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Review

Healthcare workers uniforms (HCWU)

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There is a major concern for healthcare workers (HCW) regarding transmission of bacteria to and from their patients. Because of this potential contamination, protection is a major issue. Healthcare workers uniforms (HCWU) are often used as barriers to help eliminate or reduce the risk of infection for both the doctor and the patient. Without sufficient barriers, harmful bacteria can reach and penetrate the skin of surgeons and/or patients, with an associated potential for infection. In addition, when pathogens contaminate (HCWU), they can be transmitted to other persons beyond the initial wearer. For the prevention of surgical infection through contamination from aqueous liquids and bacteria, guidelines have been issued for surgical gowns by several organizations. This paper looks into this crucial issue in order to highlight the importance of this subject and discuss the parameters that govern it.

Key words: Healthcare workers (HCW), chitosan, AEGIS microbe shield (AMS), poly-hexamethylene biguanide (PHMB), reusable, disposable.

INTRODUCTION

During every hour of a major surgical operation, about 30,000 to 60,000 organisms are deposited on a three to four meter squared sterile field and about one –half of all surgical procedures resulted in an accident where at least one medical worker was contaminated with blood (Conn et al., 1986). During these operations, one of the primary sources of contamination of healthcare workers (HCW) is from open wounds.

However, a major concern for HCW is the problem of transmission of pathogens and bacteria from their patients to themselves and the reverse contamination. Any blood contamination could pose a risk of transmission of bacteria. Because of this potential contamination, protection is a major concern. Healthcare workers' uniforms (HCWU) which include surgical gowns, scrub suits, lab coats, and nurses' uniforms, are often used as barriers to help eliminate or reduce the risk of infection for both the doctor and the patient. Surgical gowns, which were used as early as the 1800s, are traditionally made from cotton fabric (Smith and Nichols, 1991). Although cotton gowns are comfortable for wearer, unfinished cotton fabrics does not protect against bacteria penetration, or the penetration of biological liquids (e.g. blood, body fluid) and associated bacteria (Laufman et al., 1975). Without sufficient barriers, harmful pathogens can reach and penetrate the skin of surgeons and/or patients, with an associated potential for infection. In addition, when pathogens contaminate (HCWU), they can be transmitted to other persons beyond the initial wearer.

The center for disease control (CDC) has estimated that 8.8 million people work in the healthcare industry, and 27 million surgical procedures are performed in the U.S. every year (Mangram et al., 1999). From these procedures, surgical wound infections can be transferred from worker to patient or vice versa (Hughes et al., 1983). A way to combat these infections occurring from penetration or transmission is for workers to wear proper HCWU.

STANDARDS FOR HCWU

Standards for (HCWU) are very important for the welfare of healthcare workers (HCW) as well as their patients. Several organizations have made recommendations or mandates on how to protect HCW as well as patients from exposure to blood borne pathogens and bacteria. For the prevention of surgical infection through contamination from aqueous liquids and bacteria, guidelines have been issued for surgical gowns by several organizations. The following organizations have provided detailed information concerning (HCWU).

Association of operating room nurses (AORN)

AORN is a professional organization of preoperative registered nurses. This organization promotes quality patient care through education, standards, services, and representation. AORN issued standards as early as 1975 for draping and gowning materials (AORN, 1975). It proposed that surgical drapes and gowns should be made of fabrics that form an effective barrier by eliminating the passage of bacteria between sterile and non-sterile areas. An effective barrier should be fluid resistant (e.g., blood and aqueous), abrasion resistant to eliminate bacteria penetration, and lint free to reduce the number of particles in the air. These guidelines emphasized that HCW have a serious concern for barrier protection clothing. AORN also recommended that surgical gowns need to be changed after becoming visibly soiled and then laundered in an approved facility, in order to maintain their barrier properties (AORN, 1993). Most importantly, HWCU manufacturers need to provide data to customers (e.g., HCW) regarding the bacteria and liquid barrier performances of their products (AORN, 1992).

Center for disease control (CDC)

Since 1946, the CDC is the leading federal agency for the protection of health and safety of U.S. citizens both in the United States and in their travel abroad. Today, the CDC is a vital force in protecting the U.S. public from most widespread diseases that could affect public health.

