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5.1 Introduction

With the increased awareness and concerns about infectious diseases such as ‘Severe Acute Respiratory Syndrome’ (SARS), ‘swine flu’, ‘bird flu’, and multi-drug-resistance pathogens, it is important that more attention should be focused on public hygiene. The increasing threat from biofilm, which is a gelatine matrix shield formed by multiple species of bacteria to protect from antimicrobial agents, poses a huge problem in hospital infection control management. Despite a great deal of research, clinicians are still facing a serious threat from superbug multi-drug-resistant bacteria such as methicillin-resistant *Staphylococcus aureus* and methicillin-susceptible *S. aureus*, vancomycin-resistant *Enterococci*, *Pseudomonas aeruginosa*, and *Acinetobacter baumannii* in hospitals, and the treatment of microbial infections becomes more and more challenging. An expert committee appointed by the UK government has predicted that drug resistance infection will kill an extra 10 million people a year worldwide, which is more than currently die from cancer, by 2050 unless urgent action is taken to address the problem (BBC News, 2014). There are currently 700,000 deaths each year worldwide due to multi-drug-resistance superbugs. Antimicrobial resistance causes at least 50,000 deaths each year in the European Union and the United States, and the death toll could rise by more than 10-fold by 2050, severely hitting the economy, as the predicted cost would be US$100 trillion.

Bacteria, blood-borne viruses such as HIV and hepatitis B, and fungi create and aggravate problems in hospitals and other environments by their transmission through clothing, bedding, etc. Hospital-acquired infections (HAIs) are a growing major problem in hospitals. The majority of surgical-site infections (SSIs) are acquired at the time of surgical procedures. A healthy individual can disperse into the air approximately 5000 bacteria-carrying skin scales per minute while walking. The particles are 5–60 μm in size and the average number of aerobic and anaerobic bacteria carried is estimated to be about 5 per skin scale.

Textiles play a vital role in protecting against the spread of diseases not only in hospitals but also in other environments where people gather in large numbers, for example, hotels, restaurants, swimming pools, and public modes of transportation. Rajendran (2010) highlighted that ‘unfortunately, there is growing evidence that textiles act as disease vectors, transmitting infectious diseases from person to person.’ These textiles are not meant to have a therapeutic effect but serve only as protection from cross-contamination. He foresees that more natural antimicrobial agents,
including chitosan, honey, aloe vera, and tea tree oil, will be used on textile products in the medical setting in the future. Their main benefits are that they are nontoxic and compatible with human cells. On the high-tech end of the spectrum, he believes that electrospinning would be popular for protective fabrics used to control the spread of disease. It would be easy to imbue antimicrobials in the textile fibres through electrospinning. It would be expected that electrospun antimicrobial textiles may have enhanced protective power against pathogens because they possess large surface areas.

In this situation, it is highly essential that textile materials used in hospitals must have the capability to eradicate/minimise cross-infection. Textiles in any form used in hospitals are susceptible to bacterial growth under appropriate moisture and temperature conditions. Patients shed bacteria and contaminate their pyjamas and sheets. The temperature and humidity between the patient and the bed are appropriate conditions allowing for effective bacterial proliferation. Several studies have found that persons in contact with contaminated textiles are the source of transmission of micro-organisms to susceptible patients.

5.2 Infection control

5.2.1 Pathogenic micro-organisms

Infection control is a growing problem in places where good hygiene is required and, more particularly, in hospitals. It is known that micro-organisms, which include bacteria, virus, and fungi, create and aggravate problems in hospitals and other environments by transmitting diseases and infections through clothing, bedding, etc. Patients in hospitals are more prone to infection because of their illness and HAIs are among the top 10 leading causes of death (Mykkänen, 2000). When antibiotics are used incorrectly/too frequently, bacteria will adapt and become resistant to the antibiotics. Bacteria are antibiotic resistant when an antibiotic can no longer kill them. It may be noted that bacteria are usually active at pH 7.0–8.0 and fungi at 4.0–6.5. Fungal growth on textile materials is more rapid at relative humidity greater than 80% (Vigo, 1994). Thus micro-organisms exist in abundant quantities on textile materials and propagate diseases and infections and also cause damage to fibres under normal usage and storage conditions.

A broad classification of pathogenic micro-organisms is given in Tables 5.1, 5.2 and 5.3 illustrate the broad range of bacteria and fungi, respectively, and their associated diseases. Bacteria are prokaryotic cells, in which the nucleus is free in the cytoplasm. In contrast, fungi are eukaryotic and the nucleus is enclosed within a nuclear membrane. Gram is the name of the Danish scientist Hans Christian Gram, who invented a staining test method to distinguish between gram-positive and gram-negative bacteria. Gram-positive organisms retain the crystal violet stain following decolouration with acetone and appear deep violet under the microscope. Gram-negative organisms lose the violet stain after decolouration but retain a red tone, which appears pink when viewed under the microscope.
Table 5.1 Classification of micro-organisms

| MICRO-ORGANISMS | Bacteria | Fungi | Others |
|-----------------|----------|-------|--------|
| Gram-positive   | Staphylococcus aureus | Proteus vulgaris | Aspergillus niger |
|                 | Staphylococcus epidermidis | Klebsiella pneumoniae | Candida albicans |
|                 | Corynebacterium diphtheroides | Vibrio cholerae | Penicillium species |
|                 |          |        | Viruses, Mildew, etc. |
| Gram-negative   |          |        |        |
Table 5.2 **Bacteria and associated diseases**

| Organisms                   | Infections/diseases                                                                 |
|-----------------------------|------------------------------------------------------------------------------------|
| *Staphylococcus aureus*     | Superficial infections such as skin pustules, boils, surgical wounds, etc.          |
| *Staphylococcus epidermidis*| Undesirable body odour                                                              |
| *Corynebacterium diphtheroides* | Undesirable body odour                                                             |
| *Vibrio cholerae*           | Cholera                                                                            |
| *Escherichia coli*          | Acute gastroenteritis, wound infections, etc.                                       |
| *Proteus vulgaris*          | Infections of wounds, burns, and urinary tract                                      |
| *Pseudomonas aeruginosa*    | Superficial, urinary tract, ulcer, bed sores, and eye infections                    |
| *Klebsiella pneumoniae*     | Respiratory, urinary tract, and wound infections                                   |

