PROGRESS ON ANTIMICROBIAL SURGICAL GLOVES: A REVIEW

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ABSTRACT

Surgical gloves provide a protective blockade for patients and members of the surgical team. Glove integrity is critical in an era of blood-borne pathogens. Therefore, the need for improved means for prevention and also gloving and appropriate hand hygiene in a hospital setting is ostensible. This perspective highlights the progress on antimicrobial surgical gloves in deducting the microbial passage after a glove puncture in a model of wound contamination. Moreover, traditional methods to avoid microbes in the hospital and various antimicrobial agents, such as metal ions and antiseptic dyes, are reviewed. [doi:10.5254/rct.15.84882]

CONTENTS

I. INTRODUCTION

A. SURGICAL GLOVES

Blood, exposing the nature of the surgery, increases the risk of microbe transfer through contact between surgical patients and the surgical team. The transferred microbes may cause postoperative infections in patients or even blood-borne infections in both patients and the surgical team. Therefore, protecting both patients and the surgical team and decreasing the risk of microbial transfer is the center of interest. The application of protective barriers (e.g., surgical gloves) is a possible way to decrease contamination risk.[1–5] The risk of surgical site infections (SSIs) depends on factors related to the patient, surgical team, and surgical intervention but is ultimately related to the possibility of surgical wound contamination during surgery.[6,7] Using surgical gloves is an essential part of SSI prevention, as gloves provide a physical barrier to

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microorganisms present on the hands of health care workers (HCWs), in the environment, and on patients.[8,9] In addition, pathogen transmission by contaminated gloves has been recognized as an important vector for the pathogenesis of health care–associated infections.[10,11] Surgical gloves are complementary to and of equal importance as surgical hand antisepsis[12]; however, their use does not guarantee total safety for the patient or the surgical team, because of inevitable microperforations or tears.[13,14] Gloves act as barriers to microorganisms but do not eliminate them.[15] Rather, they create a moist environment, promoting and exacerbating the proliferation of microorganisms, especially when surgical antisepsis of the hands is performed insufficiently or inappropriately or is not performed at all.[16–18] Thus, glove perforation facilitates the transfer of pathogens through the holes (even microscopic), increasing the risk of surgical site contamination, which, based on the volume, virulence, and host resistance, could directly leads to an SSI.[19] Surgical gloves are usually used as a protective barrier against contamination, such as bacteria and viruses.[20,21] Therefore, these gloves should be designed to be entirely impermeable to the contaminants or microorganisms during application. This study suggests that applying antibacterial gloves can reduce bacterial transfer through surgical gloves.[1]

B. DIFFERENT MICROBES IN HOSPITALS

The health care unit is an environment that is constantly exposed to myriad microbial pathogens. In 2010, more than 69 475 cases of health care–associated infections and 81 139 pathogens were reported in the United States.[22] The pathogens varied by type of health care–associated infection (HAI; Table I), but overall, 80% of the reported pathogens were composed of *Staphylococcus aureus* (16%), *Enterococcus* spp. (14%), *Escherichia coli* (12%), coagulase-negative staphylococci (11%), *Candida* spp. (9%), *Klebsiella pneumoniae* (and *Klebsiella oxytoca*; 8%), *Pseudomonas aeruginosa* (8%), and *Enterobacter* spp. (5%). Patients themselves are hosts of a variety of endogenous microorganisms (Table I) and may inoculate themselves with pathogens or spread them to other individuals and surroundings.[23]

Previous studies have shown that HCWs' gloves might contaminate through direct and indirect contact with colonized patients or the patients' environment, which, alongside inadequate hand hygiene, would lead to HAIs.[24–26] Dramatic microbial multidrug resistance related to an increase in health care infections, such as methicillin-resistant *S. aureus* (MRSA) and vancomycin-resistant enterococci (VRE), has created a demand for a new alternative prevention material.[27,28] The application of antimicrobial gloves in all health care units (e.g., operating theatres, wards, clinics) will help to reduce the possibility of microbes' horizontal spread and prevent HAIs.

