Reservoirs of Nosocomial Pathogens in Intensive Care Units: A Systematic Review

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Abdul-Halim Osman, Samuel Darkwah, Fleischer C N Kotey, Alex Odoom, Prince Hotor, Nicholas T K D Dayie and Eric S Donkor

Department of Medical Microbiology, University of Ghana Medical School, Accra, Ghana.

ABSTRACT

BACKGROUND: Nosocomial pathogens are known to exacerbate morbidity and mortality in contemporary critical healthcare. Hospital fomites, which include inanimate surfaces, have been identified as "breeding grounds" for pathogens that cause nosocomial infections. This systematic review aimed to deliver incisive insights on nosocomial pathogens in intensive care units (ICUs) and the role of fomites as potential reservoirs for their transmission.

METHOD: An extensive exploration of electronic databases, including PubMed and Scopus, from 1990 to 2023, was carried out between 25th and 29th May 2023, per standard PRISMA guidelines. Information were extracted from articles that reported on fomites in the ICU. Studies that did not quantitatively report the fomite contamination, and those that exclusively took samples from patients in the ICU were excluded from the analysis.

RESULTS: About 40% of the total samples collected on fomites from all the studies yielded microbial growth, with species of *Staphylococcus* being the most predominant. Other prevalent microbes were *Acinetobacter baumannii*, *Escherichia coli*, *Klebsiella pneumoniae*, *Candida* spp., *Enterococcus* sp., and *Enterobacter* sp. The neonatal intensive care unit (NICU) had the highest proportion of contaminated fomites. Among known fomites, the sphygmomanometer exhibited a 100% detection rate of nosocomial pathogens. This included *E. aerogenes*, *Staphylococcus aureus*, coagulase-negative *Staphylococci* (CoNS), *E. coli*, and *K. pneumoniae*. Multidrug-resistant (MDR) bacteria, such as methicillin-resistant *S. aureus* (MRSA), vancomycin-resistant *Enterococci* (VRE), extended-spectrum beta-lactamase (ESBL)-producing *E. coli*, and MDR *Pseudomonas aeruginosa* were commonly isolated on fomites in the ICUs.

CONCLUSION: Many fomites that are readily used in patient care in the ICU harbour nosocomial pathogens. The most common fomite appeared to be mobile phones, sphygmomanometers, and stethoscopes, with *Staphylococcus* being the most common contaminant. Consequently, the need for rigorous disinfection and sterilization protocols on fomites in the ICU cannot be overemphasized. Additionally, heightened awareness on the subject among health professionals is crucial to mitigating the risk and burden of nosocomial infections caused by drug-resistant bacteria.

KEYWORDS: Fomite, nosocomial, pathogen, intensive care unit, *Staphylococcus*, *A. baumannii*, critical care, multidrug resistance, hospital, public health

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CORRESPONDING AUTHOR: Eric S Donkor, Department of Medical Microbiology, University of Ghana Medical School, Korle Bu, Accra, P.O. Box KB 4236, Ghana.
Email: esampane-donkor@ug.edu.gh

Introduction

Nosocomial infections, also known as healthcare-associated infections (HAIs), are those infections that are acquired during the process of receiving healthcare, and include occupational infections incurred by staff, health professionals, patients, and visitors.[1-3] Pathogens that are responsible for nosocomial infections are termed nosocomial pathogens, and they include a wide range of bacterial, viral, and fungal species. These pathogens and their infections pose significant problems, requiring urgent attention worldwide.[4] Critically ill patients in the intensive care unit (ICU) are often immunocompromised, and they are at a high risk for nosocomial infections than are patients in other areas of the hospital.[5] Nosocomial infections cause significant morbidity and mortality in contemporary critical care medicine, as some nosocomial pathogens are increasingly becoming multidrug-resistant.[6,7] Multidrug resistance in nosocomial infections complicates patient management, extends treatment duration, and heightens economic burden with excessive healthcare costs.[8] Nosocomial infections have prevalence rates of 1.6% to 45.8% or higher in less developed countries,[9,10] 6.5% in the European Union, and 3.2% in the United States, resulting in a cost of more than $4.5 billion for the latter. Since the global burden of HAIs is uncertain due to inadequate surveillance systems, it is probable that the prevalence of nosocomial infections is significantly higher worldwide.[11] The extent to which the hospital environment serves as a reservoir of

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nosocomial pathogens, however, remains a subject of debate, amidst limited information.[12]

Inanimate objects and surfaces can serve as reservoirs of nosocomial pathogens in the ICU.[13] Such objects are commonly referred to as fomites, a term defining objects that when contaminated with infectious agents, can transfer these agents to a new host.[14-16] In an ICU, fomites can include medical equipment, surfaces, and other inanimate objects.[17-19] The role of hospital fomites in the transmission of nosocomial organisms is still a topical issue, but there is no clear consensus on the matter.[20] Several studies have identified fomites in the ICU to harbour nosocomial pathogens and be a contributor to their outbreak in the unit.[21-24] Disturbingly, several nosocomial pathogens are drug-resistant, and in some cases, extensively drug-resistant or multidrug-resistant due to their exposure to numerous antibiotics in the hospital setting.[25-31] Medical equipment, such as ventilators, catheters, faucet aerators, and dialysis machines, as well as other inanimate surfaces, can become contaminated with pathogens and serve as reservoirs for infections.[5,24,32,33] Proper cleaning and disinfection of equipment are essential to preventing the spread of the infections. Surfaces such as bed rails, doorknobs, pens, and countertops also harbour pathogens, and must be regularly cleaned and disinfected.[34,35] The ability of pathogens to persist on reservoirs is a significant challenge in the prevention and control of nosocomial infections in the ICU. Also, the persistence of bacteria, viruses, and fungi on inanimate surfaces vary accordingly.[36]

As it is nearly impossible to eliminate the use of equipment and other fomites in the ICU, compliance with standards and guidelines can help reduce or manage HAIs.[37] With current technological advancements and increased expectations for high-quality healthcare services, it is crucial to analyze the frequency and causes of nosocomial infections, especially, in ICUs.[4] Therefore, it is necessary to identify key inanimate reservoirs in ICUs, the common pathogens they harbour, and how long these pathogens persist on them. This would aid in devising effective infection control programmes in hospitals and help develop a reliable and sustainable plan in controlling infections in critical care units. The lack of precise information on the role of fomites in the spread of nosocomial pathogens makes it difficult to implement control plans, resulting in increased costs for both healthcare systems and patients.[4,38,39] This systematic review, therefore, aimed at providing a comprehensive analysis on fomites and their associated pathogens, as well as antibiotic resistance and persistence of these pathogens on fomites within the ICU. Its focus encompasses the neonatal intensive care unit (NICU), pediatric intensive care unit (PICU), surgical intensive care unit (SICU), burns intensive care unit (BICU), and the medical intensive care unit (MICU).

