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A Scoping Review of Fomites in Surgery Theaters and Intensive Care Units of Healthcare Facilities in Middle-Income Countries

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Abstract

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By

Tzuhsuan Peng

Background: Health care-associated infections (HCAIs) pose a substantial burden to healthcare systems and patient safety worldwide. This burden is even more critical in low- and middle-income countries (LMICs). While surgical site infection remains the most common type of HCAIs, critically ill patients in the intensive care unit (ICU) are also subject to HCAIs. A higher HCAI rate in LMICs is attributed to inadequate infection prevention and control (IPC) at healthcare facilities. Fomites, or inanimate objects that can carry pathogens, are often overlooked in IPC and decontamination instruction. As a result, this thesis aims to search the scientific literature to identify potential fomites in surgery theaters and ICUs that may serve as sources of pathogens related to HCAIs in order to inform and improve the World Health Organization's IPC guidelines.

Methods: A scoping review was conducted to search PubMed, Embase, and CINAHL databases for articles published before February 2021, written in English, and available for abstract. Four main keywords were used for the database search: HCAI, ICU or surgery theater, fomite, and names of middle-income countries. Abstract and title were screened first using inclusion criteria, and subsequently, full texts were evaluated for final inclusion based on exclusion criteria.

Results: The initial database search yielded 241 articles. Of the 45 articles that satisfied the inclusion criteria, eight and 37 studies were carried out in surgery theaters and ICUs, respectively. Multiple medical equipment and supplies (laryngoscopes, suction tips, trolleys, incubators, beds, etc.), environmental surfaces (floor, sinks, tables, operation lamps, etc.), and personal items (mobile phones, clothes, etc.) were found as potential fomites that may threaten HCAI prevention and control. The main transmission routes of pathogens from a fomite to a patient were direct contact and indirect contact through health workers' hands or gloves that touched the fomite.

Conclusions: Various fomites that may be involved in HCAIs were reported. Recommendations for the World Health Organization's IPC guidelines include monitoring bacterial resistance to disinfectants; coming to a consensus regarding the reuse of single-use medical devices; developing protocols for regular cleaning of personal items; and developing a policy on restricting mobile phone usage in theatres and ICUs.

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Abbreviations

BSI	Bloodstream infection
CD	Cesarean delivery
CDC	Centers for Disease Control and Prevention
CR-UTI	Catheter-related urinary tract infection
CR-BSI	Catheter-related bloodstream infection
ECG	Electrocardiogram
ESBL	Extended spectrum beta lactamase
HCAI	Health care-associated infection
HIC	High-income country
HCAP	Health care-associated pneumonia
ICU	Intensive care unit
IPC	Infection prevention and control
IRB	Institutional Review Board
LOS	Length of stay
LMICs	Low- and middle-income countries
MIC	Middle-income country
NICU	Neonatal intensive care unit
PVC	Peripheral venous catheter
PICU	Pediatric intensive care unit
SSI	Surgical site infection
U.S.	United States
VAP	Ventilator-associated pneumonia

Chapter 1: Introduction

Health care-associated infections (HCAIs) pose a substantial burden for the healthcare system and patient safety globally. It is an infection that is acquired during a patient's stay at the healthcare facility and is not present or incubating at the time of admission.[1] HCAIs have affected approximately 1.7 million and 3.8 million patients per year in the United States and 31 European countries, respectively.[2,3] HCAIs result in increased length of stay (LOS) in a healthcare facility and additional health care costs.[4–10] Moreover, HCAIs cause higher morbidity and higher mortality rates.[5,11–13]

Surgical site infection (SSI) has been reported as the most common type of HCAI.[14,15] SSIs accounted for 21.8% and 19.6% of all HCAIs in the United States and in 33 European countries and are associated with high mortality.[16,17] For example, Lamarsalle et al.[18] demonstrated that the mortality rate was about four times higher among patients in France who suffered from SSIs compared to those without SSIs.

Further, during the follow up period after surgeries, patients are often placed in intensive care units (ICUs). Globally, the prevalence of HCAIs in ICUs was higher than in other hospital departments regardless of a country's economics.[19] Patients who are admitted to ICUs are more susceptible to HCAIs because of the critical illness, having a weaker immune system, receiving more invasive procedures, and higher use of multiple courses of antibiotics.[20,21] Moreover, life-threatening complications, such as severe sepsis and septic shock, are more likely to occur in patients experiencing ICU-acquired infections.[22,23] Therefore, the mortality rate of ICU patients who acquire HCAIs is typically higher than uninfected ICU patients.[21]

The burden of HCAIs is even more critical in low- and middle-income countries (LMICs).[24] Allegranzi et al.[14] reported that, in LMICs, the pooled prevalence of patients with HCAIs was 13.5 per 100 patients, and the incidence of HCAI was 34.7 in every 100 patients in ICUs. Despite a lower device utilization rate in ICUs in LMICs, including mechanical ventilators, urinary catheters, and central venous catheters, the rate of device-related HCAIs in LMICs was 2 to 4.5 times higher than in a high-income country (HIC).[25] Additionally, SSI incidence is also higher in the LMICs, where cesarean delivery (CD) is the most common surgical procedure.[14,26,27] In fact, the four greatest CD rates worldwide were found in middle-income countries (MICs): Bangladesh, Egypt, Dominican Republic, and Brazil. The CD rates in these countries were higher than 55%.[28] Considering the high number of surgical procedures such as CDs in MICs, the risk of HCAI is substantial and needs to be properly addressed and prevented.

Health Care-Associated Infection Prevention and Control

It is established that a higher HCAI rate in LMICs is attributed to inadequate or lack of infection prevention and control (IPC) practices related to poor IPC infrastructure, supplies and resources, staff shortages, and absence of guidelines and surveillance.[29–34] A study that analyzed IPC practices in six LMICs[34] reported improper sterilization and disinfection of equipment due to a lack of standard operating procedures and thus urged the implementation of environmental infection control guidelines to stop the spread of HCAI.

Environmental contamination has been highlighted as having a crucial role in the control and prevention of HCAIs.[35] Herein, the U.S. Centers for Disease Control and Prevention (CDC) published a set of guidelines for environmental infection control and disinfection and sterilization as two areas of basic IPC practice.[36] The IPC guidelines from the World Health Organization (WHO) also emphasize the practice of environmental cleaning and decontamination of patient care

equipment. However, when examining the WHO guidelines,[37,38] it only focuses on decontamination of reusable medical devices. Other potential sources of pathogens from the environment that may threaten IPC are often overlooked in the disinfection instruction. In specific, ***fomites***, such as non-medical equipment (medical charts, computer keyboard, trolley, doorknob, light switch, etc.) and personal items from health workers or patients (e.g., toy), are often overlooked and require attention and protocols for disinfection.[39]

Fomites are any inanimate objects or materials that can carry pathogens. The occurrence of pathogens and fomites in different healthcare departments have been recorded in the literature.[39–43] However, which potential fomites in the ICU and surgery theater play a role in the development of HCAIs have not yet been fully reviewed and analyzed. Therefore, there is a need to search the scientific literature to identify potential fomites in surgery theaters and ICUs in order to improve IPC guidelines and address this potential source of pathogens related to HCAIs.

To reduce the HCAI rate, especially in MICs, this thesis will pinpoint major inanimate objects or materials (fomites) that have been reported in peer-reviewed literature as a source of pathogens involved in HCAI in ICUs and surgery theaters of MICs. The research questions for this thesis include:

1. What kinds of fomites facilitate the transmission of pathogens in ICUs and surgery theaters of MICs?
2. What are the potential transmission routes of different fomites that have been documented in ICUs and surgery theaters?
3. What are recommendations for IPC practices that can fill in the gap of the aforementioned WHO IPC guidelines?

Chapter 2: Literature Review

Definitions and Types of Health Care-Associated Infections (HCAIs)

The U.S. CDC has been standardizing definitions of different types of nosocomial infection since 1988 to enhance surveillance and infection control.[44] Nosocomial infection is an infection that is acquired after hospital admission and also includes an infection that was obtained in the hospital and presents after hospital discharge.[44] In 2008, the CDC[1] updated the term to "health care-associated infection (HAI or HCAI), which was defined as "a localized or systemic condition resulting from an adverse reaction to the presence of an infectious agent(s) or its toxin(s)." Most importantly, it must be an infection that is present or incubating after admission to an acute care setting.[1]

Over time the definition of HAIs evolved. With increases in outpatient care, Yardena et al.[45] made the first proposal of combining community-acquired infection and nosocomial infection (hospital-acquired) into the definition. A prospective study by Friedman et al.[46] also proposed to redefine health care-associated bloodstream infections (BSI) in order to improve antibiotic administration and monitor both community-acquired and nosocomial infections. Specifically, Friedman et al.[46] extended the definition to include infections present at hospital admission or within 48 hours of admission in cases where patients received community health care, hemodialysis or intravenous chemotherapy in the 30 days before the infection, admitted in an acute care hospital for at least 2 days in the 90 days before the infection as well as lived in a long-term care facility. These new criteria have been widely used in other studies, as demonstrated in a systematic review of HCAI definitions.[47] The review[47] suggested considering adding receipt of recent invasive procedures or broad-spectrum antibiotics as one of the criteria. The review also showed that definitions of HCAI in different settings or countries still vary.[47,48]

There are various types of HCAI. The common types are health care-associated catheter-related urinary tract infection (CR-UTI), ventilator-associated pneumonia (VAP), health care-associated pneumonia (HCAP), catheter-related bloodstream infection (CR-BSI), and SSI.[14,49–51] According to the U.S. CDC National Healthcare Safety Network's manual,[52] CR-UTI is a symptomatic UTI that the patient had used an indwelling urinary catheter for more than two successive days in an inpatient setting and has a urine culture with a bacterium. VAP is pneumonia that develops when a patient has been using mechanical ventilation for more than two days.[52] HCAP as defined by Kollef et al.[53] refers to pneumonia with positive bacterial respiratory culture finding within two days of admission that does not meet VAP definition; and that the patient was transferred from another healthcare facility, receiving long-term hemodialysis, or hospitalized within 30 days. CR-BSI is an infection where an intravascular catheter is the source of infection confirmed by a laboratory test.[51] Finally, SSIs are surgical site infections that will be discussed in the following section.