II. TRADITIONAL METHODS TO AVOID MICROBES IN THE HOSPITAL

A. DOUBLE GLOVING

To reduce the risk of bacterial transmission and provide further barrier, wearing two sets of gloves or cloth outer gloves has been suggested.[29,30] Double gloving is wearing two pairs of surgical gloves to decrease the risk of contamination origin from glove failure or penetration of the gloves by sharp objects during medical procedures.[1,31] Double gloving provides significant protection against inner glove perforation during surgical procedures as compared with a single-glove layer.[32] However, there are several reasons for not double gloving; the most cited reason by surgeons and residents is a decrease in manual dexterity and comfort. Another reason for not double gloving is adaptation time, which can vary from 1 to 120 days, according to Patterson et al.[3]

B. HAND WASHING

HCWs' hands could contaminate with bacteria in contact with the skin of hospitalized patients by touching inanimate objects in patient rooms or during cleaning procedures.[33–36] Furthermore, feeding, changing diapers, playing, and even contact with surfaces contaminated by secretions of infants infected with respiratory syncytial virus might contaminate HCWs. Furthermore, bacteria on the hands of surgeons might cause wound infections if introduced into the operative field during surgery,[37] followed by rapid bacteria multiplication under surgical gloves if hands are washed with a nonantimicrobial soap.

Although hand washing appears to be a good method for controlling bacterial contamination among HCWs, frequent hand antisepsis using alcohol-based formulations leads to skin dryness.[36]

III. TRADITIONAL ANTIMICROBIAL AGENTS FOR GLOVES

The toxicity of the antibacterial agent and its degradation products in the human body should be assessed by the manufacturers.[38]

Triclosan (2, 4, 4′-trichloro-2′-hydroxydiphenyl ether; TCS) is a broad-spectrum antibacterial agent usually used in various personal care products.[39,40] Unfortunately, there is some evidence that proves the toxicity of TCS to humans and environments.[41,42] This evidence strongly demonstrates TCS toxicity to aquatic species such as algae, invertebrates, and certain types of fish. Although it is highly toxic to algae and exerts reproductive and developmental effects in some fishes,[41] some studies reveal TCS's potential for endocrine disruption, thyroid hormone disruption, and possibly reproductive axis problems.[41,43]

IV. ANTIMICROBIAL AGENTS FOR SURGICAL GLOVES

It is extremely important to search for new materials to use in biomedical applications.[44,45] Antibiotic resistance has prompted the search for new agents that can inhibit bacterial growth. Researchers have found that graphene-based nanomaterials possess excellent antibacterial properties.[46] Although antibacterial materials are widely used in daily life, and the antibacterial properties of nanomaterials are increasingly being explored and developed as commercial products, their cytotoxicity and biocompatibility have raised questions and concerns.

As a result of the extremely thin nature of surgical gloves and the possibility of puncturing or rupturing during use, the risk of contamination seems to be tragically high. Suitable antibacterial agents include biguanides such as chlorhexidine salts (e.g., gluconate salt [CHG]) and polyhexamethyl biguanide (PHMB), quaternary ammonium salts such as benzalkonium chloride and benzethonium chloride, chlorinated phenols such as triclosan, essential oils such as farnesol, phenoxyethanol, octoxyglycerin, iodine compounds, silver salts, antifungal agents, and the like.[20]

A polymer blend films of polyvinyl alcohol and natural rubber blends show good antibacterial activity against *S. aureus*, *E. coli*, and *Acinetobacter baumannii*.[47]

An antibacterial medical glove consists essentially of an outer elastomeric body in the shape of a hand and an inner coating containing an antimicrobial agent, with the inner coating being capable of slowly releasing an antimicrobial agent in an amount and over a period of time sufficient to maintain an essentially bacteria-free and fungus-free environment within the glove after the glove has been donned.[48] Aik et al.[49] coated the inner layer of a surgical glove with the cationic antibacterial agents CHG or PHMB. In this patent, cornstarch was applied as an antiblocking agent to immobilize the CHG and PHMB in place and control the slow secretion of CHG and PHMB during surgical glove application.[20] Figure 1 is an example of applying an antimicrobial material in a surgical glove.

