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ANTIMICROBIAL TEXTILE TREATMENTS – A LITERATURE REVIEW OF RISKS, BENEFITS AND APPLICATIONS

by
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14. ABSTRACT
This paper summarizes a literature search and review of peer reviewed sources conducted in 2014 by the US Army Natick Soldier Research, Development and Engineering Center (NSRDEC) to determine the possible risks (negative health effects) of antimicrobial treatments in textiles. These treatments are being used on many textile items, including t-shirts, socks, and sleeping bag liners, and antimicrobial yarns are being used in the Army's Alternate Physical Fitness Uniform (APFU) and Protective Undergarment (PUG). Questions addressed during this review include: (1) Does exposure to the antimicrobial treatments result in toxicity or skin irritation issues?, (2) Does prolonged exposure to antimicrobial textiles change the skin bacteria population by eliminating beneficial bacteria, allowing outgrowth of pathogens?, and (3) Will prolonged exposure result in the emergence of resistant bacteria? The paper also discusses benefits and utilization of treatments, including antimicrobial technologies, textile materials, and applications. Little concern was expressed in the sources reviewed that the compounds used for treatments are unsafe, although some individuals may experience skin sensitivity or irritation. In general, there also appears to be little evidence to support a long-term change in skin bacteria population, outgrowth of pathogens, or the emergence of resistant bacteria. However, there have been very few studies on the effects of prolonged wear, and there is no consensus in literature about these issues. In particular, there is conflicting information regarding antimicrobials and the emergence of resistance. More studies are needed to resolve issues of non-consensus and areas of insufficient research and data, particularly prolonged wear studies.

15. SUBJECT TERMS
SAFETY INFECTIONS MICROFLORA RESISTANCE (BIOLOGY) SKIN IRRITATION
HYGIENE IRRITATION TREATMENTS ANTIMICROBIAL AGENTS EXPOSURE (GENERAL)
TEXTILES PATHOGENS ANTIMICROBIAL ANTIMICROBIAL COATINGS RISK ODORS
TOXICITY TINEA PEDIS ATHLETE'S FOOT PATHOGENIC MICROORGANISMS FUNGI
BACTERIA SENSITIVITY SKIN (ANATOMY) ANTIMICROBIALLY-TREATED FABRICS FIBERS

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ANTIMICROBIAL TEXTILE TREATMENTS – A LITERATURE REVIEW OF RISKS, BENEFITS AND APPLICATIONS

1. Introduction

This paper summarizes a literature search and review conducted by the US Army Natick Soldier Research, Development and Engineering Center (NSRDEC), from December 2013 to April 2014, to determine the risks (negative health effects) of the incorporation of antimicrobial treatments into textiles. These treatments are being used on many items, including T-shirts, socks, and sleeping bag liners. This review was conducted in response to questions regarding the safety of wearing treated textiles that were raised by PM-Soldier Clothing and Individual Equipment (PM-SCIE) during the review of a proposed effort (Defining Antimicrobial Textile Requirements and Performance) to define the requirements of antimicrobial textiles (AMTs). Requirements are issued by the US Army Training and Doctrine Command (TRADOC); however, no requirement currently exists for antimicrobial functionality in any issued item. Previous safety evaluations of Army AMTs have included evaluation of antimicrobial yarns for the Alternate Physical Fitness Uniform (APFU) and the Protective Undergarment (PUG) by the Army Public Health Command and the Office of the Surgeon General.

A number of comprehensive reviews describing antimicrobial technologies used to treat textiles [1, 2, 3, 4, 5] were found during NSRDEC's search, but did not address the health risks of their use that are relevant to the topic of this report. The information presented provides a synopsis of the potential issues regarding safety, effect on skin microflora and applications of antimicrobial textiles (AMTs). Most of the information is sourced from peer-reviewed manuscripts or book chapters including universities, hospitals, and vendors. One source, however, was a vendor's website that contains information regarding efficacy of the vendor's product that has not been peer-reviewed.

The negative health effects found fall into two categories: 1) effects due to the presence of the treatment and 2) effects due to the antimicrobial action of the treatment on the microflora; these are discussed in Sections 2 and 3, respectively. Section 4 contains examples of AMTs to highlight the applications for which they are used and their reported benefits. Conclusions from these findings are presented in Section 5, and their implications on future research are presented in Section 6.

2. Skin Effects due to Presence of Treatment

The presence of any chemical on a textile may cause issues such as skin irritation, rashes and dermatitis in sensitive individuals. Before an antimicrobial compound can be used on textiles, approval for human use must be obtained from the appropriate regulatory agency, i.e., the US Environmental Protection Agency (EPA) and the US Food and Drug Administration (FDA). Safety tests such as skin absorption, acute toxicity, chronic toxicity, etc. must be conducted by the vendor and the results presented to the regulatory agency for review. The risks of negative health effects from the compounds used as the antimicrobial treatment are considered to be minimal. However, as with any chemical, a small number of individuals may experience adverse reactions despite the rigorous approval process.