The guidelines of the CDC mandate that surgical gowns and drapes, either disposable or reusable, should be impermeable to liquids and viruses and be comfortable to wearer (Bolyard et al., 1998). If a HCWU (e.g., scrub suit) is soiled, contaminated, or penetrated by any infectious material, the CDC recommends that it be changed immediately.

Occupational safety and health administration (OSHA)

OSHA is a division of the Department of Labor and was established in 1971 to save lives, prevent injury, and protect workers health. OSHA recommends that appropriate protective clothing must be worn to form an effective barrier when an employee has a potential for exposure on the job (OSHA, 1989). The type of clothing needed depends upon the occupational task and the degree of potential exposure. If the clothes are potentially soiled from blood or other potentially infectious materials, protective clothing must be worn to prevent the employees underlying clothing from contamination. Fluid-resistant clothing must be worn when workers could become contaminated through splashing or spraying of blood or other potentially infectious materials. Because a larger volume of blood and other potentially infectious materials are associated with the work of the HCW, a specific protective type of barrier clothing is needed.

OSHA further recommends that the contaminated uniform should be removed at the end of the work shift. A contaminated uniform should not be taken home but be left at the work area for cleaning, laundering, and/or disposing. Furthermore, Matthews et al. (1985) stated that HCWU should be comfortable, cheap, durable, non-toxic, and able to resist transfer of bacteria. Bacteria have different modes of transports (that is, air particles, blood, body fluids).

LIFE CYCLES OF TEXTILES FOR HCWU

Fabrics that are used for HCWU have two life cycles: Reusable and disposable. Reusable fabrics are usually made of woven fabric and often woven from cotton or polyester yarns or a blend of these two fibres. These fabrics are laundered and sterilized after use in order to remove stains and kill bacteria.

Based on Batra's (1992) report approximately 20% of surgical gowns are of the reusable type. In a cost study, reusable fabrics were found to be more cost-effective than disposable fabrics (DiGiacomo et al., 1992). The benefits of reusable fabric include less solid waste from limited disposal and more comfort to the wearer. In contrast, the problems associated with reusable fabrics include the loss of durability and the reduction of barrier protection after repeated washing (Laufman et al., 1975). If the barrier protection of the fabric is removed or weakened after repeated washing, the fabric becomes useless as protection for HCW.

On the other hand, disposable gowns are for single use only. Furthermore disposable fabrics are mainly used in surgical gowns but reusable fabrics are found in various (HCWU) (e.g., nurses. uniforms, lab coats, and scrub suits). They are generally made from a non-woven fabric and contain either wood pulp/polyester fibers or olefin (that is, polypropylene) fibers (Huang and Leonas, 1999). They are good in providing protection. However, the problems associated with disposable fabrics are high-risk contamination, environmental issues through waste and landfill, expense, and discomfort if they are reinforced with a plastic film (DiGiacomo et al., 1992; Hatch, 1993). Two benefits of disposable fabrics are that they do not need washing after use (that is, they are not reused), and they are already sterilized prior to use. By adding a plastic film to disposable fabrics, they can be made impermeable to bacteria. Reusable HCWU is usually more comfortable than disposable fabrics; however, reusable cotton fabric without a finish does not protect against bacterial penetration (Leonas, 1993).

Leonas (1993) studied disposable surgical gowns and found that improved repellency and reduced pore size of these gowns contributed to barrier protection. Some problems associated with disposable fabrics are expense, risk of contamination with disposal outside of the hospital setting, and other environmental issues related to disposal (DiGiacomo et al., 1992). In addition, although a plastic film added to disposable fabrics can increase protection, it could make the fabric bulky, hot, and uncomfortable to the wearer (Hatch, 1993), and increases the problems for disposal solutions.

BARRIER PROTECTION OF TEXTILES FOR HCWU

Both reusable and disposable HCWU have been used to provide barrier protection for HCW (Leonas, 1993, 1998; Leonas and Jinkins, 1997). Study results have shown that disposable HCWU) could provide better barrier protection if they were reinforced with a plastic film, and reusable HCWU could provide better protection if a textile finish such as a water-repellent finish or antibacterial finish was applied (Huang and Leonas, 1999; Laufman et al., 1975). A textile finish is defined as .the process of applying mechanical energy, thermal energy, or chemical materials to a textile product to alter its end-use performance (American Association of Textile Chemist and Colorists (AATCC), 2000: 397). One specific textile finish is the barrier protection finish. The barrier protection finish is usually a chemical finish, which is formed by bonding a chemical to the fiber or fabric. Such a finish forms a barrier or coating on the fabric and enhances the fabric's barrier protection properties. Examples of barrier protection finishes are oil/water-repellent and antibacterial finishes. Oil/water-repellent finishes cause oil/water to bead on the fabric surface, while allowing perspiration to pass through the spaces between the fabrics warp and filling yarns (Hatch, 1993). Fabrics with the oil/water-repellent finish can reduce the spread, wetting, and penetration of oil or water on and into the fabric.