Method

Search strategy

The systematic review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines.[40] Between 25th and 29th May 2023, we carried out an extensive exploration of electronic databases, including PubMed and Scopus, spanning 1990 to 2023. In order to ensure that our search was comprehensive, the following search terms were used: ""intensive care unit" and fomite", "fomite in intensive care unit," "fomite and pathogen in intensive care unit," "intensive care unit," "fomite and infection," "nosocomial infection," "intensive care unit," "inanimate surface," and "pathogen persistence on fomites in ICU." Moreover, "fomite" and "intensive care unit" were included in the following search queries: nosocomial infections, persistence, bacteria, fungi, and viruses. Furthermore, the citations of each study identified during the primary search were evaluated for possible relevance, as were similar articles that appeared with the search results on PubMed.

Inclusion and exclusion criteria

Based on the research keywords, we incorporated studies that presented both qualitative and quantitative data on nosocomial pathogens present on fomites, as well as their prevalence on inanimate surfaces in the ICU. The types of studies used included cross-sectional, longitudinal, prospective, and outbreak studies. In the case of outbreak studies, we included those that collected samples from patients and fomites and further reported on the organisms that were recovered from the fomites; in such instances, we only included the fomite part of the outbreak reports. Our selection was limited to articles that were accessible to us, available in full text, and published in the English language. Publications excluded from the review were reports, case-control studies, commentaries, and letters to editors. Published review articles and textbooks were also excluded. Besides, studies that reported on pathogens that were not associated with fomites were excluded. Moreover, studies that did not specify sample size for various fomites and did not report on the number of positive samples were also excluded, as were preprints and studies whose sample sizes were each less than 10.

Study selection

The Scopus and PubMed searches yielded 623 articles, which were screened using the Zotero reference tool (Version 6.0.30, made by Corporate for Digital Scholarship), to identify and download articles that are available for free. After eliminating duplicates using Zotero, the resulting 507 records were examined based on their titles and abstracts in relation to the inclusion criteria. Subsequently, 41 potential articles were each subjected to careful independent evaluations, with only articles published in the English language considered. Finally, 33 articles were included in this study after a systematic evaluation was carried out on the complete texts of the remaining 81 studies to ascertain their eligibility per the criteria specified in the study, as shown in Figure 1.

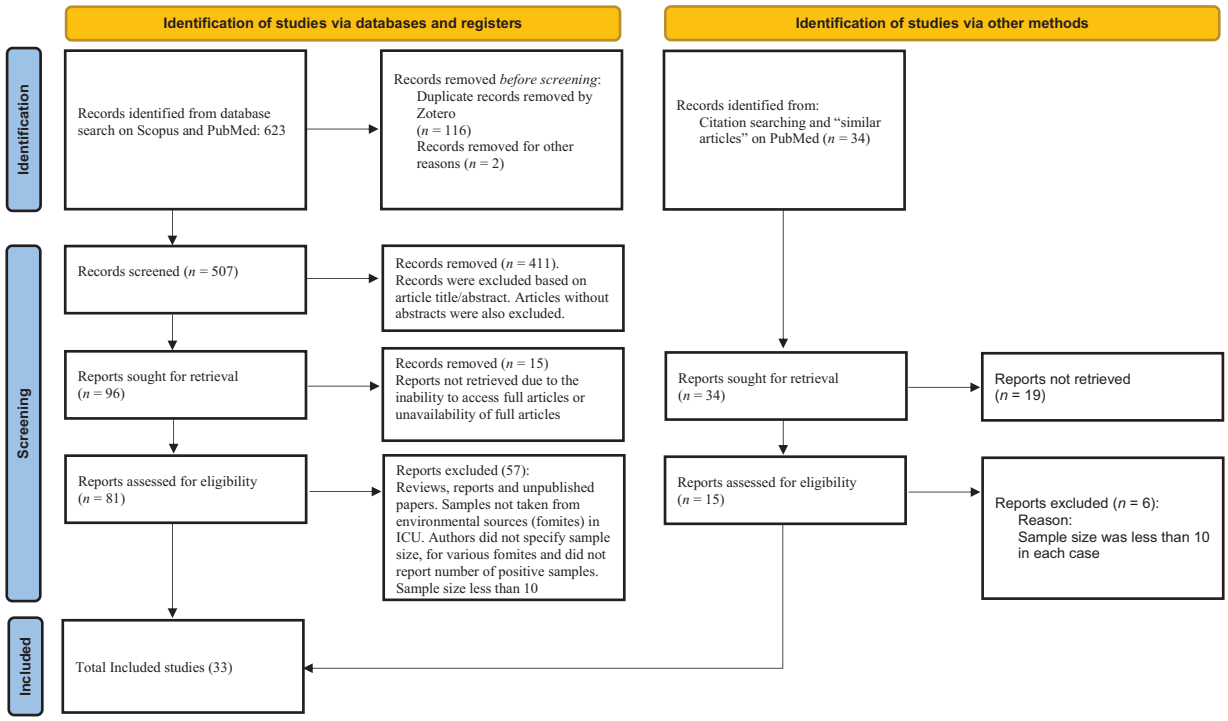

Figure 1. A flow diagram of our systematic review process (PRISMA guide).

Quality assessment

This study was established on the basis of previously published research articles with observational evidence. All duplicates were carefully inspected and eliminated in order to retain the quality of the review. The abstracts of searched articles were thoroughly checked and verified before analysis to ensure that quality and relevant information in the literature were included in the review process. The quality of the articles selected was evaluated independently by authors A.-H.O., S.D. and A.O.

Data extraction

Data were extracted by A.-H.O. and E.S.D. from individual studies using a form and database developed for the purposes of this review in the Microsoft Excel 2013 software. The form captured data such as authors' names, title of the study, year of publication, study setting, keywords, fomites assessed, sampling method, microbial identification method, pathogens assessed, prevalence of nosocomial pathogens, and the duration of pathogens on the fomites. For studies that reported their findings in percentages, the percentages were converted to whole numbers to ensure uniformity.

Results

Overview

In accordance with the inclusion and exclusion criteria and the PRISMA checklist,[40] we selected 33 articles that investigated reservoirs of pathogens in ICUs. The studies were carried out across a diverse range of 17 countries, spanning various regions globally. Three articles were on outbreak or post-outbreak studies[41-43]; two targeted human adenoviruses/rotavirus.[44,45] Additionally, two other studies[46,47] specifically targeted *Staphylococcus aureus* and SARS-CoV-2, respectively. The computer, computer mouse, the space bar on the computer keyboard, and other parts of the computer were collectively labeled as "Computer and its parts" for the purpose of uniformity in this review. Similarly, the sink, sink outlet, and drain were labeled as "Sink". The total number of fomites identified in this study was 29, as shown in Table 1. Overall, about 40% of the total samples collected on these fomites yielded microbial growth, and *Staphylococcus* was the most isolated genus of bacteria. *S. aureus* was the most predominant species identified. Of the 33 studies, 27 isolated bacteria[6,19,23,32,41-43,46,48-65], three isolated viruses,[44,45,47] and only one study examined fungi.[66] Two studies[67,68] isolated both bacteria and fungi on fomites in the ICU. Among the studies that reported on bacteria, fifteen[6,19,32,43,46,49,53,56-58,60,61,63,64] reported on the antibiotic susceptibility profiles of the isolates. None of the studies assessed the longevity or persistence of nosocomial pathogens on a fomite in the ICU. However, the persistence of common nosocomial pathogens on inanimate surfaces has been studied and reviewed in other reports.[69,70] Thus, the persistence of the common nosocomial pathogens in our review were inferred from these reports and other similar studies for discussion purposes.