Although overall there have not been significant safety issues associated with antimicrobial agents (Table I), compound safety can be affected by parameters such as chemical form (monomer vs polymerized forms) and mode of application. Non-toxicity effects on the skin can occur; some antimicrobials such as silane quaternary ammonium compounds (QAC) and triclosan have been associated with skin sensitivity [6, 7]. However, the data are incomplete and further studies are needed.

Table I. Safety characteristics of antimicrobial compounds used to treat textiles [7]

Antimicrobial compound	Dermal resorption	Toxicity	Allergenicity	Mutagenicity	Carcinogenicity
Silver	no	little to none	none	none	none
QAC	yes	moderate to high	moderate	none	none
Polyhexamethyl biguanide (PHMB)	no	little to none	none	none	none
Triclosan	yes	little to none	low	none	none
Copper	no	dose dependent	none	possible	none

Chlorhexidine (an antimicrobial used in hygiene wipes) is reported to have a good safety record [8], although allergic reactions have been observed [7]. There are, however, limited data regarding chronic exposure, and additional research is needed [6]. In addition, there are little data in the existing literature regarding the effect of antimicrobial compounds when used on textiles.

3. Microflora Effects due to Action of AMTs

3.1 Shift in Microflora Population

Most of the antimicrobials used for textile treatments are effective against a broad spectrum of bacteria and fungi (Table II). One concern, however, is that use of these antimicrobial compounds may result in a shift in the skin microflora composition and lead to outgrowth of pathogens. Since changes in microflora composition and consequent growth of pathogens have been observed in gut microbial population with use of antimicrobials (antibiotics), there is concern that the same might occur to the skin microflora [9].

Table II. Spectrum of target organisms of selected compounds used to treat textiles

Antimicrobial compound	Activity against:		
	Gram-positive	**Gram-negative**	**Fungi**
Silver [3]	highly active	highly active	highly active
QACs [3]	active	not active	not active
PHMB [3]	active	active	active
Triclosan [3]	active	not active	active
Copper [3]	active	active	active
N-halamine [10]	active	active	not reported
Chlorhexidine [11]	active	active	not reported

There is a lack of data regarding the effects of AMTs on healthy skin microflora, although insight about the effects of AMTs can be gained from application of topical antimicrobials to the skin. These compounds are classified as disinfectants (e.g., iodine, alcohols) that are highly active; by definition they exhibit >5 log reduction in bacterial levels. Tests with topical antimicrobials resulted in an immediate reduction of population that lasted for short time, but ultimately recovered to initial levels [12, 13]. Since AMTs are not as active as disinfectants, exhibiting at most a 3-4 log reduction using standard laboratory test methods, the microflora reduction/recovery behavior of AMTs would be expected to be the similar to that observed with topical compounds. The few studies conducted on the effect of AMTs on skin microflora confirmed this expectation. Silver-coated AMTs swatches were shown to steadily reduce the skin microflora population during 9 h of exposure. This level was maintained for an additional 9 h, followed by a full recovery by 36 h [7]. In a 4-week prolonged wear study, skin microflora numbers were tracked on subjects who wore specially constructed T-shirts (placebo-controlled right side and a silver-treated left side) for a minimum of 8 h/day, but did not engage in physical activity and wore a new T-shirt each week. Although the treated fabric exhibited antimicrobial functionality as determined by standard laboratory methods, there was no evidence of significant changes in the microflora levels during the study or the week after the wear period [13]. While there is close contact of treated fabric with test bacteria in laboratory tests, contact of a treated AMT with the skin is limited and may in part explain this result. It is unclear what outcome might occur with constant exposure for extended periods (greater than 4 weeks) and with the subjects performing physical activity, a condition that would be more relevant to the Warfighter environment. The effects of prolonged wear of AMTs in the presence of sweat may produce a different outcome.

3.2 Induction of Resistant Organisms

There is concern that prolonged exposure to sub-lethal concentrations of AMTs may lead to an increase in resistant microorganisms. Many of the mechanisms found for resistance against compounds used in AMTs are the same as those in found in antibiotics that resulted in changes in microflora composition and emergence of resistant microorganisms in the gut, as mentioned in Section 3.1. These mechanisms include efflux pumps, modification of cellular targets, inactivation and plasmid mediated resistance [14]. In general, there is conflicting information in literature regarding antimicrobials and the emergence of resistance. Some authors continue to express concern that prolonged antimicrobial use will select for resistant bacteria as did the antibiotics used in the gut, which share some of the same resistance mechanisms as for metals found in AMTs [15]. Other literature states that, in general, antimicrobial treatments are not expected to result in the emergence of resistant organisms due to the multiple modes of action and level of use. Due to the difficulty of testing all bacterial strains under realistic environmental conditions, a definitive conclusion is difficult to construct [6].