Burden of HCAI

HCAIs affect millions of patients every year regardless of the economic development status in a country. Burke[49] summarized that approximately two million patients acquire an HCAI each year in the United States. Kärki et al.[54] also estimated that 3.8 million patients acquire an HCAI each year in the European Union and European Economic Area, where the prevalence of HCAI in acute care hospitals was 6.5%. A point prevalence survey conducted in the United States[17] reported that 4% of patients had at least one HCAI. In Africa, a systematic review[55] found that the hospital-wide HCAI prevalence ranged from 2.5% and 14.8%. In other systematic review and meta-analysis studies,[14,56] the pooled prevalence of overall HCAI was reported 9% in Southeast Asia and 10.1%

in developing countries. Although a high variation of HCAI prevalence was noted from studies in developing countries, the high burden of HCAI is quite striking compared to developed countries.[14]

HCAI is a leading cause of increased hospital LOS and additional healthcare costs.[57–59] A meta-analysis study[10] reported the annual extra costs for HCAIs were $9.8 billion in total in the United States. Similarly, a German hospital surveillance study[60] showed that total extra costs for patients with HCAIs varied between $7,453 and $15,155 per case, depending on the disease progression. This study also revealed additional LOS was approximately eight days. Other studies[57,59,61] that examine extra LOS and costs by a specific type of HCAI or a specific hospital department in HICs reported similar findings. That is, HCAI attributes to prolonged hospital stays and additional healthcare costs.

The relevant literature regarding the extra LOS and associated costs for HCAI was less in LMICs. In Argentina, a MIC, a prospective matched case-control study[62] reported an extra LOS for nine days on average and an additional cost of $2,238 per case in ICUs among those who had an HCAP compared to non-infected patients. Likewise, patients with an HCAI were found to have extra mean LOS and hospital costs of 12.73 days and $3,510, respectively, in a tertiary hospital in Thailand—another MIC.[63] A recent study[64] that used the multi-state model for analysis found extra LOS of only 2.56 days in a tertiary hospital of China, a third MIC.

Additionally, HCAI is a significant cause of morbidity and mortality.[2,49,58,65,66] A seven-years repeated cross-sectional study from Norway,[67] a HIC, reported that the mortality rate of patients with an HCAI within 30 days and a year was 10.8% and 28.4%, respectively. By contrast, the mortality rate among patients without an HCAI was 4.1% within 30 days and 15.3% within a year. A study using 2002 data from the U.S. National Nosocomial Infections Surveillance system[2]

found 155,668 deaths among 1.7 million patients with an HCAI. Moreover, about 64% of these deaths were contributed by HCAIs.

As previously mentioned, the burden of HCAI is worse in developing countries, but the peer-reviewed literature is relatively scarce. A systematic review of device-associated infections in the ICUs of eight MICs,[25] including Argentina, Brazil, Colombia, India, Mexico, Morocco, Peru, and Turkey, reported the mortality rate varied between 35.2% (CR-BSI) and 44.9% (VAP).

HCAI and Fomites in the Surgery Theater

An SSI refers to an infection that is related to the operative procedure and occurs within 30 days; or within one year if there is an implant after the operative procedure.[1] SSI is the most common type of HCAIs globally.[14,15,17,55] Kärki et al.[54] reported that SSIs accounted for 18.4% of all HCAIs in 28 countries of the European Union and European Economic Area, and one in three HCAIs on admission was SSI. A high SSI prevalence was also reported as 29% of all HCAIs in developing countries from 1995 to 2008.[14] Moreover, another systematic review and meta-analysis[68] showed the prevalence of SSI and the pooled incidence of SSI was 7.9% in the sub-Saharan Africa region and 14.8% in the Eastern Mediterranean region, respectively. Further, a five-year prospective cohort surveillance study conducted in 30 countries[69] demonstrated that SSIs occurred in 2.9% of all surgical procedures.

In LMICs, the CD is the most frequently undertaken surgery.[27,70] Globally, the four highest CD rates were found in MICs: Bangladesh, Egypt, Dominican Republic, and Brazil, which were greater than 55%.[28] A recent systematic review and meta-analysis study[71] showed that the pooled prevalence of SSI following CD was 9.72% in Ethiopia, a low-income country. Furthermore, a review[70] reported that the incidence of CD-associated SSI and wound infection was 15.6% and

10.3%, respectively, in sub-Saharan Africa. Overall, like all surgical procedures, patients are at risk of SSIs when they undergo CD, including wound infections and endometritis.[72]

The risk factors for SSIs include patient's age, patient's underlying diseases (e.g., diabetes mellitus, malnutrition, obesity, immunodeficiency), preoperative LOS, unhygienic medical device and environment (e.g., contaminated surgical equipment or environmental surfaces, poor ventilation), and hygiene compliance and skills of healthcare workers (e.g., poor hand hygiene, inadequate surgical scrub, failure to perform skin antisepsis, prolonged duration of operation).[73,74] While patient factors are inevitable, environmental and human factors are adjustable and controllable.[75]

A fomite, or an inanimate object, has been identified as a reservoir of pathogens and one of the primary routes of infectious disease transmission from healthcare workers to patients in the surgery theater.[76] Specifically, pathogens could be transferred from fomites to patients by healthcare workers' hands (skin-to-skin contact) or direct physical contact.[76,77] For example, mobile phones carried by healthcare workers and telephones in the surgery theater were found to be reservoirs of multiple bacteria associated with HCAIs.[77–79] Another example were stuffed toys brought into the surgery room by children could potentially be involved in the spread of pathogens to surgical wounds.[80]

HCAI and Fomites in the ICU

An international study of 1,265 ICUs in 75 countries[81] reported that the HCAI rate in the ICU was 51.4%. In LMICs specifically, the pooled incidence of HCAI in the ICU was 34.7%.[14] The incidence of HAI in neonatal ICU (NICU) was 7.8% in four MICs, including Argentina, Colombia, Mexico, Peru and Turkey.[82] According to Rosenthal and colleagues,[25] despite the lower

device use rates, the rates of device-associated HCAI in the ICUs of LMICs were 2 to 4.5 times higher than in the United States. Similarly, the pooled peripheral venous catheter (PVC) associated BSI was 2.65 per 1000 PVC-days in eight MICs (China, India, Malaysia, Mongolia, Nepal, Philippines, Thailand, and Vietnam),[83] which was also higher than 0.5 per 1000 PVC-days in HICs.[84]

Many reasons contribute to the susceptibility of HCAIs among patients who are admitted to the ICU. A systematic review[50] reported that ICU admission and longer days of ICU hospitalization are risk factors of HCAI. Moreover, ICU patients are usually critically ill and immunocompromised.[50] Some intrinsic risk factors of HCAI are often seen from ICU patients, such as acute respiratory distress syndrome, acute renal failure, leukocytosis, and hypoalbuminemia.[85] During treatment for these critical illnesses, ICU patients are likely to be subject to the use of more invasive devices (central venous catheter placement, tracheal intubation, urinary catheter, etc.) or procedures (surgery, hemodialysis, etc.) and higher use of multiple courses of antibiotics.[20,30] Meanwhile, obtaining these medical treatments poses a risk of acquiring HCAI for ICU patients.[85] As a result, it is not surprising that HCAI is more prevalent in ICU compared to other healthcare departments.[19]

In ICUs, the risk of fomite transmission from healthcare workers to patients might increase due to multiple medical devices and non-medical equipment used at the patients' beside.[86,87] Computer keyboard, computer mouse, infusion pump, ventilator, and trolleys in ICU patients' rooms have been found to have different types of bacterial colonies.[86] In addition, personal items from healthcare workers or patients can also be fomites. For instance, Caldwell et al.[88] examined the contamination of common access cards and identity badges from healthcare workers in burn ICUs. They not only identified the bacterial contamination, but also confirmed the contamination

could be controlled by different disinfectants. Apart from this, a longitudinal study[89] reported that 98% of surface samples from toys in the NICU grew bacteria. Moreover, 63% of positive blood cultures from infants had the same type of bacteria that had been detected on their toys. And yet, another study[90] demonstrated a decrease in HCAI in the NICU after implementing disinfection practices to toys in infants' beds. In conclusion, IPC compliance is salient to reduce fomite transmission and the critical problem of HCAI in the ICU.[87,91,92]

HCAI Prevention and Control

IPC measures are imperative to save lives and healthcare costs, especially when the risk of HCAI is notably higher in LMICs.[93,94] A cross-sectional study[29] compared hospitals' IPC practices between eight HICs and 16 MICs. The finding revealed only 63.2% of hospitals in MICs had annual IPC programs despite the fact that almost 95% of the hospitals had IPC committees. Besides, less than 45% of hospitals in MICs had prevention bundles for various types of HCAI recommended by the department of health, while more than 60% of HICs' hospitals had prevention bundles available. Another recent review paper[31] noted that the challenges for IPC in LMICs included inadequate staffing, limited IPC professionals, inadequate disinfection practices, and a lack of infrastructure and medical supplies (personal protective equipment, soap, etc.).

To prevent HCAI in LMICs, Bardossy et al.[32] summarized a three-phased approach from short-term (low-cost) to long-term (high-cost) activities. The measures for interrupting fomite transmission are all included in the first phase. These are cleaning and hospital environmental policies, hand hygiene campaign, and basic IPC training for staff. Other activities in the first phase are identifying IPC gaps, establishing an infection control committee, and appointing at least one infection control practitioner and one epidemiologist. For phase two, activities include training of infection control recommendations for infection control professionals, contact precautions for

patients with high-risk infections, process surveillance, outcome surveillance among high-risk patients, developing and applying bundles for prevention of most common HCAI, and developing and implementing infection control policies. For phase three, activities are outcome surveillance among all patients, research in infection control and epidemiology, and an antimicrobial stewardship program.

WHO Development of IPC guidelines

As HCAI emerged as a patient safety issue, WHO launched the World Alliance for Patient Safety in 2004.[95] The "Clean Care is Safer Care" program, which was implemented as the first challenge, focused on improving hand hygiene to reduce HCAI.[96] In 2007, the second challenge "Safe Surgery Saves Lives" was carried out, in which SSI prevention was one of the focus areas.[97] In its guidelines,[98] one of the objectives is to use known methods consistently to minimize the risk of SSIs, including disinfection of surfaces and sterilization of surgical instruments.

