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Disposable and reusable medical textiles

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Abstract: As infectious diseases circle the globe, medical costs skyrocket and the waste stream continues to grow, it is imperative to look for medical textiles with improved protective performance, low costs, and minimized environmental impacts. Medical textiles include surgical gowns, gloves, drapes, facemasks, dresses, and linens, which could be disposable or reusable based on uses. The selection of reusable and disposable textiles is determined by many factors, such as cost, protective and comfort properties of the textiles, government regulations, and possibly social and psychological perceptions of both types of textile. This chapter intends to provide a broad view on both disposable and reusable textiles, as well as suggestions on improved protection against transmission of infectious diseases by textile materials.

Key words: medical textiles, biocidal functions, disposable, reusable.

8.1 Introduction: disposable versus reusable

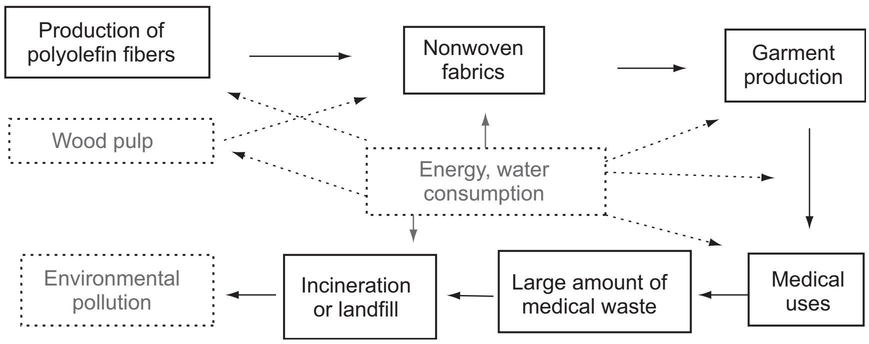
Disposable and reusable textiles are two popular but competing types of products employed in healthcare and other fields requiring protection against biological and chemical hazards. All healthcare workers must wear or use protective textiles such as gowns, gloves, drapes, and facemasks when in contact with patients to reduce or prevent disease transmission (NIOSH, 1988). Whereas disposable textiles are often perceived to have protective advantages over reusable textiles, they must be immediately discarded as bio-hazardous materials. In contrast, reusable protective textiles can be sterilized and laundered for reuse, with a lifetime of more than 50 cycles; however, reusable textiles may be perceived as less protective and more time-consuming to maintain. The repeated laundering of reusable medical textiles may consume more energy and generate more waste water to the environment. Currently, the political dispute between disposable and reusable health protective textiles is very intense, with proponents of each claiming to have economic or protective advantages over the other (Zins, 2006).

The current divide on disposable/reusable medical textiles pertains to a larger dilemma of how to protect individuals from biological and chemical agents. Surgeons and their assistants, for example, have worn protective clothing since the nineteenth century (Laufman *et al.*, 2000). Gowns and drapes, initially made of cotton, over time were constructed into more tightly woven fabrics, which were eventually treated with fluid-repellent chemicals. During the Second World War, the US Army developed very densely woven materials treated with fluorocarbon and pyridinium compounds. After the war, hospitals quickly adopted these applications (Belkin, 1975). Until the 1960s, hospitals used reusable woven fabrics almost exclusively for surgical gowns and drapes (Bernard and Beck, 1975); new woven materials with improved protective performance and durability were used in healthcare facilities by the 1970s (Laufman *et al.*, 1975).

Simultaneously, since the 1950s, nonwoven materials have been produced with enhanced physical and liquid-resistance properties; manufacturers have aggressively promoted these materials to the surgical community. As a result, disposable nonwoven textiles have gained a significant market share in healthcare and other institutional contexts. This trend is continuing: the North American market is predicted to have a 7% annual increase in the next five years (INDA). Disposable textiles have become the most popular materials for surgical gowns, chemical-protective clothing and other institutional textiles in the US, and they are gaining more market share in developing countries such as China. In contrast, reusable textiles are retaining market share in Europe due to increasing concerns about the environmental pollution caused by the disposal of used disposable textiles (Schmidt, 2000). Hence, from a global perspective, the selection of protective textiles becomes a varied and complicated process affected not only by material functionality, but also by cultural, economic, and environmental factors.

