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MINI-REVIEW

Textiles as fomites in the healthcare system

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Abstract

Nosocomial infections or healthcare-associated infections (HAIs) are acquired under medical care in healthcare facilities. In hospital environments, the transmission of infectious diseases through textiles such as white coats, bed linen, curtains, and towels are well documented. Textile hygiene and infection control measures have become more important in recent years due to the growing concerns about textiles as fomites in healthcare settings. However, systematic research in this area is lacking; the factors contributing to the transmission of infections through textiles needs to be better understood. The review aims to critically explore textiles as contaminants in healthcare systems, and to identify potential risks they may pose to patients and healthcare workers. It delineates different factors affecting bacterial adherence on fabrics, such as surface properties of bacteria and fabrics, and environmental factors. It also identifies areas that require further research to reduce the risk of HAIs and improve textile hygiene practices. Finally, the review elaborates on the strategies currently employed, and those that can be employed to limit the spread of nosocomial infections through fabrics. Implementing textile hygiene practices effectively in healthcare facilities requires a thorough analysis of factors affecting fabric-microbiome interactions, followed by designing newer fabrics that discourage pathogen load.

Key points

- *Healthcare textiles act as a potential reservoir of nosocomial pathogens*
- *Survival of pathogens is affected by surface properties of fabric and bacteria*
- *Guidelines required for fabrics that discourage microbial load, for hospital use*

Keywords Nosocomial infections · Hospital textiles · Persistence · Biofilm · Microbial load

Introduction and scope of review

Nosocomial infections or healthcare-associated infections (HAIs), acquired when receiving healthcare treatment, are a major concern in hospitals. These infections are responsible for increased morbidity and mortality and treatment expenses due to extended stays in hospitals (Haque et al. 2018; Monegro et al. 2020; Sikora and Zahra 2021). In 2019, the World Health Organization recognized six pathogens as significant in nosocomial infections: *Pseudomonas aeruginosa*, *Acinetobacter baumannii*, *Escherichia coli*, *Streptococcus pneumoniae*, *Klebsiella pneumoniae*, and *Staphylococcus aureus* (Murray et al. 2022). Many inanimate surfaces and medical equipments, including ultrasound machines and bedrails, have been reported to harbor drug-resistant pathogens in healthcare facilities (Kiros et al. 2021; Jablonska-Trypuc et al. 2022).

Natural fabrics are considered excellent substrates for microbial adherence because their organic constituents provide a strong base for bacterial attachment and biofilm development (Fijan et al. 2017; Achinas et al. 2019). Moreover, fabrics retain bodily fluids like human sweat, blood, sebum, and wound fluid, which provide essential nutrients for microbial growth (Mollebjerg et al. 2021). Hence, soft surfaces like fabrics act as fomites contributing to the spread of infections (Mitchell et al. 2015; Owen and Laird 2020; Jose et al. 2023). Healthcare apparel like nurses' white coats, doctor's coats, and surgical gowns, and

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other textiles such as scrubs, bedsheets, pillow covers, curtains, and towels have been reported to play an imperative role in the transfer of pathogens (Ambrosch et al. 2019; Goyal et al. 2019; Mishra et al. 2020). The contribution of fabrics in the transmission of antibiotic resistant strains including methicillin-resistant *Staphylococcus aureus* (MRSA), vancomycin-resistant *Enterococcus* (VRE), and *P. aeruginosa* has also been realized (Lopez et al. 2013; Pace-Asciak et al. 2018). Several studies have reported that most transmission of infection occurs through surface contact between patients and healthcare staff or vice versa as well as through the environment (Lopez et al. 2013; Dyer et al. 2019) (Fig. 1). Transmission of bacterial infection can also occur during the collection and storage of infected hospital textiles (Abney et al. 2021; Sharma et al. 2022). Hence, controlling microbial growth on textile surfaces, and their subsequent transmission in healthcare settings, is crucial. Breaking the chain of infection can be achieved by inactivating or removing microorganisms from textiles by laundering using agents like temperature, detergents, or mechanical action (Bockmuhl et al. 2019).