Table 5.3 **Fungi and associated diseases**

| Fungi                   | Infections                                                                 |
|-------------------------|--------------------------------------------------------------------------|
| *Aspergillus*           | Infections of ear, nose, lungs, etc.                                     |
| *Penicillium*           | Ear and lung infections                                                  |
| *Dermatophytes*         | Tinea nigra of palms, white pildra of beard, etc.                        |
| *Candida*               | Cutaneous infections, diaper rash, and infections of lungs or endocardium |
| *Trichophyton*          | Athlete’s foot and hair infections                                       |
| *Epidermophyton*        | Ring worm, tinea, etc.                                                   |
| *Cryptococcus*          | Pulmonary, skin, and mucosa infections                                   |

Gram-positive bacteria have a much thicker cell wall (mucopeptide layer) than gram-negatives. The outside the cell wall of gram-positive bacteria is a layer of teichoic acid, which is a complex of sugar and phosphate. Gram-negative bacteria have a layer of lipopolysaccharide, which is a complex of sugars, fatty acids, and phosphates. Both types of bacteria are enclosed in a capsule composed of a layer of gelatinous material produced by the bacterium itself, which adheres to the outside of the cell and shields the bacterium from the host defence mechanism. Resistance to antimicrobial agents is mainly due to the production of drug-destroying enzymes and the resistance of the cell membrane.
5.2.2 **Antimicrobial activity**

5.2.2.1 **Principal requirements of antimicrobial finishes**

An antimicrobial finish on a textile should:

- Protect the user of the textile product, for aesthetic, hygienic, or medical purposes, against microorganisms;
- Protect the fibres and textile structures from biodeterioration caused by bacteria, mould, mildew, etc.;
- Preserve fibres from insects and other pests;
- Prevent fibre discolouration, usually by fungi and insects.

5.2.2.2 **Principal requirements of antimicrobial textiles**

The major requirements of antimicrobial textiles include:

- A wide spectrum of antimicrobial, antifungal, and antiviral properties;
- Effectiveness against already existing antibiotic-resistant micro-organisms;
- Protection against the development of micro-organisms that are resistant to the active component;
- Safe to use on humans and the environment, including not causing skin irritation or sensitisation.

In addition, they must remain highly effective when bound into the fabric, kill bacteria rapidly and completely, be durable to industrial washing procedures, and be easy to apply.

5.2.3 **Application of antimicrobial finish to textiles**

Antimicrobial agents can be applied to textile substrates by pad-dry cure, exhaust, spray, coating, and foam techniques. The substances can also be applied by directly application onto the fibre spinning dope. It would be possible to apply commercial antimicrobial agents during the online dyeing and finishing operations. Several methods for improving the durability of the finish include:

- Coating the surface of the fabric;
- Microencapsulation of antibacterial agents;
- Chemical modification of fibres;
- Insolubilisation of the active substances in the fibre;
- Treating the fibre with resin, condensates, or crosslinking agents;
- Graft polymerisation, homo-polymerisation, and co-polymerisation;
- Imbuing antibacterial agents into the fibres.

The various techniques involved in converting textile substrates into antimicrobials have been discussed by Bshena et al. (2011). These include surface modification, inclusion of antimicrobial compounds that can leach from the polymer, and the introduction of polymer-bound moieties that provide the polymer with antimicrobial properties.
It should be noted that antimicrobial refers to a negative effect on the vitality of the microbes and the term ‘cidal’ refers to their significant destruction, and ‘static’ represents inhibition of microbial growth without much destruction.

5.2.4 Antimicrobial materials

With a view to developing antimicrobial textile materials, considerable research has been carried out by making use of organic and inorganic compounds, antibiotics, heterocyclics, quaternary ammonium compounds, and so on. The biocidal properties of silver compounds have been known for thousands of years and are being increasingly used nowadays to impart antibacterial properties to textile materials for hospital use. Vigo (1983), Vigo and Danna (1996), and Vigo et al. (1998) have carried out several studies ranging from fundamental aspects to development of antimicrobial fabrics. Antibacterial polyester fabrics have been developed by imbuing antibacterial agents into the structure of fibres rather than depositing them on the surface, for longer durability and effect. It is stated that the efficacy of the finished fabric at arresting the growth of S. aureus and Escherichia coli is about five times higher than that of conventional materials. A synergistic system of formulation comprising inorganic chemicals involving a metal salt of a monocarboxylic acid, a carbamic acid derivative, a chelating agent, a boron compound, a dimethylene siloxane derivative, and an alkane polymer has been proved to serve as an effective antimicrobial agent in arresting the growth of several bacteria (gram-positive and gram-negative), fungi, and mildew (Rajendran et al., 1996; Rajendran and Anand, 2002). Hospital trials showed a dramatic decrease in bacteria, fungi, and mildew growth in treated fabrics. The treatment also prevents the deterioration of fabrics by micro-organisms. Chitosan treatment on cotton provides antimicrobial activity. Chitosan-treated cotton fabric showed a high reduction rate in the number of colonies (Lee et al., 1999). Fabrics made from viscose fibres containing polysilicic acid (Visil) and aluminium silicate (Visil AP) have been given urea peroxide treatment to make them antibacterial as well as deodorants (Anon, 1998). Instead of treating the surface of the fabric with polymer coating, antibacterial additives have been imbedded into the fabric’s polymer fibres for the production of antibacterial gowns (Anon, 2001). Holme (2003) has reviewed the current commercial antimicrobial finishes. A non-woven composite barrier fabric comprising a microporous thermoplastic film thermally bonded to layers of spunlaid non-woven polyolefin has been made to resist penetration by blood-borne pathogenic organisms (Anon, 1997). In addition, the fabric possesses a microporous structure that allows air and water vapour to pass through, but not liquids, and is of immense benefit especially in operating room (OR) protective clothing and cover sheets. It must be stressed that OR fabrics should meet three primary requirements: non-transmission of fluids and micro-organisms, high absorbency, and air and vapour permeability or breathability (Bottcher, 1995). In addition to antibacterial materials, special bedding products that are impermeable to dust mites have also been developed (Love, 1993). It is reported that polyamide fibres retain more odour-causing microorganisms than natural fibres (Vigo, 1994). Polyester and other synthetic fibres are also prone to the growth of pathogenic micro-organisms. Micro-organisms deteriorate
cellulosic fibres and reduce the wear life of the materials (Seventekin and Ucarci, 1993). Microbes adhere to the surface of the fibres and gradually corrode inwards layer by layer, disintegrating the primary and secondary walls of the fibres, causing considerable damage (Siu, 1951). It is interesting to note that the cross-linking agent dimethylol-5,5-dimethylhydantoin, which is commonly used in the wet processing industry to improve functional properties of textile fabrics, possesses a certain level of