8.2 Life cycles of disposable and reusable textiles

Both disposable and reusable medical use textiles are made of polymeric fibers, but they have different fabric structures. Disposables, usually nonwoven fabrics, are produced by closely entangling fibers into a web and then layering the resulting material into sheets. The fibers employed in making nonwoven fabrics for medical use are predominately polyethylene, polypropylene and polyester, and their blends; in general, they are synthetic polymers derived from fossil oil. Many disposable textiles also contain wood pulp fibers as a major component. Disposable textiles generally serve only as single-use products in healthcare facilities and many other institutional protective clothing applications. After usage, these have to be immediately discarded as hazardous materials. Such a use pattern provides perceptions of sanitation and proper protection for users, but creates an overwhelming amount of wastes. In particular, products made from non-renewable energy resources from the earth have become problematic. The disposal of biologically contaminated nonwoven materials has been traditionally done by incineration. When burned, hospital waste and medical/infectious waste emit various air pollutants, including hydrochloric acid, dioxin/furan, and toxic metals such as lead, cadmium, and mercury. In the US, medical waste incinerators are a major source of mercury and dioxin air emissions, in particular (EPA, 2009). In 1997, the EPA issued the first federal rule to protect public health by significantly reducing the harmful air pollution from medical waste incinerators (EPA, 2009). Under this rule, emissions

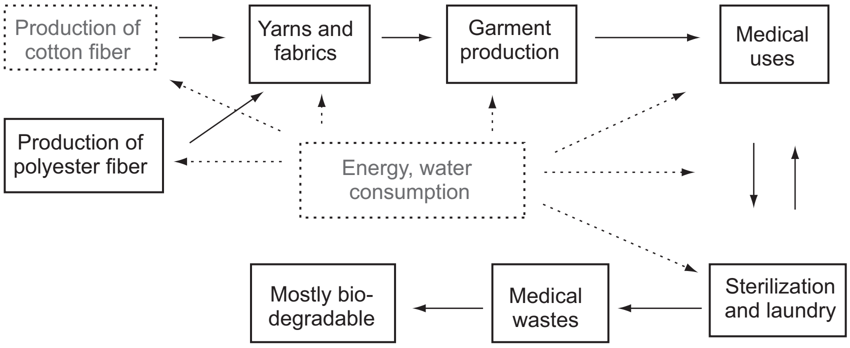


8.1 Life cycle of disposable medical textiles (emissions also occur from each box – hydrochloric acid, dioxin/furan, and toxic metals including lead, cadmium, and mercury).

at medical waste incinerators must be reduced by 74 percent for mercury and 95 percent for dioxin and other toxins in five years from the baselines given in the document. Another way of medical waste disposal is to use landfill, which is very costly. A complete life cycle for disposable medical textiles is shown in Fig. 8.1. The energy consumption in the cycle is shown by arrows indicating how one product is converted to another.

In contrast, reusable textiles, which were traditionally made of cotton fiber and currently are made of polyester, can be repeatedly used in healthcare facilities. After each usage, the textiles should be professionally laundered following the CDC's guidelines (CDC, 1997, 2001). When laundered, the used textiles are not only cleaned but also disinfected with bleaching agents such as diluted sodium hypochlorite solution or concentrated hydrogen peroxide solution. Thus, laundering is a very necessary process in the life cycle of reusable textiles. This process consumes large amounts of water and consequently produces the same amount of wastewater. And, even if the resulting wastewater is fully treated and recycled to reduce deleterious effects to the environment, there is still the problem of energy consumption during the laundry operation. From a material life cycle perspective, however, reusable textiles (woven or knitted fabrics) have the advantage of a longer lifetime, capable of surviving more than 50 commercial laundry cycles and thereby offering an additional saving to users and the environment. The final products are biologically degradable if cotton or biodegradable polyester fibers such as polylactic acid (PLA) are the major component. If incineration is used, the emissions are thus about 1/50 (2%) of those for disposable textiles. A brief life cycle of reusable textiles is illustrated in Fig. 8.2.

Comparing the above two systems, it seems that reusable textiles may have advantages over disposable materials in terms of natural resource use and sustainability. The latter consumes non-renewable fossil oil as the basic material and generates large amounts of wastes in the life cycle. Moreover, disposable



8.2 Life cycle of reusable medical textiles (emissions also occur from each box).

materials release more toxic compounds such as dioxins and mercury into the environment during the disposal process. However, reusable textiles are not perfect. The laundering of reusable textiles consumes more energy and water, and adds more wastewater to the environment. Cotton fiber, for example, is a naturally renewable material that is often perceived by consumers to render excellent comfort and performance. But it is almost all replaced by polyester due to durability and cost concerns. The superior durability of reusable textiles made of polyester fibers means more repeated uses and, hence, significant environmental advantages over disposable materials in the amount of waste produced. However, other concerns, such as the cost and protective performance of the two clothing materials, are also of great importance to healthcare systems. Unfortunately, existing comparisons between disposable and reusable textiles tend to be anecdotal rather than comprehensive, and political or economic interests often intervene in these analyses.

