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La eficacia de los textiles antimicrobianos como herramientas para el control de las Infecciones Hospitalarias (IH)

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Resumen: Cada año, las Infecciones Hospitalarias (IH) en EE. UU. causan 98,000 muertes y a su vez representan una carga económica de US $28 a US $45 mil millones. En un día cualquiera, aproximadamente uno de cada 31 pacientes hospitalizados tiene al menos una IH. Aunque la higiene de las manos ha sido el principal enfoque en el control de infecciones, creciente evidencia sugiere que existe una correlación entre la carga biológica ambiental en un hospital y el riesgo de que un paciente adquiera una infección.
En ámbitos hospitalarios, las superficies blandas dominadas por materiales textiles pueden llegar a estar altamente contaminadas con microorganismos patógenos que pueden causar colonización o infección. La literatura relevante muestra evidencia del crecimiento microbiano en productos textiles y de la calidad subóptima de los procesos de lavado de ropa hospitalaria como posibles fuentes de infección.
Se han desarrollado fórmulas seguras y eficaces para impartir propiedades antimicrobianas a los materiales textiles. Muchos de estos desarrollos se han implementado con éxito en la ropa deportiva. Las líneas más recientes de investigación se centran en evaluar la eficacia de los textiles antimicrobianos en aplicaciones médicas para reducir la carga biológica de microorganismos patógenos en las superficies textiles y a su vez evitar la contaminación cruzada.
Este artículo tiene la intención de hacer una revisión sobre el uso de productos textiles en entornos hospitalarios y la posible contribución de los materiales textiles en el desarrollo de IH, y a su vez analizar la eficacia de las tecnologías antimicrobianas en textiles médicos utilizados como estrategias para el control de infecciones.

Palabras claves: textiles - Infecciones Hospitalarias - antimicrobianos - tecnología - medicina - higiene - moda - productos - medioambiente - industria.

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1. Introduction

Healthcare-Associated Infections (HAIs) are infections acquired within the healthcare system while receiving treatment for other conditions (McKibben et al., 2005). They affect approximately 1.7 million patients annually in the US, with as many as 98,000 infections ending up in death, and an economic burden of US $28 to US $45 billion annually (Haque et al., 2018).
The main approach for HAIs prevention has been hand hygiene. In the mid-1800s, the physicians Ignaz Semmelweis and Oliver Wendell Holmes showed that hospital-acquired diseases were being transmitted via the hands of the healthcare workers and after implementing hand disinfection practices, a dramatic decrease in mortality rates was produced (World Health Organization, 2009). In the 1980s, the role hands play in the transmission of pathogenic microorganisms was confirmed and the first national hand hygiene guideline was published (World Health Organization, 2009). Over time, it has been proven that good hand hygiene can reduce infections by 30-50% (Andersen, 2019).
HAI rates indicate that hand hygiene is not enough, and current research is focused on understanding the role of the healthcare environment in the transmission of pathogens. A study analyzed 160 samples from hard and soft surfaces and 65% resulted positive for bacteria, showing a need for strengthening current principles of cleaning and disinfection of hospital surfaces (Afle et al., 2019). Textiles are suitable surfaces for microorganisms to grow and in the healthcare environment, they can easily become dangerous sources of cross-contamination by microbial deposition and spreading. Latest research studies are evaluating the use of antimicrobial textiles to reduce the bioburden of the hospital environment and decrease the incidence of HAIs.

2. Healthcare-Associated Infections (HAIs)

2.1. Categories

According to the Centers for Disease Control and Prevention (CDC) (Centers for Disease Control and Prevention, 2014), there are four HAI types: Central Line-associated Bloodstream Infection (CLABSI), Ventilator-associated Pneumonia (VAP), Catheter-associated Urinary Tract Infection (CAUTI), and Surgical Site Infection (SSI). These are described in **Table 1**.