Laufman et al. (1975) used the water-repellent finish, Quarpel, as a barrier protection finish against the bacteria *Serratia marcesens* and found that the finish inhibits bacterial penetration. Three types of mechanisms (that is, controlled-release, regeneration, barrier block) for antibacterial agents are used to control or inhibit bacteria. Those mechanisms are:

1. The controlled-release mechanism: It is the most commonly used among the antibacterial agents (Brumbelow, 1987). In the controlled-release finish, chemicals in the finish, are released from the fabric in enough quantities to kill or inhibit the growth of bacteria. The antibacterial agent, triclosan has been used as a controlled released mechanism on non-woven fabrics (Huang and Leonas, 1999);
2. The regeneration model: It was first established by Gagliardi in 1962. In this model, an antibacterial chemical finish is applied to the fabric and is continually replenished by a bleaching agent during laundering. The antibacterial agent, monomethylol-5,5- dimethylhydantoin (MDMH) has been used as a regeneration mechanism on woven fabrics (Sun and Xu, 1999);
3. Barrier-block mechanism: It inhibits bacteria through direct surface contact. The antibacterial agent bonds (yhat is, covalent, ionic) to the fabric surface thus making the fabric an effective barrier against bacteria and remains durable during laundering.

The first two antibacterial finish methods have known problems in usage with HCWU. Problems with the controlled-release mechanism are its durability after laundering and leaching of the agents from the fabric. Leaching can often cause problems if the antibacterial agents come in contact with skin of HCW. These agents have the potential to affect the normal skin flora, which could lead to extreme skin irritation and cause dermatitis (Sun and Williams, 1999). In addition, leaching can make skin bacteria build a tolerance to the agent. Additional problems for HCWU also occur for fabrics using a regeneration mechanism. The agents that use the regeneration mechanism require chlorine bleaching to activate its antibacterial properties after laundering; however, over time chlorine can degrade natural fibers such as cotton, which is often used in reusable HCWU (Hatch, 1993).

Barrier-block mechanisms do not pose the problems currently found with the other two methods. The agent that uses the barrier-block mechanism does not leach on the fabric surface and does not need bleaching to continue its effectiveness. They are bonded on the fabric surface and remain fixed to the surface, thereby killing any bacteria that come in contact with the fabric (Malek and Speier, 1982). Chitosan, AEGIS Microbe Shield (AMS), and poly-hexamethylene biguanide (PHMB) are three agents that use the barrier-block mechanism and are currently available in the marketplace. Chitosan has been used in many applications such as dietary additives because of its biodegradability and non-toxicity to mammals (Kim et al., 1998). However, Lin et al. (2002) indicated that chitosan has water fastness problems after repeated laundering, and therefore, it is not appropriate to be used on HCWU.

AMS, in contrast to chitosan, is found in many antibacterial-containing products such as socks, bed linen, and camping materials (Burlington Industries and Dow Corning Corporation, 1985). Many of these personal use items are often washed. PHMB is found in swimming pool sanitizers, preservation, and personal care products (Payne amd Kudner, 1996). In the studies on the efficacy of AMS and PHMB, these two agents have been evaluated as antibacterial agents on the reduction of odor

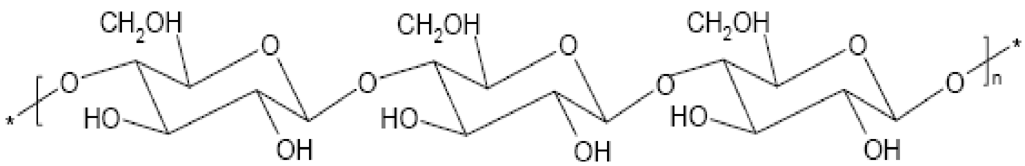

Figure 1. Polymer structure of cellulose.

