This measurement was collected after the patient was administered general anesthesia and prior to the commencement of the surgical procedure. There was a statistically significant decrease in aerosol concentrations of aerosols between 0.30 – 0.90 μm during MT insertion compared to baseline. The results of this study suggest that beyond the induction of anesthesia, aerosols do not increase during MT insertion. This data indicates that MT may not be an AGP.

In Dharmarajan et al. (2020), endonasal surgery was simulated in a surgical laboratory to measure the aerosols produced during drilling and identify mitigation strategies. Researchers simulated surgery using 3D-printed sinonasal models and cadaver heads to determine the presence of small aerosols and particles when drilling with a 6-mm cutting burr versus a 4-mm coarse diamond burr. For this review, the experiments that were of greatest interest were the field contamination study and the impactor study, which addressed the dispersions of large aerosols and assessed the generation of aerosols, respectively.

The field contamination study tested whether drill burr type, among other factors, affected the degree and pattern of contamination on providers' PPE and a tarp placed in the surgical field. The impactor study used an 8-stage cascade impactor to determine the presence of aerosols (<15 μm). The impactor was used to separate particles based on their aerodynamic size, but it was not effective in determining aerosol dispersion in the environment. Each stage of the impactor was calibrated to the following aerodynamic particle diameter: 14.1 μm (stage 1), 8.61 μm (stage 2), 5.39 μm (stage 3), 3.30 μm (stage 4), 2.08 μm (stage 5), 1.36 μm (stage 6), 0.98 μm (stage 7), and small particles without a defined value (stage 8).

The researchers were interested in the aerodynamic diameter of particles, as it indicates where they are likely to deposit in the airway if inhaled. The results from the field contamination and impactor study revealed that aerosols less than 15 μm were consistently generated by both the cutting burr and coarse diamond burr during endonasal surgery. The cutting burr generated more debris and larger particles between the sizes of 3.30 μm to 14.1 μm. The particle size detected from the use of the coarse diamond burr was <0.98 μm to 3.30 μm, indicating that it produced less debris and finer particles.

In Guderian et al. (2021), researchers simulated various ENT surgical techniques to compare the generation of particles and aerosols. The study defined aerosols as droplets <5 μm; however, no definition was provided for particles. The techniques tested included mechanical stress with a passive instrument (with and without suction), CO_2 laser treatment, drilling with a 3.5 mm cutting drill, and bipolar electrocoagulation. For the purpose of this review, the scenario of mechanical stress with suction was not considered since the focus was on aerosol and particle generation rather than mitigation strategies. The simulation was carried out in a test chamber using both soft and hard porcine tissues.

During the experiment, particles were trapped on an acrylic plate inside the sample chamber and then the quantity and diameter of the detected particles were measured using a digital optic microscope. To detect aerosols, a full-HD video camera recorded the sample chamber at 25 frames per second. The video was then analyzed, and the turbidity of the camera view was used as an indirect indicator of aerosol density in the sample chamber.

Following the series of experiments, no particle or aerosol formation was detected during mechanical stress with a passive instrument. However, all active instruments (CO_2 laser treatment, electrocoagulation, and drilling) released particles and aerosols, but there were clear differences between the respective techniques. During laser treatment, the emission of small aerosols was observed, whereas drilling resulted in less particle formation and greater dispersion of tissues. Electrocoagulation generated 4.2 times more particles than drilling and produced an average particle size of 266.2 ± 25.3 μm. Assuming that aerosol generation and related exposures can increase the risk of infectious pathogen transmission from patients to HCWs, these findings suggest that simple interventions that do not involve the use of active instruments carry a lower risk of infection, whereas the use of electrocautery may produce potentially infectious material.

In Loth et al. (2021), surgical tracheotomy was simulated in an operating room to evaluate aerosol exposure. Experiments were conducted using a breathing simulator that replicated the surgical conditions of a tracheotomy. The airflow was made visible using a fog generator and recorded using a camera with a recording speed of 25 frames per second. The recordings were used to quantify the density of the fog and estimate aerosol exposure.

Six different experimental conditions were tested using the model. Two of the conditions involved the use of laminar airflow to mitigate aerosol exposures (Conditions 3 and 5), while the remaining four conditions did not. For this review, the results from the conditions without laminar airflow were considered and included: closed airway with expiration (condition 1), closed airway with coughing (condition 2), open airway with expiration (condition 4), and open airway with coughing (condition 6). No aerosols were detected during conditions 1 and 2. In condition 4, aerosols traveled upward from the surgical site toward the surgeon’s facial area, resulting in exposure. In condition 6, aerosol patterns were similar to condition 4, but the aerosols spread at a higher speed. The visualization of aerosol exposure during tracheotomy demonstrates that aerosol distribution during the procedure may result in HCW exposure.

In Murr et al. (2021), an OPS was used to quantify increases in aerosol concentrations during endoscopic endonasal surgeries. Aerosol concentrations were measured at three different positions (surgeon, circulating nurse, anesthesia provider) in the operating room during live-patient surgeries. Measurements were taken at various stages of the patient's surgery, including before entering the operating room, during setup, while using different instruments (cold instrumentation with suction, microdebrider, and drill), and before extubation.

Nearly all particles measured (99%) were smaller than 1.0 µm. During endonasal surgery, the use of drilling and the use of a microdebrider were linked to a rise in small particle concentrations. These increases were localized to the surgeon's area, which was 0.39 m from the nasal tip. The study supports the evidence that the use of powered instrumentation during endonasal procedures leads to an increase in aerosolized particles. However, the increase was only observed in the immediate vicinity of the operating surgeon.

In Thamboo et al. in 2020, researchers reviewed the literature available on the procedures performed by otolaryngologists during surgeries related to the head and neck. Due to the proximity of providers to patients during these procedures, the researchers aimed to analyze the available evidence related to potential AGPs and distinguish which procedures generate aerosols, therefore requiring high-level precautions. The review analyzed 37 studies that were grouped into 10 categories based on the type of procedure. These procedures include nasal endoscopy, sinonasal and anterior skull base surgery, packaging and treatment of nosebleeds, CO2 laser ablation, electrocautery, tracheotomy, endotracheal suctioning, oropharyngeal surgery, dental procedures, mastoid surgery, and the use of nasal nebulizers or atomizers. The articles' evidence was reviewed and graded, and recommendations for practice were provided accordingly.

As per this review, all the procedures mentioned should be considered droplet-generating. However, only surgical procedures involving electrocautery, (CO_2) laser vaporization, high-speed powered rotating instruments like microdebriders, drills, and saws, along with endotracheal procedures like endotracheal suctioning and tracheotomies, are recommended to be considered as AGPs.

In Ye et al. (2021), aerosol production was measured during simulated orbital repair using a cadaver. An OPS was used to measure the aerosol production (0.30 µm to 10.0 µm) during the procedures. Incisions were made using a standard monopolar electrocautery handpiece in three orbits, while a smoke-evacuating handpiece was used in the other three.

During the orbital repair, droplets created by electrocautery were found close to the surgical site. However, no droplets were produced by the smoke-evacuating handpiece. There were spikes in aerosol concentrations following electrocautery and drilling. When standard electrocautery was used, the concentration of aerosols was higher. Most aerosols produced were in the small size range of 0.3 to 0.374 μm. The data supports orbital repair as an AGP.

In Zheng et al. (2021), researchers aimed to quantify the aerosolized particles generated during laryngology procedures based on the surgical event and anesthesia type. The study included 10 patients, and multiple surgical events were recorded for each patient. The recorded surgical events included bronchoscopy, rigid esophagoscopy, direct laryngoscopy, ultrasonic aspirator use during direct laryngoscopy, and CO_2 laser use. Two anesthesia types were used—general endotracheal anesthesia (GETA) and jet ventilation anesthesia. The aerosol measurements were taken using an optical particle counter placed to the left of the surgeon, 60 cm from the patient's oral cavity. The measurements taken during the procedure were compared to the baseline aerosol counts collected immediately before the start of the surgery.