TABLE I
BACTERIA COMMONLY FOUND ON THE SURFACES OF THE HUMAN BODY[23]

Bacterium	Skin	Conjunctiva	Nose	Pharynx	Mouth	Lower GI	Ant. urethra	Vagina
S. epidermidis	++	+	++	++	++	+	++	++
S. aureus[a]	+	+/−	+	+	+	++	+/−	+
S. mitis				+	++	+/−	+	+
S. salivarius				++	++			
S. mutans[a]				+	++			
E. faecalis[a]				+/-	+	++	+	+
S. pneumoniae[a]		+/−	+/−	+	+			+/−
S. pyogenes[a]	+/−	+/−		+	+	+/-		+/−
Neisseria sp.		+	+	++	+		+	+
N. meningitidis[a]			+	++	+			+
Enterobacteriaceae[a]		+/−	+/−	+/−	+	++	+	+
Proteus sp.		+/−	+	+	+	+	+	+
P. aeruginosa[a]				+/−	+/−	+	+/−	
H. influenzae[a]		+/−	+	+	+			
Bacteroides sp.[a]						++	+	+/−
B. bifidum						++		
Lactobacillus sp.				+	++	++		++
Clostridium sp.					+/−	++		
Clostridium tetani						+/-		
Corynebacteria	++	+	++	+	+	+	+	+
Mycobacteria	+		+/−	+/−		+	+	
Actinomycetes				+	+			
Spirochetes				+	++	++		
Mycoplasmas				+	+	+	+/−	+

[a] Potential pathogen. ++ = nearly 100%; + = common (about 25%); +/− = rare (<5%).

A. METAL ION PARTICLES

1. Silver ion particles. — It has been known for a long time that ionic silver is a common antibacterial metal oxide against the pathogens including *E. coli*.[50,51] It is believed that silver particles bind into bacterial DNA content and prevent cell replication and interruption and inactivation of the electron transport chain of metabolic enzymes by binding to their sulfhydryl group,[52,53] according to Figure 2.

In the study by Li et al.,[55] the silver nanoparticles' antibacterial activity in *E. coli* was explored and revealed that 10 μg/mL of the silver nanoparticles completely inhibit the growth of 107 cfu/mL *E. coli* cells in liquid Mueller–Hinton medium.

The presence of silver nanoparticles at a concentration of 10 μgcm^{-3} prevents *E. coli* growth by 70%, whereas it is significantly reduced on plates with a concentration of 20 μgcm^{-3}.[56,57] A concentration of 50–60 μgcm^{-3} caused 100% inhibition of bacterial growth (Figure 3). As expected, the inhibition of bacterial growth depends on the number of cells applied in the test.[58–60]

2. Copper Ion Particles. — Copper has been recognized as having the potential for antibacterial activity.[61,62] Copper shows bactericidal activity against a range of bacteria including E. coli, MRSA, Listeria monocytogenes, Clostridium difficile, yeasts, and viruses.[63–66] Casey et