(Malek and Speier, 1982; Payne and Kudner, 1996); however, their efficacy as antibacterial agents on the reduction of bacteria after laundering has been examined only in a limited arena. Malek and Speier (1982), in one study, examined the efficacy of AMS and found that it had significant antibacterial activity when used with a woven fabric. In addition, one study was found on the examination of antibacterial activities of PHMB combined with a fluoro-chemical compound, a water-repellent agent, on non-woven gowns before laundering (Huang and Leonas, 1999). The results showed that PHMB had significant antibacterial activity alone and when it was added to the fluoro-chemical compound. Payne and Kudner (1996) hypothesized that PHMB would show better durability than AMS due to its ability to bind at the different surfaces of cotton fabric. Their claim was supported by the information that AMS is bound to the fabric through one cationic group, but PHMB is bound to the fabric by multiple cationic groups. However, no study was found with the comparison of the antibacterial activity between AMS and PHMB on fabrics after repeated laundering.

The antibacterial agent, 3-trimethoxysily-propyldecyl-dimethyl ammonium chlorine (AEGIS Microbe Shield (AMS)) has been used as a barrier-block mechanism on cotton and cotton blended fabrics (Malek and Speier, 1982) as well as PHMB, which is commercially known as Reputex, has been used on woven and non-woven fabrics (Huang and Leonas, 1999; Wallace, 2001). Antibacterial finishes can be found on many products such as hosiery, shoe insoles, towels, underwear, bedding, and active wear (Thirty, 2001).

TYPES OF HEALTHCARE WORKERS UNIFORM (HCWU)

Healthcare workers uniform (HCWU) includes surgical gowns, scrub suits, lab coats, and nurses uniforms. They are categorized as reusable or disposable. Scrub suits, lab coats, and nurses uniforms are often made of reusable fabrics (Neely and Maley, 2000). However, surgical gowns are frequently made of either reusable or disposable fabrics (Granzow et al., 1998). The characteristics of reusable and disposable HCWU are dependent on fiber type, construction, and finishes to determine its optimal usage for protection. Reusable fabrics used for HCWU can be used over 50 times after laundering and sterilization (Sun and Xu, 1998); whereas, disposable fabrics for HCWU are used only once before being discarded.

Reusable HCWU

Reusable (HCWU) is used in many aspects of the healthcare industry such as in clinics, hospitals, and veterinary offices. Batra (1992) reported that reusable surgical gowns continue to represent 20% of the total number of (HCWU) being used. Reusable (HCWU) are often made of cotton, polyester, or cotton and polyester blend woven fabrics with a plain weave (Neely and Maley, 2000). In a plain weave, the warp yarn operates in an over-one and under-one pattern with the filling yarn throughout the fabric (Hatch, 1993). This weave pattern can provide a sturdy, comfortable fabric when made from cotton or a cotton/polyester blend fibers.

Cotton fabric is used for HCWU because of its properties of comfort, durability, and ease of care (Lee et al., 1999). The kidney bean shape permits the cotton fiber to contact skin randomly instead of continually, which is considered comfortable especially when the wearer perspires (Hatch, 1993).

The problem associated with cotton use for (HCWU) is its ineffectiveness in protection of HCW against bacterial penetration and transmission (Pissiotis et al., 1997). Cotton is hydrophilic due to its many hydroxyl (OH) groups (Figure 1). The OH groups make the fiber polar, which enables the fiber to attract water molecules. This property can increase the wearing comfort of HCWU containing cotton. Absorbency is important to comfort because cotton fibers can wick perspiration from the body of the wearer; however, the water molecules can discharge static electricity on the fiber, which accumulate and act as carriers for bacteria (Vigo, 1978). In addition, the hydrophilic nature of cotton allows for seepage and penetration when cotton HCWU is splashed with liquids (e.g., blood, body fluids).

Polyester is a synthetic fiber, which is usually a transparent white or off-white color. The longitudinal view of the polyester fiber reveals a smooth, rod-like shape, and its cross section is round or trilobal (Needles, 1981). The most common type of polyester is polyethylene terephthalate (PET), and it is composed of methylene groups, carbonyl groups, ester links, and benzene rings (Figure 2).