Extensive research has been performed on developing antimicrobial textiles and different biocidal nanoparticles that limit the growth and load of microorganisms (Goyal et al. 2019). While this has provided a partial solution to mitigate nosocomial infections, its applicability is not universal due to the toxic impact of antimicrobials on human health and the environment (Condo et al. 2015). A possible eco-friendly approach might be to develop fabrics that discourage microbial adherence and subsequent transmission.

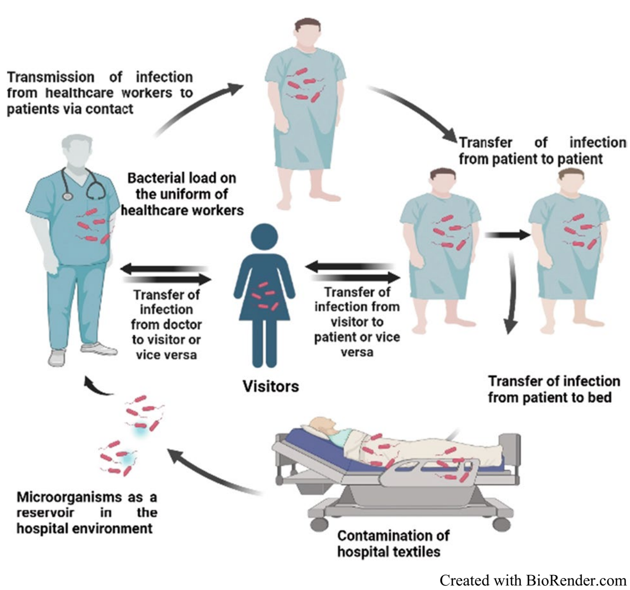

Fig. 1 Transmission of nosocomial infections through contaminated hospital textiles

For this, gaining an in-depth understanding of various factors affecting fabric microbe interactions is important.

Factors contributing to the adhesion of pathogens on soft-surfaced fabrics and their transmission leading to nosocomial infections are yet to be comprehensively assessed. Several properties of fabrics and bacteria have been found to affect bacterial adhesion (Hemmatian et al. 2021; Sanders et al. 2021; Varshney et al. 2021). Understanding of the role of various abiotic and biotic factors contributing to microbial adhesion on fabrics and transmission can help develop guidelines related to types of fabrics that should be used in healthcare settings, and the laundering protocol to be followed to minimize the risks of nosocomial infections through fabrics. In many nations, including India, limited data is available on the endemic epidemiology of nosocomial infections, due to the absence of comprehensive surveillance systems, under reporting of infections, differences in reporting criteria, limited resources for data collection and analysis, and limited research (World Health Organization 2020).

Limited efforts have been made toward compiling reports related to fabric-microbe interactions and the role of fabrics as fomites in healthcare setting. While Facciola et al. (2019) brought together papers pertaining to various surfaces (mostly hard) in healthcare associated infections, Goyal et al. (2019) restricted their review to the contamination of white coats and surgical scrubs. Stephens et al. (2019) summarized the available literature on the contamination of fomites in general in the built environment, and the implications of such contamination and transmission of pathogens to human, on human health. To the best of our knowledge, the first review to comprehensively compile papers related to the contribution of textiles in transferring infections was by Owen and Laird (2020). They also outlined current laundering procedures for hospital textiles. Since then, there has been substantial development in our understanding of the interactions between fabrics and microbes in healthcare settings. An in-depth understanding of fabric-microbe interactions will help design newer fabrics that limit the pathogen load. This will also help in drafting guidelines for preferred fabrics in healthcare settings.

While the significance of fabrics in spread of infections is of utmost importance in several settings including hospitality sector, and other public places (Pillai et al. 2021), the present review has been restricted to highlight the role of fabrics in the transmission of nosocomial infections in healthcare settings. It includes an updated, extensive compilation of epidemiological research showing a direct correlation between nosocomial infections and contaminated healthcare fabrics. The review brings together the current understanding of the role of hospital fabrics in the transmission of infections, factors affecting bacterial adherence on fabrics, persistence of pathogens on fabrics, and approaches for minimizing the microbial load on fabrics in healthcare settings. The review will serve as an excellent platform for deciding the next lines of research related to the strategies to limit nosocomial infections.