During direct laryngoscopies with GETA, smaller particles (0.3 to 0.5 μm and 0.5 to 1.0 μm) increased while larger particles (1.0 to 25.0 μm) decreased compared to the baseline. Direct laryngoscopy with GETA was linked to small increases in particle concentration. When direct laryngoscopies with jet ventilation anesthesia were performed, there were no major changes in cumulative particles compared to the baseline, but there was an increase in larger particles. During bronchoscopy and esophagoscopy, there was no substantial increase in cumulative particles. However, during the use of an ultrasonic aspirator, there was an increase in cumulative particles, and the greatest increase was observed in small particles. Jet ventilation anesthesia was not associated with a prominent change in aerosolized particles. The surgical event associated with the greatest increase in aerosolized particles was the use of a CO_2 laser. This supports laryngoscopy as an AGP and identifies surgical events that may be of greater concern to HCWs based on aerosol generation.

These studies demonstrate the variability in aerosol generation across surgical procedures. Certain procedures or processes within these procedures may result in elevated aerosol concentrations. The results underscore the importance of recognizing AGPs to minimize potential aerosol exposures for HCWs.

3.2.2 **Non-surgical Procedures**

Aerosols may be generated from patients during routine care without the manipulation of tissues (e.g., surgical procedures). The use of oxygen delivery systems, nebulizers, and suctioning required in tracheostomy care have been linked to aerosol generation. The potential to generate and disperse respiratory aerosols can contribute to the spread of infectious diseases. However, because the transmission risks associated with these procedures are generally unknown, PPE recommendations vary. To best protect HCWs, it is important to understand which procedures require higher levels of protection. This section examines literature related to potential non-surgical AGPs and includes two experimental studies, two review articles, two observational studies, and one case report.

In Berges et al. (2021), aerosolized particle generation was measured during simulated tracheostomy care on a manikin. An OPC, placed at a level approximate to a provider’s head, was used to measure aerosolized particles produced during simulated care, including during cough, airway nebulization, and open suctioning. Cough simulation was repeated to measure particle concentration at various HCW positions in a patient room. Particle concentration was also measured during tracheostomy open suctioning and nebulization.

The study found that coughing generated the highest concentration of particles, followed by open suctioning and airway nebulization. All measured locations showed an increase in aerosol particle concentrations during coughing events. Open suctioning and nebulization of the tracheostomy increased the amount of respirable aerosolized particles. Moreover, researchers discussed the potential of suctioning and nebulization to cause tracheal irritation and coughing, which in turn generate more aerosols. Open suctioning and nebulization of the tracheostomy are considered possible AGPs, and this study demonstrates that these procedures can increase the amount of respirable aerosolized particles as measured by an OPC.

Brown & Chan (2020) conducted a literature review to identify the evidence supporting chest compressions as an AGP and identify the gaps in knowledge contributing to inconsistencies in guidelines. The researchers reviewed eight studies that focused on the transmission of respiratory infections through chest compressions. These studies comprised one systematic review, one retrospective case-control study, one case study, one cross-sectional study, two retrospective cohort studies, and two non-peer-reviewed simulation studies.

Although CPR was found to be associated with disease transmission in HCWs (e.g. MERS, SARS) in all the peer-reviewed studies, it could not be definitively determined as the primary cause of transmission, as chest compressions were often performed in conjunction with other AGPs. The simulation study found that aerosols were visible during chest compressions and spread toward HCWs, but the experiment's model and methodology were flawed and unclear.

The evidence is not definitive on whether chest compressions generate aerosols. However, current evidence suggests chest compressions could potentially generate aerosols. There is insufficient evidence to suggest that chest compressions are not AGPs.

In Christian et al. (2004), researchers investigated a case of attempted CPR that may have resulted in a cluster of SARS-CoV infections in HCWs. In the case described, nine HCWs were present at the time of CPR. Although HCWs used either contact or droplet precautions and had a brief exposure, several AGPs were performed on the patient, which may have increased the likelihood of transmission. Interviews were conducted with the HCWs present during CPR, and serologic testing was performed on consenting providers (n=5). One out of the five HCWs tested positive for the virus.

Researchers described noninvasive positive pressure ventilation, intubation, and high-frequency oscillatory ventilation as procedures that had been previously associated with the aerosolization of SARS-CoV. In the reported case, the patient was ventilated with a bag-valve-mask without a bacterial/viral filter before being intubated without suctioning—no respiratory secretions were observed. Based on their investigation, the researchers concluded that there were two explanations for the observed transmission. The first was that the use of droplet precautions was not sufficient relative to the quantity of airborne viral particles present, and the second was that the coughing patient or asynchronous chest compressions and ventilations using the bag-valve-mask may have generated airborne viruses. This investigation highlights the potential danger that AGPs may pose to HCWs.

In Dhillon et al. (2021), researchers investigated aerosols generated during tracheal intubation and extubation in an operating theatre setting using particle image velocimetry and air sampling to observe the generation of large (>5 μm) and small aerosol particles (≤5 μm), respectively. This study sought to determine and characterize which intubation and extubation processes generated aerosols. The participants sampled were elective endonasal pituitary surgery patients (n=3), but sampling was not performed during the surgical procedure.

Prior to administering general anesthesia, researchers established a baseline by measuring particle concentrations during normal operating theatre movements. After positioning the patient on the operating table, oxygen was administered for three minutes while they breathed normally. Once the anesthesia was administered, the patient was given bag-mask ventilation before being intubated. At the end of the surgery, the tracheal tube was removed once the patient was breathing adequately and responding to commands.

Particle concentrations were found to be 12 times higher during tracheal intubation and extubation. During intubation, it was observed that passive oxygenation, laryngoscope introduction, and throat pack insertion did not result in an increase in aerosols when compared to the baseline. However, bag-mask ventilation, tracheal tube insertion, and cuff inflation were found to produce mostly small particles. Similarly, during extubation, the use of the laryngoscope, oropharyngeal suction, tracheal tube cuff deflation, and removal of the tube did not increase aerosol generation. The generation of small particles was observed from bag-mask ventilation, throat pack removal, and patient cough. The data demonstrates that tracheal intubation and extubation are AGPs. Among the steps involved, bag-mask ventilation and patient coughing generated aerosols multiple times over baseline. The researchers determined that their findings provide strong evidence that certain aspects of the intubation and extubation processes can generate more aerosols and highlight the need for appropriate safety measures.

Harding et al. (2020) conducted a review to summarize the evidence and identify any gaps related to the transmission of SARS-CoV-2 through AGPs. However, the researchers could not find any literature that directly addressed the potential for transmission. The researchers aggregated and described data related to potential AGPs that could be relevant in the context of viral transmission. The review provided an analysis of the data and findings from the literature on potential AGPs and rated the quality of evidence. The evidence used to support various procedures as AGPs was considered limited. The procedure with the strongest evidence was intubation.

The researchers observed that intubation, as described in six studies, demonstrates a substantial increase in transmission risk. Resuscitation procedures like CPR, manual ventilation, and tracheostomy are often associated with intubation, making them high-risk for infection transmission. Studies have not independently shown an association between manual ventilation and CPR with pathogen transmission.

The literature pertaining to the remaining procedures was limited in supporting them as AGPs. For bronchoscopy, while there is an observed increase in aerosol production during the procedure that raises concerns, there is limited evidence regarding transmission or infection risk. Exhaled viruses or aerosols have not been detected during non-invasive ventilation, and evidence indicating an elevated risk of respiratory infections is weak. While studies suggest potential droplet production and dispersion, there is insufficient evidence to confirm an associated infection risk for high-flow nasal cannulas or oxygen masks as AGPs. Research on nebulizer treatment's transmission risk is limited, lacking investigation into particle origin or virus isolation. Nasopharyngeal swabbing and sputum collection procedures suggest an increased infection risk through droplet transmission is likely due to coughing in close proximity, but no relationship exists with pathogen transmission. Additionally, there is no evidence supporting the generation of aerosols or an increased virus transmission risk during endoscopy or transoesophageal echocardiography.

Upon reviewing the existing literature, researchers concluded that the inconsistent classification of AGPs is most likely linked to insufficient evidence supporting these procedures. There is currently no consensus regarding which procedures pose a high risk of transmitting viral infections, indicating a gap in knowledge that might be endangering HCWs.