Table 1. *Healthcare-Associated Infections.*

Healthcare-Associated Infections	
Central Line-associated Bloodstream Infection (CLABSI)	
Cause	Germs entering the bloodstream through central venous catheter (Centers for Disease Control and Prevention, 2014). Microorganisms reach the skin and later through hand or any other fomite, and travel from catheter insertion portion to the surface of device (Hsu, 2014)
Microorganisms	*S. aureus, Coagulase-negative staphylococci,* and *Enterococcus* species (Hsu, 2014)
Complications	12% to 35% of in-hospital mortality rate and increase in length of stay (Doshi et al., 2009)
Prevention	Proper insertion technique and sterilization of central venous catheter and proper skin preparation before device insertion (Hsu, 2014)
Catheter-associated Urinary Tract Infection (CAUTI)	
Cause	Develops in urinary system when a urinary catheter is used (Centers for Disease Control and Prevention, 2014) and is inappropriately inserted, which happens in 38% of procedures, or when there is a prolonged use of the catheter when no longer needed (Hsu, 2014)
Microorganisms	*Escherichia coli, Pseudomonas aeruginosa,* and *Klebsiella* species (Hsu, 2014)
Complications	Most common device infection since 15% to 25% patients receive urinary catheters during their stay (Hsu, 2014)
Prevention	Proper insertion technique of catheter, collection system, and collection bag (Doshi et al., 2009)
Ventilator-associated Pneumonia (VAP)	
Cause	Lung infection that develops in a patient who is on a ventilator (Centers for Disease Control and Prevention, 2014). Microbes invade the lower respiratory tract through the aspiration of contaminated oropharyngeal secretions (Timsit et al., 2017)
Microorganisms	*S. aureus, P. aeruginosa,* and *Klebsiella* species (Hsu, 2014)
Complications	High mortality rates: from 30% to 70% (Hsu, 2014)
Prevention	Right timing, quality, and sterilization of ventilation, and avoid intubation unless it is absolutely necessary (Hsu, 2014)
Surgical Site Infection (SSI)	
Cause	Occurs after surgery in the part of the body where the surgery took place. It can affect the skin, tissues under the skin, organs, or implanted material (Centers for Disease Control and Prevention, 2014). Most SSI originate in endogenous skin or fecal flora at surgical procedures (Hsu, 2014)
Microorganisms	*S. aureus, Coagulase-negative staphylococci,* and *E. coli* (Hsu, 2014)
Complications	Increases length of stay from 4 to 32 days (Haque et al., 2018)
Prevention	Ensure there are no preexisting infections before surgery; remove hair using clippers instead of razors, and proper patient skin preparation (Hsu, 2014)

Some hospitalized patients have a weakened immune system that compromises their ability to respond normally to infections, even in cases with microorganisms with low pathogenicity. This condition places them at a higher risk of infection (Marcel et al., 2008), usually in areas such as: skin and soft tissue; ear, eye, nose, and throat; lower respiratory tract; bone and joint, central nervous system; cardiovascular; and reproductive tract (Magill et al., 2018).

2.2. Causative microorganisms

Microorganisms are present in humans and the environment without being dangerous; however, there are some pathogenic microorganisms that can cause illness to humans (Andersen, 2019).
Between 12 and 17 microorganisms are responsible for causing more than 80 % of HAIs, including *S. aureus*, *Enterococcus* species like *faecalis* and *faecium*, *E. coli*, *Coagulase-negative staphylococci*, *Candida* species like *albicans* and glabrata, *K. pneumoniae* and *Klebsiella oxytoca*, *P. aeruginosa*, *A. baumannii*, *Enterobacter* species, *Proteus* species, *Yeast NOS*, and *Bacteroides* species (Haque et al., 2018). Also, six main groups of pathogens called 'the ESKAPE bugs' are believed to cause almost all HAI: *Enterococcus faecium*, *Staphylococcus aureus*, *Klebsiella pneumoniae*, *Acinetobacter baumannii*, *Pseudomonas aeruginosa*, and *Enterobacter* species. These microorganisms become highly virulent, antibiotic resistant and able to survive on surfaces for long time (Hanczvikkel et al., 2018).

2.3. Approaches

Approaches for preventing HAIs include administrative support, educating health care personnel, and hand hygiene and isolation precautions before and after any procedure or patient contact (Hsu, 2014). Some institutions have also implemented additional measures: use of disposable equipment and high efficiency particulate air filters, healthcare staff education for improved hygiene, increased number of nurses and infection control personnel, isolation of infected patients, better ventilation management, improved disinfection regimens, and use of aggressive antibiotic control programs (Borkow, 2014).
The right infection control program should include measures and controls for patients and healthcare workers (Mitchell et al., 2015). To guarantee the effectiveness of measurements, they must have a scientifically practical foundation practical to implement, and also reviewed regularly in order to maintain their precision and validity (Scheckler et al., 1998).