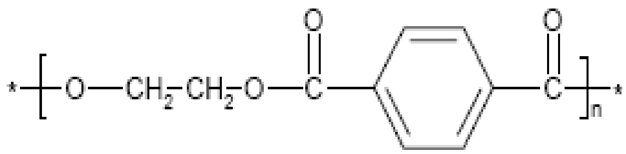

Figure 2. Polymer structure of polyester.

HCWU made of polyester are very durable due to the strength of the fibers. The well-aligned amorphous region of the polyester fiber makes the fiber very durable. The round, smooth, and flat shape of polyester can become uncomfortable because the fiber can directly stick to the skin of the wearer.

Polyester is a hydrophobic fiber, which means that it is non-polar and, therefore, does not attract water. The hydrophobicity of polyester can create a fabric environment that becomes uncomfortable if the wearer perspires. The polyester fibers would not be able to wick the perspiration or moisture away from the body, due to lack of hydrogen bonding in comparison to the structure and wicking properties of cotton. In addition, because of the hydrophobic characteristic of polyester, if the garment becomes contaminated, stains will become difficult to remove through laundering (Gohl and Vilensky, 1983).

A fabric with a polyester and cotton blend fiber content is the most common fabric type used in HCWU (Neely and Maley, 2000). Neely and Maley (2000) reported that polyester and cotton blended fabrics are used primarily for scrub suits, lab coats, and nurses uniforms. One of the reasons why the blending of polyester and cotton fibers is so successful for HCWU is their combined properties of comfort from cotton fibers and durability from polyester fibers (Hatch, 1993). Fabrics containing a polyester and cotton blend are stronger than fabrics made of 100% cotton and are more absorbent than fabrics made only of 100% polyester.

Comparison of various types of reusable gowns

The fiber content and bacterial transmission have been the focus of some studies using various fabrics found in HCWU. Laufman et al. (1975) conducted a study of bacterial transmission on various surgical gowns fabrics. One gown was made of a double layer of 100% regular cotton fabric, and the other gown was made of a single layer of tightly woven 100% Pima cotton fabric. Pima cotton has longer and more uniform staple fibers than regular cotton. No treatment was applied on the double layer regular cotton fabric. The Pima cotton fabric was evaluated in various conditions: (a) Before a water-repellent finish; (b) After a water-repellent finish but before washing, and (c) after a water-repellent finish and 2, 25, 55, and 75 launders cycles and sterilization. The tests for transmission were conducted after 5 and 30 s as well as after 1, 5, 15 and 30 min. Pressures were exerted on the gowns with weights to simulate stresses that a surgeon exerts during surgical operations. The results showed that the untreated, double layer, regular cotton fabric and the untreated Pima cotton fabric did not prevent bacterial transmission. The treated Pima cotton fabric did not show any transmission even after 75 laundering cycles when the test was conducted after 15 min of contact. When the test was conducted after 30 min of contact, treated Pima cotton fabric that had been laundered for 75 cycles did show bacterial transmission. Comfort changes were not measured in this study.

Leonas (1998) conducted a study that examined the protection properties of several reusable fabrics after laundering. Three woven fabrics, containing one of three fiber contents - (a) cotton, (b) polyester, or (c) polyester and cotton blend were compared. The results showed that only the polyester fabric did not exhibit any penetration of *Staphylococcus aureus* (*S. aureus*) after laundering.

Contrasting results have been found in other studies, which also examined fiber content as a variable in preventing bacterial penetration and transmission. Smith and Nichols (1991) conducted a study on various gown fabrics. One gown was made of a single layer of 50/50% polyester and cotton blend fabric, and the other gown was made of a double layer of 100% polyester fabric. The researchers used an apparatus to simulate abdominal pressure that occurs during surgery. The pressures were evaluated from 0.25 to 2.0 psi between 1 s and 5 min. Both gowns allowed maximum 37 and 53% penetration, respectively after 5 min at pressures exceeding 1.0 psi. Another study was conducted by Leonas and Jinkins (1997) on three reusable surgical gowns. One gown was made of a single layer of 100% polyester fabric, a second gown was made of a double layer of 100% polyester fabric, and the third gown was from a fabric with a single layer of 50/50% polyester and cotton blend. The gowns were tested for liquid penetration and bacterial transmission against *S. aureus* and *Escherichia coli* (*E. coli*). The results showed that both the single and double layers of the 100% polyester gowns had liquid penetration in three of the six trials. The gown with the double layer of polyester allowed bacterial transmission of *E. coli* and the gown with a single layer of polyester allowed liquid penetration of *S. aureus*. The single layer, 50/50% polyester and cotton blend gown provided no resistance to either liquid penetration or bacterial transmission of *S. aureus* and *E. coli*.