Ip et al. (2007), investigated the exhaled airflows produced by three different types of oxygen masks—simple, nonrebreathing, and Venturi-type masks. The study was carried out in a clean room (12 air changes per hour), using an artificial lung model that could simulate a spontaneously breathing patient. To capture and characterize the dispersal of exhaled airflows, smoke was injected into the lung model. Images of exhaled flows captured by a digital video camera were used to estimate the dispersal distance of aerosols from each mask, but the size of aerosols was not quantified.

Three respiratory models were developed to simulate different patient scenarios (i.e., varying respiration rates and tidal volumes). Respiration rates and tidal volumes for Model 1, Model 2, and Model 3 were 14 breaths/min and 500 mL, 24 breaths/min and 330 mL, and 30 breaths/min and 235 mL, respectively. The oxygen masks were fitted to respiratory models at varying flow rates between 6 and 15 L/min depending on the mask type.

The distances traveled by exhaled plumes depended on the mask type. The simple oxygen mask resulted in an estimated maximum dispersal distance of 20.7 ± 1.2 cm at a flow rate of 15 L/min. In comparison, the nonrebreathing oxygen mask had an estimated maximum dispersal distance of 35.8 ± 3.2 cm at a flow rate of 8 L/min. The Venturi-type mask, which had a flow rate of 6 L/min and 40% O2, had the longest estimated maximum dispersal distance of 39.7 ± 1.6 cm.

The results suggest that flow rate and mask type affect the dispersion distances of exhaled plumes; however, the researchers note that the visible “exhaled flows can only be a guide to the real behavior of infectious droplets in exhaled air” (Ip et al., 2007). This leads to the conclusion that the use of respiratory assist devices, such as oxygen masks, at high flow rates can result in the spread of infectious aerosols. This potential for infectious aerosols to as oxygen and air at high flow rates, the potential for increased transmissibility is evident. This may be considered an AGP.

In Millar & Moorhouse (2023), aerosol generation was measured using a particle counter during the delivery of continuous flow nitrous oxide (N_2O) for the sedation of pediatric patients. The study included 30 participants and all sedations were performed in the same procedure room using a closely fitted mask with a viral filter. The particle counter was placed at the head of the patient’s bed at a height approximate to standing staff members (1.45 m). Throughout the procedures, only patients remained unmasked.

Prior to patient entry, a baseline measurement was taken in the empty procedure room. The researchers measured aerosol particle counts when the patient entered the room, during the initial administration of N_2O, during the procedure, during the N_2O washout period with oxygen, after the mask was removed, and after the staff and patient had left the room. Compared to average baseline measurements, particle counts slightly increased when patients entered the room and remained relatively constant for the duration of the process. The researchers noted that higher levels during the procedure phase likely reflected staff movement. The predominant particle size of the average counts collected was 0.3 µm; moreover, the number of particles decreased as particle size increased. Based on these findings, the researchers determined that the particle counts that HCWs were exposed to during N_2O administration posed a low risk to providers.

Overall, the findings from these articles do not provide clarification regarding which non-surgical procedures have the potential to generate and transmit infectious aerosols. The evidence for most AGPs is not sufficient to prove or disprove potential risks for transmission.

4. DISCUSSION

The HICPAC guidelines differentiate between two types of infectious aerosol transmission: droplet and airborne transmission. Droplet transmission is defined by large infectious aerosols (>5 µm) that travel no more than 6 ft from an infected individual due to their size. In contrast, airborne transmission is distinguished by small infectious aerosols (≤5 µm) that can remain suspended in the air for an extended period of time, allowing them to travel further. Although evidence exists supporting overlap between these modes of transmission, such as the spread of droplet-transmitted pathogens like influenza through small aerosols, HICPAC holds firm on the distinction between droplet and airborne transmission and their respective precautions (HICPAC, 2023a).

The transmission of potentially infectious aerosols presents a considerable hazard to HCWs, particularly in patient care settings where they have little control over their exposures. This was made abundantly clear during the recent SARS-CoV-2 pandemic, where many procedures considered aerosol-generating were deemed high-risk to providers and avoided whenever possible. However, due to the lack of consensus regarding AGPs, there was no clear standard of which procedures were high-risk and required additional precautions (e.g., enhanced PPE). Therefore, it is necessary to have a thorough understanding of how infectious aerosols can spread and the processes and procedures that can increase the risk of exposure to such hazards.

This review evaluates the relationship between the identified studies and the prevailing guidelines governing PPE usage in healthcare settings. This analysis provides insights into the alignment between current research and established recommendations, identifying potential gaps or areas where further alignment is needed for effective infectious aerosol hazard mitigation in healthcare. However, it is important to note that this review does not take into account the practical considerations that may have informed the development of the guidelines.

The aims of this literature review included:

1) Characterizing the literature for infectious aerosol hazards in healthcare and their relevance and appropriateness to PPE, and

2) Describing the alignment, or lack thereof, of the literature with existing guidelines.

4.1 **Key Findings**

The process of aerosol generation and dispersion is dynamic and complex. While particle size can impact transmission, it is not the only factor that determines aerosol behavior. This is evident in the review conducted by Bahl et al. (2022), where several studies demonstrate that droplet-sized aerosols (sizes undefined) can travel distances greater than 6 ft and as far as 26 ft. This phenomenon is exemplified in the study conducted by Bischoff et al. (2013), where viral RNA was detected in samplers placed 6 ft away from patients positive for influenza during routine care (no AGPs were performed). Since influenza is classified as droplet transmission, the presence of viral RNA particles in collected samples suggests that HCWs may have been exposed to infectious aerosols beyond the distance associated with droplet transmission.

According to Bahl et al. (2022), Tang et al. (2006), and Zhang and Duchaine (2020), droplet-sized aerosols can evaporate and become smaller particles (i.e., droplet nuclei) that can transmit over long distances. In Rhee et al. (2022), Tang et al. (2006), and Zhang and Duchaine (2020), researchers discuss how breathing, talking, and sneezing naturally generate aerosols of various morphologies. That is, the particles produced by natural aerosol generation belong to a wide range of sizes. When considering the implication of these findings related to infectious particles, this suggests that different concentrations of infectious agents may be present in aerosols of all sizes. It suggests that the modes of transmission exist on a continuum, rather than as distinct categories. Together, these findings highlight the complex nature of aerosol dispersion and contribute to evidence of transmission overlap. Based on the findings from this literature review, there is limited scientific evidence supporting the dichotomy between droplet and airborne transmission. The evidence indicates that aerosol dispersion is not solely dictated by particle size. This is an important finding, as the perceived mode of transmission is a key factor in determining the selection and use of PPE by HCWs.

Healthcare workers who engage in patient care are inherently exposed to infectious aerosols and rely on PPE to mitigate the risk of contact with infectious agents. The studies conducted by Bischoff et al. (2013), Lindsley et al. (2018), Rule et al. (2018), Yan et al. (2021), and Yip et al. (2019) delineate the infectious aerosol hazards encountered by HCWs in the workplace, specifically regarding exposure during patient care. In Lindsley et al. (2018), researchers observed the dispersion of aerosols (0.3 to 7.5 μm) produced by a simulated patient cough. The aerosols quickly traveled in the direction of the cough before spreading throughout the entire space, suggesting that HCWs who are either in the path of the cough or in the room over time may be at a higher risk of exposure to patient-produced aerosols as they disperse in the environment.

The studies conducted by Bischoff et al. (2013), Rule et al. (2018), Yan et al. (2021), and Yip et al. (2019) illustrate the movement of aerosols generated by patients with confirmed viral illnesses, revealing the potential for HCWs to be exposed to infectious aerosols. Aerosol samples collected in proximity to patients with suspected or confirmed viral infections during patient care had detectable viral RNA (Bischoff et al., 2013; Rule et al., 2018; Yan et al., 2021; Yip et al., 2019). Influenza virus RNA was detected from aerosol samplers positioned ≥6 ft from positive patients, as observed in studies by Bischoff et al. (2013) and Yip et al. (2019). Additionally, HCWs in close proximity to patients had detectable viral RNA in their breathing zones (Yip et al., 2019), particularly those with frequent patient contact and who performed AGPs (Rule et al., 2018). In the study by Yan et al. (2021), viral RNA was detected in the air of negative pressure rooms housing SARS-CoV-2-positive patients, both intubated and not intubated, even in the absence of AGPs and with strict precautions in place. While these studies do not provide direct evidence of aerosolized viral RNA particles resulting in infectious disease transmission, their presence indicates the potential aerosolization of virus-laden particles.