In 2016, WHO published the *Guidelines on Core Components of Infection Prevention and Control Programmes at the National and Acute Health Care Facility Level*.[38] Eight key elements make up the guidelines and include implementation of IPC guidelines, HCAI surveillance, multimodal strategies for IPC interventions, monitoring and evaluation, improving workload, staffing and bed occupancy, and building environment, material and equipment for IPC. The strategy that is most relevant to this thesis relates to activities to ensure a clean and hygienic health care environment.[38]

Later on in 2020, WHO issued the *Core Competencies for Infection Prevention and Control Professionals*.[37] The Core Competencies suggest developing and implementing policies

and guidelines for environmental cleaning, disinfection of non-critical patient care equipment, and decontamination and sterilization of reusable equipment and medical devices.

Chapter 3: Methodology

To review and analyze potential fomites in the ICU and surgery theater of MICs that may be involved in HCAIs, this thesis conducted a scoping review according to Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Review (PRISMA-ScR) guideline.[99] The four key aspects used for database searches were the HCAI, ICU or surgery theater, fomite, and MICs. The list of MICs was adopted from the World Bank's classification for the 2021 fiscal year. Three databases were searched up to February 2021: PubMed, Embase, and CINAHL. The search string on PubMed was confirmed first (Table 1). The same combination of these terms with an adaptation based on respective databases' search function was used as the search strategy on Embase and CINAHL.

Table 1. Search String on PubMed

((((Cross Infection) OR "healthcare-associated infection" OR "healthcare-associated infections" OR "health care-associated infection" OR "health care-associated infections" OR "healthcare-acquired infection" OR "healthcare-acquired infections" OR "health care-acquired infection" OR "health care-acquired infections" OR "hospital-acquired infection" OR "hospital-acquired infections" OR "hospital-associated infection" OR "hospital-associated infections" OR "nosocomial infection" OR "nosocomial infections")
AND ("Delivery Room" OR "Delivery Rooms" OR "Intensive Care Unit" OR "Intensive Care Units" OR "Burn Unit" OR "Burn Units" OR "Coronary Care Unit" OR "Coronary Care Units" OR "Intensive Care Units, Pediatric"[Mesh] OR "Intensive Care Units, Neonatal"[Mesh] OR "Recovery Room" OR "Recovery Rooms" OR "Respiratory Care Unit" OR "Respiratory Care

Units" OR "Operating Room" OR "Operating Rooms" OR "surgical site" OR "surgery room" OR "surgery rooms" OR "operating theatre" OR "operating theater" OR "operating theaters"))

AND (Fomites OR (Disease Reservoirs) OR "Equipment Contamination" OR "medical device contamination"))

AND (("Developing Countries"[Mesh] OR individual names of upper-middle-income and lower-middle-income countries)

All studies published before February 2021 in journals, written in English, and available for abstract were eligible for inclusion. A case study, book, or document was ineligible. The search results were exported into Zotero, and then duplicate articles were removed.

Abstract and title were first screened, and the irrelevant studies were excluded based on the following criteria. The articles for inclusion must be investigations of inanimate objects as a contamination source conducted in ICUs or surgery theaters in MICs, including all types of ICUs, delivery rooms, and recovery rooms. Studies were not included if they aimed for bacteriological identification and prevalence estimation of a specific type of infection and collected relevant medical devices that have contacted patients right after removal (e.g., endotracheal tubes and connectors). In addition, articles without available full text were not included for the next step.

Full-text articles were then assessed for final inclusion. Articles were excluded using the following criteria:

1) The study did not introduce the study location in terms of the country or hospital.
2) The study did not report any contaminated inanimate object as the research results.

3) The study surveyed multiple hospital departments in addition to the surgery theater or ICU, but they did not report contaminated inanimate objects respectively by hospital departments.

The flow chart and list of exclusions will be discussed in the results section.

Ethical Consideration

Non-Human Subjects Research Determination Electronic Form of Emory Institutional Review Board (IRB) was used on March 8, 2021 to determine if IRB approval is needed. As this scoping review does not meet the definitions of “human subjects research” or “clinical investigation” as defined in the federal regulations, Emory IRB review is not required.

Chapter 4: Results

After searching in PubMed, Embase, and CINAHL, 241 articles were identified. From these, 31 articles were excluded as duplicates, and 55 articles were excluded due to ineligible article types, ineligible language, or no abstract available. The titles and abstracts of 155 articles were then screened. In this step, 87 articles were excluded as they did not address the research questions of this thesis. The excluded articles were mostly related to HCAI surveillance and experiments of disinfection methods. Also, four articles were excluded since two article types did not meet eligibility and two did not have full text available.

Subsequently, 64 full-text articles were assessed for final inclusion. Three articles were excluded since they did not introduce the country or hospital where the study was conducted. Eleven studies that did not mention the study location in the title or abstract were found to not be carried out in a MIC, so they were excluded in this step. One systematic review was not included because it covered multiple countries that were not MICs and various hospital departments in addition to the surgery room and ICU. Besides, four articles were excluded because they did not report any fomites (2) or they did not report fomites according to the hospital departments where they were surveyed (2). Finally, 45 articles met inclusion criteria. A flow diagram demonstrating the review process is represented in Figure 1.

Characteristics of Studies Included in the Review

Twenty-eight of the 45 studies were undertaken in ten upper-MICs, including Argentina,[100] Brazil,[101–107] China,[108–114] Iraq,[115] Jordan,[116] Jamaica,[117] Mexico,[118–120] Peru,[121,122] South Africa,[123,124] and Turkey.[125–127] The remaining 17 studies were conducted in seven lower-MICs,

including Ghana,[128] India,[129–135] Nigeria,[136–138] Morocco,[139] Palestine (West Bank and Gaza),[140] Pakistan,[141,142] and Tunisia.[143,144] These studies were published between 1990 and 2020.

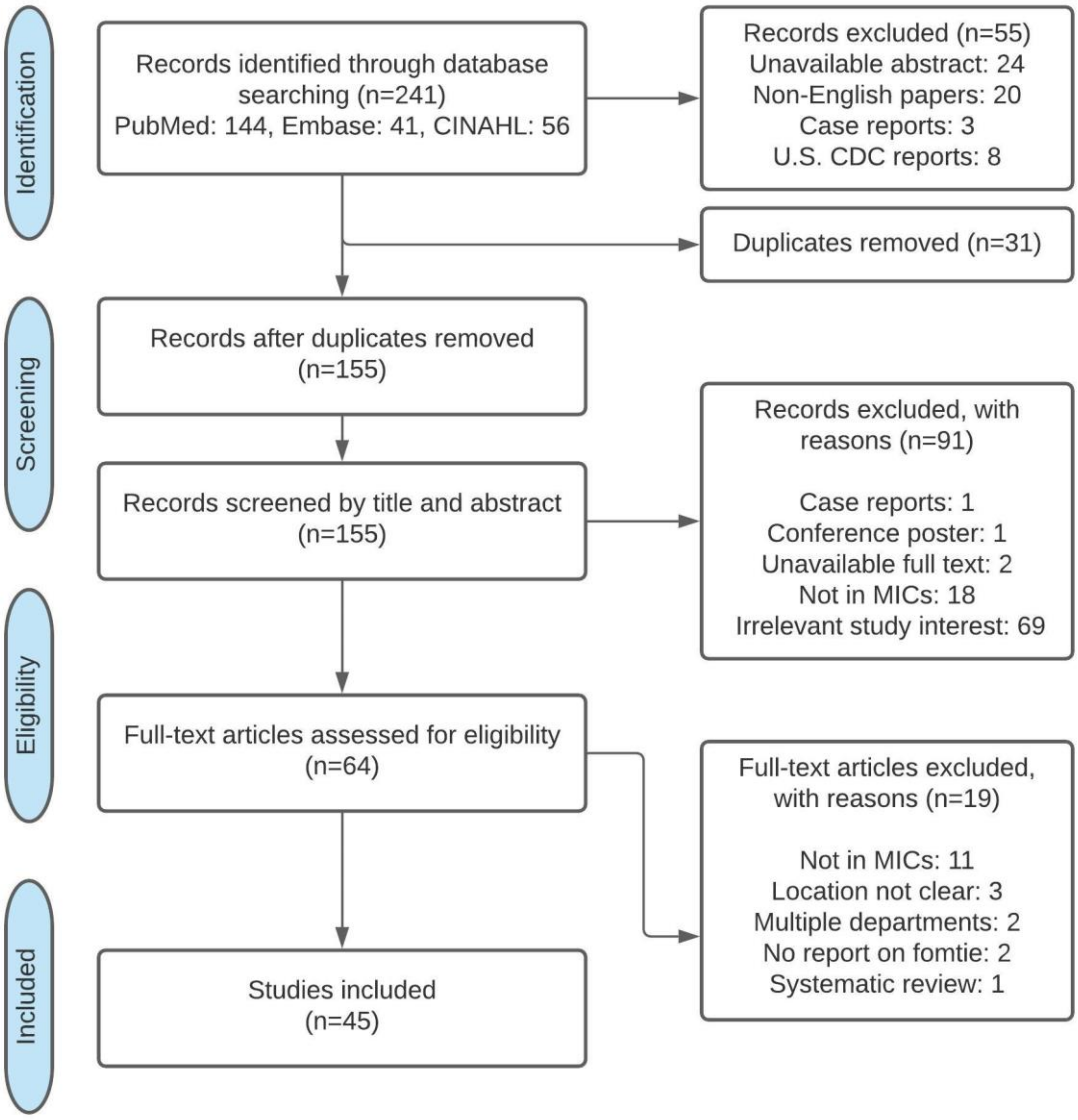

Figure 1. Flow Diagram of Review Process

Study Fomites

In the following section, fomites were reported according to the health facility location where they were found; either in the surgery theater (Appendix 1) or the ICU (Appendix 2). Within

each of these locations, the type of fomite was categorized as related to "medical equipment and supplies", "environmental surfaces", and "personal items".

Fomites in the Surgery Theater

Eight studies reported fomites in the surgery theater of seven MICs, including Brazil,[107] China,[114] India,[129,130] Jordan,[116] Mexico,[118] Nigeria,[137] and Palestine.[140] No study was conducted in Europe.