Role of hospital fabrics in the transmission of infections

In healthcare settings, fabrics are integral to the patients' and healthcare workers' immediate environment. Uniforms of healthcare workers are made either from reusable or disposable fabrics. Reusable fabrics are woven in nature that can be laundered and sterilized to kill microorganisms; disposable fabrics, which include polypropylene, polyester, polyethylene, are non-woven and can be used for a single day/use only. It has been established that hospital fabrics serve as a reservoir for pathogens and a potential source of contamination in the healthcare system (Table 1). In fact, fabrics (cotton and polyester) have been reported to serve as better fomites for the growth of *Candida albicans* compared to hard surfaces like glass and metal (Traore et al. 2002). However, using two model bacteria, the transfer efficiency from porous surfaces like cotton and polyester was observed to be lower when compared to non-porous surfaces, thus indicating that microbes get embedded in the porous matrix of textile, reducing their ability to act as a fomite (Lopez et al. 2013).

Transmission of pathogens from contaminated healthcare textiles to skin as well as other surfaces has been demonstrated (Lopez et al. 2013; Lena et al. 2021). These include antibiotic resistant strains like MRSA, VRE that have been reported to be transferred from white coats, bedsheets, and towels to porcine skin (Chaoui et al. 2019). The white coat of students is considered a potential source of infection transmission in clinical settings. Different regions of the white coat, such as cuffs, sleeves, and pockets, become highly contaminated when administering care, primarily during surgeries and wound care (Loh et al. 2000; Berktold et al. 2018). Students wearing white coats throughout the day had significantly higher levels of microbes on their cuffs and side pockets than the back of the white coats; however, no variation in microbial contamination between the regions of cuffs and pockets was observed (Loh et al. 2000). As hands and cuffs regularly come in contact with patients, bacteria can be easily transmitted between the two during patient examinations. Nurses' uniforms also transfer pathogenic microorganisms in healthcare settings when directly contacting patients, their belongings, and linen (Owen and Laird 2020). Patients, coworkers, and the public come into contact directly or indirectly with their uniforms during shifts, and serve as a vector for spreading virulent pathogens (Kanwar et al. 2019).

Another transmission route is air-borne, which is due to the generation of microbial aerosol during the movement of contaminated textiles between rooms (Ather et al. 2020). During bed preparation for patients, the dispersion of bacteria occurs through hands and clothing, which contributes to the transmission of bacteria to the surroundings (Kanwar et al. 2019; Popovich et al. 2021). The friction between the surface of the skin and the clothing may lead to the dispersion of skin scales, which in turn encourages the dispersion of bacteria (Hathway 2008). Healthcare fabrics have been associated with several outbreaks. At Jichi Medical University Hospital of Japan, an outbreak of *Bacillus cereus* was reported with bed linens identified as the cause; approx. 660 colony forming units (CFU) cm^{-2} of *B. cereus* were detected on them (Sasahara et al. 2011). Recently, a life-threatening healthcare-associated mucormycosis outbreak was found associated with contaminated healthcare linens

Table 1 Microorganisms reported on different apparel used in healthcare settings

Healthcare textiles	Microbes detected	References
Bedsheet	*Acinetobacter* spp., *Bacillus subtilis*, *Enterococcus faecalis*, *Streptococcus* spp., *Staphylococcus epidermidis*, *Pseudomonas aeruginosa*, *Escherichia coli*, *Staphylococcus aureus*, *Proteus* spp., *Citrobacter freundii*, *Klebsiella* spp., *Serratia* spp.	Okareh 2018; Hassan et al. 2019; Varshney et al. 2022
Gloves	*Acinetobacter baumannii*	Morgan et al. 2012
Healthcare staff gowns	*Bacillus* spp., coliforms, *Streptococcus* spp., *Acinetobacter baumannii*, *Staphylococcus aureus*, *Serratia rubidae*, *Klebsiella pneumoniae*, *Stenotrophomonas maltophilia*	Pilonetto et al. 2004; Morgan et al. 2012; Bache et al. 2013
Hospital privacy curtains	*Acinetobacter* spp., MRSA, VRE	Das et al. 2002
Medical shoe cover	*Acinetobacter baumannii*, *Escherichia coli*, *Enterococcus faecium*, *Pseudomonas aeruginosa*, *Staphylococcus aureus*, *Staphylococcus epidermidis*	Galvin et al. 2016
Towel	MRSA, *Klebsiella pneumoniae*	Hassan et al. 2019
White coats	*Clostridium difficile*, MRSA, *Acinetobacter* spp., *Escherichia coli*, *Staphylococcus* spp., *Pseudomonas aeruginosa*, *Klebsiella* spp., VRE, *Salmonella* spp., *Streptococcus* spp.	Gupta et al. 2017