Collectively, the findings of Bischoff et al. (2013), Lindsley et al. (2018), Rule et al. (2018), Yan et al. (2021), and Yip et al. (2019) contribute to the understanding of the potential for aerosol transmission of infectious agents from patients to HCWs. The aerosols emitted by patients in healthcare settings can disperse rapidly and expose HCWs. These insights underscore the role of adequate PPE in safeguarding HCWs against infectious disease hazards encountered in the workplace.

In the context of AGPs, the role of PPE is of particular importance as it protects HCWs from inhaling aerosolized particles, thus minimizing the risk of infection transmission in high-risk scenarios. The lack of consensus surrounding AGPs remains a notable challenge in the field of infection control and healthcare practices. While some procedures, such as intubation and tracheotomy, are widely recognized as AGPs, the inclusion of other procedures as AGPs is not universally agreed upon, as evident in the literature. This disagreement may be attributed to variations in study methodologies, as the data collection methods used were not standardized.

Through this review, evidence was identified in support of tracheostomy (Berges et al., 2021) and intubation and extubation (Dhillon et al., 2021; Harding et al., 2020) as AGPs. In procedures such as tracheostomy care and endonasal surgery, certain processes or instrument use were found to generate more aerosols. In endonasal surgery, drilling (Dharmarajan et al., 2020) and microdebrider use (Murr et al., 2021; Thamboo et al., 2020) were associated with increased aerosol generation. During tracheotomy, an open airway and cough production were associated with higher aerosol exposures compared to closed airways and only expiration, no cough (Loth et al., 2021). In surgical procedures, CO_2 laser use (Zheng et al., 2021) and electrocautery were found to generate more aerosols compared to the use of cold instrumentation (Berges et al., 2021; Thamboo et al., 2020). Procedures that demonstrated low aerosol generation were MT insertion (Campiti et al., 2021), orbital repair (Ye et al., 2021), and the administration of continuous flow nitrous oxide (Millar & Moorhouse, 2023).

There is limited evidence supporting that procedures like CPR and chest compressions can generate aerosols. It is difficult to determine if the procedure itself generates aerosols or if they are generated by related interventions, such as intubation (Brown & Chan, 2020; Christian et al., 2004; Harding et al., 2020). Oxygen delivery systems, such as masks, nasal cannulas, and non-invasive ventilation, have been considered as potentially aerosol-generating due to their ability to disperse aerosols (Ip et al., 2007). However, studies have not shown a clear increase in transmission risk associated with these procedures (Harding et al., 2020). In a review conducted by Harding et al. (2020), many procedures that were previously considered potentially aerosol-generating were called into question. According to the researchers' findings, there is limited evidence to support the classification of bronchoscopy, non-invasive ventilation, and tracheostomy, among other procedures, as AGPs (Harding et al., 2020). These procedures, which are generally considered high-risk, do not have strong evidence to support an association with increased transmission.

The HIPAC guidelines acknowledge bronchoscopy, endotracheal intubation, CPR, and open suctioning of the respiratory tract as AGPs (HICPAC, 2023a). However, as reinforced by the findings in this review, there is a lack of consensus on which medical procedures should be considered aerosol-generating or the level of risk these procedures pose in relation to transmission. This lack of agreement can contribute to inconsistent recommendations regarding the types of PPE HCWs should use during specific procedures. Establishing standardized protocols and comprehensive infection prevention strategies is challenging without consensus.

4.2 **Implications**

The hazards to HCWs associated with the transmission of potentially infectious aerosols are multifaceted. Exposure to these aerosols and the adequacy of PPE are critical factors that demand attention in infection prevention and control strategies. Achieving a thorough grasp of aerosol dispersion is essential for improving HCW protection and has important implications for practical applications in healthcare settings. Notably, the current HICPAC guidelines diverge from current evidence on aerosol transmission, revealing shortcomings in the dichotomy of droplet and airborne transmission. This review underscores the flaws in the existing classification and emphasizes the importance of implementing robust safety measures to ensure the well-being of HCWs. Considering these findings, it is reasonable to suggest that a reassessment of the current PPE guidance associated with transmission precautions is necessary to optimize HCW protection from infectious aerosols.

The lack of consensus regarding AGPs and their risk for disease transmission presents challenges for HCWs and PPE implementation. Varying interpretations of AGPs and inconsistent recommendations for PPE use during specific medical procedures not only impact the overall safety and well-being of healthcare professionals in the workplace but also impede the development of standardized protocols. This emphasizes the need for continued research and consensus-building efforts to enhance clarity and promote effective infection control measures in diverse healthcare settings.

At the time of this review, HICPAC is in the process of updating its infection prevention and control guidelines. The forthcoming *2024 Guideline to Prevent Transmission of Pathogens in Healthcare Settings*, will replace the 2007 HICPAC guidelines. However, it is important to note that there is concern among the professional community (i.e., HCWs, occupational health experts, aerosol scientists, infection preventionists, etc.) regarding the proposed new guidelines and their potential to weaken infection prevention and control strategies. One of the main changes in the new guidance is the recategorization of aerosol transmission precautions into three categories: Routine Air Precautions, Special Air Precautions, and Extended Air Precautions. Unfortunately, the new precautions largely maintain the disproven droplet-airborne transmission model. The recommendations for Respiratory and Extended Air Precautions are consistent with droplet and airborne precautions, respectively. Special Air Precautions reduce the established safeguards for HCWs regarding patient isolation, as they don't require an isolation room to minimize exposure to new respiratory pathogens. Although the changes proposed by the new guidance have yet to be approved, it is evident that little has been done to reduce the risk of infectious disease exposure to HCWs.

4.3 **Limitations**

The first limitation of this literature review was that it was not conducted according to a systematic methodology. It is important to approach the findings with care and recognize any potential gaps in the literature. Because this review does not follow a systematic methodology, reproducibility may be hindered.

Another limitation of this review is that it is probable that not all relevant studies were captured. Because the science related to aerosol dynamics spans multiple disciplines, it would be challenging to aggregate all the necessary terms to produce relevant literature. The literature is diverse, making it difficult to narrow the scope of the search. When refining the search parameters, several search iterations were conducted as the search concepts and keywords were modified. With each search iteration, the modifications made to the search may have omitted pertinent studies. Additionally, the literature identified in this review uses different data collection methods to sample and categorize aerosol particles. This includes defining aerosol sizes differently in the study interpretations, measuring aerosols at different sizes, and collecting samples at different proximities to patients and procedures. Despite the varying methodologies, the studies were equally compared in this literature review.

Finally, this literature review specifically addresses the scientific evidence related to infectious aerosol hazards, rather than focusing on epidemiological studies that examine factors related to disease-specific transmission. The scope of this review does not examine the dynamic nature of aerosol-transmitted diseases which also are also used to inform infection prevention guidelines. Neglecting epidemiological literature may overlook important practical implementation considerations.

5. CONCLUSION

Personal protective equipment is fundamental in preventing the spread of infectious agents to providers in healthcare settings. Healthcare workers rely on PPE to minimize potential exposures during patient care. Personal protective equipment selection is guided by documents like the 2007 HICPAC guidelines, so it is crucial that the evidence used to inform the development of recommendations is current.

The present literature review has identified a potential misalignment between the literature and the aerosol-related guidance provided by the 2007 HICPAC guidelines. This discrepancy may result in the improper selection of PPE for HCWs engaged in patient care, potentially exposing them to unnecessary risks associated with infectious aerosols. Moreover, the lack of consensus surrounding AGPs adds to the complexity, leaving the risk of transmission associated with these procedures largely unknown. There is a need for more research and guidance regarding the selection of PPE in healthcare settings to ensure the protection of HCWs.

This literature review aims to provide an overview of infectious aerosol control within healthcare settings. As the healthcare community navigates these uncertainties, it becomes imperative to bridge the gap between current evidence and guideline recommendations to establish more accurate and protective protocols for HCWs in the dynamic landscape of infectious disease transmission.