Some results showed that a 100% polyester fabric resisted penetration better than a 50/50% polyester and cotton blend fabric (Smith and Nichols, 1991). In contrast, some results showed no difference among fabrics with varying fiber contents. Lastly, no difference in barrier protection was found in one study between reusable fabrics with a single layer and reusable fabrics with double layers of the same fiber type (Leonas and Jinkins, 1997).

Disposable HCWU

Disposable HCWU are mainly used for surgical applications. In most operating rooms, non-woven fabrics are the most commonly used disposable textiles and represent an expenditure of over $1.5 billion per year (Huang and Leonas, 1999). Non-woven fabrics are used in approximately 80% of all surgical procedures. An average of three billion square yards of non-woven fabrics is consumed for surgical textiles each year (Sun et al., 2000). Another disposable fabric used for HCWU is tissue, usually fiber or scrim reinforced (Laufman et al., 1975). Scrim reinforced tissue is strengthened by a polyester fiber web, and varies from fiber tissue which is tissue made from fibers (that is, cotton or polyester).

COMPARISON OF VARIOUS TYPES OF DISPOSABLE GOWNS

Laufman et al. (1975) tested various disposable surgical gown fabrics for bacterial penetration of *Serratia marcesens*. These fabrics came from different manufacturers and were made of a (a) single layer of spun-laced non-woven, (b) single layer of wet-laid non-woven, (c) scrim reinforced tissue, (d) fiber reinforced tissue, and (e) spread tow plastic film composite. A pressure of two kilograms was used to simulate a surgeon's elbow as he/she leans on the operating table. After five minutes of contact, the fiber reinforced tissue allowed bacterial transmission in most of the trials, and the wet-laid non-woven failed in one of six trials. After 15 min of contact, both the scrim reinforced tissue and the spun-laced non-woven allowed some bacterial transmission. After 30 min of contact, all of the tested surgical gown fabrics allowed bacterial transmission except one fabric. Only the spread tow plastic film composite fabric remained impermeable to bacterial transmission.

Smith and Nichols (1991) also studied various types of disposable gown fabrics. One was made of wood pulp/polyester spun-lace, and the other was an olefin SMS. The evaluated gowns were (a) a single layer of fabric, (b) a reinforced fabric with a layer of the same fabric, or (c) a fabric reinforced with an impervious material. The fabrics were tested with a pressure apparatus.

The single layer, wood pulp/polyester spun-laced gown fabric had a maximum of 92% liquid penetration. The double layer fabric of wood pulp/polyester spun-laced had a maximum penetration of 73%. The single and double layers of olefin SMS gown fabrics allowed 30 and 9% penetration, respectively. All of the gown fabrics that were reinforced with impervious fabrics had no (0%) penetration.

Leonas (1993) studied bacterial transmission on five disposable fabrics that were commercially available. Three of the fabrics were made of wood pulp/polyester, and two were made of olefin. Among the three wood pulp/polyester fabrics, two were a single layer composition but were manufactured by separate companies. The third wood pulp/polyester fabric was a double layer composition. The two olefin fabrics were either a single or double layer. The bacteria used in the test were *S. aureus* and *E. coli*. The results showed that all fabrics allowed no bacterial transmission, except one of the single layer wood pulp/polyester fabrics. The author indicated that this fabric allowed bacterial transmission because the pore size of this fabric was significantly larger than pore size of the other fabrics. Leonas and Jinkins (1997) conducted a similar study on disposable gowns from several manufacturers and found similar results to Leonas study. The gowns in the Leonas and Jinkins study were made of either wood pulp/polyester or olefins that were either single or double layers. The single and double layered fabrics of the wood/pulp polyester content gowns did not result in any liquid penetration; however, both the single and double layers of olefin content gowns had liquid penetration in one and two of the six trials, respectively. Although the olefin content gowns did allow some liquid penetration, none of the gowns allowed bacterial transmission of *S. aureus* and *E. coli*.