Sampled surfaces

The sampling of surfaces designated as fomites or potential fomites varied extensively across the different studies. Furthermore, the scope presented diversity in terms of the

Table 1. Summary of individual studies methodologies, bacterial identification methods, and quantitative reports.

FOMITES	SITE OF STUDY	ORGANISM ISOLATED	NUMBER OF COLLECTED SAMPLES	NUMBER OF POSITIVE SAMPLES	PERCENT POSITIVE (%)	SAMPLING METHOD	ORGANISM IDENTIFICATION METHOD	ARTICLE/ SOURCE
Incubators and their Door Locks	ICU	Human adenovirus (HAdV)	48	3	6	A minimum of 50% of fomite surfaces were scraped using swabs.	Genomic quantification and sequencing	Ganime et al.[45]
Mattresses and Pillows	ICU	MRSA, VRE, ESBL producers (52% of all isolates were MDR)	11	8	73	Cutting out a segment of material using sterile gloves	PCR, Vitek2 GPS-IX or Vitek 2 AST-N149 cards	Hu et al.[58]
Gowns/Coats	ICU	*S. aureus*, *Acinetobacter baumannii*, *Stenotrophomonas maltophilia*, *Klebsiella pneumoniae*, and *Serratia rubidae*; 22.2% of the Gram-negative bacteria were MDR.	31	15	48	Use of moistened swab on 4 cm^2 areas of cuffs and abdominal regions of gowns.	Automated identification tests (Vitek System)	Pilonetto et al.[64]
Yankauer Catheters and Suction Machines	ICU	*S. aureus* (15% were MRSA), *Pseudomonas aeruginosa* and *Escherichia coli*, *Candida* spp., CoNS, and *Enterococcus* spp. (10% were VRE)	20	16	80%	Tip soaking (Submerging 3 cm catheter tips in 8 mL thioglycollate broth)	Standard microbiological techniques	Brown & Willms et al.[32]
Trolleys/ Trays		*S. aureus* (20.6% were MDR)	82	10	12	Swabbing	PCR and standard microbiological methods	Veloso et al.[46]
	ICU	*Enterococcus* spp., *S. aureus*, Gram-negative rods, and moulds	174	8	5	A sterile rayon-tipped swab (D2-Tupfer; Heinz Herenz, Hamburg) moistened with sterile saline solution was used to sample the surfaces.	Microbiological testing	Hartmann et al.[67]
Thermometers	ICU	CoNS and MDR *S. haemolyticus*	18	18	100	Cotton swab moistened with sterile normal saline	Standard microbiological methods and biochemical tests	Sued et al.[19]
	NICU	MDR *Klebsiella* spp.	12	1	8	Swabbing	Identification by API 20E identification system, and DNA fingerprinting	Macrae et al.[43]
Parenteral Nutrition (PN) or Expressed Breast Milk	NICU	MDR *Klebsiella* spp.	32	5	16	Swabbing	Identification by API 20E identification system, and DNA fingerprinting	Macrae et al.[43]
Pulse Oximetry	NICU	MDR *Klebsiella* spp.	12	4	33	Swabbing	Identification by API 20E identification system, and DNA fingerprinting	Macrae et al.[43]
Surrounding Air	ICU	*Penicillium* spp., *Aspergillus* spp., *Curvularia* spp., *Alternaria* spp., *Paecelomyces* spp., *Zygomycetes*, *Fusarium* spp., *Cladosporium* spp., and sterile mycelium	40	43	83	Sedimentation plate method	Visualization of the macro- and micro-morphology characteristics of the growing colonies	Gonçalves et al.[66]

(Continued)

Table 1. (Continued)

FOMITES	SITE OF STUDY	ORGANISM ISOLATED	NUMBER OF COLLECTED SAMPLES	NUMBER OF POSITIVE SAMPLES	PERCENT POSITIVE (%)	SAMPLING METHOD	ORGANISM IDENTIFICATION METHOD	ARTICLE/ SOURCE
Mobile Phones	ICU	ESBL-producing *Enterobacter* spp., ESBL-producing *Klebsiella pneumoniae*, *Klebsiella oxytoca*, and *E. coli*; 53.3% of all these were MDR.	491	104	21	A sterile cotton swab moistened with trypticase soy broth was rotated on the entire surface of each phone.	Microbiological procedures	Loyola et al.[60]
	ICU	*Staphylococcus epidermidis, Staphylococcus hominis, Bacillus* spp., *S. aureus*, *Staphylococcus warneri*, *S. haemolyticus, Streptococcus mitis*, and *Streptococcus oralis*	130	93	72	Surface swabbing of each mobile phone's buttons, using a sterile gel swab that is moistened with saline.	Microbiological methods and MicroScan	Al-beeshi et al.[48]
	ICU	SARS-CoV-2	51	2	4	Nylon FLOQ Swab	RT-PCR and viral culture	Espinoza et al.[47]
	ICU	*Streptococcus* spp., MRSA, CoNS, *Enterococcus* spp., Non-fermentative Gram-negative bacteria, coliforms, moulds, and yeasts	200	189	95	A sterile swab moistened by saline was rotated on the surfaces.	Biochemical tests	Ulger et al.[68]
	ICU	CoNS, *S. aureus*, *Sarcina* spp., *Bacillus* spp., *Corynebacterium* spp., and *Neisseria* spp.	50	40	80	A sterile saline-moistened swab (Copan S.p.A, Brescia, Italy) was rotated across both sides of mobile phones' surfaces.	Standard microbiological methods and biochemical tests	Kotris et al.[59]
	ICU	CoNS, MRSA, *Micrococci*, and ESBL-producing *E. coli*	55	48	87	Saline-wet-sterile swab sticks were rubbed over the entire surface area of each phone.	Standard microbiological techniques	Anupriya et al.[49]
	ICU	CoNS, *Bacillus* spp., and MRSA, *Acinetobacter* spp., moulds, *Paenibacillus* spp., *Streptococcus viridians*, and *Aerococcus* spp.	50	50	100	Used "E-Swab COPAN"	Standard microbiological methods and biochemical tests	Galazzi et al.[56]
	ICU	CoNS, *Streptococcus viridans*, *S. aureus* (1.4% were MRSA), *Micrococcus*, *E. coli,* Diphtheroids, *Bacillus* spp., *Pantoea* spp., *Moraxella osloensis*, *Pseudomonas stutzeri, Sphingomonas paucimobilis*, *Acinetobacter lwoffii*, and *A. baumannii*	213	157	74	Sides, backs and screens of mobile phones, and in some cases, phone covers, were swabbed using sterile swabs.	Microbiological methods	Heyba et al.[57]
	ICU	*P. aeruginosa, Acinetobacter* spp., MRSA, VRE, and MDR *Enterococcus* spp.	491	107	22	A sterile cotton swab moistened with trypticase soy broth was rotated on the entire surface of each phone.	Standard microbiological methods and biochemical tests	Loyola et al.[61]
	ICU	*S. epidermidis*, *S. aureus*, *E. coli*, *K. pneumoniae*, *P. aeruginosa*, *Acinetobacter* spp., *Bacillus* spp., *Proteus*, and *Streptococcus*. None of the isolates were sensitive to sulfamethoxazole-trimethoprim, tetracycline and ampicillin.	56	53	95	Saline-wet-sterile swab sticks (Sterilin, UK) were rubbed over the entire surface area of each phone.	Standard bacteriological procedures	Nwankwo et al.[62]