8.3 Costs of disposable and reusable textiles

The selection of reusable or disposable textiles involves a very complicated decision-making process. At least eight social, economic, and behavioral factors are affecting this process, including costs, marketing efforts of manufacturers, user perceptions, comfort, and performance of materials, industry or government standards, and government regulations. The costs and impact of the medical textiles on the environment have had increasing influence on the decision-making process in recent years. The following sections highlight some of the issues revealed in a study that was financially sponsored by the US National Science Foundation.

Nonwoven fabrics for medical use have a market size of 5.5 billion square yards per year worldwide, and represent $7 billion in end product sales (Lickfield, 2002). Most nonwoven products are marketed by large companies, although there are many smaller companies as well. Nonwoven fabrics for disposable surgical gowns usually are made of meltblown and spunbond polypropylene and polyethylene fibers with dense fiber entanglement. In order to increase waterproofing functions, spunbond/meltblown composite nonwoven fabrics and nonwoven laminated with thin plastic films are popular fabric structures. Nonwoven fabrics can prevent almost all possible strike-through of blood and body fluid – a common risk to surgeons in operations. However, excellent barrier properties to liquids make the fabrics non-permeable to air and moisture, and thus uncomfortable to wear, particularly for lengthy operations. The energy consumption and overall cost of manufacturing nonwoven fabrics are lower than those of woven fabrics, in general, because nonwovens are made directly from fibrous webs, similar to paper production, without manufacturing yarns and going through weaving and other processes.

When disposable textiles were first introduced to the healthcare market, they were characterized as more protective, more cost-effective, more convenient, and more comfortable for wearers. In the 1970s and 1980s, many hospitals and healthcare facilities began using disposable materials in their surgical gowns and drapes. But later on, hospitals and healthcare facilities realized that the surgical gown materials might have substantial impact on increased healthcare costs, and they became more cautious in selecting non-renewable materials (Wong *et al.*, 1994). The cost components of both disposable and reusable textiles can be divided into: (a) direct purchasing costs, (b) setup and changing costs, (c) handling and laundry costs, (d) storage and inventory costs, and (e) disposal costs. Using this framework, the unit purchasing cost of a disposable surgical gown is lower than that of a reusable one. However, as the reusable materials can be laundered and reused, the overall cost of using them becomes significantly lower based on some calculation (Zins, 2006). Independent studies have revealed that the use of disposable clothing can be 4–10 times more costly than that of reusable materials, on a per-use-cost basis (Badner *at al.*, 1973a,b). Another comparative study between two similarly sized hospitals demonstrated that the hospital using reusable materials could save $100 000 more than the hospital using disposables only (DiGiacomo, 1992). A recent review of single-use and reusable gowns and drapes in healthcare facilities, however, found no clear superiority for either materials in terms of costs (Rutala and Weber, 2001).

In a recent survey of healthcare administrators and infection control professionals in over 200 hospitals across the USA, about one third of the surveyed hospitals still use reusable surgical gowns and drapes (Sun *et al.*, 2004), but many are considering changing to disposables. The hospital administrators weigh barrier properties as the most important factor, and antimicrobial function as third and environmental impact fifth important factors, in making their decisions. The survey also suggests that the intent to change to disposables is linked to their virgin-clean image as well as economic and protective values.

A similar perception is being fostered in many developing countries, such as in China, where the government prefers disposable textiles as a symbol of modern science. However, the European Union countries hold a different view – one that views progress in relation to environmental protection. The European Union has banned the construction of incinerators for the use of medical waste disposal, and reusable medical textiles are gaining in market share as environmental concerns and increasing disposal costs have led to their revival. The same principle applies to the use of disposable/reusable diapers in the EU.