2.4. Costs and litigations

Infections prolong a patient's hospital stay, increasing the consumption of costly resources. The following are the approximate costs of treating one patient: SSI $28,219; CLABSI

$48,108; VAP $47,238; and CAUTI $13,793 (NORC at the University of Chicago, 2017). As declared by the Centers for Medicare & Medicaid Services (CMS) in 2007, the hospital is responsible for covering these costs of treatment (Medicare & Medicaid Services (CMS), 2017).
HAIs can open the possibility of legal actions against the healthcare provider and/or the hospital, having an unfavorable impact on the reputation of the affected healthcare organization to its consumers (Scheckler et al., 1998), and may create litigation costs from clinical negligence claims such as: failure or delay to diagnose/treat the condition; incorrect or inappropriate treatment; or failure to prevent the acquisition of an avoidable HAI (Goldenberg et al., 2012).

3. Textiles in the Healthcare Environment

Approximately 20% of HAIs can be attributed to environmental surfaces, although the actual proportion is unknown due to the complexity of determining if the infection was caused by an organism present in the patient prior to the infection or transmitted from person to person (Steinberg et al., 2013).

3.1. Hard and Soft Surfaces

Increasing evidence suggests that contaminated hard surfaces (e.g., floors, shower stalls, sink basins, drain covers, walls, countertops, bed rails, and instrument trays) and soft surfaces (e.g.,. linen, apparel, incontinence products, curtains, and upholstery) can contribute to the development of HAIs, establishing a correlation between the environmental bioburden and the potential risk for a patient of acquiring an infection (Borkow, 2014). Unfortunately, these surfaces are not treated equally for cleaning and disinfection purposes, with greater efforts placed on hard surfaces (Mitchell et al., 2015).
Patients when hospitalized tend to shed bacteria to the environment through processes like bodily secretions and breached skin. When these pathogens are in the environment, they can survive on surfaces for varying periods of time and proliferate with the appropriate amount of moisture and temperature (Butler, 2018).
Cloth furnishings have an associated risk from the cleaning process since the aerosols created from the vacuuming can be detrimental for patients with preexisting lung diseases and lead to an HAI (Centers for Disease Control and Prevention, 2003). Privacy curtains can represent a source of hand contamination from healthcare workers (Jarvis, 2022). A three-week study to determine the bacterial contamination of 43 curtains found MRSA and VRE the most frequent microorganisms (Ohl et al., 2012). Woodland et. al. identified high microbial deposition of *Coagulase-negative Staphylococcus* and *Micrococcus* species on cubicle curtains (Woodland et al., 2010). Carpets have proven to contain bacteria and fungi (Centers for Disease Control and Prevention, 2003) and their cleaning can reduce the level of pathogens only temporarily, because microorganisms quickly return to the

bacterial amount they had before cleaning, with a risk of airborne contamination to occur during the cleaning process (Jarvis, 2022).

3.1.1. Cross-contamination

It is common to find an exchange of commensal flora between humans at any environment and, in a typical hospital setting, this is enhanced due to the number of patients being simultaneously treated and the numerous direct contacts happening daily between healthcare workers, patients, and visitors (Marcel et al., 2008). There is evidence supporting that contaminated surfaces can contaminate the hands of healthcare workers (Beggs et al., 2014).

Cross-contamination can happen directly from patient to patient, indirectly by the contaminated hands of a healthcare worker, or by hand transfer from previously contaminated surfaces in the environment and patient-care equipment (Centers for Disease Control and Prevention, 2003). Antibiotic-Resistant Gram-Positive Cocci such as *Vancomycin-resistant enterococci* (VRE), *Methicillin-resistant Staphylococcus aureus* (MRSA), and *S. aureus* present high risk of cross-contamination. *Clostridium difficile*, able to form spores, also presents risks due to its capability to persist in the environment for long periods of time, especially in soiled and dry surfaces (Centers for Disease Control and Prevention, 2003).

3.2. Medical Textiles

Medical Textiles are materials engineered to meet precise requirements needed for medical, healthcare, and surgical applications (Horrocks & Anand, 2000). These include implantable materials, used in effecting repairs to the body; extra-corporeal devices, defined as mechanical organs and mainly used for blood purification; non-implantable materials, used for external applications on the body which may or may not be in contact with the skin; and healthcare/hygiene products, used for the hygiene, care and safety of staff and patients (Rigby et al., 1997).