(Continued)

Table 1. (Continued)

FOMITES	SITE OF STUDY	ORGANISM ISOLATED	NUMBER OF COLLECTED SAMPLES	NUMBER OF POSITIVE SAMPLES	PERCENT POSITIVE (%)	SAMPLING METHOD	ORGANISM IDENTIFICATION METHOD	ARTICLE/ SOURCE
Faucets and Aerators	ICU	*S. paucimobilis, P. aeruginosa, C. meningosepticum*, *Achromobacter xylosoxidans*, *Burkholderia cepacia*, and *S. maltophilia*	162	54	33	Sterile cotton swabs were used on the inner surfaces of the faucet aerators.	Standard biochemical methods	Wang et al.[23]
	ICU	*S. aureus* (MRSA), *Enterobacter*, and *Enterococcus*	64	7	11	Rolling of saline-moistened-sterile rayon-tipped swab (Baxter Healthcare Corporation, Deerfield, Ill), on the entire surface being tested	VITEK system and API 20E, pulsed-field gel electrophoresis	Bures et al.[6]
	NICU	*P. aeruginosa*	28	18	64	Swab and first-flush cold water	qPCR	Bédard et al.[41]
Pens	ICU	CoNS and *Micrococcus* spp.	20	17	85	Swabbing	Standard microbiological techniques	Wolfe et al.[35]
Sphygmomanometers	ICU	*E. aerogenes*, *S. aureus* (58.7% were MDR), CoNS (28.3%), *E. coli* (72.7%), and *K. pneumoniae*	18	18	100	Sterile cotton-tipped applicator sticks, moistened with sterile normal saline, were employed.	Colony morphology, Gram staining and biochemical tests	Darge et al.[53]
	ICU	CoNS and MDR *S. haemolyticus*	24	24	100	Cotton swab moistened with sterile normal saline	Standard microbiological methods and biochemical tests	Sued et al.[19]
Bedside Tables	ICU	*S. aureus* (58.7% were MDR), CoNS (28.3%), *E. coli* (72.7%), and *C. freundii* (20%)	19	19	100	Sterile cotton-tipped applicator sticks, moistened with sterile normal saline, were employed.	Colony morphology, Gram staining, and biochemical tests	Darge et al.[53]
	ICU	Rotavirus A (RVA) and human adenovirus (HAdV)	120	52	43	A minimum of 50% of fomite surfaces were scraped using swabs	Genomic quantification and sequencing	Ganime et al.[45]
Computer and its Parts	ICU	Rotavirus A (RVA) and human adenovirus (HAdV)	60	22	37	A minimum of 50% of fomite surfaces were scraped using swabs.	Genomic quantification and sequencing	Ganime et al.[45]
	ICU	MRSA, *Enterobacter*, and *Enterococcus*	80	19	24	Rolling of saline-moistened-sterile rayon-tipped swabs (Baxter Healthcare Corporation, Deerfield, Ill), on the entire surface being tested	VITEK system and API 20E, pulsed-field gel electrophoresis	Bures et al.[6]
	ICU	*Enterococcus* spp., *S. aureus*, Gram-negative rods, and moulds	444	26	6	A sterile rayon-tipped swab (D2-Tupfer; Heinz Herenz, Hamburg) moistened with sterile saline solution was used to sample the surfaces.	Microbiological testing	Hartmann et al.[67]

(Continued)

Table 1. (Continued)

FOMITES	SITE OF STUDY	ORGANISM ISOLATED	NUMBER OF COLLECTED SAMPLES	NUMBER OF POSITIVE SAMPLES	PERCENT POSITIVE (%)	SAMPLING METHOD	ORGANISM IDENTIFICATION METHOD	ARTICLE/ SOURCE
Hand Sanitizer Dispensers	SICU	CoNS, *S. aureus, Micrococcus* spp., *Bacillus* spp., Diphtheroids, Aerobic *Actinomycetes*, non-lactose-fermenting non-enterics, and lactose-fermenting enterics	17	17	100	Sterile cotton-tipped swabs moistened with sterile saline	Biochemical test and Vitek 2	Eiref et al.[55]
	ICU	Human adenoviruses	14	8	57	A minimum of 50% of fomite surfaces were scraped using swabs	Genomic quantification and sequencing	Ganime et al.[44]
Stethoscopes	ICU	CoNS, *S. aureus*, *K. pneumoniae*, *E. coli*, *C. freundii*, *E. aerogenes*, and *P. vulgaris*	61	61	100	Sterile cotton-tipped applicator sticks, moistened with sterile normal saline, were employed.	Colony morphology, Gram staining, and biochemical tests	Darge et al.[53]
	ICU	Normal flora, *A. iwoffi*, *A. baumannii*, MRSA, and *Acinetobacter radioresistens*	46	15	33	Swabbing of diaphragm and bell of stethoscopes using sterile cotton bud moistened with sterile saline	Standard protocols	Whittington et al.[65]
	ICU	CoNS	18	18	100	Cotton swab moistened with sterile normal saline	Standard microbiological methods and biochemical tests	Sued et al.[19]
Identity Badges and Common Access Cards (CACs)	BICU	CoNS, *Micrococcus* spp., Gram-positive rods, *S. aureus*, *Stomatococcus* spp., and *Streptococcus viridans*	118	89	75	Swabbing	Standard microbiological methods	Caldwell et al.[50]
Door Knobs and Handles	ICU	Human Adenovirus	21	8	38	A minimum of 50% of fomite surfaces were scraped using swabs.	Genomic quantification and sequencing	Ganime et al.[44]
	ICU	*S. aureus* (20.6% MDR of total S. aureus isolates)	36	6	17	Swabbing	PCR and standard microbiological methods	Veloso et al.[46]
Infusion Pumps	ICU	*S. aureus* and moulds	214	2	1	A sterile rayon-tipped swab (D2-Tupfer; Heinz Herenz, Hamburg) moistened with sterile saline solution was used to sample the surfaces.	Microbiological testing	Hartmann et al.[67]
Ventilators	ICU	*Enterococcus* spp., *S. aureus*, Gram-negative rods, and moulds	222	8	4	A sterile rayon-tipped swab (D2-Tupfer; Heinz Herenz, Hamburg) moistened with sterile saline solution was used to sample the surfaces.	Microbiological testing	Hartmann et al.[67]
Medical Charts (Records Books)	ICU	CoNS, *S. aureus* (MRSA), *E. faecalis, Streptococcus viridans, A. baumannii, Corynebacterium* spp., *Bacillus* spp., *E. coli*, *S. paucimobilis*, MRSA, *P. aeruginosa*, *Pantoea* spp., and *K. pneumoniae*	422	272	64	Swabbing	Microbiological, biochemical laboratory techniques, and automated methods	Chen et al.[51]