| Fabric     | Micro-organism          | Log reduction of bacterial challenge | 2% DMDMH | 6% DMDMH |
|------------|-------------------------|--------------------------------------|----------|----------|
| Cotton     | Escherichia coli        | 6                                    | 6        | 6        |
| Cotton/PET | Escherichia coli        | 6                                    | 6        | 6        |
| Cotton     | Staphylococcus aureus   | 6                                    | 6        | 6        |
| Cotton/PET | Staphylococcus aureus   | 6                                    | 6        | 6        |
| Cotton     | Salmonella choleraesuis | 6                                    | 7        |          |
| Cotton/PET | Salmonella choleraesuis | 7                                    | 6        |          |
| Cotton     | Shigella                | 6                                    | 6        |          |
| Cotton/PET | Shigella                | 6                                    | 7        |          |
| Cotton     | Candida albicans        | 2                                    | 6        |          |
| Cotton/PET | Candida albicans        | 6                                    | 6        |          |
| Cotton     | Brevibacterium          | 8                                    | 8        |          |
| Cotton/PET | Brevibacterium          | 8                                    | 8        |          |
| Cotton     | Pseudomonas aeruginosa  | 6                                    | 6        |          |
| Cotton/PET | Pseudomonas aeruginosa  | 6                                    | 6        |          |
| Cotton     | Methicillin-resistant S. aureus | /                                |          | 3        |
| Cotton/PET | Methicillin-resistant S. aureus | /                                |          | 6        |
| Cotton     | Vancomycin resistant Enterococcus | /                                |          | 6        |
| Cotton/PET | Vancomycin resistant Enterococcus | /                                |          | 6        |

PET, polyethylene terephthalate.
antibacterial effect on plain woven cotton and polyester/cotton (65/35) plain woven fabric (Sun et al., 2001) (Table 5.4).

The use of natural products as potential antimicrobial agents on textiles has received much attention because of the awareness of environmental issues. It is stressed that although the synthetic antimicrobial agents are effective against a range of microorganisms and provide a durable effect on textiles, they possess limitations in use, such as associated side effects, action on non-target micro-organisms, and water pollution. Longer durability of the antimicrobial effect can be achieved by imbuing antibacterial agents into the structure of the fibres rather than depositing them on their surface. It is important that antimicrobial textiles provide protection against a wide range of gram-positive and gram-negative bacteria, including superbugs.

Research on 100% cotton plain-weave fabric finished with a synergistic formulation comprising inorganic chemicals involving a metal salt of a monocarboxylic acid, a carbamic acid derivative, a chelating agent, a boron compound, a dimethylene siloxane derivative, and an alkane polymer has shown that the treated fabrics (Figure 5.1) were imparted with antimicrobial activity that arrested the growth of several bacteria (gram-positive and gram-negative), fungi, and mildew (Rajendran and Anand, 2001). Bed linens, patients’ gowns, and staff aprons were tailored using both the treated and the untreated fabrics and were put to use in postoperative, gynaecology, and labour wards of a reputable hospital. The presence of bacteria on treated and untreated items was tested after several use—wash—use cycles. It was observed from the results after 50 cycles (Table 5.5) that, while the untreated samples were rich in some types of bacteria, the treated ones were almost devoid of them. It should be mentioned that the users did not experience any discomfort such as skin irritation, disagreeable odour, or unpleasantness during the trial. It is also interesting to note that the treatment prevented the deterioration of the fabrics by micro-organisms (Figures 5.2 and 5.3).

Plain- and twill-weave woven fabrics (Table 5.6) are used as reusable OR surgical gowns (Aibibu et al., 2006). A microbial barrier effect has been achieved by using microfilament polyester as well as by controlling the pore size in the woven structure.
It is established that the barrier efficiency of the woven fabrics directly depends on the arrangement of the filaments in the yarn and the construction of the woven fabric. Research indicates that a desized, scoured, and bleached plain-weave cotton fabric weighing 130 g/m² finished with a natural antimicrobial agent, neem seed, showed 99.5% antibacterial activity against *S. aureus* (Joshi et al., 2007). It should be mentioned that neem seed is obtained from the neem tree, *Azadirachta indica*, which

### Table 5.5 Antibacterial activity of woven fabrics washed 50 times: hospital trial

| Wards         | Organisms isolated from aprons, gowns, and linens | Observation (growth of organisms) |
|---------------|--------------------------------------------------|-----------------------------------|
| Postoperative | *Escherichia coli*                              | Moderate                          |
|               | *Klebsiella aerosens*                           | Moderate                          |
|               | *Staphylococcus pyogenes*                       | Heavy                            |
|               | *E. coli*                                        | Moderate                          |
|               | *S. pyogenes*                                    | Moderate                          |
|               | *Pseudomonas pyocyaneus*                        | Moderate                          |
|               | *E. coli*                                        | Heavy                            |
|               | *Klebsiella pneumoniae*                         | Heavy                            |
|               | *S. pyogenes*                                    | Heavy                            |

#### Figure 5.2 Untreated woven fabric on storage.
is abundantly found in the Indian subcontinent. It has an excellent potential as an antimicrobial agent and its main constituents, such as azadirachtin, salannin, and meliantriol, are proven insect growth regulators and antifeedant (Chatterjee and Pakashi, 1994). It is observed that the particle size of the natural polymers influences the antibacterial activity (Wazed Ali et al., 2011). It has been reported (Arora et al., 2013) that the use of antimicrobial polymers enhances the antimicrobial effect and minimises the environmental problems. The antimicrobial polymers are produced by attaching an active antimicrobial agent to a polymer backbone via an alkyl or acetyl linker.