APPENDIX

TABLE XV
FULL-TEXT REVIEW EXCLUSIONS

Authors (Year) *Title*	Reason for Exclusion
Klompas et al. (2021) *Current Insights into Respiratory Virus Transmission and Potential Implications for Infection Control Programs: A Narrative Review*	Narrative review
Wilson et al. (2020) *Airborne Transmission of Severe Acute Respiratory Syndrome Coronavirus-2 to Healthcare Workers: A Narrative Review.*	Narrative review
Ling et al. (2022) *A Practical Approach to Defining Aerosol-Generating Procedures*	Not an article; "To the editor"
Subramaniam et al. (2021) *A Simulation Study Investigating the Spread of Water Droplets During Oxygen Therapy: Where is it Safe to Stand?*	Not an article; "To the editor"
Terp & Moran (2012) *Occupational Exposures in the Emergency Department*	Not an article; book section
Lindsley et al. (2020) *COVID-19 and the Workplace: Research Questions for the Aerosol Science Community*	Not an article; editorial
MacIntyre et al. (2020) *Current COVID-19 Guidelines for Respiratory Protection of Health Care Workers are Inadequate*	Opinion piece: Perspectives from the Medical Journal of Australia
Fennelly (2020) *Particle Sizes of Infectious Aerosols: Implications for Infection Control*	Opinion piece: Viewpoint from the Lancet

TABLE XIII (continued)
FULL-TEXT REVIEW EXCLUSIONS

Authors (Year) *Title*	Reason for Exclusion
Adhikari et al. (2019) *A Case Study Evaluating the Risk of Infection from Middle Eastern Respiratory Syndrome Coronavirus (MERS-CoV) in a Hospital Setting Through Bioaerosols*	Study design: Modeling MERS-CoV exposure scenario using Quantitative Microbial Risk Assessment to assess risks and interventions for HCWs, nurses, visitors, and other patients from a single index patient (no human subjects or simulations).
Jones (2020) *Relative Contributions of Transmission Routes for COVID-19 Among Healthcare Personnel Providing Patient Care*	Study design: Modeling of SARS-CoV-2 transmission to assess infection risk among HCWs caring for infectious patients, considering contact, droplet, and inhalation exposure (no human subjects or simulations).
Guo et al. (2022) *Visualization of the infection risk assessment of SARS-CoV-2 through aerosol and surface transmission in a negative-pressure ward.*	Study design: Modeling SARS-CoV-2 distribution in a negative-pressure ward to assess and manage infection risk using computational fluid dynamics (no human subjects or simulations).
Mac Giolla Eain et al. (2022) *Aerosol Release, Distribution, and Prevention During Aerosol Therapy: A Simulated Model for Infection Control*	Study intervention: Attaching a bacterial filter to a nebulizer to mitigate the release and spread of fugitive aerosols (no differentiation between treatment and simulated patient-produced aerosols) during aerosol therapy.
Verbeure et al. (2021) *Aerosol Generation and Droplet Spread During Nasogastric Intubation in the COVID-19 Era*	Study intervention: Quantifies aerosols produced by patients wearing a mask over their mouths to mitigate aerosol production during nasogastric intubation.
Dinsmore et al. (2021) *Efficacy of Various Facial Protective Equipment for Infection Control in a Healthcare Setting*	Study intervention: Tested the efficacy of face shields for droplet transmission.
Heymer et al. (2023) *Simulation of Aerosol and Droplet Spread during Upper Airway and Gastrointestinal Endoscopy*	Study intervention: Use of a barrier (i.e., plastic drape) during upper airway endoscopy to reduce aerosol dispersion during the procedure.

TABLE XIII (continued)
FULL-TEXT REVIEW EXCLUSIONS

Authors (Year) *Title*	Reason for Exclusion
Koehler et al. (2021) *Bronchoscopy Safety Precautions for Diagnosing COVID-19 Associated Pulmonary Aspergillosis—A Simulation Study*	Study outcome: Address contamination produced by simulated bronchoscopy in intubated patients, through PPE use by HCWs and covering the bronchoscope tube opening.
Soma et al. (2020) *Operative Team Checklist for Aerosol Generating Procedures to Minimise Exposure of Healthcare Workers to SARS-Cov-2*	Study outcome: An operative team checklist developed to minimize aerosol exposures during high-risk AGPs in the context of SARS-CoV-2, using guidance from various agencies and emerging literature.
Nicas (1995) *Respiratory Protection and the Risk of Mycobacterium Tuberculosis Infection*	Study outcome: Assess cumulative risk of TB to HCWs and efficacy of respiratory protection (i.e., particle penetration).
Cheng et al. (2015) *Infection Control Preparedness for Human Infection with Influenza a H7N9 in Hong Kong*	Study outcome: Assess infection control measures, including surveillance of HCWs, in response to H7N9 exposure.
Abdul Bari et al. (2023) *Assessment of the Occupational Risk of Tuberculosis & Air Borne Infection Control in High-Risk Hospital Wards and Its Implications on Healthcare Workers in a Tertiary Care Hospital in South India*	Study outcome: Assess the microbiological quality of hospital air and evaluate the related burden/risk of TB for HCWs based on deficient infection control practices.
Lescanne et al. (2020) *Best Practice Recommendations: ENT Consultations During the COVID-19 Pandemic*	Study outcome: Best practices for ENT consultations, office reception, advice to patients, and other SARS-CoV-2-related updates pertaining to medical practices.
Romano-Bertrand et al. (2021) *How to Address SARS-Cov-2 Airborne Transmission to Ensure Effective Protection of Healthcare Workers? A Review of the Literature*	Study outcome: Characterize infectious disease risks to HCWs posed by SARS-CoV-2 to inform mitigation strategies (understanding shedding, respirator/surgical mask use, environmental contamination, etc.)

TABLE XIII (continued)
FULL-TEXT REVIEW EXCLUSIONS

Authors (Year) *Title*	Reason for Exclusion
Lindsley et al. (2013) *A Cough Aerosol Simulator for the Study of Disease Transmission by Human Cough-Generated Aerosols*	Study outcome: Design and development of a cough simulator.
Park et al. (2004) *Lack of SARS Transmission Among Healthcare Workers, United States*	Study outcome: Examine exposure and transmission of SARS in the US by assessing unprotected and protected encounters (PPE use) between HCWs and infected patients, including infection-control practices.
Gamage et al. (2005) *Protecting health care workers from SARS and other respiratory pathogens: A review of the infection control literature*	Study outcome: Examine literature on factors influencing protection of HCWs from infectious hazards, considering factors at organizational and individual levels.
Lee et al. (2020) *Asymptomatic Carriage and Transmission of SARS-Cov-2: What Do We Know?*	Study outcome: Information regarding SARS-CoV-2 transmission for HCWs and measures to mitigate the risk of transmission.
Drewry et al. (2018) *Identifying Potential Provider and Environmental Contamination on a Clinical Biocontainment Unit Using Aerosolized Pathogen Simulants*	Study outcome: Measures simulated aerosol contamination within a biocontainment unit (room and donning and doffing areas) to better inform containment practices.
Porteous et al. (2016) *Resurgence of Vaccine-Preventable Diseases in the United States: Anesthetic and Critical Care Implications*	Study outcome: Provides information regarding vaccine-preventable diseases to clinicians who may be unfamiliar with progression of and/or treatment of described diseases.
Fawcett et al. (2023) *Transmission Risk of Severe Acute Respiratory Coronavirus Virus 2 (SARS-Cov-2) to Healthcare Personnel Following Unanticipated Exposure to Aerosol-Generating Procedures: Experience from Epidemiologic Investigations at an Academic Medical Center*	Study outcome: Retrospective assessment of AGPs performed by HCWs without respirators or eye protection on SARS-CoV-2 positive patients; does characterize aerosol production, proximity of HCWs, or transmission risk.