8.4 Protection provided by disposable and reusable materials

Disposables have a cleaner image than reusables, because disposables have never been used by anyone else. This image is psychologically important to both healthcare workers and patients. However, clinical investigations of the protective value of surgical gowns and drapes against surgical related infections have never provided convincing results to support this perception. Garibaldi used a randomized method to study the surgical infection rates or wound contamination with either disposable or reusable gowns and drapes, and found the rates were almost the same – 2.2% for both single-use and reusable (Garibaldi *et al.*, 1986). This has been confirmed by other researchers, with infection rates of 5.25% for single-use and 5.08% for reusable materials being found by Bellchambers *et al.* (1999). Belkin (1998) reported a prospective and crossover clinical investigation in which the surgical site infection rates were 5.0% for single-use and 6.0% for reusable textiles. On the other hand, some researchers have found significant differences between the two textile materials. One study reported that the infection rate using single-use textiles was only one third that of reusables – 2.27% versus 6.41% (Moylan and Kennedy, 1987). Another study revealed a similar result, i.e. that disposables could reduce the infection rate to one third (Baldwin *et al.*, 1981). Textile researchers have conducted many lab-scale tests to evaluate barrier properties and protective values of nonwoven and woven fabrics, and their results have indicated that laminated nonwoven fabrics perform better than reusable woven fabrics in blocking the penetration of *Staphylococcus aureus* and liquids (Leonas and Jinkins, 1997; Granzow *et al.*, 1998).

Both disposable and reusable textiles can be designed to provide a defensive barrier to liquids and particles. However, the greater the barrier, the lower the air and moisture permeability the fabric possesses (Bernard, 1999). Furthermore, barrier textiles cannot completely protect healthcare workers and patients from infections, because bacteria can survive on textiles for days or even months (Neely *et al.*, 2000a,b, 2001). The outbreaks of severe acute respiratory syndrome among healthcare workers directly indicated the insufficient protection provided by the barrier protective clothing materials (Scales *et al.*, 2003; Lau *et al.*, 2004). The only solution to reduce material-related infections while maintaining comfort properties is to develop and employ biocidal textiles that can completely inactivate any micro-organisms upon surface contact. Theoretical risk assessment study has shown that the use of biocidal textiles can reduce risk of transmission of infectious diseases in hospitals (Nicas and Sun, 2006). For protective purposes, biocidal functions – especially the rapid and efficient inactivation of a broad spectrum of micro-organisms – are required. Technologies for producing biocidal textiles are available nowadays (Sun and Worley, 2006; Kenway *et al.*, 2007; Badrossamay and Sun, 2009a,b), thanks to vigorous research efforts in recent years. These textiles can kill micro-organisms rapidly and completely, while regular antimicrobial functions can only inhibit growth of micro-organisms (biostatic effect). More importantly, the halamine biocidal functions are durable and refreshable in laundry.

8.5 Biocidal woven and nonwoven textiles

Biocidal functions can be incorporated into nonwoven, woven, or other fabric structures for optimal use in medical textiles (Badrossamay and Sun, 2009b). Careful studies of biocidal mechanisms have revealed the promising nature of halamine compounds – the structures, for example, that are widely used in swimming pools (Worley *et al.*, 1988, 1996; Sun and Worley, 2006). These structures are similar to, but are safer than, free chlorine. Halamine structures are not likely to produce carcinogens ($HCCl_3$) in water when used as water disinfectants. Halamines inactivate micro-organisms mainly by oxidation mechanisms rather than biological functions; thus, wide usage of them does not result in biological resistance from micro-organisms, a significant environmental concern. When halamine moieties are covalently connected to polymers, a reversible redox reaction can then be introduced on the solid materials according to Equations 8.1 and 8.2. Covalent bonding between polymers and agents provides a permanent connection between biocidal sites and the fabric. Furthermore, the antimicrobial function can be easily regenerated by a chlorine bleaching process. The design of modified cellulosic and synthetic fabrics, the activation or regeneration of halamine structures, and the inactivation of micro-organisms have been successfully demonstrated so far (Sun and Worley, 2006). Rapid and rechargeable antibacterial functions were found on both woven and nonwoven textile materials that have been incorporated with halamine moieties (Tables 8.1 and 8.2) (Sun and Sun, 2002; Badrossamay and Sun, 2009a). Table 8.1 provides results on woven fabrics incorporated with halamines, while Table 8.2 shows the results of polypropylene fibers that can be used in nonwoven fabrics. Both are rechargeable with diluted chlorine bleach solutions.

$$\rangle N{-}Cl + H_2O \rightleftharpoons \rangle N{-}H + Cl^+ + OH^- \qquad [8.1]$$

$$\rangle N{-}Cl \underset{\text{Bleach}}{\overset{\text{Kill bacteria}}{\rightleftharpoons}} \rangle N{-}H \qquad [8.2]$$