The healthcare/hygiene product category is defined by the characteristics of the healthcare environment where it is used. Materials used in the operating room/theater aim to build a clean space and maintain a strict infection control, including apparel and accessories like surgeons' gowns, caps, masks, patient drapes, and cover cloths. Materials used in hospital rooms are developed for patient's care and hygiene, including bedding, apparel, mattress covers, incontinence products, cloths, and wipes (Rigby et al., 1997).

The healthcare/hygiene market is divided into two product categories: reusable, usually made of woven and/or knitted structures and disposable, usually made of nonwovens (Qin, 2015). Disposable products dominate the market, and their use continues to rise. Nonwovens consumption for medical applications is expected to reach 427,000 tons by 2023 (Olivo, 2018).

Prevalence towards disposable products is explained as a way to avoid and reduce HAIs and deaths associated with them and also to fight against new viruses and multi-resistant bacteria (Anand et al., 2010). Disposable products offer benefits like high absorbency, comfort, and non-adherent compression (Bartels, 2011), and limitations like low resistance and poor drapeability (Bartels, 2011). There are also environmental implications for the waste they generate, and they can become expensive (Rajendran & Anand, 2002). Reusable products present environmental advantages due to the waste reduction and cost savings, and they also have physical and performance benefits in terms of wearer comfort (Bartels, 2011). Efforts have been made to evolve and improve reusable products, but many studies still support the use of disposable products for infection control reasons (Olivo, 2018).

3.2.1. Microbial growth in textiles

A textile's large surface area combined with the ability to retain moisture can create the perfect habitat for microorganisms to grow (Morais et al., 2016), causing undesirable effects including: unpleasant odor, stains, discoloration, and reduction in material's strength levels (Gao & Cranston, 2008).

Bacteria tend to grow fast when the setting provides warmth and moisture (Ramachandran et al., 2004). There are actions that can accelerate bacterial growth, like having long periods between the washing of an item and having a special micro-climate (Hamzah et al., 2015). The quality and amount of bacterial adherence on textile materials will depend on the time of contact, type of bacteria, physicochemical characteristics of the fabric, substrate and bacterial cell wall hydrophobicity, and characteristics of the surface with rougher surfaces more prone to the retention of microorganisms (Sun, 2016).

Natural fibers are more susceptible to microbial growth due to their ability to retain water. As stated by Gupta (2007) "If 10×10^5 colonies in 1ml water are applied to approximately 0.5g cotton, after a few hours, a logarithmic growth is observed, and the population increases from 10×10^5 to 10×10^9 colonies" (p. 254). Synthetic fibers show slower microbial growth due to their limitation in preserving water; however, they support perspiration which can act as microbial multiplication enhancer (Sun, 2016).

4. Linen Management in Hospitals

The CDC states that laundry of textile-based healthcare products should follow basic principles of hygiene and common sense, following consensus guidance (Centers for Disease Control and Prevention, 2003). However, literature has shown that some microorganisms are able to survive on textile surfaces even after the laundering process (Fijan & Turk, 2012).

Hospital linen includes mattress, pillow covers, blankets, bed sheets, towels, screens, curtains, doctor's coats, theatre cloth and tablecloths (Laico, 2004). During their use, linen can become highly contaminated with potentially infected body fluids, which can lead to having 1×10^4 to 1×10^6 colony-forming units of bacteria per square centimeter of fabric (Sehulster, 2015).

4.1. Laundry process

Linen is exposed to laundry processes to remove soil and pathogens (Sehulster, 2015) with two purposes: a non-microbiological function of improving/restoring the appearance of textile-based products while preventing deterioration; and a microbiological function of reducing the number of microorganisms present in the material (Fijan & Turk, 2012).
The laundering process has an antimicrobial action through a combination of mechanical, thermal, and chemical factors: microorganisms are removed through the water's dilution and agitation, soaps and detergents are used to remove soils and provide microbiocidal properties, and hot water provides an effective way to destroy microorganisms. Chlorine bleach can also be used to have an additional margin of safety; however, it may not be compatible with all fabric types (Centers for Disease Control and Prevention, 2003).
A proper laundry process begins when the contaminated materials are collected and ends with the clean products stored. These are the main steps in the laundry process: 1. Collect soiled/contaminated textiles; 2. Perform laundering cycle; 3. Perform drying cycle; 4. Fold and package cleaned items for transport and distribution; 5. Store laundered products in a dry environment free from soil and contamination at ambient temperature and relative humidity ranges (Sehulster, 2015).
Contaminated laundry items should be handled with minimal agitation to prevent generation of possible contaminated lint aerosols that could be detrimental for patient-care areas, and placed into leak-resistant containments to transport them to the laundry facility (Centers for Disease Control and Prevention, 2003).