(Jordan et al. 2022). In England, a Group A *Streptococcus* (*Streptococcus pyogenes*) outbreak has been associated with home healthcare (Nabarro et al. 2022).

Outbreaks have also been associated with contaminated healthcare textiles during laundering (Schmithausen et al. 2019; Boonstra et al. 2020). Washing machines have been reported to be a source of the spread of nosocomial infections when used for washing contaminated attire (Whitehead et al. 2022). The shedding of microbes colonized on washing machines, onto the fabrics during laundering, especially in domestic settings, has been observed. The transport of soiled lines and laundered textiles also lead to contamination with microbes resulting in the proliferation of infections (Owen and Laird 2020). The microbial load on laundry is influenced by several factors like type of fabrics, storage conditions, usage, type of detergent, and washing detergent (Abney et al. 2021).

Several other fabric-based patient care items like bandages, blood pressure monitors, dressings, and protective clothing serve as fomite and contribute to the transmission of infection (Kanamori et al. 2017; Akinbobola et al. 2022). Floor cleaning mops also act as reservoir for microbes; thus, proper cleaning of mops should be assured to reduce the risk of infection transmission. Singh et al. (2021) reported a significant reduction in bacterial load after mechanised laundering of mops when compared with manual washing.

Factors affecting bacterial adherence on fabrics

Several key factors affect the microbial load on textiles, including surface properties of bacteria and fabrics, and environmental conditions (Zheng et al. 2021). These factors greatly influence microbial adhesion, their growth, and subsequently their transmission from fabrics.

Bacterial surface properties

The surface charge of bacteria, determined by amino acids, carboxyl acids, and phosphate compounds on the surface, influences the type of interaction between the bacteria and textile surfaces (Poortinga et al. 2002; Tuson and Weibel 2013). Carboxyl, phosphate, and several other anionic groups dominate, conferring a net negative charge on bacterial surfaces. The hydrophobicity of bacteria is determined by their cell wall (Terada et al. 2006). Several factors, such as the type of bacterial strains, pH, and ionic concentration of the nutrient medium, affect the strength of bacterial hydrophobicity (Achinas et al. 2019; Krsmanovic et al. 2021). Depending on the type of surface, the hydrophobicity of microorganisms can affect their ability to adhere (Krasowska and Sigler 2014). Most studies on the effect of hydrophobicity have been done on hard surfaces (Krasowska and Sigler 2014; Kiros et al. 2021), with only a few assessing bacterial contamination on soft surfaces (clothing fibre/fabrics) (Gupta et al. 2017, 2019; Varshney et al. 2019, 2021). It is imperative to gain a deeper understanding of the effect of the surface chemistry of bacteria on minimizing the spread of nosocomial infections through fabrics.

Several surface features of bacterial cells, like adhesins, lipoteichoic acid, surface fibrils, outer membrane protein, and oligosaccharides may impact bacterial adherence on distinct surfaces (Krasowska and Sigler 2014). Bacterial EPS mainly consists of polysaccharides, with small fractions of proteins, lipids, and phospholipids (Simoes et al. 2010). *P. aeruginosa* PA14 strain has a *Pel* gene cluster that plays a crucial role in forming glucose-rich matrix essential for forming thick pellicle and resistance to biofilms. Mutation in *Pel* genes has been reported to adversely affect the adhesion capability of *P. aeruginosa* on solid surfaces (Vasseur et al. 2005). The outer layer of gram-negative bacteria comprises lipopolysaccharide (LPS) that impacts the process of bacterial adherence on surfaces (Donlan 2002). In *E. coli*, truncated LPS inhibits the synthesis of fimbriae type I and flagella, reducing attachment (Wang et al. 2021). EPS has also been reported to obstruct the initial adherence of *E. coli* O157: H7 to stainless steel (SS) (Ryu et al. 2004).