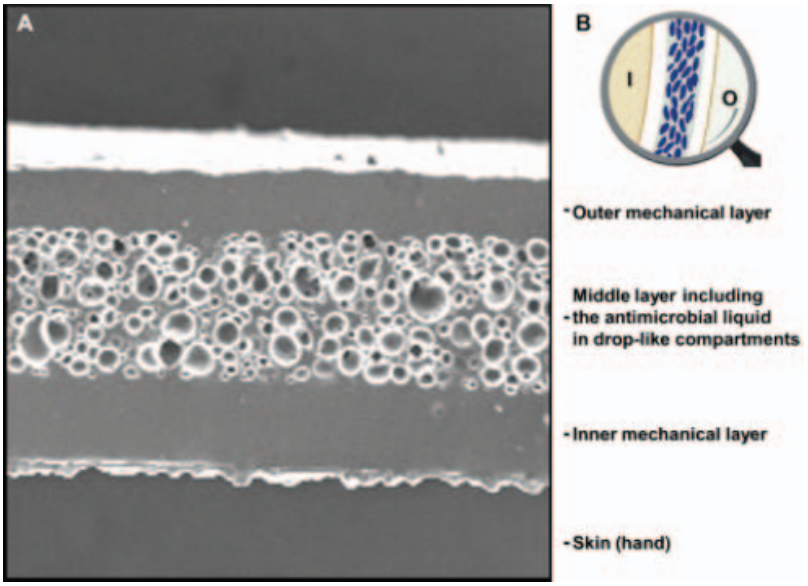

FIG. 1. — (A) Microscopic picture of trilayer surgical glove showing middle layer containing droplike mixture of chlorhexidine and quaternary ammonium salts. (B) Artist rendition of trilayer surgical glove demonstrating inner (I) and outer (O) surfaces adjacent.[1,2]

al.[61] reported that copper-containing surfaces continuously reduce environmental microbial contamination. It has been shown that copper is strongly antibacterial against MRSA, EMRSA-1, and EMRSA-16, preventing their long-term persistence.[63] Copper alley bactericidal activity varies from 30 s (against Saccharomyces cerevisiae)[67] to 576 h (against Aspergillus niger wet spores).[68] In another study, a copper-coated respiratory face mask showed significant biocidal activity against influenza virus.[69]

B. Antiseptic Dyes and Salts

1. Gardine. — Gardine is an innovative antiseptic dye with broad-spectrum antibacterial effects prepared by combining brilliant green and chlorhexidine.[24,70] Although brilliant green and chlorhexidine have low antibacterial activity when applied separately, using their combination revealed enormous antibacterial activity due to the synergistic effect of their mixture.[71,72] The safety of gardine solution for human use was granted. For instant, brilliant green commonly has been applied in skin lesions as an anti-infective agent.[73] Daily application of low-concentration chlorhexidine proves to be nontoxic, and it is widely used in mouthwash solutions along with other antiseptics.[74] Even though the noncytotxicity of brilliant green and chlorhexidine has been demonstrated, more studies should be performed to test the cytotoxicity of the gardine.

Gardine-treated bacteria cultures show significant reduction within 30 s for all tested organisms including MRSA,[75] VRE, *E. coli*, *Acinetobacter*, and *Candida albicans*.[76,77] Complete kill was achieved within 30 s for MRSA and *E. coli*, 10 min for *Acinetobacter*, and 30 min for *C. albicans*.[24] Another study performed by Paul et al.[71] confirmed that gendine-coated stainless provided significant baseline antimicrobial efficacy against MRSA for long durability of 2 weeks. Antiseptic dyes interfere with cell-cell communication, which inhibits bacteria aggregation and creation of biofilm and finally leads to lysis of the bacteria membrane.[78]

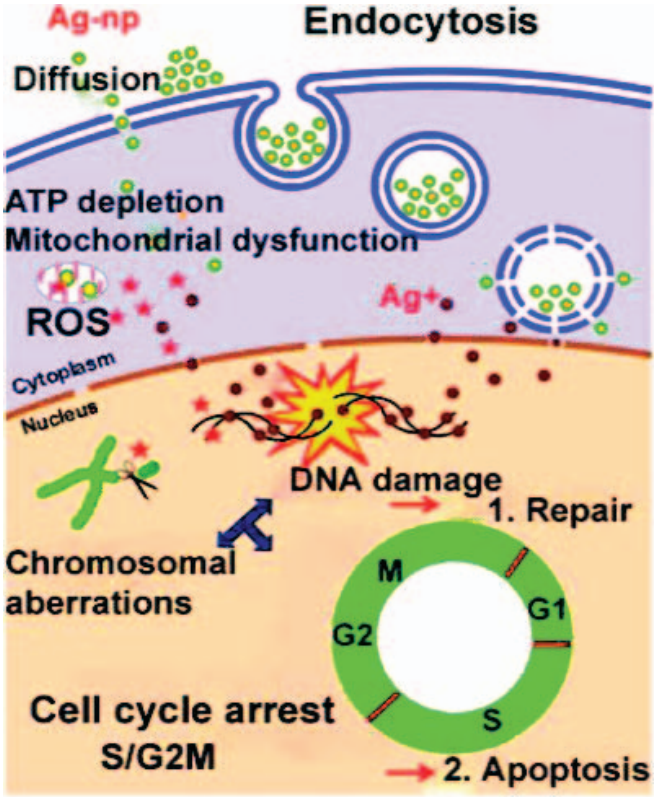

FIG. 2. — Silver particles bind into bacterial DNA content and prevent cell replication and interrupting and inactivating the electron transport chain of metabolic enzymes by binding to their sulfhydryl group.[52,54]