Tiwari et al. (2014) reviewed the application of neem for infection control management. It is obvious that all parts of neem (leaf, bark, seed, and root) possess some biological and medicinal properties. A study involving neem leaves, prickly chaff flower (Achyranthus aspera), tulsi leaves (Ocimum basilicum), and pomegranate rind (Punica granatum) demonstrated that the active ingredients of these herbs exhibit antimicrobial activity against S. aureus and E. coli (Thilagavathi et al., 2005). Similarly, clove oil, neem oil, tulsi oil, and karanja oil exhibit good antibacterial properties. The durability of the effect can be increased by finishing the cotton fabrics with the above oils using dimethylol dihydroxyethylene urea as a cross-linking agent (Sarkar et al., 2002). The antibacterial effect of neem seed oil against 14 strains of pathogenic bacteria in vitro was assessed, and it was found that pathogens were killed more rapidly at 4 °C than at 37 °C. The activity was mainly due to the inhibition of cell-membrane synthesis in the bacteria (Baswa et al., 2001). The antiviral and virucidal effects of the methanolic extract fraction of neem leaves were studied regarding its activity and possible mechanism of action against the coxsackie B group of viruses and it was found that the active ingredients of neem possess antiviral action against the coxsackie B group of viruses in vitro (Badam et al., 1999). Joshi et al. (2005) have demonstrated that praneeem polyherbal formulations containing purified extracts of A. indica show activity against HIV and sexually transmitted disease pathogens. The product also has contraceptive properties.

Figure 5.3 Antimicrobial-treated woven fabric on storage.
Table 5.6 Specifications of plain and twill weave operating room surgical gowns

| Sample | Type of weave | Fineness of filament in dtex | Cross section of filament | Number of filaments in the yarn | Fineness of filament yarn in tex | Yarn density/10 cm | Fabric density/8/ |
|--------|---------------|-----------------------------|---------------------------|--------------------------------|---------------------------------|-------------------|-----------------|
|        |               | warp | weft   | warp   | weft   | warp | weft | warp | weft | warp | weft |               |
| P 4    | plain         | 0.85 | 0.85   | Deformed | Deformed | 112  | 102  | 9.5  | 8.5  | 456  | 370  | 0.55           |
| P 5    | plain         | 2.60 | 1.25   | Triangular | Round | 48   | 198  | 13.0 | 25.0 | 572  | 313  | 0.98           |
| P 6    | Twill \(\frac{2}{1}\) | 0.60 | 1.35   | Round | Round | 206  | 69   | 9.5  | 12.5 | 458  | 362  | 0.37           |
A comparison of the antibacterial activity of normal chitosan, nanochitosan, and silver-loaded nanochitosan applied on woven polyester fabrics showed that the nanoparticle form of chitosan imparted much enhanced antibacterial activity, as indicated by a reduction in minimum inhibitory concentration (MIC) from 0.5% to 0.01% (Wazed Ali et al., 2011). The silver-loaded chitosan nanoparticle showed a further increase in activity (MIC 0.001%) due to the synergistic effect of Ag and chitosan nanoparticles. These particles additionally show a release mechanism as evident from a clear zone of inhibition (Figure 5.4(a–d)).

Research has demonstrated the antimicrobial activity of bioactive-treated fabric (BTF) that contains silver for use in the hospital environment (Mariscal et al., 2011). Unlike other biocides used in hospital fabrics, the prolonged use of silver has not been related to the appearance of resistant bacteria or cross-resistance to

![Figure 5.4](image_url) (a) Untreated polyester woven fabric. (b) Chitosan-treated polyester woven fabric. (c) Nanochitosan-treated polyester woven fabric. (d) Nano silverchitosan-treated polyester woven fabric.
antibiotics, despite being extensively used in some treatments. The antibacterial activity of the treated fabrics was tested against 33 hospital strains and showed a significant reduction in the number of bacteria present on the BTF. The physical, mechanical, moisture, and vapour transmission and water-repellence properties of antibacterial cotton/Amicor woven fabrics containing various woven structures and that are intended to be used as antimicrobial hospital sheets are published elsewhere (Harpa et al., 2008). It will be borne in mind that Amicor is an acrylic-based fibre into which organic antibacterial and antifungal additives are imbued.