Fomites Related to Medical Equipment and Supplies in Surgery Rooms

Three studies evidenced the laryngoscope as a fomite (Table 2).[107,116,140] Takrouri et al.[116] identified pathogens on laryngoscopes that were ready to reuse in different operating rooms of a hospital in Jordan, in which cleaning laryngoscopes with soap and water was the hospital's standard due to financial constraints. In Brazil, Negri de Sousa et al.[107] also found nearly 86% of ready-to-use laryngoscope blades in the surgical center were contaminated with microorganisms and blood due to ineffective disinfection and sterilization.

Table 2. Most Common Fomites and Associated Pathogens in the Surgery Theater
Table 2 is an adaptation of the full list of fomites in the theatre (see Appendix 1 for full list).

Author (year)	Fomite	Pathogen Involved	Country	Study Time Period
Takrouri et al.[116a] (1990)	Ready-to-use laryngoscopes	*Pseudomonas aeruginosa*, *Escherichia coli, Klebsiella pneumoniae*, *Proteus* sp., *Enterobacter* sp., *Streptococcus* sp., *Neisseria* sp.	Jordan	1987-1988
Soto et al.[118a] (1991)	Operating theater lamp	*Mycobacterium chelonae* subsp. *abscessus*	Mexico	1988
Al Laham[140a] (2012)	Laryngoscope, overhead light	*Staphylococcus* spp., *Enterobacter* spp., *Escherichia coli, Klebsiella* spp., *Acinetobacter* spp.,	Palestine	2008-2009

		Pseudomonas spp., *Streptococcus* spp.[b]		
Nwankwo[137a] (2012)	Operation lamp	*Streptococcus* spp., coagulase negative staphylococci, *Bacillus circulans*	Nigeria	2009
Negri de Sousa et al.[107] (2016)	Ready-to-use laryngoscope blades	*Enterococcus faecalis*, *Streptococcus agalactiae*, *Staphylococcus aureus*, Airborne fungi, *Brevundimonas diminuta*, *Pseudomonas putida*, *Neisseria* sp., *Streptococcus* sp., *Micrococcus* sp., *Bacillus* sp., *Corynebacterium* sp., *Staphylococcus* sp. [c]	Brazil	2011

[a] More fomites were reported by the study (see Appendix 1) and not listed in this table.
[b] Pathogens were not reported respectively to fomites.
[c] Only pathogens identified in the surgical center, NICU, and obstetrics center of institution one were included. 21, 15, and 6 samples were collected in the surgical center, obstetrics center, and NICU, respectively. Pathogens were not reported respectively to fomites.

The suction tip and trolley were both found to be contaminated in two studies.[137,140] A study in Gaza Strip, Palestine by Al Laham[140] indicated that the instrument trolley, anesthesia trolley, and suction tip were contaminated before and after surgeries, mostly for combat injuries. The suction tip was responsible for the highest number of contaminated samples in the study. The contaminations that were found before surgeries were likely resulted from improper decontamination practices due to insufficient quality disinfectants, antiseptics, and sterilization techniques during the complete siege of the Gaza Strip. Additionally, other fomites that were only evidenced by one study are listed in Table 3.

Table 3. Fomites Related to Medical Equipment and Supplies in the Surgery Theater Reported by One Study

Categories	Fomites
Surgical equipment	Outer sleeves of the reusable laparoscopic instrument,[130] otorhinolaryngology equipment,[118] cautery, washing pan, sterilizing

	pan, operation bed,[140] bedcover on the operating room bed, scissor, suction tube[137]
Anesthetic equipment	Ready-to-use endotracheal tube, ready-to-use oxygen mask, ready-to-use suction catheter,[116] oxygen device[140]
Other	X-ray screen,[140] adhesive tape[118]

Fomites Related to Environmental Surfaces in Surgery Rooms

Three studies found lighting equipment as a fomite, including the operation lamp and overhead light (Table 3).[118,137,140] One of these studies[137] collected samples from operation lamps before surgery in a hospital in Nigeria. The findings revealed that the operation lamp in the main surgery theater was contaminated with bacteria. Moreover, in the same study two types of bacterial isolates were discovered on the operation lamp in the maternity theater. Unfortunately, the study did not investigate where these isolates came from.

Two studies in India examined laparoscopic surgeries where disinfectant trays were sources of contamination.[129,130] The first study[130] reported that plastic disinfectant trays were contaminated by *Mycobacterium abscessus*, *Staphylococcus aureus*, and *Pseudomonas* spp. while the second[129] did not specifically indicate the material of disinfectant trays that were found to be contaminated by *Mycobacterium chelonae*.

The floor and wall were also fomites, demonstrated by two studies in Nigeria and Palestine.[137,140] The study in Nigeria[137] was the first study in North-western Nigeria that aimed to evidence the presence of known pathogens on fomites in the operating rooms by collecting samples from different sites before surgery. The study results showed floors in the main surgery theater and maternity theater were contaminated by fungus and different types of bacteria while the floor in the gynecology theater was contaminated by bacteria only. Besides, walls were contaminated by two types of bacteria. In addition, a study in a post-war context in Palestine[140] revealed that the

highest number of environmental surface contaminations were floor and wall, which were positive for bacterial contamination before and after operations. Neither of the studies aforementioned researched how pathogens were spread to these environmental surfaces.

Other fomites identified in the environment of surgery rooms (see Appendix 1) included the water tank,[118] sink,[137] door, waste container, and air conditioner.[140]

Fomites Related to Personal Items in Surgery Rooms

Personal items as a fomite in surgery theatres were only investigated in two studies (see Appendix 1). In one study in Palestine where medical resources were limited due to the war,[140] facemask and clothes from surgeons were found to be contaminated by bacteria. However, only one sample from these personal items was positive for contamination, and the origin of contamination was not surveyed. Another study in operating rooms of an orthopedic hospital in China[114] demonstrated surgeons' medical lead clothes (i.e. the personal protective equipment for using C-arm fluoroscopic X-ray) were contaminated with multiple types of bacteria and blood. The cause of the contamination was proposed to be patients' blood and body fluid splashed during orthopedic surgeries.

Fomites in the ICU

Thirty-seven studies reported fomites in the ICU of 15 MICs, including Argentina,[100] Brazil,[101–107] China,[108–113] Ghana,[128] India,[131–135] Iraq,[115] Jamaica,[117] Mexico,[119,120] Morocco,[139] Nigeria,[136,138] Peru,[121,122] Pakistan,[141,142] South Africa,[123,124] Tunisia,[143,144] and Turkey.[126,127]

These studies collected samples from one type of ICU or multiple types of ICUs; either ICUs, NICUs, or pediatric ICUs (PICUs). Assessments in NICUs and PICUs were undertaken by 15[102,104,105,108,120–123,128,131–133,135,138,143] and five[105,121,122,132,134] of 37 studies, respectively.

Fomites Related to Medical Equipment and Supplies in ICUs

The contamination levels of incubators were assessed by seven studies in NICUs[102,108,128,131,133,135,138] and one study in a multidisciplinary ICU[136] (Table 4). Three studies specifically examined the inside,[108,128] outside,[128] door lock,[102] and handle of the incubator.[108] Newman[128] evaluated environmental hygiene in a NICU in Ghana where crowded space, limited personal protective equipment (gowns, mask, caps, etc.), understaffing were notable issues. Several cots and incubators were shared by two neonates. The results showed outside and inside of incubators were contaminated, and more types of the pathogen were identified outside of the incubators. In another study in China, Dong and colleagues[108] investigated a necrotizing enterocolitis outbreak in NICU and revealed that the highly associated pathogen was found on the handle and inner wall of an incubator.

Table 4. Incubators as a Fomite and Associated Pathogens
Table 4 is an adaptation of the full list of fomites in the ICU (see Appendix 2 for the full list).

Author (year)	Fomite	Pathogen Involved	Country	Study Time Period
Gupta et al.[133a] (1991)	Baby placement sites: incubators (closed, open)[b]	*Klebsiella* spp., *Escherichia coli*, *Pseudomonas* spp., *Staphylococcus aureus*, *Staphylococcus epidermidis*	India	1989-1990
Chandrashekar et al.[135a] (1997)	Incubators	Diphtheroids, *Bacillus subtilis*, *Klebsiella pneumoniae*, *Escherichia coli*	India	1992-1994
Newman[128a] (2002)	Incubators, outside	Coagulase negative *Staphylococcus*, *Bacillus* species, *Escherichia coli*, *Klebsiella*, *Pseudomonas aeruginosa*, moulds	Ghana	-
	Incubators, inside	Coagulase negative *Staphylococcus*, *Klebsiella*, moulds		

Krishna et al.[131a] (2007)	Incubators	Extended spectrum beta lactamase (ESBL)-producing *Klebsiella pneumoniae*	India	2003
Iregbu & Anwaal[138a] (2007)	Incubator	*Klebsiella pneumoniae*	Nigeria	2002
Ikeh & Isamade[136a] (2011)	Incubator[c]	*Staphylococcus aureus*, coagulase negative staphylococci, *Bacillus alvei*	Nigeria	-
Ganime et al.[102a] (2016)	Incubator door locks	Human adenovirus	Brazil	2011-2012
Dong et al.[108a] (2020)	Inner wall of necrotizing enterocolitis-infant incubator	*Clostridium butyricum*	China	2016
	Handle of necrotizing enterocolitis-infant incubator	*Clostridium butyricum*, *Clostridium sporogens*		

[a] More fomites were reported by the study (see Appendix 2) and not listed in this table.
[b] Fomites were reported as a group.
[c] Samples were collected in a multidisciplinary ICU.

Fomites that were demonstrated by at least three articles are shown in Table 5. Other medical equipment and supplies that were found to be contaminated in less than three studies are included in Table 6.