4.2. Risk of laundry procedures

Suboptimal laundry procedures can cause disease transmission. Disease transmission attributed to the laundry process is usually due to textiles that have not been handled or sorted properly, for example, through shaking soiled linens (Centers for Disease Control and Prevention, 2003).
The laundry process can have a considerable impact on the microbial levels of the textile material and lead to an increase in the risk of infection transmission (Fairbanks, 2019). The most common term used to refer to safe healthcare textiles is hygienically clean, which can be defined as a textile that is free of pathogens in enough numbers that would cause human illness, but, this term does not quantitatively estimate what sufficient numbers mean, and that number may be dependent of the textile construction, type of microorganisms, or impacted by the way the contaminated items are handled, transported, washed, and stored (Fairbanks, 2019).
There is evidence of survival of microorganisms on textile-based products after laundering processes at varied laundering conditions (Fijan & Turk, 2012). Also, there is evidence of outbreaks associated with contaminated linen. An outbreak of *Bacillus bacteremia* associated with contaminated linen was reported at Queen Mary's hospital in Hong Kong, presumably due to suboptimal hospital laundry conditions (Cheng et al., 2017); and, at the same institution, an outbreak of pulmonary and cutaneous zygomycosis was also reported,

with suboptimal conditions of the washing, drying, and storage processes contributing to the linen contamination (Cheng et al., 2016).

5. Antimicrobial Textiles

Antimicrobial textiles are materials chemically treated to kill or inhibit the growth of harmful microorganisms (Bureau Veritas, 2006). Nowadays there are effective and safe formulas to cover a wide range of applications. Consumers are more informed and conscious of the importance of a hygienic lifestyle, increasing the possibilities in the antimicrobial textiles market (Ramachandran et al., 2004).

5.1. Requirements

Antimicrobial textiles must protect from an extensive range of microbes; be safe for the user, showing low toxicity levels; be durable in terms of laundering, dry cleaning, and hot pressing; not compromise the original properties of the material; be compatible with the ongoing textile chemical processes; be cost effective; and avoid producing substances that could harm the manufacturers or the environment (Gao & Cranston, 2008). Also, antimicrobial finishes should have an easy method of application, resistant to body fluids and disinfectants or sterilization (Ramachandran et al., 2004).
For healthcare applications, any company that wants to make public antimicrobial claims in the U.S. must have approval and registration of the Environmental Protection Agency (EPA) and present proper test results against *Pseudomonas aeruginosa* ATCC 15442 and *Staphylococcus aureus* ATCC 6538 (Environmental Protection Agency (EPA), 2020). In addition, any medical device that wants to incorporate antimicrobial properties for commercial use in the US must have the Food and Drug Administration (FDA) approval (Environmental Protection Agency (EPA), 2020).

5.2. Agents and methods of application

Microbes show an outermost cell wall that serves to maintain the integrity of all the cellular components, protecting them from the environment. A microorganism's survival and growth exclusively depend on the cell integrity. Antimicrobial agents act against the microbial cell function or integrity by two effects: the biostatic effect inhibits the cell growth, whereas the biocidal effect kills the microorganism (Morais et al., 2016). Most agents currently used for commercial antimicrobial textiles in the healthcare sector have biocidal effects, therefore, that group will be further described on **Table 2.**