(Continued)

Table 1. (Continued)

FOMITES	SITE OF STUDY	ORGANISM ISOLATED	NUMBER OF COLLECTED SAMPLES	NUMBER OF POSITIVE SAMPLES	PERCENT POSITIVE (%)	SAMPLING METHOD	ORGANISM IDENTIFICATION METHOD	ARTICLE/ SOURCE
Patient Files	ICU	*P. aeruginosa* (32.3% were MDR), MRSA, *S epidermidis*, *K. pneumoniae* (14.7% were MDR), *A. baumannii* (13.7% were MDR), and *S. marcesens* (0.9% were MDR)	102	87	85	Swabbing	Biochemical tests, API 20E, and API 20 NE	Panhotra et al.[63]
Accompanying Arm Chairs	ICU	Rotavirus A (RVA) and human adenovirus (HAdV)	96	49	51	A minimum of 50% of fomite surfaces were scraped using swabs.	Genomic quantification and sequencing	Ganime et al.[45]
Cardiac Monitor Keyboards	NICU	Rotavirus A (RVA) and human adenovirus (HAdV)	36	4	11	A minimum of 50% of fomite surfaces were scraped using swabs.	Genomic quantification and sequencing	Ganime et al.[45]
Sink, Outlet and Drains	ICU	MDR *P. aeruginosa*	76	37	49	Swabbing	Biochemical tests and matrix-assisted laser desorption/ ionization time-of-flight (MALDI-TOF) mass spectrometry	De Jonge et al.[54]
	ICU	*S. maltophilia*	12	3	25	Swabs and preflush water	Matrix-assisted laser desorption/ionization time-of-flight (MALDI-TOF) mass spectrometry	Guyot et al.[42]
	NICU	*P. aeruginosa*	28	25	89	Swabbing	Culture, qPCR	Bédard et al.,[41]
	ICU	*S. aureus* (20.6% were MDR)	36	8	22	Swabbing	PCR and standard microbiological methods	Veloso et al.[46]
Tap water	ICU	*P. aeruginosa*	233	81	35	Collection of first 250 mL of flush of water	API20 NE identification system	Coppry et al[52]
	NICU	*P. aeruginosa*	28	14	50	Swab and first-flush cold water in sterile polypropylene bottle	qPCR	Bédard et al.,[41]
Companion Chairs	ICU	Human adenoviruses	19	5	26	A minimum of 50% of fomite surfaces were scraped using swabs.	Genomic quantification and sequencing	Ganime et al.[44]

Abbreviations: MDR, multidrug-resistant; MRSA, methicillin-resistant *Staphylococcus aureus*; VRE, vancomycin-resistant *Enterococcus*; ESBL, extended-spectrum beta-lactamase; CoNS, coagulase-negative Staphylococci; ICU, intensive care unit; NICU, neonatal intensive care unit; BICU, burns intensive care unit; SICU, surgical intensive care unit; PCR, polymerase chain reaction; DNA, deoxyribonucleic acid.

inclusion of various types of inanimate surfaces during the sampling process. Among the pool of inanimate surfaces sampled, parenteral nutrition (PN),[71] pulse oximetry,[72] and curtains[73] had relatively lower sample sizes of less than 10, and were, therefore, excluded from further analysis in order to ensure a higher statistical power of this study.[74] Overall, of the 29 fomites, the three most sampled in the ICU included mobile phones,[47-49,56,57,59-62,68] sinks,[41,42,46,54] and faucets[6,23,41] (Table 1).

Laboratory methods

Culture analysis was used in all the studies, except for those of Ganime et al.[44] and Ganime et al.[45] who employed molecular techniques. All the selected studies utilized moisturized swabs for collecting samples on single surfaces, except the Gonçalves et al.[66] study which used the sedimentation plate method and other means[32,52,58,66] (Table 1). With regard to pre-culture media, nine studies used broths such as Letheen broth,[64] thioglycollate broth,[6,32] trypticase soy broth[51,60], tryptone soya broth,[58] and brain heart infusion broth. De Jonge et al.[54] used an unspecified selective broth in their study. Most of the studies commonly used culture media such as MacConkey agar, mannitol salt agar, blood agar, and chocolate agar, but Sued et al.[19] and Chen et al.[51] did not clearly indicate the media they used. Organisms other than bacteria were cultured via different means such as Vero cells, Dulbecco's modified eagle's medium, and cysteine-lactose electrolyte-deficient (CLED) plates[42,44,45,47] (Table 2). Reported incubation temperatures ranged from 18 °C to 38 °C for 15 hours to 168 hours. However, the majority of the studies had their incubation temperatures ranging between 35 °C and 38 °C. Four studies[42,44,45,51] did not report on incubation time and temperature (Table 2).

The method for bacterial identification varied across the studies. All the articles reported standard microbiological techniques, including colony morphology, Gram stain reaction, microscopic morphology, biochemical reactions, molecular microbial methods, and modern automated identification techniques, such as the MALDI-TOF mass spectrometry, in the identification of microbes (Table 1). The most common identification methods included biochemical tests and conventional automated identification machines. Metagenomic analysis was also adopted in identifying and further analyzing the processed samples from the fomites.[19,23,41-47,58,61]

Frequency of contamination and microbial presence

A significant number of the fomites showed contamination of more than 40% across all studies. However, contamination frequency varied from study to study. Interestingly, certain surfaces displayed a higher percentage of contamination despite being sampled less frequently. For instance, the sphygmomanometer, although subjected to a lower sampling frequency, exhibited a 100% detection rate of organisms commonly associated with nosocomial infections, including *E. aerogenes*, *S. aureus*, CoNS, *E. coli*, and *K. pneumoniae*.[19,53] This was also the case for the thermometers[19,43], Yankauer catheters and suction machines,[32] and mattresses and pillows[58] which showed higher percentages of contamination with nosocomial pathogens. Mobile phones emerged as the fomite with the most extensive body of research. Notably, the sampling frequency of mobile phones within each study was consistently high and revealed its substantial capacity to harbour nosocomial pathogens[47-49,56,57,59-62,68] (Table 1).