5.2.5 Hospital protective garments

Protective garments are widely used in medicine to protect both patients and medical professionals from infection and cross-infection. Most of the clothing and garments used to protect against cross-infections from patient to patient and from patient to medical personnel possess barrier properties that resist the entry not only of blood and liquids but also of micro-organisms. Typically these materials are used as gowns, laboratory coats, coveralls, headwear, footwear, and facial protection. The gowns are designed as either single layer or reinforced double and multilayer depending on the level of protection needed in hospital environments such as operating rooms, post-operative blocks, and beding areas. A single-layer gown could be a highly repellent fabric intended for use where minimal fluid is present. Reinforced and multilayer gowns are intended for use in areas where a high level of protection is required. A highly protective three-layer gown consists of a tough outer layer that resists abrasion and puncture, a middle layer that provides resistance to fluid penetration, and an inner soft layer, which adds comfort in addition to protection. The pore size of the gowns is designed to prevent the penetration of micro-organisms but allows gaseous exchange. Impervious gowns prevent strike-through during fluid intensive procedures. Drapes are designed to prevent HAIs and are for single or multiple uses. Single-use and reusable gowns and drapes are usually made from cotton, polyester, polypropylene, and their blends and are widely available in Europe. A good source of reference for further reading can be found elsewhere (Patel et al., 1998a; Belkin and Koch, 1998; Laufman et al., 2000). It is obvious that such hospital garments, for instance, surgical gowns, gloves, and drapes, are not comfortable to wear for a long periods owing to the barrier properties. The performance of hospital textiles, thus, demands a balance between barrier and comfort properties. Initially cotton was mostly used in gowns and drapes and now polyester and polypropylene fibres dominate in most of the hospital textiles. Rutala and Weber (2001) and Patel et al. (1998b) have reviewed the single-use and reusable gowns and drapes in hospitals. The efficiency of the gowns in protecting against cross-infections has not been scientifically studied. However, it has been found that higher barrier properties against micro-organisms could be achieved in surgical gowns that possess higher fabric repellency and smaller pore size (Leonas and Jinkins, 1998). Bacterial contamination in fabric stethoscope covers represents a potential infection control problem because they are used for prolonged periods and seldom laundered (Milam et al., 2001). The Centers for Disease Control and Prevention in Atlanta, Georgia, USA, has established that there are limited
clinical data on the relationship between the properties of gowns and drapes and the SSI risk (Anon, 1999). It is interesting to note that reusable towels used in hospitals can interfere with the action of common hospital disinfectants and may increase the risk for transmission of pathogens in hospitals. In addition, hospital laundering practices may not completely remove microbial contaminants but may add contaminants to the towels (Sifuentes et al., 2013). Research (Diab-Elschahawi et al., 2010) that involved the use of four different types of cleaning cloths (microfibre cleaning cloth, cotton cloth, sponge cloth, and disposable paper towels) commonly used in hospitals revealed that microfibre cloths showed the best results when used in new condition. However, after 10 cycles of laundering at 90 °C for 5 min, cotton cloth showed the best overall efficacy. Moore and Griffith (2006) also found that microfibre cloth significantly reduces the microbial load compared to the paper towel.

Non-woven medical products are being increasingly used in hospitals although the disposability of single-use products poses environmental concerns. Both spunlaced and spunlaid composites are used to produce surgical gowns and drapes. Spunlaced material provides enhanced comfort and aesthetic properties, but spunlaid materials offer superior barrier properties. Spunbond—meltblown—spunbond (SMS) products possess the highest level of protection, and their softness and comfort have been improved considerably. A typical isolation and cover gown consists of a single-layer spunbonded basic cover or a three-layer SMS fabric for increased barrier properties, softness, and comfort. SMS fabrics are also used to produce laboratory coats, jackets, and coveralls. Woven textiles, specifically plain and twill weaves, are largely used in hospitals as reusable materials such as patients’ bed sheets and curtains. Their contribution in spreading infection is enormous.

5.2.6 Testing of protective garments

According to the European Medical Devices Directive 93/42/EEC, medical products including gowns and drapes must provide a high level of protection for patients, users, and others. Surgical gowns, drapes, and clean air suits are classified as non-invasive medical devices as they are used for the prevention of diseases. Surgical gowns and drapes protect patients and medical personnel against the transmission of infection and diseases and prevent transmission of contaminated agents between the patient and the surgeon during surgery or invasive procedures. All medical devices placed on the market must bear the CE certification mark. The Medicines and Healthcare Products Regulatory Agency of the United Kingdom views surgical gowns and surgical drapes used in the OR as medical devices. However, other gowns and drapes not described as ‘surgical’ should not be CE marked as medical devices (MHRA, 2004).

The CEN Committee of the European Standards Organisation (CEN/TC205/WG14) has developed European standards for gowns, drapes, and clean air suits. The directive is targeted at ensuring a high level of safety for users, patients, and others. The directive consists of three parts, of which Part I (EN 13795–1, 2002) addresses the various performance characteristics required for surgical gowns, drapes, and clean air suits to prevent transmission of infective agents between patients and clinicians during surgical procedures. EN 13795-1 does not cover surgical masks, surgical gloves, surgical
caps, and overshoes. Part II (EN 13795–2, 2004) of the standard describes the test methods to be used to evaluate the product characteristics indicated in Part I. Part III (EN 13795–3, 2006) describes the performance requirements and performance levels of products. The EN 13795 standard provides greater protection and safety for patients, nurses, surgeons, and other related medical personnel. Hospitals can enhance quality assurance and guidance in choice of products and meet the compliance standard of the EU regulations. The fabric manufacturer also receives greater benefit from this standard in terms of quality assurance, defined qualification criteria, and new goals for innovation (BS EN 13795:2011 + A1, 2013). The general characteristics to be evaluated in surgical gowns, drapes, and clean air suits are depicted in Table 5.7. Resistance to microbial penetration — the dry test method determines the ability of dry materials to resist the penetration of particles containing micro-organisms and measures the amount of micro-organisms that can pass through this material (the number of colonies seen on the surface of agar) and the results are expressed as CFU (colony-forming units),

Table 5.7 General characteristics to be evaluated in surgical gowns, drapes, and clean air suits (EN 13795–1)

| Characteristics to be evaluated in surgical gowns | Characteristics to be evaluated in surgical drapes | Characteristics to be evaluated in clean air suits |
|--------------------------------------------------|--------------------------------------------------|--------------------------------------------------|
| Resistance to microbial penetration—dry          | Resistance to microbial penetration—dry          | Resistance to microbial penetration—dry          |
| Resistance to microbial penetration—wet           | Resistance to microbial penetration—wet           | Cleanliness—microbial                            |
| Cleanliness—microbial                            | Cleanliness—microbial                            | Cleanliness—particulate matter                   |
| Cleanliness—particulate matter                   | Cleanliness—particulate matter                   | Linting                                           |
| Linting                                          | Linting                                          | Bursting strength—dry                            |
| Resistance to liquid penetration                  | Resistance to liquid penetration                  | Tensile strength—dry                             |
| Bursting strength—dry                            | Bursting strength—dry                            | Resistance to microbial penetration—dry          |
| Bursting strength—wet                            | Bursting strength—wet                            | Cleanliness—microbial                            |
| Tensile strength—dry                             | Tensile strength—dry                             |                                                   |
| Tensile strength—wet                             | Tensile strength—wet                             |                                                   |
|                                                   | Adhesion for fixation for the purpose of wound isolation |                                                   |
whereas the barrier ability of materials against micro-organisms when the fabric is subjected to the migration of a liquid is tested by using the resistance to microbial penetration — wet test method. The results are expressed as the barrier index (BI). Microbial cleanliness determines the presence of microbes on the product and the potential for microbial contamination but the cleanliness—particulate test is used to measure the number of particles of 3—25 μm that stand out on the fabric and is expressed as IPM (index for particulate matter). It should be mentioned that only particles of this size range are considered capable of carrying micro-organisms.