Bacterial appendages

Flagella act as a virulence factor, which enables the colonization of textile surfaces by pathogens (Belas 2014). Flagella facilitate adhesion, biofilm formation, and secretion of virulent factors. Surface interactions between cells and textiles are facilitated by adhesins present on the surface of flagella (Haiko and Westerlund-Wikstrom 2013). Adhesins help overcome repulsive forces that may prevent cell-surface interaction. Fimbriae (or pili) are made up of a cluster of straight and filamentous structures consisting of a protein subunit known as pilin (Dhakal et al. 2019). Pili or fimbriae are associated with the outer membrane of the bacterial surface and play an essential role in the initial adhesion of the bacterial cell to surfaces (Dhakal et al. 2019). Fimbriae types 1 and 3 present on the surface of *K. pneumoniae* encourage the bacteria's adhesion and aid in forming biofilms on a variety of surfaces (Murphy et al. 2013). In *E. coli*, surface adhesion is directly correlated with fimbrial type 1 expression levels (Blumer et al. 2005). The fimbriae of *P. aeruginosa* facilitate their adhesion to polystyrene, SS, and polyvinyl chloride surfaces (Zheng et al. 2021).

Surface properties of fabrics

Surface roughness may affect bacterial adhesion to textile surfaces (Zheng et al. 2021). During biofilm formation, topography significantly influences bacterial adhesion (Feng et al. 2014). Different mechanisms appear to be responsible for the adhesion on textile surfaces at the nanometric vs. micrometric scale (Cheng et al. 2019). A high roughness level of textile materials protects bacteria from shear forces and provides a greater surface area (Teughels et al. 2006). When bacteria adhere to rough surfaces, the irregularities on the textile surfaces create microenvironments in which they can attach themselves more strongly, thus preventing them from dislodging by shear forces. However, smoothening of the textile surface decreases surface area and surface roughness (Ionescu et al. 2012). As the surface area decreases, there are fewer attachment sites for bacteria to colonize, further limiting the growth of biofilms.

Bacterial adhesion also depends on the hydrophobicity and hydrophilicity of the surfaces (Bruinsma et al. 2001). A reduction in the hydrophobicity has been observed to increase the bacterial load on plastics (Ganesan et at. 2022). Microbes adhere to textiles based on the latter's surface charge (Zheng et al. 2021). *E. coli*, *Pseudomonas*, and *S. aureus* are more attracted to positively charged poly (acrylic acid) and poly (diallyldimethylammonium chloride) surfaces (Zhu et al. 2015). Polyelectrolyte multilayers with positive charges have been reported to enhance the adhesion of bacteria such as *S. aureus* and *E. coli* (Guo et al. 2018). *P. aeruginosa* was observed to adhere more readily to positively charged poly(allylamine hydrochloride) surfaces than to negatively charged poly(styrenesulfonate) surfaces (Kovacevic et al. 2016). In an Indian hospital, bacterial contamination on nurses' white coats was investigated on different fabrics and polyester:cotton blend patches had higher levels than polyester patches (Gupta et al. 2017). Various physicochemical properties of fabrics affecting bacterial load have been listed in Table 2.