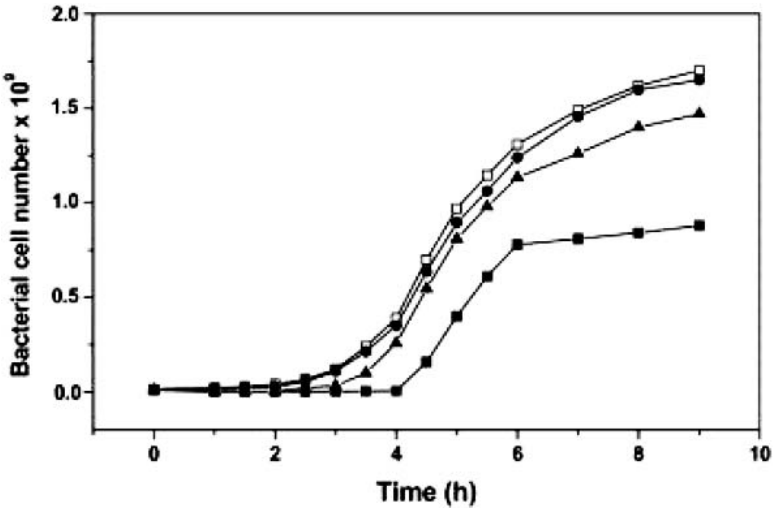

FIG. 3. — Growth curves of *E. coli* in LB medium inoculated with 107 CFU of bacteria in the presence of different concentrations of silver nanoparticles: (□) 0 μg cm^{-3}, (●) 10 μg cm^{-3}, (▲) 50 μg cm^{-3}, and (■) 100 μg cm^{-3}.[58]

2. Ammonium Compounds. — Lately, bacterial infections have grown rapidly as a social health problem.[79] Thus, safe bactericidal technique plays a significant role in human health care.[80] The most common antibacterial agents mainly used in application nowadays are divided into four groups[81]: oxidants, electrophilic agents, organic biocides, and cationic active biocides. Chlorhexidine and quaternary ammonium compounds are categorized in the last division. These compounds are mainly used in surfactants. Surfactants consist of two parts: a hydrocarbon region that shows hydrophobic properties and a hydrophilic part that has a water-attracting tail. Quaternary ammonium compounds (QACs) are classified as cationic agents. Along with their antibacterial activity, QACs are outstanding for use in cleaning hard surfaces and for deodorization. QACs have been classified as membrane-active agents for many years.[82] As has been suggested by other researchers,[83] bacteria undergo a series of events when in contact with ammonium compound cationic agents: (1) agents' adhesion and insertion into the cell wall, (2) interaction with the cytoplasmic membrane, (3) release of cytoplasmic material to the outer membrane space, (4) lysis of proteins and nucleic acids, and (5) cell wall degradation via autolytic enzymes. Overall, loss and damage of different parts of bacteria lead to bacteria death.[84]

V. CONCLUSION AND OUTLOOK

The microbial-contaminated glove is the most important cause of microbial transmission in health care. Manufacturing antimicrobial gloves seems to be a possible solution for preventing these contaminations. Because of microbial drug resistance, new effective antimicrobial drugs must be developed. Different types of antimicrobial agents have been reviewed in this study, including metal ions and antiseptic dyes. Great progress on nanoparticle-based antimicrobial gloves requires consideration of the shared interest between microbiologists and nanoengineers in developing a novel nanotechnology targeting a few major unmet challenges of antimicrobial agents.

VI. ACKNOWLEDGEMENT

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VII. CONFLICT OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this article.

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