The various benchmark values set by EN 13795 for surgical gowns, surgical drapes, and clean air suits are found in Tables 5.8—5.10, respectively. The industrial test methods, in addition to common strength tests (tensile, tear, and bursting), comfort, and absorbency, normally carried out on hospital protective textiles are presented in (Table 5.11).

Table 5.8 Performance requirements for surgical gowns (EN 13795—3)

| Characteristic                                              | Standard performance | High performance |
|-------------------------------------------------------------|----------------------|------------------|
|                                                             | Critical area        | Less critical area | Critical area | Less critical area |
| Resistance to microbial penetration—dry (log_{10} CFU)      | N/A                  | ≤2<sup>a,c</sup>  | N/A           | ≤2<sup>a,c</sup>  |
| Resistance to microbial penetration—wet (BI)               | ≥2.8<sup>b</sup>     | N/A              | 6.0<sup>b,d</sup> | N/A              |
| Cleanliness—microbial (log_{10} CFU/dm²)                   | ≤2<sup>c</sup>       | ≤2<sup>c</sup>   | ≤2<sup>c</sup> | ≤2<sup>c</sup>   |
| Cleanliness—particulate matter (IPM)                       | ≤3.5                 | ≤3.5             | ≤3.5          | ≤3.5             |
| Linting (log<sub>10</sub> lint count)                      | ≤4.0                 | ≤4.0             | ≤4.0          | ≤4.0             |
| Resistance to liquid penetration (cm H₂O)                  | ≥20                  | ≥10              | ≥100          | ≥10              |
| Bursting strength—dry (kPa)                                | ≥40                  | ≥40              | ≥40           | ≥40              |
| Bursting strength—wet (kPa)                                | ≥40                  | N/A              | ≥40           | N/A              |
| Tensile strength—dry (N)                                   | ≥20                  | ≥20              | ≥20           | ≥20              |
| Tensile strength—wet (N)                                   | ≥20                  | N/A              | ≥20           | N/A              |

The 95% confidence level means that an observer would be correct 19 times out of 20 to accept these alternatives.

<sup>a</sup> Test conditions: challenge concentration 10⁸ CFU/g talc. and 30 min vibration time.

<sup>b</sup> The least significant difference for BI when estimated using EN ISO 22610 was found to be 0.98 at the 95% confidence level. This is the minimum difference needed to distinguish between two materials thought to be different. This means materials varying by up to 0.98 BI are probably not different; materials varying by more than 0.98 BI probably are different.

<sup>c</sup> For the purpose of this standard, log_{10} CFU ≤ 2 means maximum 300 CFU.

<sup>d</sup> BI = 6.0, for the purpose of this standard, means no penetration. BI = 6.0 is the maximum achievable value.
5.2.7 Wound infection control

5.2.7.1 Wounds

Wounds can be classified into acute wounds and chronic wounds. While acute wounds take only a few weeks to heal, chronic wounds require several months to heal completely. Chronic wounds include venous leg ulcers and pressure sores. Wounds are not usually sterile. A wound may bear a level of 100,000 microorganisms per gram of tissue. Beyond this number, the wound may become infected.

In some wounds the pathogens may be able to colonise (critical colonisation) and this is considered to be detrimental for wound healing. Wound bacteria can be acquired from the patient’s own endogenous flora or from exogenous microbial contamination.

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### Table 5.9 Performance requirements for surgical drapes (EN 13795–3)

| Characteristic                               | Standard performance | High performance |
|----------------------------------------------|----------------------|------------------|
|                                              | Critical area        | Less critical area | Critical area | Less critical area |
| Resistance to microbial penetration—dry (log$_{10}$ CFU) | N/A                  | ≤2$^{ac}$         | N/A           | ≤2$^{ac}$         |
| Resistance to microbial penetration—wet (BI)   | ≥2.8$^b$             | N/A               | 6.0$^{bd}$    | N/A               |
| Cleanliness—microbial (log$_{10}$ CFU/dm$^2$)  | ≤2$^c$               | ≤2$^c$            | ≤2$^c$        | ≤2$^c$            |
| Cleanliness—particulate matter (IPM)           | ≤3.5                 | ≤3.5              | ≤3.5          | ≤3.5              |
| Linting (log$_{10}$ lint count)                | ≤4.0                 | ≤4.0              | ≤4.0          | ≤4.0              |
| Resistance to liquid penetration (cm H$_2$O)   | ≥30                  | ≥10               | ≥100          | ≥10               |
| Bursting strength—dry (kPa)                   | ≥40                  | ≥40               | ≥40           | ≥40               |
| Bursting strength—wet (kPa)                    | ≥40                  | N/A               | ≥40           | N/A               |
| Tensile strength—dry (N)                      | ≥15                  | ≥15               | ≥20           | ≥20               |
| Tensile strength—wet (N)                      | ≥15                  | N/A               | ≥20           | N/A               |

The 95% confidence level means that an observer would be correct 19 times out of 20 to accept these alternatives.