Environmental factors

Environmental factors like pH, temperature, and incubation time affect bacterial adherence on textile substrate. Variations in pH values affect bacterial adherence (McWhirter et al. 2002) as it causes alterations in the hydrophobicity of bacterial cell surface. At an isoelectric point, bacterial cells have zero net charge, which favors better bacterial adherence on hydrophobic surfaces (Palmer et al. 2007). Temperature is considered one of the most essential factors determining bacterial adherence and biofilm development (Abdallah et al. 2014; Fijan et al. 2017). The growth of microbes is adversely affected by temperatures lower or higher than their optimum. The polymer composition on the surface of bacteria changes because of temperature fluctuation, which reduces bacterial adhesion to polymer surfaces at low temperatures (Garrett et al. 2008). A study has reported longer survivability of nosocomial pathogens on cotton at room temperature compared to extremes of temperatures (Fijan et al. 2017). Relative humidity (RH) is essential for the survival of microorganisms on various surfaces (Hokunan et al. 2016; Igo and Schaffner 2019). Increased survival rate of gram-negative bacteria such as *Pseudomonas* spp. and *Klebsiella* spp. is reported at higher RH (Tang 2009), while gram-positive bacteria, such as *Staphylococcus* spp. and *Streptococcus* spp., have enhanced survival at lower RH (Kramer and Assadian 2014). This change in bacterial behavior is attributed to their cell wall composition, due to which gram-positive bacteria can tolerate dry conditions better than gram-negative bacteria (Kramer and Assadian 2014). Moisture in the fabrics acts as a lubricant and means of transport, thereby promoting the transfer of bacteria from one surface to another, compared to dry fabrics (Sattar et al. 2001; Varshney et al. 2020).

The secretion of sweat, skin shedding, naturally occurring particles in the garment and/or nutrients from the surrounding environment, all contribute to bacterial growth on clothing (Szostak-Kotowa 2004). Sweating from the underarm region of the body facilitates the transfer of bacteria to textile surfaces (van Herreweghen et al. 2020). Other body fluids like blood, sebum, wound fluid, and other materials like starch and dust also provide essential nutrients for microbial growth (Mollebjerg et al. 2021).

Persistence of pathogens on fabrics

The persistence of pathogens on hospital textiles has been well established (Lopez-Gigosos et al. 2019; Kampf 2020; Owen and Laird 2020; Akinbobola et al. 2022). Wißmann et al. (2021) reported that hospital textiles harboured pathogens for periods ranging from hours to months under controlled conditions. Pathogens like *Acinetobacter* spp., *P. aeruginosa*, *E. coli*, *S. aureus*, *K. pneumoniae*, *Enterococcus* spp., and *Streptococcus pyogenes* have been reported to survive on cotton, polyester, blend, and wool from several days to a few months at room temperature (Koca et al. 2012; Riley et al. 2017; Kampf 2020). MRSA has the longest persistence time on wool compared to other fabrics used in hospital (Koca et al. 2012). It is reported that microbial load on nurses' white coats is significantly higher after the second shift. Thus, the duration of wear can be directly correlated with microbial load and persistence time (Varshney et al. 2019). Fungal strains, such as *Candida tropicalis*, *Candida krusei*, *C. albicans*, *C. parapsilosis*, *Candida glabrata*, *Candida parapsilosis*, and *Cryptococcus neoformans*, have shown persistence from few days to a month on cotton, whereas *C. albicans* and *C.*

Table 2 Major pathogens reported on different types of fabrics used in healthcare settings