TABLE XIII (continued)
FULL-TEXT REVIEW EXCLUSIONS

Authors (Year) *Title*	Reason for Exclusion
Branch-Elliman et al. (2015) *Protecting the Frontline: Designing an Infection Prevention Platform for Preventing Emerging Respiratory Viral Illnesses in Healthcare Personnel*	Study outcome: Review of literature on preventing healthcare-associated transmission of emerging viral respiratory infections.
Silvers et al. (2022) *Re-Evaluating Our Language When Reducing Risk of SARS-Cov-2 Transmission to Healthcare Workers: Time to Rethink the Term, "Aerosol-Generating Procedures."*	Study outcome: Review of literature to evaluate AGPs as an independent risk of transmission to HCWs and the relevance for SARS-CoV-2.
Calisti (2020) *SARS-Cov-2: Exposure to High External Doses as Determinants of Higher Viral Loads and of Increased Risk for COVID-19. A Systematic Review of the Literature*	Study outcome: Review of SARS-CoV-2 literature informing the relationship between virus exposure, viral load, infection frequency, and disease severity.
Manzar et al. (2022) *Estimation of the Risk of COVID-19 Transmission Through Aerosol-Generating Procedures*	Study population/setting and intervention: Risk of SARS-CoV-2 transmission to dental healthcare professionals during AGPs and the efficacy of PPE.
Perdelli et al. (2008) *Evaluation of Contamination by Blood Aerosols Produced During Various Healthcare Procedures*	Study population/setting: Aerosol sampling during dental procedures, maxillofacial surgeries, and autopsies.
Rasmussen et al. (2021) *Occupational Risk of Exposure to Methicillin-Resistant Staphylococcus Aureus (MRSA) and the Quality of Infection Hygiene in Nursing Homes*	Study population/setting: Sampling for MRSA and MSSA in nursing homes and in the rooms of residents.

CITED LITERATURE

Abdul Bari, S., Sultana, Q., Jalily, Q. A., Dinesh Eshwar, M., & Dodda, S. (2023). Assessment of the Occupational Risk of Tuberculosis & Air Borne Infection Control in High-Risk Hospital Wards and Its Implications on Healthcare Workers in a Tertiary Care Hospital in South India. *Cureus*. https://doi.org/10.7759/cureus.33785

Adhikari, U., Chabrelie, A., Weir, M., Boehnke, K., McKenzie, E., Ikner, L., Wang, M., Wang, Q., Young, K., Haas, C. N., Rose, J., & Mitchell, J. (2019). A Case Study Evaluating the Risk of Infection from Middle Eastern Respiratory Syndrome Coronavirus (MERS-CoV) in a Hospital Setting Through Bioaerosols. *Risk Analysis*, *39*(12), 2608–2624. https://doi.org/10.1111/risa.13389

Bahl, P., Doolan, C., De Silva, C., Chughtai, A. A., Bourouiba, L., & Macintyre, C. R. (2022). Airborne or Droplet Precautions for Health Workers Treating Coronavirus Disease 2019? *Journal of Infectious Diseases*, *225*(9), 1561–1568. https://doi.org/10.1093/infdis/jiaa189

Berges, A. J., Lina, I. A., Ospino, R., Tsai, H.-W., Brenner, M. J., Pandian, V., Rule, A. M., & Hillel, A. T. (2021). Quantifying Viral Particle Aerosolization Risk during Tracheostomy Surgery and Tracheostomy Care. *JAMA Otolaryngology—Head Neck Surgery*, *147*(9), 797–803. https://doi.org/10.1001/jamaoto.2021.1383

Bischoff, W. E., Swett, K., Leng, I., & Peters, T. R. (2013). Exposure to influenza virus aerosols during routine patient care. *Journal of Infectious Diseases*, *207*(7), 1037–1046. https://doi.org/10.1093/infdis/jis773

Branch-Elliman, W., Price, C. S., McGeer, A., & Perl, T. M. (2015). Protecting the frontline: Designing an infection prevention platform for preventing emerging respiratory viral illnesses in healthcare personnel. *Infection Control and Hospital Epidemiology*, *36*(3), 336–345. https://doi.org/10.1017/ice.2014.52

Brown, E., & Chan, L. M. (2020). Should chest compressions be considered an aerosol-generating procedure? A literature review in response to recent guidelines on personal protective equipment for patients with suspected COVID-19. *Clinical Medicine*, *20*(5), E154–E159. https://doi.org/10.7861/CLINMED.2020-0258

Calisti, R. (2020). SARS-CoV-2: Exposure to high external doses as determinants of higher viral loads and of increased risk for COVID-19. A systematic review of the literature. *Epidemiology Prevention*, *44*(5–6), 152–159. https://doi.org/10.19191/EP20.5-6.S2.114

Campiti, V. J., Ye, M. J., Sharma, D., Matt, B. H., Mitchell, R. M., Ting, J. Y., Illing, E. A., Park, J. H., & Burgin, S. J. (2021). Aerosol Generation During Myringotomy With Tympanostomy Tube Insertion: Implications for Otolaryngology in the COVID-19 Era. *Otolaryngology—Head and Neck Surgery*, *165*(4), 532–535. https://doi.org/10.1177/0194599821989626

Cheng, V. C. C., Tai, J. W. M., Lee, W. M., Chan, W. M., Wong, S. C. Y., Chen, J. H. K., Poon, R. W. S., To, K. K. W., Chan, J. F. W., Ho, P. L., Chan, K. H., & Yuen, K. Y. (2015). Infection control preparedness for human infection with influenza a H7N9 in Hong Kong. *Infection Control and Hospital Epidemiology*, *36*(1), 87–92. https://doi.org/10.1017/ice.2014.2

Christian, M. D., Loutfy, M., McDonald, L. C., Martinez, K. F., Ofner, M., Wong, T., Wallington, T., Gold, W. L., Mederski, B., Green, K., Low, D. E., & on behalf of the SARS Investigation Team. (2004). Possible SARS Coronavirus Transmission during Cardiopulmonary Resuscitation. *Emerging Infectious Diseases*, *10*(2), 287–293. https://doi.org/10.3201/eid1002.030700

Dharmarajan, H., Freiser, M. E., Sim, E., Boorgu, D. S. S. K., Corcoran, T. E., Wang, E. W., Gardner, P. A., & Snyderman, C. H. (2021). Droplet and Aerosol Generation With Endonasal Surgery: Methods to Mitigate Risk During the COVID-19 Pandemic. *Otolaryngology—Head and Neck Surgery*, *164*(2), 285–293. https://doi.org/10.1177/0194599820949802

Dhillon, R. S., Rowin, W. A., Humphries, R. S., Kevin, K., Ward, J. D., Phan, T. D., Nguyen, L. V., Wynne, D. D., Scott, D. A., Yule, A., Zhao, Y. C., McNeill, P. M., & Hutchins, N. (2021). Aerosolisation during tracheal intubation and extubation in an operating theatre setting. *Anaesthesia*, *76*(2), 182–188. https://doi.org/10.1111/anae.15301

Dinsmore, J., Brands, S., Perry, S., Lopez, M., Dong, Y., Palasz, D., & Tucker, J. (2021). Efficacy of Various Facial Protective Equipment for Infection Control in a Healthcare Setting. *Western Journal of Emergency Medicine*, *22*(5), 1045–1050. https://doi.org/10.5811/westjem.2021.3.50516

Drewry, D. G., Sauer, L. M., Shaw-Saliba, K., Therkorn, J., Rainwater-Lovett, K., Pilholski, T., & Garibaldi, B. T. (2018). Identifying potential provider and environmental contamination on a clinical biocontainment unit using aerosolized pathogen simulants. *Health Security*, *16*(2), 83–91. https://doi.org/10.1089/hs.2017.0064

Fawcett, S. E., Madhusudhan, M. S., Gaddam, E. N., Almario, M. J., Masih, S. R., Klute-Evans, D. D., Johnson, J. C., Stroud, C. D., Dolan-Caren, J. A., Ben-Aderet, M. A., Luria, J., Morgan, M. A., Vail, E., & Grein, J. D. (2023). Transmission risk of severe acute respiratory coronavirus virus 2 (SARS-CoV-2) to healthcare personnel following unanticipated exposure to aerosol-generating procedures: Experience from epidemiologic investigations at an academic medical center. *Infection Control and Hospital Epidemiology*, *44*(2), 325–327. https://doi.org/10.1017/ice.2021.472

Fennelly, K. P. (2020). Particle sizes of infectious aerosols: Implications for infection control. *Lancet Respiratory Medicine*, *8*(9), 914–924. https://doi.org/10.1016/S2213-2600(20)30323-4