- Test conditions: challenge concentration 10$^7$ CFU/g talc. and 30 min vibration time.
- The least significant difference for BI when estimated using EN ISO 22610 was found to be 0.98 at the 95% confidence level. This is the minimum difference needed to distinguish between two materials thought to be different. This means materials varying by up to 0.98 BI are probably not different; materials varying by more than 0.98 BI probably are different.
- For the purpose of this standard, log$_{10}$ CFU ≤ 2 means maximum 300 CFU.
- BI = 6.0, for the purpose of this standard, means no penetration. BI = 6.0 is the maximum achievable value.

5.2.7 Wound infection control

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In some wounds the pathogens may be able to colonise (critical colonisation) and this is considered to be detrimental for wound healing. Wound bacteria can be acquired from the patient’s own endogenous flora or from exogenous microbial contamination.
### Table 5.10 Performance requirements for clean air suits (EN 13795–3)

| Characteristic                                      | Requirement<sup>c</sup> |
|-----------------------------------------------------|-------------------------|
| Resistance to microbial penetration—dry (log<sub>10</sub> CFU) | ≤2<sup>a,b</sup>         |
| Cleanliness—microbial (log<sub>10</sub> CFU/dm<sup>2</sup>) | ≤2<sup>b</sup>          |
| Cleanliness—particular matter (IPM)                | ≤3.5                    |
| Linting (log<sub>10</sub> lint count)              | ≤4.0                    |
| Bursting strength—dry (kPa)                        | ≥40                     |
| Tensile strength—dry (N)                           | ≥20                     |

<sup>a</sup> Test conditions: challenge concentration 10<sup>8</sup> CFU/g talc. and 30 min vibration time.

<sup>b</sup> For the purpose of this standard, log<sub>10</sub> CFU ≤ 2 means maximum 300 CFU.

<sup>c</sup> Performance requirements apply for all product areas of clean air suits, as clean air suits should be used in addition to surgical gowns and not as a substitute.

### Table 5.11 Industrial test methods for hospital protective textiles

| Test                                      | Standard/property                                                                 |
|-------------------------------------------|-----------------------------------------------------------------------------------|
| Hydrostatic pressure (measures the resistance of fabrics to the penetration of water under constantly increasing hydrostatic pressure) | AATCC 127—1998; test the performance of products under external pressure fluids present on the fabric |
| Water impact (measures the resistance of fabrics to the penetration of water by spray impact) | AATCC 22—2001; test the performance of products when fluids fall or spray onto the fabric |
| Mason jar (measures the resistance of fabrics to the penetration of water under constant pressure) | IST 80.5—1995; test the performance of products when fluids remain standing on one area of fabric |
| Alcohol repellency (measures the resistance of fabrics to the penetration by aqueous isopropyl alcohol) | IST 80.6—1995; test the performance of products when alcohol, blood, and body fluids come in contact with the fabric |
| Microbial resistance (measures the resistance of fabrics against micro-organisms) | AATCC 147—1998 (qualitative test) and AATCC 100—1999 (quantitative test); to determine the degree of antibacterial activity |
|                                           | AATCC 30—1999; to determine the susceptibility of materials to mildew and rot       |
The risk of infection is increased by certain wound characteristics (Table 5.12) (Anon, 2008). Matrix metalloproteinase levels rise when a wound becomes infected and they begin to degrade the extracellular matrix proteins, which delays wound healing. Wound infection can be controlled by: (a) exudate management at the wound bed, (b) antibiotic treatment, and (c) antimicrobial dressing. It is known that pooling of exudate at the wound site can aggravate the probability of the wound being infected (Benbow and Stevens, 2010) although exudate is a good and essential component of the normal wound-healing process. Preventing cross-infection is the key in reducing wound infection and this can be managed by appropriate wound dressings. Generally the wound-healing process involves three phases:

- The inflammatory phase, which occurs immediately after injury to tissue and during which swelling takes place;
- The proliferation period, in which new tissues and blood vessels are formed; and
- The maturation phase, in which tissues laid down during the proliferation stage are remodelled.

### Table 5.12 Wound characteristics associated with the risk of infection

| Acute wounds | Chronic wounds |
|--------------|---------------|
| Contaminated surgery | Necrotic tissue or foreign body<sup>a</sup> |
| Long operative procedure | Prolonged duration |
| Trauma with delayed treatment | Large in size and/or deep |
| Necrotic tissue or foreign body<sup>a</sup> | Anatomically situated near a site of potential contamination, e.g. anal area |

<sup>a</sup> Particularly in the presence of hypoxia.

Source: World Union of Wound Healing Societies (WUWHS). Principles of best practice: Wound infection in clinical practice. An international consensus. London: MEP Ltd, 2008.

(Anon, 2002). The risk of infection is increased by certain wound characteristics (Table 5.12) (Anon, 2008). Matrix metalloproteinase levels rise when a wound becomes infected and they begin to degrade the extracellular matrix proteins, which delays wound healing. Wound infection can be controlled by: (a) exudate management at the wound bed, (b) antibiotic treatment, and (c) antimicrobial dressing. It is known that pooling of exudate at the wound site can aggravate the probability of the wound being infected (Benbow and Stevens, 2010) although exudate is a good and essential component of the normal wound-healing process. Preventing cross-infection is the key in reducing wound infection and this can be managed by appropriate wound dressings. Generally the wound-healing process involves three phases:

- The inflammatory phase, which occurs immediately after injury to tissue and during which swelling takes place;
- The proliferation period, in which new tissues and blood vessels are formed; and
- The maturation phase, in which tissues laid down during the proliferation stage are remodelled.

#### 5.2.7.2 Wound dressings

Wound dressings play a vital role in preventing/controlling SSIs, formerly called surgical wound infections. The healing of wounds depends not only upon medication but also upon the use of proper dressing techniques and suitable dressing materials. Dressings should be easy to apply and painless on removal. They should be able to create the optimal environment for wound healing and should be designed to reduce nursing time by requiring fewer dressing changes.

There are numerous types of wound dressings available for the management of various kinds of wounds. Generally, the dressing is placed directly over the wound (primary dressing) and is covered with an absorbent pad (secondary dressing). The whole dressing is then retained with adhesive tape or a suitable bandage, depending on the location of the wound in the body. The primary dressing is expected to maintain the wound temperature and moisture level to permit respiration and to allow
epithelial migration. The secondary dressing must not be too absorbent as it may cause the primary dressing to dry out too quickly. Various shapes are available, which are suitable for dressing wounds in difficult positions such as heels, joints, digits, and the perineal area.