Table 2. *Antimicrobial Biocide Agents*

Antimicrobial Biocide Agents	
Quaternary Ammonium Compounds (QACs) Cationic Agents	
Mode of Action	Damage of cell membranes, denature of proteins, and inhibit of DNA production avoiding multiplication (Morais et al., 2016)
Fibers	Cotton, Polyester, Nylon, Wool (Morais et al., 2016)
Interaction	Through an ionic interaction between an anionic fiber surface and a cationic QAC (Gao & Cranston, 2008)
Efficacy	Due to a lack of physical bonding, it presents leaching from the textile (Morais et al., 2016)
Microorganisms	Gram-positive and Gram-negative bacteria, fungi, and certain viruses (Morais et al., 2016)
Triclosan Synthetic chlorinated bisphenol	
Mode of Action	Blocking of the lipid biosynthesis, therefore, affecting the integrity of the cell membrane (Morais et al., 2016)
Fibers	Polyester, Nylon, Polypropylene, Cellulose acetate, Acrylic (Morais et al., 2016)
Interaction	By migrating to the surface of the treated textiles at a slow and sustained rate (Gao & Cranston, 2008)
Efficacy	Efficient, but its widespread use is generating bacterial resistance (Morais et al., 2016)
Microorganisms	Gram-positive and Gram-negative bacteria, and also some antifungal and antiviral properties (Morais et al., 2016)
Metals and Metallic Salts Silver, Copper, Zinc, and Cobalt	
Mode of Action	Generating or catalyzing reactive oxygen species, therefore, damaging of cellular proteins, lipids, and DNA (Morais et al., 2016)
Fibers	Cotton, Wool, Polyester, Nylon (Morais et al., 2016)
Interaction	Through diffusion on the surface of the fabric during use and formation of silver ions in the presence of moisture (Gao & Cranston, 2008)
Efficacy	Used for general and biomedical textiles due to its proven efficacy. There are concerns of possible bacterial resistance (Morais et al., 2016)
Microorganisms	Wide spectrum of Gram-positive and Gram-negative bacteria, such as *Pseudomonas aeruginosa, S. aureus, Staphylococcus epidermidis, E. coli* and *Klebsiella pneumonia* (Morais et al., 2016)
Chitosan Copolymer, from the deacetylation of Chitin	
Mode of Action	Dependent on the molecular weight (Mw): Low Mw Chitosan can penetrate the cell wall and prevent protein synthesis; High Mw Chitosan can change cell membrane causing leakage of intracellular substances, or form an impermeable layer around the cell to blocks solutes to transport into the cell (Morais et al., 2016)
Fibers	Cotton, Wool, Polyester (Morais et al., 2016)
Interaction	Through the interaction between primary amine groups that provide positive charges, and residues on the surface of microbes that provide negative charges (Gao & Cranston, 2008)

Efficacy	Chitosan-metal complexes have shown efficacy. However, the poor handling and pH and temperature activity dependence of Chitosan become main disadvantages of its use (Morais et al., 2016)
Microorganisms	Wide spectrum of microorganisms such as fungi, algae and certain types of bacteria (Morais et al., 2016)
Poly (Hexamethylene Biguanide) (PHMB) Polycationic amines	
Mode of Action	Disrupting the cell membrane and producing lethal leakage of cytoplasmic materials (Morais et al., 2016)
Fibers	Cotton, Polyester, Nylon (Morais et al., 2016)
Interaction	Through electrostatic and hydrophobic interactions with the microbial cell membrane (Morais et al., 2016)
Efficacy	Has proven to be effective in the food industry. While it is used in Cotton, it does not exhaust properly in synthetic fibers (Gao & Cranston, 2008)
Microorganisms	Wide spectrum of bacteria (Gao & Cranston, 2008)
N-halamines Heterocyclic Organic Compounds	
Mode of Action	Precluding the cell enzymatic and metabolic processes, therefore, causing a the destruction of microorganisms (Morais et al., 2016)
Fibers	Cotton, Wool, Polyester, Nylon (Morais et al., 2016)
Interaction	Through an electrophilic substitution of chlorine with hydrogen in the presence of water (Morais et al., 2016)
Efficacy	They have proven to have broad range of action, low cost and long-term stability. However, they can discolor fabrics and cause unpleasant odor (Morais et al., 2016)
Microorganisms	Wide spectrum of bacteria, fungi, and viruses (Morais et al., 2016)

Antimicrobial agents can be applied into and on the surface of textiles by incorporating them into a polymer matrix in the case of synthetic fibers, applying them as a finish to the material surface of either synthetic or natural fibers, or applying them during the washing cycle as a laundry additive. Based on the application method selected, the final textile will act by contact, when the agent is located inside and on the surface of the fiber, acting only if the microorganism touches the textile surface without dispersing; or by diffusion, when the finish is applied to the fiber's surface migrating from the textile material to the external medium to act against the microbes (Morais et al., 2016). It has been stated that the best durability of the antimicrobial textile is achieved when the agent is blended into the fiber during the formation process, since the active agent will be embedded in the structure of the fiber and released slowly during the use of the textile-based product (Gao & Cranston, 2008).