Gamage, B., Moore, D., Copes, R., Yassi, A., & Bryce, E. (2005). Protecting health care workers from SARS and other respiratory pathogens: A review of the infection control literature. *American Journal of Infection Control*, *33*(2), 88–96. https://doi.org/10.1016/j.ajic.2004.11.003

Guderian, D. B., Loth, A. G., Weiß, R., Diensthuber, M., Stöver, T., & Leinung, M. (2021). In vitro comparison of surgical techniques in times of the SARS-CoV-2 pandemic: Electrocautery generates more droplets and aerosol than laser surgery or drilling. *European Archives of Oto-Rhino-Laryngology*, *278*(4), 1237–1245. https://doi.org/10.1007/s00405-020-06330-y

Guo, W., Fu, Y., Jia, R., Guo, Z., Su, C., Li, J., Zhao, X., Jin, Y., Li, P., Fan, J., Zhang, C., Qu, P., Cui, H., Gao, S., Cheng, H., Li, X., Lu, B., Xu, X., & Wang, Z. (2022). Visualization of the infection risk assessment of SARS-CoV-2 through aerosol and surface transmission in a negative-pressure ward. *Environment International*, *162*. https://doi.org/10.1016/j.envint.2022.107153

Harding, H., Broom, A., & Broom, J. (2020). Aerosol-generating procedures and infective risk to healthcare workers from SARS-CoV-2: The limits of the evidence. *Journal of Hospital Infection*, *105*(4), 717–725. https://doi.org/10.1016/j.jhin.2020.05.037

Heymer, J., Dengler, F., Krohn, A., Jaki, C., Schilling, T., Mueller-Schilling, M., Kandulski, A., & Ott, M. (2023). Simulation of Aerosol and Droplet Spread during Upper Airway and Gastrointestinal Endoscopy. *Digestive Diseases*, *41*(1), 148–153. https://doi.org/10.1159/000525482

HICPAC [Healthcare Infection Control Practices Advisory Committee]. (2023a). *2007 Guideline for Isolation Precautions: Preventing Transmission of Infectious Agents in Healthcare Settings*. U.S. Department of Health & Human Services, Centers for Disease Control and Prevention. https://www.cdc.gov/infectioncontrol/guidelines/isolation/index.html

HICPAC. (2023b, December 18). *Healthcare Infection Control Practices Advisory Committee (HICPAC)*. https://www.cdc.gov/hicpac/index.html

Hock, R. (2016). Search Engines. In P. A. Laplante (ed.), *Encyclopedia of Information Systems and Technology*. Taylor and Francis.

Hospital Infection Control Practices Advisory Committee. (1996). *Guideline for Isolation Precautions in Hospitals*. U.S. Department of Health & Human Services, Centers for Disease Control and Prevention. https://stacks.cdc.gov/view/cdc/23188

Ip, M., Tang, J. W., Hui, D. S. C., Wong, A. L. N., Chan, M. T. V., Joynt, G. M., So, A. T. P., Hall, S. D., Chan, P. K. S., & Sung, J. J. Y. (2007). Airflow and droplet spreading around oxygen masks: A simulation model for infection control research. *American Journal of Infection Control*, *35*(10), 684–689. https://doi.org/10.1016/j.ajic.2007.05.007

Jones, R. M. (2020). Relative contributions of transmission routes for COVID-19 among healthcare personnel providing patient care. *Journal of Occupational and Environmental Hygiene*, 408–415. https://doi.org/10.1080/15459624.2020.1784427

Klompas, M., Milton, D. K., Rhee, C., Baker, M. A., & Leekha, S. (2021). Current Insights Into Respiratory Virus Transmission and Potential Implications for Infection Control Programs: A Narrative Review. *Annals of Internal Medicine*, *174*(12), 1710–1718. https://doi.org/10.7326/M21-2780

Koehler, P., Cornely, O. A., & Kochanek, M. (2021). Bronchoscopy safety precautions for diagnosing COVID-19 associated pulmonary aspergillosis—A simulation study. *Mycoses*, *64*(1), 55–59. https://doi.org/10.1111/myc.13183

Lee, S., Meyler, P., Mozel, M., Tauh, T., & Merchant, R. (2020). Asymptomatic carriage and transmission of SARS-CoV-2: What do we know? *Canadian Journal of Anesthesia*, *67*(10), 1424–1430. https://doi.org/10.1007/s12630-020-01729-x

Lescanne, E., van der Mee-Marquet, N., Juvanon, J.-M., Abbas, A., Morel, N., Klein, J.-M., Hanau, M., & Couloigner, V. (2020). Best practice recommendations: ENT consultations during the COVID-19 pandemic. *European Annals of Otorhinolaryngology, Head and Neck Diseases*, *137*(4), 303–308. https://doi.org/10.1016/j.anorl.2020.05.007

Lindsley, W. G., Blachère, F. M., Burton, N. C., Christensen, B., Estill, C. F., Fisher, E. M., Martin, S. B., Mead, K. R., Noti, J. D., & Seaton, M. (2020). COVID-19 and the workplace: Research questions for the aerosol science community. *Aerosol Science and Technology*, *54*(10), 1117–1123. https://doi.org/10.1080/02786826.2020.1796921

Lindsley, W. G., King, W. P., Thewlis, R. E., Reynolds, J. S., Panday, K., Cao, G., & Szalajda, J. V. (2012). Dispersion and exposure to a cough-generated aerosol in a simulated medical examination room. *Journal of Occupational and Environmental Hygiene*, *9*(12), 681–690. https://doi.org/10.1080/15459624.2012.725986

Lindsley, W. G., Reynolds, J. S., Szalajda, J. V., Noti, J. D., & Beezhold, D. H. (2013). A cough aerosol simulator for the study of disease transmission by human cough-generated aerosols. *Aerosol Science and Technology*, *47*(8), 937–944. https://doi.org/10.1080/02786826.2013.803019

Ling, M. L., Cook, A. R., Marimuthu, K., Pada, S., Ang, B., Thoon, K. C., Foo, M. L., Ong, X. Y., Young, A., & Fisher, D. (2022). A practical approach to defining aerosol-generating procedures. *Infection Control and Hospital Epidemiology*, *43*(8), 1083–1084. https://doi.org/10.1017/ice.2021.184

Loth AG, Guderian DB, Haake B, Zacharowski K, Stöver T, & Leinung M. (2021). Aerosol Exposure During Surgical Tracheotomy in SARS-CoV-2 Positive Patients. *Shock*, *55*(4), 472–478. https://doi.org/10.1097/SHK.0000000000001655

Mac Giolla Eain, M., Cahill, R., MacLoughlin, R., & Nolan, K. (2022). Aerosol release, distribution, and prevention during aerosol therapy: A simulated model for infection control. *Drug Delivery*, *29*(1), 10–17. https://doi.org/10.1080/10717544.2021.2015482

MacIntyre, C. R., Ananda-Rajah, M., Nicholls, M., & Quigley, A. L. (2020). Current COVID-19 guidelines for respiratory protection of health care workers are inadequate. *Medical Journal of Australia*, *213*(6), 251-252.e1. https://doi.org/10.5694/mja2.50752

Manzar, Dr. S., Kazmi, Prof. F., Shahzad, Dr. H. B., Qureshi, Dr. F. A., Shahbaz, M., & Rashid, Dr. S. (2022). Estimation of the risk of COVID-19 transmission through aerosol-generating procedures. *Dental and Medical Problems*, *59*(3), 351–356. https://doi.org/10.17219/dmp/149342

Millar, R., & Moorhouse, A. (2023). Aerosol generation during paediatric procedural sedation with continuous-flow nitrous oxide suggests a low risk of airborne viral transmission to health-care workers. *Journal of Paediatrics and Child Health*, *59*(1), 123–128. https://doi.org/10.1111/jpc.16258

Murr, A., Lenze, N. R., Brown, W. C., Gelpi, M. W., Ebert, C. S., Senior, B. A., Thorp, B. D., Zanation, A. M., & Kimple, A. J. (2021). Quantification of Aerosol Particle Concentrations During Endoscopic Sinonasal Surgery in the Operating Room. *American Journal of Rhinology and Allergy*, *35*(4), 426–431. https://doi.org/10.1177/1945892420962335