COMPARISON OF REUSABLE AND DISPOSABLE GOWNS PROTECTION

Garibaldi et al. (1986) study showed that there was no difference in barrier protection from reusable gowns made of polyester/cotton blend woven fabrics and disposable gowns made of polyester spun-laced non-woven fabrics, used with inter-operative and post-operative wound infections. From the data of 500 patients operations, this study revealed that the bacterium *S. aureus* was found on 13.1% of reusable and 15.5% of disposable gown fabrics. The authors concluded that the bacteria protection of reusable and disposable fabrics were similar. Laufman et al. (1975) studied various types of reusable and disposable gowns and found that after 30 min of contact, reusable Pima cotton fabrics treated with a water-repellent finish did not allow bacterial penetration even after 55 laundering cycles.

The disposable fabrics made of a spread tow plastic film composite also did not allow any bacterial transmission. In contrast, both untreated reusable gowns and non-reinforced disposable gowns allowed bacterial penetration after 15 min of contact. The study of Smith and Nichols (1991) showed that both single and double layers of wood pulp/polyester spun-lace disposable fabrics allowed a liquid penetration of 92 and 73%, respectively. The single layer of 50/50% polyester and cotton blend reusable gown fabric allowed a maximum penetration of 37%, while the double layer of 100%

Table 1. Internet search of antimicrobial uniforms.

Manufacturer	Antimicrobial finished uniforms (Y/Yes, N/No)
Crest	N
Peaches White Swan	N
Med Gear	N
White Cross	N
PL of California	N
Caduceus	N
Cherokee	N
Barco	N
Disney	N
Scrub by Design	N
Premier	N
AllHeart	N
G.A.L.S.of California	N
ScrubMate	N
Life Uniform	N
L. A. Rose	N
Jasco	N
Graves	N
Scrubs-R-Us	N

polyester gown fabric allowed a maximum penetration of 53%. The single and double layers of olefin SMS disposable fabric allowed only 30 and 9% penetration, respectively. All disposable gowns with an impervious fabric layer prevented penetration in all trials. Leonas and Jinkins (1997) also found that reusable fabrics allowed some liquid penetration and bacterial transmission, but disposable fabrics with an impervious layer prevented liquid penetration.

CONCLUSION

As stated before, there is a major concern for the healthcare workers HCW regarding transmission of bacteria to and from their patients. Bacteria have different modes of transports (that is, air particles, blood, body fluids) that aid in their transmission. The readily available presence of bacteria on healthcare workers uniform greatly increases the potential for penetration and transmission of these bacteria. To reduce this problem and to protect the workers is to have a proper barrier as part of the HCWU. This uniform should be comfortable, durable, non-toxic, cheap, and able to resist bacteria transport. Although cotton gowns are comfortable for wearer, unfinished cotton fabrics does not protect against bacteria penetration, or the penetration of biological liquids (e.g. blood, body fluid) and associated bacteria. Studies conducted in this field have shown that some water-repellent finish can reduce bacteria transmission, such finishes have had very limited commercial use on HCWU. According to a market survey conducted by the researcher (Table 1) through the Internet, no oil/water repellent finishes were found on commercially available HCWU. Few soil-release finishes were found to be available on some reusable HCWU. However, soil-release finishes cannot provide barrier protection. This point may provide an option of using antibacterial agents to treat HCWU and create a niche for companies selling HCWU. The process of applying the antibacterial finish through padding and drying is easy and economical.

A study is needed to determine the minimum amount of finish add-on to the fabric and it would be beneficial in reducing the cost of using enough antibacterial agents to inhibit a maximum of bacteria for HCWU. More research, such as developing new agents or making derivatives from commercially available agents to enhance the properties is recommended.

Using chemicals such as fluorocarbons to create a more hydrophilic surface, soils and stains could be removed more easily from (HCWU) with a soil-release finish. In addition to a water repellent finish, researchers suggested that antibacterial fabrics could be used to create barrier protection by preventing harmful bacteria from penetrating through the fabric. However, antibacterial agents which are placed on the surface of the fabric to inhibit bacteria growth must remain effective after repeated laundering.

Clothing comfort is a state of an individual’s satisfaction indicating physiological, psychological, and physical harmony between the person and their environment. The length of time worn, type of operation for which the uniform is used, and the fiber content and construction of the garment are important factors in determining comfort for the wearer. The comfort of HCWU is important for several reasons.

When doctors feel hot in their uniforms, their performance may be impaired in the operating room or in the office. In addition, when a protective garment is not comfortable, it is not worn. If not worn, the HCWU is not providing a protective barrier to the HCW.