Table 5. Fomites Related to Medical Equipment and Supplies in the ICU Reported by at Least Three Articles

Categories	Fomites
Respiratory care device	Ventilator (including its control panel),[106,111,126,133,136] laryngoscope,[120,123,133,139] suction apparatus,[128,131,133,135] resuscitation bag and its connections,[103,119,133] pulse oximeter[105,124,127]
Other medical device	Electrocardiogram (ECG) monitor (including its probe and keyboard),[102,105,106,108,110,127] infusion pump (including its control panel),[101,106,108,110,127] phototherapy,[128,131,135] weighing scale[106,131,133]

Other	Trolley,[106,111,128,131,135,136] bed rail,[100,110,111,113,117,141] bed (including the linen and bed control),[101,106,109,115,126,127] mattress,[105,111,119,133] cot (including its control panel),[106,128,133,135] dispenser[101,105,141]

Table 6. Fomites Related to Medical Equipment and Supplies in the ICU Reported by Less than Three Articles

Categories	Fomites
Respiratory care device	Oxygen tent,[133,135] suction bottle,[123,136] suction catheter,[110,123] oxygen mask,[128,133] resuscitation equipment,[131] humidifier,[120] ventilator tube,[119] ventilator air flow sensor,[111] oxygen flowmeter,[105] the joint of sputum suction tube and suction apparatus,[110] blood-gas analyzer control panel[106]
Other medical device	Stethoscope,[108,144] sphygmomanometer,[104,127] patient monitor,[115,136] thermometer and its stand,[104,136] manifold,[139] emergency defibrillator, wheelchair,[136] instrument panel,[113] feeding tube, intravenous cannula/venflon side port, baby splint[133]
Other	Soap,[131,139] medicine container,[105,136] breast milk bag,[108] alcohol pad,[120] gloves,[111] alcohol gel support,[101] X-ray viewing box, screen,[136] ready-to-use plastic washbasin,[117] in-use ultrasound gel container, opened intravenous fluid bottle,[134] IV stand, tray[133]

Fomites Related to Environmental Surfaces in ICUs

The most common contamination sources of environmental surfaces in the ICU were the table,[101,106,119,127,128,133,136] floor,[106,115,128,133,135,136,139] and sink[117,119,128,131,133,138,141] (see Appendix 2). Even though the compositional material and placement of the tables were not mentioned in most studies, the treatment table in the NICU,[133] feeding table in the NICU,[128] service desk,[127] and coffee support table[101] were documented as contaminated surfaces. One study in India[135] pointed out that floor corners of a NICU were contaminated with 11 bacterial species and implicated in inadequate floor cleaning, overcrowding, poor ventilation system, and poor practices of wearing the gown, footwear, cap, and mask. In Ghana, Newman[128] also indicated floor corners and locker

floors as a contamination source in a NICU, likely caused by overcrowding and poor environmental cleaning.

Furthermore, Iregbu and Anwaal[138] investigated a *Klebsiella pneumoniae* outbreak in a NICU in Nigeria, which was caused by the failure in isolating the first infected patient, and found out the sink was a reservoir that facilitated cross-infection. Another study in a Nigerian multi-disciplinary ICU[136] showed the presence of bacteria on a sink and implicated poor compliance of handwashing due to only one sink available in the ICU. Other inanimate objects in the ICU environment that were proved to be carrying pathogens are listed in Table 7.

Table 7. Fomites Related to Environmental Surface in the ICU

Categories	Fomites
Clinical contact surface[a]	Medical chart,[106,113] syringe container,[105,133] door handle,[101,106] bin cover,[101,126] nursing call button,[141] patient belonging container, baby feeder container,[105] box for holding breast milk bag,[108] work surface,[131] hand towel[136]
Communication device	Telephone,[101,105,106,108] computer keyboard,[105,111,126] computer,[106] computer mouse,[105] TV remote control[101]
Furniture	Cabinet,[106,111] cupboard,[127,136] chair,[101,136] dresser,[127] drawer[117]
Plumbing	Sink handle,[117,128,141] faucet,[106,117,126] faucet aerators,[112] tap outlet, sink trap[113]
Ventilation	Air conditioner,[106,136] vent,[115] ceiling fan[136]
Other	Wall,[133,135,136] curtain,[105,111,126] switch (fan switch and room light switch),[136,141] window,[133,136] refrigerator,[106,108] counter,[106,113] lamp,[119] outlet,[128] power converter, fire extinguisher, curtain box,[136] door,[106] toilet flush button[101]

[a] clinical contact surface refers to the surface that may be frequently touched by healthcare workers while performing medical care.

Fomites Related to Personal Items in ICUs

Four studies identified the healthcare workers' mobile phones as a fomite.[121,122,125,132] Multiple bacteria were isolated from healthcare workers' phones in the ICU,[125,132] NICU, and

PICU[121,122,132] (Table 8). Loyola et al.[121] studied contamination levels on mobile phones of healthcare workers in three PICUs and two NICUs in Peru. The results demonstrated that mobile phones with keyboards had a higher percentage of positive bacterial samples compared to mobile phones with touchscreen. Types of mobile phones were not discussed in the other three studies.

Other personal items listed as fomites (see Appendix 2) were the mask,[120] cotton gown, rubber slippers,[136] staff uniform,[126] pen, and spectacle.[142]

Table 8. Personal Items as Fomites and Associated Pathogens in the ICU
Table 8 is an adaptation of the full list of fomites in the ICU (see Appendix 2 for the full list).

Author (year)	Fomite	Pathogen Involved	Country	Study Time Period
Ustun & Cihangiroglu[125] (2012)	Mobile phones	Methicillin-resistant *Staphylococcus aureus*, methicillin-sensitive *Staphylococcus aureus*, methicillin-resistant coagulase-negative *Staphylococcus* spp., methicillin-sensitive coagulase-negative *Staphylococcus* spp., ESBL-positive *Escherichia coli*, ESBL-negative *Escherichia coli*	Turkey	2010
Loyola et al.[121] (2016)	phones	*Enterobacteriaceae*	Peru	2012
Loyola et al.[122] (2018)	Mobile phones	*Pseudomonas aeruginosa*, *Acinetobacter* spp., *Staphylococcus aureus*, *Enterococcus* spp.	Peru	2012
Shah et al.[132] (2019)	Mobile phones	Coagulase-negative *Staphylococcus*, methicillin-sensitive *Staphylococcus aureus*, methicillin-resistant *Staphylococcus aureus*, *Bacillus* spp., *Corynebacterium* spp., *Enterococcus* spp., *Acinetobacter* spp., *Klebsiella pneumoniae*, *Citrobacter freundii*	India	2017

Transmission Route from Fomite to Patient

Of the studies conducted in the surgery theater, two studies[129,130] noted that surgical equipment was contaminated because of the use of a contaminated disinfectant tray in the sterilization process. Four studies[107,116,118,137] concluded that pathogens could be transmitted through an invasive procedure or direct contact between the medical equipment (fomite) and the patient. In addition, one study[137] pointed out the healthcare worker's hands could carry pathogens from a contaminated object to a patient.

In 17 studies in the ICU,[101,102,104,106,108,110,111,119–121,125,131,132,134–136,138] the pathogens were spread through hands or hands with gloves of the healthcare personnel who touched the contaminated object. One study[131] indicated poor hand hygiene of mothers before breastfeeding in the NICU could also facilitate the transmission to the neonate. Two studies[112,113] found that the pathogen could be transmitted via handwashing using contaminated plumbing (faucet and sink trap) by the healthcare worker. One study[143] stated that the disinfectant cap surface as a fomite could contaminate the handwashing solution and subsequently transfer the pathogen to the health worker's hands. Additionally, eight studies[103,104,117,120,123,124,133,134] showed that the pathogen could be transmitted through using the medical instrument or supplies (fomite) on the patient. One of these studies[103] noted that the pathogen could be spread to the patient's lower airway via aerosol while using the resuscitator.

Notably, 12 studies in the ICU did not mention the transmission route of the reported fomite.

Chapter 5: Discussion, Conclusion and Recommendations

Discussion and Recommendations

HCAIs are caused by the transmission of pathogens within the healthcare facility.[39,145,146] This thesis reviewed 45 articles that documented fomites in the surgery theater or ICU of MICs. The infection source was largely surveyed on medical equipment and supplies (cot, laryngoscope, ventilator, infusion pump, etc.) and inanimate objects in the environment (operation lamp, table, wall, etc.). Although personal items of the healthcare worker or patient, such as the mobile phone and pen, were least investigated as fomites, studies have shown they could carry infectious agents. The results of the review indicate that multiple fomites existing in the surgery theater and ICU are potential sources of infectious transmission to patients.

Of the 45 articles, 33 articles implied the potential transmission route of the fomite to the patient. The most-reported routes of transmitting the pathogen from fomite to patient were direct contact of the fomite (e.g., using a contaminated medical device) and indirect contact via the hands or gloves of one who has touched the fomite. The reusable medical instrument could also be contaminated by using a fomite in the disinfection and sterilization process. Moreover, washing hands with water or handwashing solution that was contaminated by the fomite could cause hand contamination among healthcare workers. However, only a few of these 33 studies evaluated the level of hand contamination associated with a fomite. Hence, the importance of hand hygiene, environmental cleaning, and decontamination of medical equipment and supplies is highlighted. Additionally, decontamination of personal items should not be overlooked in the discussion of IPC.

The thesis results identified various fomites in the surgery theater and ICU of MICs that harbored pathogens and may be involved in HCAIs. Similarly, Haun et al.[145] conducted a

systematic review of bacterial contamination of fomites. The study did not restrict any hospital department or country, and only the healthcare workers' clothing, personal items, and medical devices were assessed. Different fomites, such as the tablet, notebook, white coat, necktie, scrubs, purse, and ring, were included in the findings. Even though this study and the objects identified were not included in this thesis due to eligibility, these fomites might also be in the surgery theater or ICU of MICs. Moreover, many researchers have evaluated different fomites in the surgery theater and ICU of countries not limited to MICs. For instance, the identity badge, lanyard,[147,148] pager,[148] teddy bear,[80] identity card (carried by badge clip, lanyard, pocket, or wallet), and access card[88] could harbor pathogens. Although none of these studies established a clear route of fomite transmission of HCAI, cognizance of the prevention of fomites as a transmission agent in the clinical setting and the risk of HCAI is imperative.

Medical Equipment and Supplies as a Fomite

The findings of fomites demonstrate that adequate decontamination of reusable medical equipment is critical. An infectious agent can be transferred from the contaminated device to a patient during an invasive procedure. This is consistent with what has been found in the previous review studies of reusable medical equipment.[149,150] Alfa[150] pointed out that a quality management system is needed to ensure the adequacy of disinfection and sterilization. More specifically, the healthcare facility must have protocols of the decontamination process. Quality monitoring should also be implemented, including process supervision and cleaning efficacy.