Textile	Primary composition of fabrics	Characteristics of fabrics	Major microbes reported on fabrics	References
Cotton	Cellulose	Fluffy staple fibre, crystalline structure, rough surface, good absorbent, poor resistance to acids and alkali	*Acinetobacter*, *Cellulomonas* spp., *Bacillus* spp., *Enterococcus faecalis*, *Escherichia coli*, *Microbispora bispora*, *Micrococcus luteus*, *Pseudomonas aeruginosa*, *Staphylococcus* spp., *Aspergillus* spp., *Cladosporium* spp., *Trichoderma* spp., *Memnoniella* spp.	Gutarowska and Michalski 2012; Varshney et al. 2019; Chiereghin et al. 2020; Varshney et al. 2021
Linen	Mixture of cellulose, hemicellulose, lignin and pectin	Bast fibre, high strength with high capacity of moisture retention	*Acinetobacter baumannii*, *Bacillus amylobacter*, *B. subtilis*, *Klebsiella pneumoniae*, *Pseudomonas aeruginosa*, *E. coli*, *P. putida*, *Staphylococcus* spp., *Aspergillus* spp., *Penicillium* spp., *Rhizopus* spp.	Dunn 2022; Sharma et al. 2022
Polyester	An ester of a dihydric alcohol and terephthalic acid	Strong, low moisture retention, accumulates electrostatic charges on the surface, resistant to acids and alkalis	*B. subtilis*, *E. coli*, *Enterococcus*, *Pseudomonas aeruginosa*, *Staphylococcus* spp., *Aspergillus oryzae*, *Candida antarctica*, *Penicillium citrinum*, *Thermomyces* spp.	Varshney et al. 2019; Chiereghin et al. 2020; Varshney et al. 2021
Silk	Fibroin connected through a protein called sericin	Crystalline structure, linked by disulfide bridges, intra and intercellular hydrogen bonds	*Pseudomonas cepacia*, *Streptomyces* spp., *Staphylococcus* spp., *Variovorax paradoxus*, *Aspergillus. niger*, *Chaetomium* spp., *Penicillium* spp. *Enterococcus*, *Pseudomonas aeruginosa*	Szostak-Kotowa 2004; Varshney et al. 2019; Sanders et al. 2021; Varshney et al. 2021
Wool	Keratin	Highly cross-linked structure, disulfide bridges, large portion of cysteine residues in keratin	*Bacillus cereus*, *B. mesentericus*, *B. mycoides B. subtilis*, *Streptomyces* spp., *Aspergillus* spp., *Microsporum*, *Chrysosporium* spp., *Trichophyton*, *Fusarium*, *Pseudomonas aeruginosa*, *E. coli*	Gutarowska and Michalski 2012; Varshney et al. 2019; Sanders et al. 2021; Varshney et al. 2021

parapsilosis survived for 14 days on blend fabric (cotton-polyester) (Traore et al. 2002). Most viruses, including coronavirus, influenza A virus, metapneumovirus, and ebolavirus, were observed to lose their infectious properties after one day on cotton and after 2 to 4 weeks on other materials (Kampf 2020; Kampf et al. 2020). Ideal growth conditions, including large surface area, high moisture content (increased during sweat production), ambient room temperature, moderate humidity, and biofilm formation (Szostak-Kotowa 2004; Mollebjerg et al. 2021), may lead to a longer persistence time of microbes on textiles (Kampf 2020).

Approaches for minimizing the microbial load on fabrics

World Health Organization has released several infection prevention and control (IPC) guidelines since the COVID-19 outbreak in 2020, highlighting the significance of the prevention of nosocomial infections, but these policies have not settled the existing gap between scientific evidence and clinical practice (Monegro et al. 2020; Honghui et al. 2022). In healthcare settings, contaminated fabrics act as a vehicle for infection transmission, which necessitates the implementation of proper hygiene, frequent washing of fabrics and use of disinfectant on a regular basis. Besides, several strategies to prevent the growth and spread of pathogens on textiles are either in practice or proposed (Fig. 2).

The survival of pathogens on white coats, even after laundering, indicates that domestic and commercial laundering is insufficient for sterilizing healthcare uniforms (Tarrant et al. 2018; Bockmuhl et al. 2019; Gupta et al. 2019). Thus, proper laundering guidelines are needed for complete decontamination. Healthcare textiles should be laundered after every shift at required temperatures (37–60 °C) following proper laundry instructions (type of detergent, quantity of detergent) depending on the number of clothes, type of bleaching agents, the number of drying cycles, etc. (Bockmuhl et al. 2019; Abney et al. 2021). Ironing, an essential part of the laundering process, effectively decreases the microbial load on healthcare uniforms. Hence it is considered one of the critical processes to ensure the safety of patients and healthcare staffs (Owen and Laird 2020).

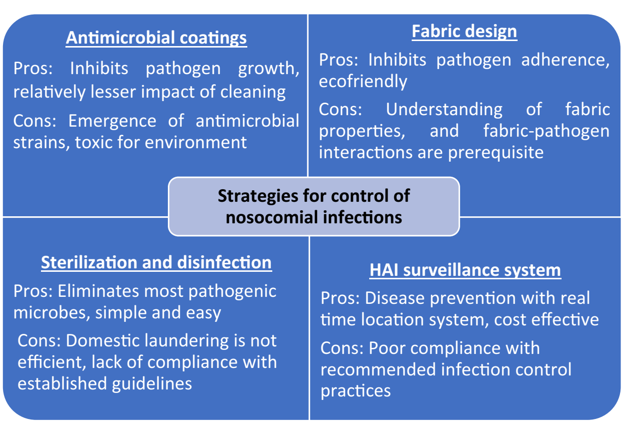

Fig. 2 Current strategies to control nosocomial infections, with their challenges and scope of improvement