Table 8.1 Percentage reduction of *E. coli* on ADMH-grafted fabrics (*E. coli* concentration: 10^5~10^6 CFU/mL) (Sun and Sun, 2002)

Fabric	ADMH graft (%)	Percentage reduction of *E. coli* at different contact times (%)			
		5 min	10 min	20 min	30 min
Nylon	4.8	99.9	99.999	99.999	99.999
PET	5.3	UD	99	99.9	99.999
PP	3.9	UD	90	99.9	99.999
Acrylic	5.4	90	99.9	99.999	99.999
Cotton	3.3	99.999	99.999	99.999	99.999
PET/cotton	4.9	99.99	99.999	99.999	99.999

ADMH, 3-allyl-5,5-dimethylhydatoin.
UD, undetectable.

Table 8.2 Influence of monomer type and contact time on the antimicrobial activity of grafted polypropylene fibers against *E. coli* (Badrossamay and Sun, 2009a). Values given are percentage bacteria reduction

	Average of diameter = 6 μm					Average of diameter = 0.6 μm				
	Contact time					Contact time				
	1 h	2 h	4 h	8 h	16 h	1 h	2 h	4 h	8 h	16 h
PP-g-ADMH	5%	25%	20%	30%	45%	30%	40%	45%	68%	80%
PP-g-NTBA	85%	99%	100%	100%	100%	90%	100%	100%	100%	100%
PP-g-AM	5%	35%	30%	60%	70%	40%	42%	40%	70%	80%
PP-g-MAM	20%	55%	80%	98%	100%	40%	80%	100%	100%	100%
PP-g-NDAM	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
PP-g-VBDMH	30%	58%	50%	80%	90%	25%	50%	80%	82%	99%

PP-g-ADMH: PP = polypropylene; ADMH = 3-allyl-5,5-dimethylhydantoin.
PP-g-NTBA: NTBA = N-t-butyl-acrylamide.
PP-g-AM: AM = acrylamide.
PP-g-MAM: MAM = methacrylamide.
PP-g-NDAM: NDAM = 2, 4-diamino-6-diallylamino-1, 3, 5-triazine.
PP-g-VBDMH: VBDMH = 3-(4′-vinylbenzyl)-5, 5-dimethylhydantoin.

Since biocidal functions consume active biocides on fabrics, a rechargeable or refreshable function is desirable for repeated uses. If rechargeable properties are considered in the selection of biocidal agents, only oxidative biocidal agents fit closely to the requirements: redox reactions are reversible or regenerable. Bleaching chemicals such as chlorine and oxygen bleaches are commonly used in institutional laundry as recommended by CDC (CDC, 1997).

A primary requirement for surgical gown and drape materials is liquid barrier properties. According to the classification of barrier performance of surgical gowns and drapes by the Association for the Advancement of Medical Instrumentation (AAMI) (AAMI PB70), a high barrier property obviously lowers comfort performance of the materials, while a lower barrier property could lead to penetration of micro-organisms, particularly wet penetration of pathogens. In fact, experimental results have shown that bacteria could wet penetrate AAMI PB 70 level 3 materials in a short contact time (Zhang, 2010), which further justifies the incorporation of biocidal functions on medical textiles. Based on the understanding of the need of biological protection in medical areas, ideal surgical gowns and drapes could be made of either woven or nonwoven structures but should have the following properties: (a) waterproofing to block strike-through of blood or body liquid; (b) comfort during wear, so as to avoid heat stress to wearers; (c) rapid inactivation of a broad spectrum of micro-organisms; (d) non-toxicity and a minimized environmental impact; (e) durability to a specified number of washes; (f) possession of a biocidal function that can be easily recharged or refreshed, and (g) ability to be eventually disposed of with minimum environmental impact.

8.6 Conclusions

Both disposable and reusable medical textiles are widely used in hospitals now, with designed barrier properties against infectious diseases. Increased biological protective functions on medical textiles create extremely low air permeability and complete liquid blockage, which reduces comfort and increases heat stress to healthcare workers. Incorporation of biocidal functions onto both textiles is necessary since such functions can improve the protection of wearers without sacrificing comfort properties. In addition, to reduce the environmental impact caused by the use of medical textiles, making nonwoven textile reusable is quite attractive, while reduction of water and energy use in laundering and transportation of textiles is also necessary.

8.7 Acknowledgment

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