Antimicrobial agents used to treat textiles may result in resistant microorganisms under ideal laboratory conditions. This has been observed with triclosan [16], silver [17], QACs [6], copper [18], and PHMB [15]. However, these results do not necessarily translate to use on textiles or medical applications, as there is a wide gap between laboratory studies and potential development of resistance under environmentally relevant conditions. For example, while triclosan levels in the environment could theoretically cause resistance, there is a lack of evidence that this has actually occurred [6]. Silver has been perhaps the best studied antimicrobial compound, including modes of action and resistance mechanisms [19]. In spite of the various mechanisms that have been demonstrated, silver has had a long history of use with no evidence of emergence of resistant organisms, including a prolonged wear test of silver AMTs and during use as coatings on textiles and catheters [13]. Increasing resistance to QACs has been reported [20], related to QAC application in human medicine and the food industry. However, most QAC studies have been done on the antimicrobial compounds not in association with textiles; additional studies of QAC AMTs are needed, especially with prolonged exposure.

4. Applications and Beneficial Effects of AMTs

The use of antimicrobials has been reported in literature to provide benefits in a number of applications (Table III). Much of the literature reports are with regard to antimicrobial compounds used for medical applications, but the studies of AMTs are more limited.

Table III. Examples of applications utilizing antimicrobials

Application	Material	Antimicrobial	Reference	Document
Infection control	Wound dressings	Silver	Kramer et al (2006)[7]	Peer-reviewed book chapter
		Copper	Borkow et al (2010)[21]	Peer-reviewed paper authored by vendor
		PHMB	McGhee et al [22]	Vendor website
Post-op infection control	Sutures	Silver, Triclosan	Kramer et al (2006)[7]	Peer-reviewed book chapter
Atopic dermatitis	Textile	Silver	Haug et al (2006)[23]	Peer-reviewed book chapter
Skin/soft tissue infections	Wipes	Chlorhexidine	Whitman (2010)[8]	Peer-reviewed paper
Reduction of MRSA infections	Textile	Silver, zinc zeolite; chitosan	Takai et al (2002)[24]	Peer-reviewed paper
Odor control	T-shirt	Silver	Hoefer and Hammer (2011)[13]	Peer-reviewed paper
Fungal control	Socks	Copper	Borkow and Gadday (2004)[25]	Peer-reviewed paper authored by vendor

As mentioned in Section 3.2, silver has perhaps been the most widely studied antimicrobial compound and has been shown to be effective in preventing/treating bacterial infection when used on catheters and in wound dressings. Triclosan and silver impregnated sutures are effective in the prevention of post-operative infection. The literature has many reports on the benefits of AMTs, including reduction of odor and skin irritation and prevention of fungal infection. On textiles, silver is reported to help prevent *Staphylococcus aureus* colonization of inflamed skin that results from atopic dermatitis, a condition caused by allergenic hypersensitivity. The use of antimicrobials for the mitigation of athlete's foot has also been reported. Most studies of AMTs are done in sports apparel, which test under similar conditions (e.g., intense physical activity) to military relevant environments, while other aspects, such as access to laundry and shower facilities, are not. While much can be learned from the sports apparel studies, additional research is needed to determine efficacy of antimicrobials on textile surfaces in military relevant environments.

5. Conclusions

No significant negative health effects are known to be caused by the antimicrobial compounds used to treat textiles. However, there are only a few reports in literature regarding the safety of AMTs.

To date there is little data regarding the effect of antimicrobials on the ecology of the skin bacterial population. Silver AMTs have been shown to temporarily reduce the density of skin microflora, but not to eliminate them. Additional studies are needed to determine the effect of AMTs with other antimicrobial treatments. Studies are also needed to determine treatment safety and efficacy during prolonged exposure.

Although there are increasing reports of genes encoding for antimicrobial resistance, there is no evidence of the emergence of resistant organisms with use of antimicrobials on surfaces. However, data are conflicting, and additional studies are needed to evaluate AMTs.

6. Future Efforts

Antimicrobial treatments have been used for a variety of hygiene issues. While benefits have been shown in medical applications, additional work is needed for non-medical applications. Such future studies should address the following questions:

- Are there toxicity and safety issues posed by AMTs?
- How does long-term exposure to AMTs affect the density and composition of skin microflora?
- Will long-term use of AMTs result in the emergence of resistant organisms?

In particular, investigation of prolonged wear of treated textiles is needed. A controlled laboratory study (e.g., utilizing US Army Research Institute of Environmental Medicine efforts in the NSRDEC Doriot Chamber) or field studies would allow evaluation of the various gaps outlined above and allow testing under more operationally relevant conditions.

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