Nicas, M. (1995). Respiratory protection and the risk of Mycobacterium tuberculosis infection. *American Journal of Industrial Medicine*, *27*(3), 317–333. https://doi.org/10.1002/ajim.4700270302

Park, B. J., Peck, A. J., Kuehnert, M. J., Newbern, C., Smelser, C., Comer, J. A., Jernigan, D., & McDonald, L. C. (2004). Lack of SARS Transmission among Healthcare Workers, United States. *Emerging Infectious Diseases*, *10*(2), 217–224. https://doi.org/10.3201/eid1002.030793

Perdelli, F., Spagnolo, A. M., Cristina, M. L., Sartini, M., Malcontenti, R., Dallera, M., Ottria, G., Lombardi, R., & Orlando, P. (2008). Evaluation of contamination by blood aerosols produced during various healthcare procedures. *Journal of Hospital Infection*, *70*(2), 174–179. https://doi.org/10.1016/j.jhin.2008.06.012

Porteous, G. H., Hanson, N. A., Sueda, L. A. A., Hoaglan, C. D., Dahl, A. B., Ohlson, B. B., Schmidt, B. E., Wang, C. C., & Fagley, R. E. (2016). Resurgence of Vaccine-Preventable Diseases in the United States: Anesthetic and Critical Care Implications. *Anesthesia and Analgesia*, *122*(5), 1450–1473. https://doi.org/10.1213/ANE.0000000000001196

Rasmussen, P. U., Uhrbrand, K., Bartels, M. D., Neustrup, H., Karottki, D. G., Bültmann, U., & Madsen, A. M. (2021). Occupational risk of exposure to methicillin-resistant Staphylococcus aureus (MRSA) and the quality of infection hygiene in nursing homes. *Frontiers of Environmental Science and Engineering*, *15*(3). https://doi.org/10.1007/s11783-020-1333-y

Rhee, C., Baker, M. A., & Klompas, M. (2022). Prevention of SARS-CoV-2 and respiratory viral infections in healthcare settings: Current and emerging concepts. *Current Opinion in Infectious Diseases*, *35*(4), 353–362. https://doi.org/10.1097/QCO.0000000000000839

Romano-Bertrand, S., Carré, Y., Aho Glélé, L.-S., & Lepelletier, D. (2021). How to address SARS-CoV-2 airborne transmission to ensure effective protection of healthcare workers? A review of the literature. *Infectious Diseases Now, 51*(5), 410–417. https://doi.org/10.1016/j.idnow.2021.05.005

Rule, A. M., Apau, O., Ahrenholz, S. H., Brueck, S. E., Lindsley, W. G., de Perio, M. A., Noti, J. D., Shaffer, R. E., Rothman, R., Grigorovitch, A., Noorbakhsh, B., Beezhold, D. H., Yorio, P. L., Perl, T. M., & Fisher, E. M. (2018). Healthcare personnel exposure in an emergency department during influenza season. *PLoS ONE, 13*(8). https://doi.org/10.1371/journal.pone.0203223

Silvers, A., Brewster, D. J., Ford, A., Licina, A., Andrews, C., & Adams, M. (2022). Re-evaluating our language when reducing risk of SARS-CoV-2 transmission to healthcare workers: Time to rethink the term, "aerosol-generating procedures." *Virology Journal, 19*(1), 189. https://doi.org/10.1186/s12985-022-01910-2

Soma, M., Jacobson, I., Brewer, J., Blondin, A., Davidson, G., & Singham, S. (2020). Operative team checklist for aerosol generating procedures to minimise exposure of healthcare workers to SARS-CoV-2. *International Journal of Pediatric Otorhinolaryngology*, *134*. https://doi.org/10.1016/j.ijporl.2020.110075

Subramaniam, J., Meeks, D., Forbes, A., Wong, D. J. N., Ward, C., & McKechnie, A. (2021). A simulation study investigating the spread of water droplets during oxygen therapy: Where is it safe to stand? *Canadian Journal of Anesthesia, 68*(9), 1448–1449. https://doi.org/10.1007/s12630-021-02003-4

Tang, J. W., Li, Y., Eames, I., Chan, P. K. S., & Ridgway, G. L. (2006). Factors involved in the aerosol transmission of infection and control of ventilation in healthcare premises. *Journal of Hospital Infection*, *64*(2), 100–114. https://doi.org/10.1016/j.jhin.2006.05.022

Terp, S. & Moran, G. J. (2012). Occupational exposures in the emergency department. In S. V. Mahadevan & G. M. Garmel (Eds.), *An Introduction to Clinical Emergency Medicine* (2nd ed., pp. 697-705). Cambridge University Press. https://doi.org/10.1017/CBO9780511852091.058

Thamboo, A., Lea, J., Sommer, D. D., Sowerby, L., Abdalkhani, A., Diamond, C., Ham, J., Heffernan, A., Cai Long, M., Phulka, J., Wu, Y. Q., Yeung, P., & Lammers, M. (2020). Clinical evidence based review and recommendations of aerosol generating medical procedures in otolaryngology – head and neck surgery during the COVID-19 pandemic. *Journal of Otolaryngology-Head & Neck Surgery*, *49*(1), 28. https://doi.org/10.1186/s40463-020-00425-6

Verbeure, W., Geeraerts, A., Huang, I.-H., Timmermans, L., Toth, J., Geysen, H., Cools, L., Carbone, F., Schol, J., Devriese, H., Haesaerts, R., Mori, H., Vanuytsel, T., & Tack, J. (2021). Aerosol generation and droplet spread during nasogastric intubation in the COVID-19 era. *Gut*, *70*(10), 2017–2019. https://doi.org/10.1136/gutjnl-2020-323836

Wilson, N. M., Norton, A., Young, F. P., & Collins, D. W. (2020). Airborne transmission of severe acute respiratory syndrome coronavirus-2 to healthcare workers: A narrative review. *Anaesthesia*, *75*(8), 1086–1095. https://doi.org/10.1111/anae.15093

Yan, K., Lin, J., Albaugh, S., Yang, M., Wang, E., Cyberski, T., Abasiyanik, M. F., Wroblewski, K. E., O'Connor, M., Klock, A., Tung, A., Shahul, S., Kurian, D., Tay, S., & Pinto, J. M. (2022). Measuring SARS-CoV-2 aerosolization in rooms of hospitalized patients. *Laryngoscope Investigative Otolaryngology*, *7*(4), 1033–1041. https://doi.org/10.1002/lio2.802

Ye, M. J., Vadhul, R. B., Sharma, D., Campiti, V. J., Burgin, S. J., Illing, E. A., Ting, J. Y., Park, J. H., Koehler, K. R., Lee, H. B., Vernon, D. J., Johnson, J. D., Nesemeier, B. R., & Shipchandler, T. Z. (2021). Aerosol and droplet generation from orbital repair: Surgical risk in the pandemic era. *American Journal of Otolaryngology*, *42*(4). https://doi.org/10.1016/j.amjoto.2021.102970

Yip, L., Finn, M., Granados, A., Prost, K., McGeer, A., Gubbay, J. B., Scott, J., & Mubareka, S. (2019). Influenza virus RNA recovered from droplets and droplet nuclei emitted by adults in an acute care setting. *Journal of Occupational and Environmental Hygiene*, *16*(5), 341–348. https://doi.org/10.1080/15459624.2019.1591626

Zhang, X. S., & Duchaine, C. (2020). SARS-CoV-2 and health care worker protection in low-risk settings: A review of modes of transmission and a novel airborne model involving inhalable particles. *Clinical Microbiology Reviews*, *34*(1), 1–29. https://doi.org/10.1128/CMR.00184-20

Zheng, M., Lui, C., O'Dell, K., M. Johns, M., Ference, E. H., & Hur, K. (2021). Aerosol Generation During Laryngology Procedures in the Operating Room. *Laryngoscope*, *131*(12), 2759–2765. https://doi.org/10.1002/lary.29729

VITA

NAME:	Marina V Tecuanhuey
EDUCATION:	B.A., Public Health, University of Illinois Chicago, Chicago, Illinois, 2021
	M.S., Public Health Sciences, University of Illinois Chicago, Chicago, Illinois, 2024
PROFESSIONAL MEMBERSHIP:	American Society of Safety Professionals American Industrial Hygiene Association