Microorganisms that have the potential of causing nosocomial infections were isolated on various surfaces in the ICU, with the NICU emerging as the predominant unit. Data were presented as a percentage of positive sampling based on the frequency of positive results from the number of surfaces sampled (Table 1). The examined literature demonstrated a high prevalence of nosocomial pathogens, particularly for CoNS, *S. aureus*, and MRSA, in the ICUs (Tables 1 and 3). Though CoNS are considered normal flora in healthy individuals, *S. epidermidis* and *S. haemolyticus* (the most common species in CoNS) are common causes of infections associated with invasive procedures, indwelling devices or implanted foreign bodies, and among the immunocompromised. Infections from these pathogens include bacteraemia, urethritis, and endocarditis, among others.[75]

All the ESKAPE pathogens, including *Enterococcus faecium, Staphylococcus aureus, Klebsiella pneumoniae, Acinetobacter baumannii, Pseudomonas aeruginosa*, and *Enterobacter* spp., were encountered on fomites such as patient files, medical charts (records books), stethoscopes, sphygmomanometers, bedside tables, and many more fomites (Table 1). These ESKAPE pathogens are a group of bacteria that have the ability to "escape" the effects of commonly used antibiotics, posing a significant challenge to healthcare systems worldwide. Other organisms commonly associated with nosocomial infections detected in various ICUs included *E. coli, Candida* sp., *Enterococcus* sp., *S. haemolyticus*, and *Pantoea* spp. (Tables 1 and 3).

Nosocomial pathogens and their prevalence on the fomites

Although nosocomial pathogens were identified across all the studies, a notable presence of specific pathogens was consistently associated with certain fomites, suggesting a potential role of these fomites as reservoirs within the ICU. Notably, *S. aureus* was found on the majority of the fomites examined, emphasizing its widespread distribution. Additionally, *Klebsiella* spp. and *P. aeruginosa* were particularly prominent in "sink and tap" samples. Alongside *Staphylococcus* sp., *P. aeruginosa* and *K. pneumoniae* were frequently associated with mobile phones, reinforcing their significance as potential carriers of these organisms. Furthermore, *P. aeruginosa* exhibited a common

Table 2. Details of methodologies and geographical location of the individual studies.

ARTICLES	MEDIA USED	BROTH USED	INCUBATION TEMPERATURE AND DURATION	COUNTRY
Al-Beeshi et al.[48]	Sheep blood agar and MacConkey agar	NA	37 °C for 48 h	Saudi Arabia
Anupriya et al.[49]	Nutrient agar, blood agar and MacConkey's agar	NA	37 °C for 24 h	India
Bédard et al.[41]	Reasoner's 2A agar	NA	22 °C for 24-48h	Canada
Brown & Willms et al.[32]	Thioglycollate broth, blood agar, chocolate agar, colistin-nalidixic acid blood agar, and MacConkey agar	Thioglycollate broth	35 °C to 37 °C for 24, 48, and 72 h	United States
Bures et al.[6]	Trypticase soy agar, blood agar MacConkey agar, and Columbia colistin-nalidixic acid agar	Thioglycollate broth	37 °C for 48 h	United States
Caldwell et al.[50]	Trypticase soy agar with 5% sheep blood (Beckton, Dickinson, and Company), MacConkey II agar, and fluid thioglycollate medium	NA	35 to 37 °C for up to 48 h	United States
Chen et al.[51]	Sheep blood agar and eosin-methylene blue agar	Trypticase soy broth	Not stated	Taiwan
Coppry et al.[52]	Cetrimide agar plates	NA	37 °C for 24 and 48 h	France
Darge et al.[53]	Blood agar, MacConkey agar, and mannitol salt agar	NA	37 °C for 24 h	Ethiopia
De Jonge et al.[54]	MacConkey agar	Selective broth; not specified	38 °C for 15-18 h	Netherland
Espinoza et al.[47]	Vero cells	NA	NA	Brazil
Eiref et al.[55]	Trypticase soy agar and blood agar	NA	35 °C for 24-72 h	United States
Galazzi et al.[56]	Brain heart infusion agar plus 5% sheep blood	NA	35 ± 2 °C for 48 h	Italy
Ganime et al.[44]	Dulbecco's modified eagle's medium	NA	NA	Brazil
Ganime et al.[45]	Dulbecco's modified eagle's medium	NA	NA	Brazil
Gonçalves et al.[66]	Trypticase soy agar and Chapman agar	NA	25 °C for 7 d (168 h)	Brazil
Guyot et al.,[42]	Cysteine-lactoseelectrolyte-deficient (CLED) agar	NA	NA	United Kingdom
Hartmann et al.[67]	Blood agar	NA	36 °C for 48 h	Germany
Heyba et al.[57]	Blood agar and chocolate agar	NA	37 °C for 48 h	Kuwait
Hu et al.,[58]	Horse blood agar	Tryptone soya broth	37 °C-37 °C for 18-48h	United Kingdom
Kotris et al.[59]	Blood agar	NA	35 °C ± 2 for 18-24 h	Croatia
Loyola et al.[60]	MacConkey agar	3 mL trypticase soy broth	35 °C for 18-24 h	Peru
Loyola et al.[61]	MacConkey agar, mannitol salt agar, and blood agar	Trypticase soy broth	18-24 h at 35°C	Peru
Macrae et al.[43]	MacConkey agar agar	NA	Not stated	United Kingdom
Nwankwo et al.[62]	MacConkey and blood agar	NA	37 °C for 18-24 h	Nigeria
Pilonetto et al.[64]	Letheen broth, MacConkey agar, XLD agar, cetrimide agar, and mannitol salt agar	Letheen Broth	35 °C for 48 h	Brazil

(Continued)

Table 2. (Continued)

ARTICLES	MEDIA USED	BROTH USED	INCUBATION TEMPERATURE AND DURATION	COUNTRY
Panhotra et al.[63]	Blood agar and MacConkey agar	NA	37 °C for 48 h	Saudi Arabia
Sued et al.[19]	5% sheep blood agar and Mueller Hinton agar	NA	35 °C for 48 h	Brazil
Ulger et al.[68]	Blood agar supplemented with 5% defibrinated sheep blood and eosin methylene blue agar	NA	37 °C for 48 h	Turkey
Veloso et al.[46]	Mannitol salt agar	Brain Heart Infusion broth	35-37 °C for 24 and 48 h	Brazil
Wang et al.[23]	Sheep blood agar	NA	37 °C for 3-5 d	Taiwan
Wolfe et al.[35]	10% sheep blood agar	NA	35 °C for 24 h and 48 h	United States
Whittington et al.[65]	Blood agar and MacConkey agar	NA	37 °C for 24 h	United Kingdom

Abbreviation: NA, not available.

association with sink outlets, faucets, and aerators. Nosocomial pathogens were widely isolated from Yankauer catheters and suction machines in one study. A number of viral and fungal isolates were reported in some studies, but at lower frequencies compared to those of bacteria. Mobile phones,[47] bedside tables,[45] bed rails,[45] companion chairs,[44] and incubators and their door locks[45] harboured viruses and at relatively lower frequencies. Twelve studies[6,23,32,35,48,51,53,60,62-64,68] further provided the total number of bacterial isolates, making it possible to determine the most prevalent contaminants of fomites in the ICU. *Staphylococcus* sp., comprising mainly CoNS, *S. aureus*, and MRSA, were predominant, and were detected in all the 12 studies, except two[23,60] (Table 3). Furthermore, *P. aeruginosa* and *Klebsiella* sp. were randomly isolated across all studies at moderate frequencies.