5.3. Antimicrobial Efficacy Testing: Agar Diffusion and Suspension Tests

Agar Diffusion Tests, such as AATCC 147-2004; JIS L 1902-2002; and SN 195920-1992 (Gao & Cranston, 2008), obtain qualitative data by inoculating bacterial cells on agar plates and then placing the textile samples on top of and in intimate contact with the inoculated bacterial cell layer. Absence of bacterial growth underneath the textile sample indicates antimicrobial activity (Gao & Cranston, 2008). This method is simple to perform and recommended for large number of samples; however, it can only be performed on diffusive finishes (Ramachandran et al., 2004).
Suspension Tests, such as AATCC 100-2004; JIS L 1902-2002; and SN 195924-1992 (Gao & Cranston, 2008), provide quantitative data by using a small amount of bacterial inoculum in a growth media and then absorbing it into the textile samples. The antimicrobial activity is expressed in terms of the percentage reduction of the initial population size with that following the incubation period. Controls should be included to assure the statistical relevance of the results, making Suspension Tests more time consuming than Agar Diffusion Tests.

5.4. Antimicrobial Textiles for Infection Control

Healthcare and hygiene textiles can become highly contaminated with body tissues and fluids, such as blood, skin, stool, urine, and vomitus (Fijan & Turk, 2012). These fluids can transmit and/or spread bacteria that can cause colonization or infection (Mitchell et al., 2015). There is evidence of the presence of microorganisms in textile-based products; reports that identify textiles as possible sources of infection; and reports where unclean linen and contaminated laundry were possible sources of infections of healthcare workers (Fijan & Turk, 2012). There is a need for antimicrobial textiles that can effectively reduce microbe infestation and avoid cross-infections by pathogens (Hamzah et al., 2015).
Copper is one of the main antimicrobial agents being investigated. A study evaluated whether the replacement of hospital linens by replacing regular linen products with copper oxide-impregnated linens could reduce HAIs. The analysis included two types of pathogens: *C. difficile* and multi drug resistant organisms (MDRO). In a 240-day period, there was a 42.9% reduction in *C. difficile* incidences and a 19.2% reduction in MDRO (Butler, 2018). However, during the study educational efforts were undertaken to improve the disinfection and microbe testing practices. These additional efforts may have implications in the results of the study. A systematic review analyzed seven studies that assessed the effect of copper on microbial contamination. Results confirmed that using copper on hospital surfaces reduced the number of bacteria. Nonetheless, data obtained were considered to be of low quality because studies were neither randomized nor blinded. The evidence also showed limited information about the durability of the copper effect (Muller et al., 2016).
Quaternary Ammonium Compounds (QACs) are also being evaluated and, even though they appear to be effective for different fibers and applications, research showed that they were not effective as medical textiles. A study evaluated the effectiveness of cotton samples treated with citric acid and with QACs. Results showed that QACs, usually effective

against bacteria and fungi, were not able to become crosslinked with the cellulose fibers and, as a result, showed limited durability to washing (Budimir et al., 2011). Another study examined the survival capacity of 60 healthcare workers who were exposed to multidrug resistant agents isolated on untreated cotton, cotton treated with QACs, and cotton treated with silver. Results from fabrics treated with T99-19-QAC showed that the agent was not significantly efficient to protect against healthcare-associated isolates (Hanczvikkel et al., 2018).
Silver has proven to be highly effective against several pathogenic microorganisms. A randomized controlled trial in an Intensive Care Unit (ICU) evaluated the effectiveness of 100% polyester curtains with silver-based antimicrobial treatment. Results showed that the antimicrobial technology increased the time to first contamination as compared with standard curtains, reaching the conclusion that using antimicrobial privacy curtains has the potential to increase the time between washings, which would lead to a decrease in pathogen transmission (Schweizer et al., 2012). Some studies show that there is a need for further research on the use of silver for HAIs prevention. A study evaluating multidrug resistant isolates and analyzing current literature on the subject, detected that silver antimicrobial agents proved to be effective against Gram-positive bacteria. Further research and product development is needed to improve their efficacy against Gram-negative pathogens (Hanczvikkel et al., 2018).