Antimicrobial coatings on textile effectively discourage microbial colonization (Ibrahim et al. 2021). Such fabrics are currently in use by healthcare workers and doctors to prevent the spread of infections (Gulati et al. 2022). Inorganic nanoparticles and their composites are the most commonly used antibacterial compounds for textile coatings but are associated with several limitations as they are expensive, and unstable, thus easy to release into the immediate surroundings resulting in toxicity (Nawab et al. 2022). Antimicrobial silver ions at high concentrations have been reported to cause cytotoxicity with the emergence of silver-resistant bacteria (Silver et al. 2006; Wu et al. 2018). The development of antibiotic resistance in bacteria has also been reported due to the extensive use of antibiotics in surface coating under release-based coating strategies (Simoncic and Tomsic 2010). In developing countries, there is no actual information and/or statistical data on the causes of antimicrobial susceptibility (Khan et al. 2015). Thus, it is incredibly challenging to develop and implement an effective plan to control infections when dealing with antimicrobial or antibiotic resistant pathogens (Obiero et al. 2015).

Another method includes textile surface modification by nanotechnologies, plasma treatment, microencapsulation to impart microbe repellent properties (Mahmud and Nabi 2017; Peng et al. 2023). Advanced, eco-friendly, and non-toxic approaches like Sharklet technology are urgently needed to combat these issues (Mann et al. 2014).

It is generally agreed upon that surveillance systems facilitate the assessment of the regional burden of nosocomial infections and aid in early detection, including major outbreaks (Murhekar and Kumar 2022). Conclusively, there is an urgent need for best practices and effective HAI surveillance that should be followed in hospitals to limit the spread of nosocomial infections.

Conclusions

In healthcare settings, apart from direct contact with patients and body fluids (blood, saliva, sweat, urine), common hospital fabrics are a major contributor to nosocomial infections. This review highlights the significance of fabric-mediated transmission of nosocomial infections to healthcare workers, patients, and other environmental surfaces. This type of transmission is generally overlooked and may pose a significant burden on the entire healthcare system. Healthcare workers' attires, soiled linens, and surroundings near patients remain associated with several pathogens and are reported to be a risk factor for outbreaks. A major limitation of research related to the contamination of healthcare textiles is that they do not differentiate between endogenous and exogenous microorganisms, leading to a blurred picture of fabrics serving as fomites. Moreover, studies have not been performed to correlate the microbial load of textiles with the rate of nosocomial infections. It is only recently that this area has gained appreciable attention from the research community worldwide. Further research is warranted since various aspects of healthcare textiles serving as a significant infection source are currently inconclusive. The adherence of bacteria onto textiles subsequently leads to biofilm formation that helps in the transfer of bacteria; thus, the study of biofilm formation on different fabrics should be one of the subjects of future research. Thorough investigations on the infectivity of microbes adhered onto textiles for a specific period need to be performed, as this information may give further insight into the transmission of pathogens from textiles to hospital staff and patients. While fabrics coated with antimicrobials can limit microbial growth, they can also pose health risks and environmental problems. Hence, another crucial area of study is designing newer fabrics by surface modifications that discourage microbial load. Additionally, implementation of textile hygiene practices, training of hospital staff, analysis of fabric-microbe interactions, framing guidelines for preferred fabrics in healthcare settings, and advancement of infection control programs using efficient epidemiological surveillance systems are some suggested future research areas to manage and control healthcare-associated infections in clinical settings.

Author contribution SS conceived the idea; SD and SV performed literature survey and compiled and synthesized the papers; SD, SV, and SS wrote the manuscript; SS and DG were awarded funding, and critically reviewed the manuscript. All authors read and approved the manuscript.

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Data Availability Data sharing not applicable to this article as no datasets were generated or analysed during the current study.

Declarations

Conflict of interest The authors declare no competing interests.

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