In the studies that reported on antimicrobial susceptibility, mattress and pillow appeared to harbour multiple drug-resistant bacteria, such as MRSA, VRE, and ESBL producers.[58] Similarly, bedside table, which is often proximal to patients, appeared to harbour numerous drug-resistant bacteria, showing 100% contamination in the study of Darge et al.[53]. Mobile phones also randomly harboured ESBL-producing *E. coli*, ESBL-producing *Enterobacter* sp., and ESBL-producing *K. pneumoniae*.[60] The sink, outlet, and drain were contaminated with MDR *P. aeruginosa*.[53]

Discussion

In recent years, a plethora of evidence has emerged regarding the colonization of nosocomial pathogens on inanimate surfaces within hospital settings.[76,77] The literature further provide compelling evidence that microorganisms present in the healthcare environment are a source of nosocomial infections. This corresponds to the fact that patients in ICUs are vulnerable to fomite-associated nosocomial infections and, thus, necessitates the need to frequently evaluate fomites in critical care units.[78,79] Prior to the current study, a comprehensive review that quantifies the prevalence of these pathogens within the ICU had not been conducted. Consequently, we undertook this systematic review to help address that significant gap in literature. In this present study, we generally observed mobile phones, aerators and faucets, the stethoscope, and the sphygmomanometer to be the most potentially contaminated fomites in the ICU. The prevalence of the different nosocomial pathogens in the overall samples varied greatly, but *S. aureus* led the charts. The microbiological methods employed by all the studies for sampling and microbial identification in the ICU are capable of effectively recovering microbes from fomites. It is worth mentioning that the utilization of modern techniques, such as MALDI-TOF, would have been more efficient in recovering and identifying isolates at the species level in studies that relied only on biochemical tests.[80]

We observed that some studies focused on specific organisms and utilized techniques tailored to isolate only those targeted organisms. The generally high prevalence of nosocomial pathogens in ICUs reported here (40%) is consistent with other findings.[81,82] The observed variation of nosocomial pathogens on the fomites is also comparable with those in the reports of Abubakar et al.[81] and Bhatta et al.[83] which noted variable pathogens in the ICU and other hospital settings, respectively. Such variations could be attributed to the fact that these pathogens persist under different conditions, such as temperature, humidity, and the characteristics of the fomite they contaminate. Some microbes, such as *Acinetobacter* sp., are capable of surviving on both dry and wet surfaces for a long period of time (several weeks) in a wide range of temperatures and pH. Studies by Kramer et al.[36] and others[84] reported that Gram-positive bacteria, such as *Enterococcus* spp. (including VRE strains), *S. aureus* (including MRSA strains), and *S. pyogenes* survive for months on dry surfaces. The authors further found that Gram-negative species, such as *Acinetobacter* sp., *E. coli*, *Klebsiella* sp.,

Table 3. Studies that reported the total number of isolates and the number of various bacteria isolated.

STUDIES THAT REPORTED THE MOST PREVALENT ISOLATES	TOTAL NUMBER OF ISOLATES	*STAPHYLOCOCCUS* SPP. (CONS & MRSA)	*BACILLUS* SPP.	*A. BAUMANNII*	*E. COLI*	*P.AERUGINOSA*	*KLEBSIELLA* SPP.	*STREPTOCOCCUS* SPP.	OTHERS (*PROTEUS MIRABILIS*, *S. PAUCIMOBILI*, *CANDIDA*, YEAST, *ACHROMOBACTER*, *C. MENINGOSEPTICUM*,*SERRATIA RUBEDIA*, *C. FREUNDII*, OTHER ENTEROBACTER
Al-Beeshi et al.[48]	159	104	9	NA	NA	NA	NA	6	40
Brown & Willms et al.[32]	25	9	NA	NA	NA	NA	NA	NA	9
Bures et al.[6]	33	16	NA	NA	NA	NA	NA	NA	8
Chen et al.[51]	409	245	17	14	23	6	9	20	52
Darge et al.[53]	171	93	NA	NA	NA	NA	10	NA	13
Loyola et al.[60]	105	NA	NA	NA	105	NA	23	NA	48
Nwankwo et al.[62]	97	38	18	3	8	11	4	8	7
Panhotra et al.[63]	87	24	NA	14	NA	33	15	NA	1
Pilonetto et al.[64]	18	11	NA	2	NA	NA	2	NA	3
Wang et al.[23]	66	NA	NA	NA	NA	14		NA	47
Ulger et al.[68]	307	231	NA	NA	NA	NA	NA	12	64
Wolfe et al.[35]	20	17	NA	NA	NA	NA	NA	NA	NA

Abbreviations: NA, not available.

P. aeruginosa, *Serratia marcescens*, and *Shigella* sp., can thrive on inanimate surfaces over months. In another study that aimed at determining the longevity of pathogens on objects made of cotton, wool, silk, and cotton-polyester, *S. aureus*, *E. coli*, *P. aeruginosa*, and *A. baumannii* persisted for weeks.[85]

In this present study, bacteria dominated on the studied fomites; only a few fomites harboured viral and fungal organisms. Viral infections have been associated with many infectious outbreaks,[86] but often receive less attention and are somewhat overlooked compared to bacteria, despite their significant impact.[87] Less frequent groups of organisms like *Candida*, although rare, have a high mortality rate among immunocompromised patients,[88] and most drugs for their treatment have significant side effects.[89]

In 2019, the World Health Organization recognized six pathogens as significant in nosocomial infections: *P. aeruginosa*, *A. baumannii*, *E. coli*, *S. pneumoniae*, *K. pneumoniae*, and *S. aureus*.[48,90,91] At least, one or more of these nosocomial pathogens have been isolated from at least one fomite, although there seems to be no record regarding their isolation from either of companion chairs, accompanying armchairs, incubators and their door locks, and cardiac monitor keyboards. The alarming distribution of these nosocomial pathogens across the fomites in this study is consistent with the findings of Muhammad et al.[82]