The method of disinfection or sterilization should be executed based on how the medical equipment contacts a patient. Three categories can be adopted while making the decision: critical items (contacts sterile tissue or vascular system), semi-critical items (contacts mucous membranes or nonintact skin), and noncritical items (contacts only intact skin), according to the U.S. CDC's

Guideline for Disinfection and Sterilization in Healthcare Facilities.[151] Recommended levels of disinfection or sterilization for each category are introduced in this guideline. However, as McDonnell and Burke[152] argued, the classification did not promise the efficacy of decontamination. To prevent the failure of decontamination, microbial resistance profiles should be considered before determining disinfection and sterilization approaches.[152] Moreover, ongoing monitoring of reprocessing should be applied.[151]

Additionally, various pathogens were detected on the reused single-use medical devices due to improper decontamination and reprocessing in this thesis results, such as the suction catheter,[116,123] endotracheal tube,[116] and oxygen mask.[116,128] Limited resources are the main reason for the reuse of single-use medical devices in LMICs.[153,154] The WHO guideline for IPC professionals does not ban the reuse of single-use medical devices. Instead, it recommends that an IPC professional should be knowledgeable about restrictions and risks for reprocessing single-use items.[37] A randomized control study demonstrated no bacterial growth on sterilized endotracheal tubes, following the CDC guideline of decontamination of semi-critical items.[155] Nevertheless, studies have shown that reprocessing single-use medical devices can affect the materials of the medical device and lead to malfunction.[155–157] On the other hand, according to another WHO guideline,[38] ensuring sufficient amount of single-use devices is required in order to avoid unsafe practices of reuse of medical devices. So then, globally, there is no consensus of whether single-use medical devices can be or should be reused.[153,154]

The findings of various non-invasive medical equipment as contamination sources are in line with previous research findings. A study[158] assessed the contamination of thermometers and blood pressure cuffs in multiple hospital departments in Nigeria, and various bacterial isolates were found. However, the causal relationship between these medical equipment being

contaminated and HCAIs was not followed up in this study. Notwithstanding, Otter et al.[159] reviewed and illustrated evidence that contaminated surfaces or equipment can be directly or indirectly involved in the HCAI transmission route. For the indirect pathway of transmission, pathogens of contaminated surfaces and equipment can be acquired by healthcare workers' hands. Subsequently, contaminated hands of a healthcare worker can pass pathogens to a susceptible patient. This suggests that interventions such as hand hygiene and cleaning and disinfection of non-invasive medical equipment should be performed, following the WHO's guidelines.[37]

Environmental Surfaces as a Fomite

The thesis results indicate that pathogens can be transferred from environmental surfaces via water and human contact (bare hands or gloved hands). More pathways of transmission (aerosol, food, etc.) were surveyed by other studies not included in this review. A study in five hospitals in the United States[160] showed that hands or gloved hands were contaminated after touching the personal items, medical devices and supplies, and linens that were placed on the floors of patient rooms. Rashid et al.[161] reviewed the transmission dynamics between contaminated floors and humans and showed that aerosolization was also involved in the transmission of infectious agents in healthcare settings. As a result, environmental cleaning should not be overlooked in the IPC practices. As WHO's guidelines outlined,[37] monitoring the environmental cleaning practices with standardized programs and indicators is also essential. However, routine supervision of bacterial contamination in the environment is not required.[38]

Personal Items as a Fomite

Personal items were the least evidenced fomites in the thesis results. This suggests that there is a need to identify and document more potential fomites of this type. In the WHO's

guidelines,[37,38] only personal protective equipment (mask, goggle, face shield, gowns, etc.) was discussed. Personal protective equipment is suggested to be single-use and should be changed after directly contacting isolated patients. For reusable items, such as medical lead clothes, a policy and standard operating procedure for decontamination and storage must be enforced.[38]

As mobile phones were the most common contaminated personal items, developing a policy and guideline of regular cleaning and/or restricting the use of specific personal items should be considered. This is supported by findings of a review study[162] where other infection prevention strategies for healthcare workers included increasing awareness of mobile phones' role in the transmission of nosocomial pathogens.

The thesis finding on healthcare personnel attire as a fomite was in accordance with findings published by Haun et al.[145] However, there is no substantial evidence related to the transmission dynamic of pathogens from clothing to patients.[163] Furthermore, the guidelines of use and decontamination of healthcare personnel attire have not been introduced by the WHO. Further research of healthcare personnel attire regarding the cross transmission and laundering protocol is needed to make recommendations for WHO's IPC guidelines.[163]

Limitations and Recommendations

There are three major limitations in this thesis. Firstly, in the scoping review process, fomites that were not identified in the surgery theater or ICU were excluded. This may have excluded those fomites that can potentially be found in the surgery theater or ICU. The eligibility criteria also excluded studies that surveyed fomites in high-income and low-income countries. Those fomites may not be listed in the thesis results but may still be present in the MICs. Since a department's resources and setting vary in healthcare facilities, future studies may focus on

identifying specific inanimate objects in other healthcare departments and their contamination levels.

A second limitation is that the review included studies written in English only from PubMed, Embase, and CINAHL. The results of the most commonly reported fomites may be different when including non-English studies. Therefore, non-English literature should be considered in future review studies to complement all kinds of fomites and improve IPC practices.

A third limitation is that 15 of 37 articles in intensive care settings were set in NICUs. The findings of fomites and associated pathogens in NICUs may not apply to different types of ICU (e.g., for adults). Thus, to identify prominent fomites in other ICU departments, future review studies may focus on other ICU departments regardless of whether there is an infectious disease outbreak.

Lastly, the recommendations for IPC practices in this thesis cannot provide precise and effective approaches to decontaminate fomites because potential transmission routes were not reported by all reviewed studies. Transmission pathways from a fomite to a patient require more exhaustive research and definitive results from a well-designed study. Nevertheless, the findings of this thesis are still able to provide an actionable advancement in current IPC practices.

Conclusion

HCAIs remain a patient safety issue in MICs. This thesis identified several fomites in the surgery theater and ICU of MICs by scoping review. Various medical equipment, medical supplies, environmental surfaces, and personal items were involved in HCAIs. In the surgery theater, laryngoscopes and operation lighting equipment were the most frequently reported fomites. In the intensive care setting, incubators, trolleys, bed rails, beds, ECG monitors, floor, sinks, tables, and

mobile phones were the most common fomites in each category. To control and prevent HCAIs, recommendations for IPC practices should be taken into consideration to bridge the gap of WHO's guidelines as follows:

1) Microbial resistance to disinfectants needs to be monitored to improve decontamination quality.
2) A consensus of the reuse of single-use medical devices should be met.
3) The policy and protocol of regular cleaning personal item should be studied and developed.
4) A policy restricting personal mobile phone usage among healthcare workers should be implemented.

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Appendices

Appendix 1: Fomites and Associated Pathogens in the Surgery Theater

Author (year)	Fomite	Pathogen Involved	Country	Study Time Period
Takrouri et al.[116] (1990)	Ready-to-use endotracheal tube	*Pseudomonas aeruginosa*, *Escherichia coli*, *Klebsiella pneumoniae*, *Proteus* sp., *Enterobacter* sp., *Citrobacter* sp., coagulase negative staphylococci, *Streptococcus* sp.	Jordan	1987-1988
	Ready-to-use oxygen masks	*Escherichia coli*, *Proteus* sp., coagulase negative staphylococci, *Staphylococcus aureus*, *Streptococcus* sp., *Bacillus* sp.		
	Ready-to-use laryngoscopes	*Pseudomonas aeruginosa*, *Escherichia coli*, *Klebsiella pneumoniae*, *Proteus* sp., *Enterobacter* sp., *Streptococcus* sp., *Neisseria* sp.		
	Ready-to-use suction catheters	*Pseudomonas aeruginosa*, *Klebsiella pneumoniae*, *Proteus* sp., *Enterobacter* sp., coagulase negative staphylococci, *Staphylococcus aureus*, *Streptococcus* sp.		
Soto et al.[118] (1991)	Operating theater lamp, adhesive tape, otorhinolaryngology equipment, water tanks	*Mycobacterium chelonae* subsp. *abscessus*	Mexico	1988
Vijayaraghavan et al.[130] (2006)	The bottom of disinfectant trays, outer sleeves of re-usable laparoscopic instruments	*Mycobacterium chelonae*	India	2002-2003

Al Laham[140] (2012)	Operation bed, instrument trolley, anesthesia trolley, sterilizing pan, washing pan, suction tip, oxygen device, laryngoscope, X-ray screen, cautery, floor, door, wall, waste container, air conditioner, overhead light, the clothes and facemasks of the surgeons[a]	*Staphylococcus* spp., *Enterobacter* spp., *Escherichia coli*, *Klebsiella* spp., *Acinetobacter* spp., *Pseudomonas* spp., *Streptococcus* spp. [b]	Palestine	2008-2009
Nwankwo[137] (2012)	Operation lamp	*Streptococcus* spp., coagulase negative staphylococci, *Bacillus circulans*	Nigeria	2009
	Floor	*Penicillium*, *Micrococcus*, *Aspergillus* spp., *Bacillus circulans*, *Micrococcus*, *Salmonella choleraesuis*, *Escherichia coli*		
	Wall	*Streptococcus* spp., coagulase negative staphylococci		
	Sink	*Pseudomonas aeruginosa*, *Proteus mirabilis*		
	Suction tube	*Pseudomonas aeruginosa*, *Proteus mirabilis*, *Aspergillus* spp.		
	Suction tip	*Streptococcus* spp., *Staphylococcus aureus*, *Enterococcus faecalis*, *Pseudomonas aeruginosa*, *Proteus vulgaris*		
	Scissors	Coagulase negative staphylococci, *Micrococcus*		
	Trolley	*Penicillium*, *Bacillus circulans*, *Streptococcus* spp.		
	Bedcover on the theatre operating room bed	Coagulase negative staphylococci, *Bacillus* spp., *Micrococcus*, *Proteus* spp., *Pseudomonas putida*, *Streptococcus* spp., *Escherichia coli*, *Penicillium*, *Rhizopus*, *Mucor*		
Chen et al.[114] (2016)	Medical lead clothes	Gram-positive cocci, gram-positive bacilli, gram-negative cocci, gram-negative bacilli	China	2015

Negri de Sousa et al.[107] (2016)	Ready-to-use laryngoscope blades	*Enterococcus faecalis*, *Streptococcus agalactiae*, *Staphylococcus aureus*, Airborne fungi, *Brevundimonas diminuta*, *Pseudomonas putida*, *Neisseria* sp., *Streptococcus* sp., *Micrococcus* sp., *Bacillus* sp., *Corynebacterium* sp., *Staphylococcus* sp.[c]	Brazil	2011
Ghosh et al.[129] (2017)	Disinfectant tray (plastic)	*Mycobacterium abscessus*, *Staphylococcus aureus*, *Pseudomonas* spp.	India	2015

[a] Contaminated samples before operation: washing pan, oxygen device, and facemasks of the surgeons; after operation: sterilizing pan, laryngoscope, X-ray screen, cautery, overhead light, and the clothes of the surgeons; before and after operation: operation bed, instrument trolley, anesthesia trolley, suction tip, floor, door, wall, waste container, and air conditioner.