In order to achieve comfort, a balance of heat produce by the body and the change in environmental conditions are needed. Moisture transmission, heat transmission resistance, and air permeability are the three factors that can mimic this balance. For a garment to be considered comfortable, water vapor transmission from the skin must occur. Cotton reusable HCWU are usually more comfortable than HCWU made from other fiber contents because of its better water vapor transmission, which enables water to wick from workers skin. The air permeability of a reusable gown is affected by yarn and fabric structure. The tighter the twist of the yarn and the closeness of the fabric, the less air will permeate through the fabric. The air permeability of a non-woven disposable gown is affected by the distribution of the fibers and the pore size in the fabric.

Disposable gowns reinforced with a plastic film are usually hotter than reusable gowns because no air can permeate through the plastic reinforcement. Studies have reported that if a worker is uncomfortable in their uniform, they are more likely not to wear it properly.

Generally, the length of contact of fluids on the gowns made a difference in the amount of transmission (that is, the longer the contact, the greater rate of bacterial transmission). Variations in fiber content and fabric construction provided varying degrees of protection against bacterial transmission. Olefin SMS non-woven was better than wood pulp/polyester spun-laced non-woven in protection against liquid penetration; however, regular olefin non-woven fabrics had similar results in bacterial transmission to the wood pulp/polyester non-woven fabric. In addition, contradictory results were found regarding the function of layers in bacterial protection. In one study, non-woven gowns with double layers of woven fabrics were superior to those with a single layer; however, two other studies showed that no differences in bacterial transmission were found between non-woven gowns with a single layer and double layers of the same non-woven fabric. One constant result was that non-woven gowns with plastic or some other impervious fabric did not allow any liquid penetration or bacterial transmission.

Reported results varied in the comparison of reusable and disposable gowns for barrier protection. One study showed that disposable gowns had better protection than reusable gowns and the other study showed no difference. To prevent bacterial penetration, a finish such as water-repellent finish possibly needs to be added to reusable fabrics, and an impervious layer needs to be added to disposable fabrics.

With regard to the different mechanisms mentioned, it is clear that the controlled-release mechanism and the regeneration model have known problems in usage with HCWU. Problems with the controlled-release mechanism are its durability after laundering and leaching of the agents from the fabric. Leaching can often cause problems if the antibacterial agents come in contact with skin of HCW. These agents have the potential to affect the normal skin flora, which could lead to extreme skin irritation and cause dermatitis. In addition, leaching can make skin bacteria build a tolerance to the agent. Additional problems for HCWU also occur for fabrics using a regeneration mechanism. The agents that use the regeneration mechanism require chlorine bleaching to activate its antibacterial properties after laundering; however, over time chlorine can degrade natural fibers such as cotton, which is often used in reusable HCWU.

Barrier-block mechanisms do not pose the problems currently found with the other two methods. The agent that uses the barrier-block mechanism does not leach on the fabric surface and does not need bleaching to continue its effectiveness

The costs of reusable and disposable HCWU are difficult to ascertain because the cost of a gown represents not only the manufacturing and retail cost but also the values of safety and comfort. In general, disposable gowns are considered to cost more because of the large storage space needed for fresh gowns and the continued disposal fees for used gowns. DiGiacomo et al. (1992) reported a study comparing the expenses of operation rooms in two hospitals. One hospital used disposable gowns and the other used reusable gowns. The hospital that used disposable gowns spent $155,664 per year compared to an expenditure of $35,680 in the hospital that used reusable gowns. The figure for the expense of disposable gowns included the disposal cost, and the figure for the reusable gowns included the long-term expense of reusable gowns such as cost of washing, sterilizing, and repackaging. However, these comparisons are not exact because data from surgical gown companies are not standardized. The Baxter Healthcare Corporation stated that disposable and reusable gowns cost $3.10 and 3.60 per use, respectively (Jinkins, 1994). Another surgical gown company, Medline, calculated that reusable gowns cost about $3 per use and disposable gowns were $4 per use (Anders, 1993). According to the market survey through the Internet by the researcher, it was found that in 2008, reusable gowns ranged between $15 and 25 per gown depending on brand and style with an expected lifetime of at least 25 times, and most disposable gowns cost between $40 and 100 for 30 to 50 pieces per case with an average per gown price of $2.

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