6. Conclusions

Even though hand hygiene has reduced infection rates considerably, HAIs are still a serious problem in the US. Healthcare/hygiene textiles can become highly contaminated with pathogenic microorganisms, and literature has shown evidence of microorganism survival in textile-based products and reports of suboptimal laundry procedures as possible sources of infection. Antimicrobial textile technologies are being evaluated for their possible use as infection control measures to help decrease the high HAIs rates.
Linen treated with antimicrobial agents such as copper and silver have shown promising results for their efficacy against some of the pathogenic microorganisms responsible for HAIs. However, there is a need for further laboratory studies and clinical trials that present robust study designs to help better understand the contribution of textile materials in the development of HAIs and the efficacy and durability of antimicrobial technologies as infection control tools.
The implementation of antimicrobial technologies represents an added cost for the healthcare institution, therefore, further research to evaluate antimicrobial treated textiles for specific medical purposes is needed in order to determine if the benefits of implementing these technologies would outweigh the added costs (Borkow & Gabbay, 2008).

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Abstract: Each year, Hospital Infections (IH) in the U.S. cause 98,000 deaths and in turn represent an economic burden of US$28 to US$45 billion. On any given day, about one in 31 hospitalized patients has at least one IH. Although hand hygiene has been the primary focus in infection control, growing evidence suggests that there is a correlation between the environmental bioburden in a hospital and a patient's risk of acquiring an infection.

In hospital settings, soft surfaces dominated by textile materials can become highly contaminated with pathogenic microorganisms that can cause colonization or infection. The relevant literature shows evidence of microbial growth in textile products and of suboptimal quality of hospital laundry processes as possible sources of infection.

Safe and effective formulas have been developed to impart antimicrobial properties to textile materials. Many of these developments have been successfully implemented in sportswear. The most recent lines of research focus on evaluating the efficacy of antimicrobial textiles in medical applications to reduce the biological burden of pathogenic microorganisms on textile surfaces and in turn avoid cross-contamination.

This article intends to review the use of textile products in hospital settings and the possible contribution of textile materials in the development of IH, and in turn analyze the efficacy of antimicrobial technologies in medical textiles used as strategies for infection control.

Keywords: textiles - Hospital infections - antimicrobials - technology - medicine - hygiene - fashion - products - environmen - industry.

Resumo: A cada ano, as Infecções Hospitalares (IH) nos EUA causam 98.000 mortes e, por sua vez, representam um fardo econômico de US$ 28 a US$ 45 bilhões. Em qualquer dia, cerca de um em cada 31 pacientes hospitalizados tem pelo menos uma HI.

Embora a higienização das mãos tenha sido o foco principal no controle de infecções, evidências crescentes sugerem que há uma correlação entre a carga biológica ambiental em um hospital e o risco de um paciente adquirir uma infecção.
Em ambientes hospitalares, superfícies moles dominadas por materiais têxteis podem se tornar altamente contaminadas com microrganismos patogênicos que podem causar colonização ou infecção. A literatura relevante mostra evidências de crescimento microbiano em produtos têxteis e de qualidade subótima dos processos de lavanderia hospitalar como possíveis fontes de infecção.
Fórmulas seguras e eficazes foram desenvolvidas para conferir propriedades antimicrobianas aos materiais têxteis. Muitos desses desenvolvimentos foram implementados com sucesso em roupas esportivas. As linhas de pesquisa mais recentes concentram-se na avaliação da eficácia de têxteis antimicrobianos em aplicações médicas para reduzir a carga biológica de microrganismos patogênicos em superfícies têxteis e, por sua vez, evitar a contaminação cruzada.
Este artigo pretende revisar o uso de produtos têxteis em ambientes hospitalares e a possível contribuição dos materiais têxteis no desenvolvimento da HI e, por sua vez, analisar a eficácia de tecnologias antimicrobianas em têxteis médicos utilizados como estratégias de controle de infecção.

Palavras-chave: têxteis - Infecções hospitalares - antimicrobianos - tecnologia - medicina - higiene - moda - produtos - meio ambiente - indústria.

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