[b] Pathogens were not reported respectively to fomites.

[c] Only pathogens identified in the surgical center, NICU, and obstetrics center of institution one were included. 21, 15, and 6 samples were collected in the surgical center, obstetrics center, and NICU, respectively. Pathogens were not reported respectively to fomites.

Appendix 2: Fomites and Associated Pathogens in the ICU

Author (year)	Fomite	Pathogen Involved	Country	Study Time Period
Gupta et al.[133a] (1991)	Resuscitation equipment: ventilators, suction apparatus, laryngoscope, ambu bag and its connections, oxygen hood and face mask	*Klebsiella* spp., *Escherichia coli*, *Pseudomonas* spp., *Staphylococcus epidermidis*, *Salmonella* spp.	India	1989-1990
	Baby placement sites: incubators (closed, open), baby cots (frame, mattress), weighing scale, treatment table	*Klebsiella* spp., *Escherichia coli*, *Pseudomonas* spp., *Staphylococcus aureus*, *Staphylococcus epidermidis*		
	Medications handled by nurses: emergency drug tray, procedure tray, injection tray, syringe box	*Klebsiella* spp.		
	Formula feeds: feeding tubes, milk container (bowl, feeding tray)	*Klebsiella* spp., *Escherichia coli*, *Pseudomonas* spp., *Staphylococcus aureus*, *Staphylococcus epidermidis*, *Salmonella* spp.		
	Inanimate environment: walls, floors, windows, sink/drains, furniture/tables	*Klebsiella* spp., *Escherichia coli*, *Pseudomonas* spp., *Staphylococcus aureus*, *Staphylococcus epidermidis*		
	Miscellaneous: intravenous cannulae/venflon side ports, IV stand, baby splint	*Klebsiella* spp., *Escherichia coli*, *Pseudomonas* spp., *Staphylococcus aureus*, *Staphylococcus epidermidis*		
Arredondo-García et al.[120] (1992)	Alcohol pads, humidifying devices, laryngoscope, masks	*Klebsiella pneumoniae*	Mexico	1988-1989

Chandrashekar et al.[135] (1997)	Cradles	*Staphylococcus aureus*, *Staphylococcus epidermidis*, *Enterococcus*, Diphtheroids, *Bacillus subtilis*, *Klebsiella pneumoniae*, *Escherichia coli*, *Pseudomonas*, *Proteus*, *Citrobacter*, *Clostridium tetani*	India	1992-1994
	Incubators	Diphtheroids, *Bacillus subtilis*, *Klebsiella pneumoniae*, *Escherichia coli*		
	Radiant heaters	*Staphylococcus aureus*, *Staphylococcus epidermidis*, *Enterococcus*, *Bacillus subtilis*, *Klebsiella pneumoniae*, *Escherichia coli*, *Pseudomonas*, *Proteus*		
	Oxygen tents	Diphtheroids, *Bacillus subtilis*, *Klebsiella pneumoniae*, *Escherichia coli*, *Pseudomonas*		
	Phototherapy	Diphtheroids, *Bacillus subtilis*, *Klebsiella pneumoniae*, *Escherichia coli*, *Pseudomonas*		
	Suction pump	*Staphylococcus aureus*, *Staphylococcus epidermidis*, *Bacillus subtilis*, *Klebsiella pneumoniae*, *Escherichia coli*, *Pseudomonas*, *Proteus*		
	Trolley	*Staphylococcus aureus*, *Staphylococcus epidermidis*, Diphtheroids, *Bacillus subtilis*, *Klebsiella pneumoniae*, *Escherichia coli*, *Pseudomonas*, *Proteus*, *Citrobacter*		
	Walls	*Staphylococcus aureus*, *Staphylococcus epidermidis*, *Enterococcus*, Diphtheroids, *Bacillus subtilis*, *Klebsiella pneumoniae*, *Escherichia coli*, *Pseudomonas*, *Proteus*, *Citrobacter*, *Clostridium tetani*		
	Floor corners	*Staphylococcus aureus*, *Staphylococcus epidermidis*, *Enterococcus*, Diphtheroids, *Bacillus subtilis*, *Klebsiella pneumoniae*,		

		Escherichia coli, *Pseudomonas*, *Proteus*, *Citrobacter*, *Clostridium tetani*		
Catalano et al.[100] (1999)	A bed rail	*Acinetobacter baumannii*	Argentina	1996
Pillay et al.[123] (1999)	Suction catheter, suction bottles, surface of a laryngoscope	*Acinetobacter* spp.	South Africa	1997
Corona-Nakamura et al.[119] (2001)	Ventilator tubes, sinks, lamps, table tops, resuscitation bags, mattresses	*Pseudomonas aeruginosa*	Mexico	1998
Newman[128] (2002)	Cots	Nonhemolytic *Streptococcus*, coagulase negative *Staphylococcus*, *Bacillus* species, *Escherichia coli*, *Klebsiella*, Diphtheroids, *Candida*, other gram-negative rods	Ghana	-
	Incubators, outside	Coagulase negative *Staphylococcus*, *Bacillus* species, *Escherichia coli*, *Klebsiella*, *Pseudomonas aeruginosa*, moulds		
	Incubators, inside	Coagulase negative *Staphylococcus*, *Klebsiella*, moulds		
	Outlet	Coagulase negative *Staphylococcus*, *Bacillus* species, *Escherichia coli*, *Klebsiella*, *Pseudomonas aeruginosa*		
	Suction machine	*Escherichia coli*		
	Phototherapy	Coagulase negative *Staphylococcus*, *Bacillus* species, *Escherichia coli*		
	Table tops	Coagulase negative *Staphylococcus*, *Bacillus* species, *Escherichia coli*		
	Sink tap handles	Coagulase negative *Staphylococcus*, *Bacillus* species, *Candida*		
	Sink outlets	*Bacillus* species, *Escherichia coli*, *Pseudomonas aeruginosa*		

	Feeding table	Coagulase negative *Staphylococcus*, *Bacillus* species, *Escherichia coli*, *Pseudomonas aeruginosa*		
	Floor corners	Coagulase negative *Staphylococcus*, *Bacillus* species, *Escherichia coli*, *Klebsiella*		
	Trolleys	Coagulase negative *Staphylococcus*, *Bacillus* species, moulds		
	Locker floors	Coagulase negative *Staphylococcus*, *Bacillus* species, Diphtheroids		
	Oxygen masks	Nonhemolytic *Streptococcus*, coagulase negative *Staphylococcus*, *Bacillus* species		
Aygün et al.[127] (2002)	Bed	*Acinetobacter baumannii*, *Enterobacteriaceae*, mixed flora (*Staphylococcus* spp., *Diphtheroid bacillus*, C*andida*, other)	Turkey	1999
	Table	*Acinetobacter baumannii*, mixed flora (*Staphylococcus* spp., *Diphtheroid bacillus*, C*andida*, other)		
	Dresser	*Acinetobacter baumannii*, *Enterobacteriaceae*, *Pseudomonas*, mixed flora (*Staphylococcus* spp., *Diphtheroid bacillus*, C*andida*, other)		
	Infusion pump	*Acinetobacter baumannii*, *Enterobacteriaceae*		
	Pulse oximeter	*Acinetobacter baumannii*, mixed flora (*Staphylococcus* spp., *Diphtheroid bacillus*, C*andida*, other)		
	ECG probe	*Enterobacteriaceae*		
	Blood pressure cuff	*Acinetobacter baumannii*, *Enterobacteriaceae*, mixed flora (*Staphylococcus* spp., *Diphtheroid bacillus*, C*andida*, other)		
	Cupboard	*Acinetobacter baumannii*, mixed flora (*Staphylococcus* spp., *Diphtheroid bacillus*, C*andida*, other)		

	Service desk	*Acinetobacter baumannii*, *Pseudomonas*		
Krishna et al.[131] (2007)	Incubators, phototherapy units, weighing scale, medicine trolley, sink, work surfaces, resuscitation equipment, suction apparatus, soaps	ESBL-producing *Klebsiella pneumoniae*	India	2003
Iregbu & Anwaal[138] (2007)	Incubator, sink	*Klebsiella pneumoniae*	Nigeria	2002
Ben Saida et al.[143] (2009)	Disinfectant bottles (inside surface of cap)	Methicillin-resistant *Staphylococcus haemolyticus*, staphylococci (*Staphylococcus epidermidis*, *Staphylococcus haemolyticus* and *Staphylococcus hominis*)	Tunisia	2004-2006
Ake et al.[115] (2011)	Beds, vent, patient monitor[b]	*Klebsiella pneumoniae*	Iraq	2007-2008
	Floor, vent[b]	*Escherichia coli*		
Ikeh & Isamade[136] (2011)	Air conditioner, hand washbasin, fan switch, window, ceiling fan, inner wall, bedside monitor, bedside monitor board, thermometer stand, x-ray viewing box, cotton gown, table, hand towel, trolley, rubber slippers, floor, fire extinguisher, wheelchair, power converter, ventilator, and screen[c]	*Staphylococcus aureus*, coagulase negative staphylococci	Nigeria	-
	Poison box, chair back, suction bottle, incubator, curtain box, emergency defibrillator, cupboard[c]	*Staphylococcus aureus*, coagulase negative staphylococci, *Bacillus alvei*		