Out of the 29 fomites identified in this study, *S. aureus*, the most commonly isolated organism, was present on 19. Furthermore, studies that reported the number of isolates show that *Staphylococcus* sp., comprising mainly CoNS and MRSA, were the most predominant across all reported studies, except in the case of Loyola et al.[60] and Wang et al.[23] This observation is similar to those of a number of studies[4,81,90,91] focusing on ambulances and other hospital-associated environments. Some fomites were constantly 100% contaminated across all the studies, as observed in regard to the sphygmomanometer and stethoscope. These are instruments commonly used in measuring blood pressure and listening to internal sounds of patients' bodies in hospital settings, and as a result, are highly exposed to multiple contacts between clinicians and patients.[92,93] Sphygmomanometers recorded 100% contamination in two studies and the isolates were MDR bacteria associated with nosocomial infections, especially among immunocompromised patients.[43,94] The sphygmomanometer has several parts, but a notable part capable of harbouring organisms is the cuff, whose physical features make it an optimum reservoir of microbes. The cuff is usually in direct contact with patients and often rubs around their upper arm.[95] The high contamination rate in this present study corroborates the findings of Zargaran et al.[96] who reported a 85% contamination rate of sphygmomanometer cuffs in clinical settings. We also observed that the stethoscope harboured *Staphylococcus* species, such as *S. aureus* (MRSA) and CoNS, in all the studies alongside other nosocomial pathogens such as *E. coli* and *A. baumannii*. Some fomites, such as taps, persistently harboured *P. aeruginosa*, which is reported to be effective in biofilm formation, an attribute that enhances its longevity in water and moist surfaces (including the surface of soaps and in liquid soap).[13,97,98]

ESKAPE pathogens were commonly distributed on many fomites. A considerable number of drug-resistant bacteria were reported on several fomites. Mattresses and pillows, which are in direct contact with hospitalized patients, tend to be contaminated with pathogens such as MRSA, VRE, and ESBL producers. All these pathogens have been previously reported in outbreaks in ICUs.[99-101] As a result, mattresses and pillows may be involved in the cross-transmission of pathogens among critically ill patients.[102,103] Furthermore, mobile phones appeared to be potential reservoirs of MDR nosocomial pathogens, such as ESBL-producing *Enterobacter* sp. and ESBL-producing *Klebsiella* sp. This report aligns with the predictions and findings of Tekerekoğlu et al.[104] and Olsen et al.,[105] but contradicts the findings of Muhammad et al[82] who reported no MDR pathogens on mobile phones in hospitals. The absence of MDR pathogens in Muhammad et al.'s[82] report could be attributed to their strict reporting on only the healthcare workers' mobile phones. The detection and reports of MDR pathogens associated with nosocomial infections on these commonly used inanimate surfaces in the proximity of immunocompromised patients need prompt attention.

One goal of this study was to report fomite contamination based on the specific ICU types, but this information was available for only seven fomites. Among these fomites, the NICU recorded both the highest prevalence of nosocomial pathogens and the largest number of fomites, encompassing six distinct inanimate surfaces: thermometers, PN, pulse oximetry, faucets and aerators, cardiac monitor keyboard, sink, and tap water. The high prevalence of nosocomial pathogens and the abundance of fomites in the NICU pose significant risks to neonates, especially, considering their vulnerable and still-developing immune systems. These factors can potentially compromise the health and well-being of these fragile infants. *Clostridium difficile* is also a common nosocomial pathogen reportedly associated with numerous hospital-acquired infections. It had been anticipated that it would be reported on due to its recognized ability to survive for extended periods on inanimate surfaces.[106] However, none of the studies reported on here identified *C. difficile* contamination on any of the fomites in the ICU.

Given the challenges associated with isolating or recovering certain clinically relevant organisms, such as viruses and *C. difficile*, metagenomic analysis emerges as a valuable tool for investigating and characterizing microbial communities present on inanimate surfaces in the ICU. In this present study, the articles that implemented metagenomics in identifying bacteria observed a remarkable organism recovery from the fomites involved, which may have escaped traditional microbiological

methods.[19,41,43-45] Specifically, recovering viruses for microbiological studies presents a significant challenge; however, metagenomic analysis yielded positive results in recovering SARS-CoV-2 and human adenoviruses on fomites.[44,45,47]

The use of this approach further provided insights into the diversity, abundance, and potential pathogenicity of bacteria found on these fomites and helped in tracing a potential source of bacterial outbreak by analyzing the genomics of the samples on potential fomites and the clinical isolate.[42,43,46] Likewise, through genome analysis, Wang et al.[23] found *C. meningosepticum* from faucet cultures to be similar to the *C. meningosepticum* isolates recovered from four different patients located in different units. Similarly, Hu et al.[58] who performed metagenomics and subsequent phylogenetic analysis, revealed that closely related microbiomes contaminate similar categories of fomites. Tracking the presence of antibiotic resistance genes in bacteria is necessary to deduce appropriate measures to avoid their spread via horizontal or vertical gene transfer[107-112] or other factors of interest; ESBL-producing bacteria isolated from mobile phones of healthcare workers were found to harbour *bla* genes, which have long been linked to antibiotic resistance.[61]

The identification of these nosocomial pathogens in the ICUs is a pressing issue that demands swift action. Interventions such as the use of copper-silver alloy coats (which possess antibacterial activity) on commonly touched surfaces, such as tap handles and door handles, could be employed.[113-116] It is also important to develop suitable disinfection methods that will help to reduce or eliminate nosocomial agents in ICUs. Several research studies have reported the use of disinfectants, UV irradiation, and phages to curb infections as a result of contaminated fomites.[117-120] Furthermore, the efficacy of disinfection of fomites in the ICU depends on several factors, including concentration of disinfectants, fomite pathogenic load, the frequency of disinfection, and the type of pathogens present on the fomites.[121-123] Hence, efficient methods for disinfection and elimination of nosocomial pathogens in ICU fomites are needed, especially those that can remediate against a broad range of resistant nosocomial pathogens.

This systematic review had some limitations, including the difference in study periods across all the articles analyzed. Some studies were conducted during or after an outbreak, and some only targeted organisms that matched the interests of the investigators, and these may have introduced unintended bias in the results. Moreover, identification methods varied greatly, as some studies used highly sensitive methods in recovering and identifying organisms while others employed relatively fewer sensitive methods. Consequently, some isolates could not be identified and reported on to the species level. Also, the varying microbiological methods across the studies could not allow for an extensive meta-analysis.

Conclusion

Many fomites that are readily used in patient care in the ICU carry nosocomial pathogens. The most common fomite appeared to be mobile phones, sphygmomanometers, and stethoscopes, with *Staphylococcus* being the most common contaminant. Hence, the need for rigorous disinfection and sterilization protocols on fomites in the ICU cannot be overemphasized. Additionally, heightened awareness on the subject among health professionals is crucial to mitigating the risk and burden of nosocomial infections caused by drug-resistant bacteria.

ORCID iDs

Samuel Darkwah https://orcid.org/0000-0003-0868-1798
Fleischer C N Kotey https://orcid.org/0000-0003-0286-3638
Alex Odoom https://orcid.org/0000-0001-5761-1564
Prince Hotor https://orcid.org/0000-0001-9529-2728
Nicholas T K D Dayie https://orcid.org/0000-0003-4491-6902
Eric S Donkor https://orcid.org/0000-0002-5179-546X

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