Ustun & Cihangiroglu[125] (2012)	Mobile phones	Methicillin-resistant *Staphylococcus aureus*, methicillin-sensitive *Staphylococcus aureus*, methicillin-resistant coagulase-negative *Staphylococcus* spp., methicillin-sensitive coagulase-negative *Staphylococcus* spp., ESBL-positive *Escherichia coli*, ESBL-negative *Escherichia coli*	Turkey	2010
Campos et al.[106] (2012)	Refrigerator, faucet, infusion pump control panel, hospital ventilator control panel, scales, telephone, blood-gas analyzer control panel, computer, hospital cots, hospital cot control panel, floor, infusion pump, handles, prescription records, hospital countertops, heart monitor, cabinets, hospital bed, air conditioner, table, door, emergency cart	*Staphylococcus aureus*	Brazil	-
Sui et al.[109] (2013)	Bed linen	*Acinetobacter baumannii*, Methicillin-resistant *Staphylococcus aureus*	China	2010-2011
Fanfair et al.[117] (2013)	Drawers, bed rails, sinks, faucets, sink handles, ready-to-use plastic washbasin	*Trichosporon asahii*	Jamaica	2009-2010
Ganime et al.[101] (2014)	Toilet flush buttons, companion chairs, bed controls, TV remote controls, coffee support tables, exterior bathroom door handles, interior door handles, alcohol gel supports, Chlorhexidine	Group A rotaviruses, human adenoviruses	Brazil	2009

	dispensers, keyboard infusion pumps, telephones, common trash bin covers			
Kirkgöz & Zer[126] (2014)	Bed, ventilator screen, in front of door curtain in patient room, outer cover of dustbin, staff uniform, faucet, computer keyboard	*Acinetobacter baumannii*	Turkey	2010-2011
Shi et al.[110] (2015)	Suction catheter, Infusion pump, bedside rail restraint	*Staphylococcus aureus*	China	2014
	The joint of the sputum suction tube and suction apparatus, an ECG monitor	Methicillin-resistant *Staphylococcus aureus*		
Ye et al.[111] (2015)	Computer keyboards, bed rails, nurses' supply carts, ventilator control panel, curtains, ventilator air flow sensor, bedside cabinet, mattress, gloves	Imipenem-resistant *Acinetobacter baumannii*	China	2011
Abdelhakim et al.[139] (2015)	laryngoscope, manifold, soap, ground[d]	*Staphylococcus* sp., *Acinetobacter baumannii*, *Micrococcus*, *Escherichia coli*, *Klebsiella* sp., *Pseudomonas aeruginosa*[e]	Morocco	2009
Loyola et al.[121] (2016)	Cell phones	*Enterobacteriaceae*	Peru	2012
Ganime et al.[102] (2016)	Cardiac monitor keyboard	Rotavirus A, human adenovirus	Brazil	2011-2012
	Incubator door locks	Human adenovirus		
Murad & Inam Pal[142] (2016)	Pen	*Acinetobacter*, *Candida*	Pakistan	2013
	Spectacle	Vancomycin-resistant *Escherichia coli*		

Zhou et al.[113] (2016)	Bed rails, one counter, one instrument panel, one medical chart, tap outlets, sink traps	*Pseudomonas aeruginosa*	China	2011
Pinheiro Lima Aires Gomes et al.[103] (2017)	Manual resuscitators	*Acinetobacter baumannii*, *Pseudomonas aeruginosa*, *Serratia marcescens*, *Proteus mirabilis*, *Serratia fonticola*, *Citrobacter koseri*, *Enterobacter cloacae* complex	Brazil	-
Sued et al.[104] (2017)	Sphygmomanometers, thermometers	*Staphylococcus haemolyticus*	Brazil	2006
Loyola et al.[122] (2018)	Mobile phones	*Pseudomonas aeruginosa*, *Acinetobacter* spp., *Staphylococcus aureus*, *Enterococcus* spp.	Peru	2012
Solaimalai et al.[134] (2019)	In-use ultrasound gel containers, opened intravenous fluid bottles	*Burkholderia cepacia* complex	India	2016
D'Souza et al.[141] (2019)	Nursing call button, bedside rail, main room light switch, sink handles (inside the patient room), alcohol hand foam dispenser	*Pseudomonas fluorescens*, *Acinetobacter baumannii*, *Enterococcus faecium*, *Klebsiella pneumoniae*, *Pseudomonas stutzeri*, *Pseudomonas aeruginosa*, *Stenotrophomonas maltophila*, *Serratia marcescens*, *Enterobacter cloacae*, *Escherichia coli*, *Pseudonomas putida*, *Acinetobacter junii*, *Pseudomonas oleovorans*, *Pandorea apista*, *Psuedomonas luteola*, *Ochrobactrum antrhopi*, *Empedobacter brevis*, *Alcaligenes faecalis*, *Acinetobacter johnsonii*, *Achromobacter xylosidans/dentrificans*, *Shewanella putrefaciens*, *Pseudomonas viridiflava*, *Providencia rettgeri*, *Pantoea dispersa*, *Klebsiella oxytoca*, *Atlantibacter hermannii*, *Citrobacter farmeri*, *Citrobacter freundii*, *Brevudimonas diminuta*, *Acinetobacter* spp., *Acinetobacter lwoffii*[e]	Pakistan	-

Desai et al.[124] (2019)	Pulse oximeter probes	*Acinetobacter baumannii* complex, coagulase-negative *Staphylococcus*, *Klebsiella pneumoniae*, *Pseudomonas aeruginosa*, *Paenibacillus lautus*, *Arthrobacter globiformis*, *Staphylococcus aureus*, *Enterobacter cloacae* complex, *Bacillus megaterium*, *Candida auris*, *Candida parapsilosis*, *Escherichia coli*, *Enterococcus faecalis*, *Enterobacter hormaechei*	South Africa	2018
Haddad et al.[144] (2019)	Stethoscopes	Methicillin-sensitive coagulase negative *staphylococcus, bacillus,* coagulase negative *staphylococcus, Pseudomonas Aeroginosa*	Tunisia	2014
Costa et al.[105] (2019)	Alcohol dispenser	*Staphylococcus*, *Streptococcus*, *Corynebacterium*, *Cloacibacterium*, *Synechococcus*, *Elizabethkingia*, *Paracoccus*	Brazil	-
	Baby feeder container	*Staphylococcus*, *Streptococcus*, *Corynebacterium*, *Cloacibacterium*, *Acinetobacter*, *Pseudomonas*, *Synechococcus*, *Elizabethkingia*, *Paracoccus*, ESBL-producing *Klebsiella*		
	Mattress, needle container, patient belonging container	*Staphylococcus*, *Streptococcus*, *Corynebacterium*, *Paenibacillus*, *Cloacibacterium*, *Acinetobacter*, *Pseudomonas*, *Stenotrophomonas*, *Synechococcus*, *Elizabethkingia*, *Paracoccus*		
	Computer mouse	*Staphylococcus*, *Streptococcus*, *Corynebacterium*, *Paenibacillus*, *Cloacibacterium*, *Acinetobacter*, *Pseudomonas*, *Synechococcus*, *Elizabethkingia*		
	Finger pulse oximeter	*Staphylococcus*, *Streptococcus*, *Corynebacterium*, *Cloacibacterium*, *Paenibacillus*, *Cloacibacterium*, *Acinetobacter*, *Pseudomonas*, *Stenotrophomonas*, *Synechococcus*, *Elizabethkingia*		

	Medicine container	*Staphylococcus*, *Streptococcus*, *Corynebacterium*, *Paenibacillus*, *Cloacibacterium*, *Pseudomonas*, *Stenotrophomonas*, *Synechococcus*, *Elizabethkingia*, *Paracoccus*		
	Telephone key	*Staphylococcus*, *Streptococcus*, *Corynebacterium*, *Cloacibacterium*, *Acinetobacter*, *Pseudomonas*, *Stenotrophomonas*, *Synechococcus*, *Elizabethkingia*, *Paracoccus*, ESBL-producing *Klebsiella*, vancomycin-resistant *Enterococcus*		
	Soap dispenser	*Staphylococcus*, *Streptococcus*, *Corynebacterium*, *Paenibacillus*, *Cloacibacterium*, *Acinetobacter*, *Pseudomonas*, *Stenotrophomonas*, *Synechococcus*, *Elizabethkingia*		
	Oxygen flowmeter	*Staphylococcus*, *Streptococcus*, *Corynebacterium*, *Pseudomonas*, *Stenotrophomonas*, *Synechococcus*, *Elizabethkingia*, *Paracoccus*		
	Computer keyboard	*Staphylococcus*, *Streptococcus*, *Corynebacterium*, *Paenibacillus*, *Cloacibacterium*, *Acinetobacter*, *Pseudomonas*, *Stenotrophomonas*, *Synechococcus*, *Elizabethkingia*, *Paracoccus*, ESBL-producing *Proteus*		
	Curtain	*Staphylococcus*, *Streptococcus*, *Corynebacterium*, *Pseudomonas*, *Synechococcus*, *Elizabethkingia*		
	ECG machine keypad	*Staphylococcus*, *Corynebacterium*, *Acinetobacter*, *Pseudomonas*, *Stenotrophomonas*, *Synechococcus*, *Elizabethkingia*		
Lv et al.[112] (2019)	Faucet aerators	Carbapenem-resistant *Acinetobacter baumannii*	China	2019
Shah et al.[132] (2019)	Mobile phones	Coagulase-negative *Staphylococcus*, methicillin-sensitive *Staphylococcus aureus*, methicillin-resistant *Staphylococcus aureus*, *Bacillus* spp.,	India	2017

		Corynebacterium spp., *Enterococcus* spp., *Acinetobacter* spp., *Klebsiella pneumoniae*, *Citrobacter freundii*		
Dong et al.[108] (2020)	Inner wall of breast milk bag	*Clostridium sporogens*	China	2016
	Inner wall of necrotizing enterocolitis-infant incubator, ECG monitor, infusion pump, stethoscope, public phone	*Clostridium butyricum*		
	Handle of necrotizing enterocolitis-infant incubator, inner wall of refrigerator, inner wall of a box for holding breast milk bag	*Clostridium butyricum*, *Clostridium sporogens*		

[a] Fomites were reported as groups.
[b] Samples were collected in a large patient care room serving as a recovery ICU as well as an inpatient ward.
[c] Bear medical and suction pan were excluded due to not understanding the nature of the objects.
[d] Surface of romper and lid of romper were excluded due to not understanding the nature of the objects.
[e] Pathogens were not reported respectively to fomites.