### 5.2.7.3 Antimicrobial wound dressings

Wound-dressing materials are mainly classified as absorbent and non-absorbent, depending on the types of fibres used. Dressings vary with the type of wound and wound management and no single dressing is universally applicable. An ideal dressing is normally expected to:

- Provide a barrier against micro-organisms, dirt, and other foreign bodies;
- Provide a humid environment at the wound surface;
- Control exudates; and
- Be capable of being removed without trauma.

The ideal dressing should protect the wound, keep it moist and warm, remove exudate, promote healing, and reduce the risk of infection (Anon, 1991b). Primary wound dressings should have considerable capacity to absorb liquids. The absorbent dressing should be changed frequently to avoid wound infection owing to maceration and wound odour and also to prevent the development of dermatitis of the surrounding skin. Switching to an occlusive dressing after the initial treatment stage provides the optimal moist environment for promoting wound healing. Occlusive dressings (i.e. hydrocolloids, hydrogels, and alginates) retain wound fluids that contain growth factors, enzymes, and immune cells, which help to accelerate wound healing. In comparison to non-occlusive dry dressings, occlusive dressings also prevent bacteria from entering into the wound, thereby reducing the likelihood of infection (Bolton et al., 1992).

Antimicrobial dressings can be produced by making use of known synthetic and natural antimicrobial agents. A wide range of antimicrobial agents are available and some specific antimicrobials that are exclusively used in wound dressings are:

- Povidone
- Silver and nanosilver
- Polyhexamethylene biguanide
- Triclosan
- Honey

Many types of wound dressings have been developed, both non-medicated and medicated. Commercially available synthetic wound dressings consisting of a polyurethane membrane are capable of minimising evaporative water loss from the wound and preventing bacterial invasion and thus are useful in the management of superficial second-degree burns. The desirable structure of an ideal dressing consists of an outer membrane and an inner three-dimensional matrix of fabric or sponge. The outer membrane prevents body fluid loss, controls water evaporation, and protects the wound from bacterial invasion. The inner matrix encourages wound adherence by tissue growth into the matrix. Silver/nanosilver is mostly
incorporated into the wound dressing and provides an antimicrobial shield against a wide range of bacteria. The antibacterial effect of silver was already known in ancient times. Silver tools and containers were used in around 4000 BC for storing and transporting water, to prevent the formation of germs, and to ensure high water quality. A number of wound dressings containing silver have been developed. Thomas and McCubbin (2003) critically discussed the role of silver in wound dressing. These dressings function by the sustained release of low concentrations of silver ions over time and generally appear to stimulate healing as well as inhibiting micro-organisms. The evaluation of silver-impregnated dressings, as with other topical therapies, includes in vitro antibacterial studies, animal models, and clinical testing.

It has been argued that antimicrobial efficacy alone is an insufficient benefit in modern wound dressings and that additional properties promoting wound healing are required. Based on this, the ability to remove any undesirable bacterial products in the wound environment that impinge on healing would be a bonus, for example, binding bacterial endotoxin (toxins released on cell death) to a silver dressing would be of benefit. Materials incorporated into modern silver-based dressings such as hydrocolloids, charcoal, and polymers are included as an aid to wound management, but also modulate the release of silver ion. Silver exhibits a selective toxicity in bacterial cells and yeasts through its action on cell membranes, respiratory enzymes, and DNA. Silver-impregnated polyamide cloths (nylon) are effective antibiotics and are designed to deliver silver ions to wound sites without potential side effects; the silver is rendered harmless as it is lost naturally as the wound heals. The systemic toxicity of silver is not well documented, but silver sulphadiazine used in the treatment of burn wounds is implicated as a cause of leucopenia and renal damage. In addition to silver, natural products such as honey, aloe vera, and neem are potential antibacterial agents for modern wound dressing.

Some of the facts about honey are:

- Honey produces enzymes that contain hydrogen peroxide.
- Manuka honey possesses stable antibacterial effects.
- Properties include antimicrobial, debriding, deodorising, and anti-inflammatory and it stimulates the growth of new tissues.
- Secondary dressing is needed to prevent the honey from oozing out of the wound dressing. Occlusive dressing is the best choice.

A systematic review of the use of honey in wound dressing has been published elsewhere (Moore et al., 2001). The application of aloe vera as an antimicrobial agent in wound dressing has been a subject of research in recent years (Ali et al., 2014). The active ingredients of aloe vera gel have a wide range of activities such as moisturising, anti-inflammatory, antibacterial, antifungal, antiviral, antiodour, etc. (Krinsky et al., 2003; Lee et al., 2009). The wound-healing properties of aloe vera have been extensively studied. Glycoprotein and mannose 6-phosphate present in aloe vera have good wound-healing properties (Choi and Chung, 2003). Polysaccharides and barbaloain in aloe gel are mainly responsible for its antimicrobial activity (Krinsky et al., 2003; Ramachandra and Rao, 2008).
5.3 Conclusions

To address the growing problems associated with multi-drug-resistant infections/diseases and the threats of new viruses, public health authorities need to adopt better infection control measures in hospitals. The use of appropriate antibacterial textiles, protective garments, and antimicrobial wound dressings in hospitals would enhance the infection control measures. Textile materials and garments such as gloves, gowns, laboratory coats, coveralls, headwear, footwear, and facial protection used in various wards and ORs should have the capability to protect patients from infectious and disease-causing microbes. Smart antimicrobial materials deliver such attributes to protect against cross-infections from patient to patient and from patient to medical personnel. The effectiveness and the level of protection against a range of pathogenic micro-organisms relate to various factors but are mainly confined to the use of appropriate antimicrobial agents on textile materials. The natural antimicrobial biopolymers highlighted in this chapter are considered as alternatives to the synthetic antimicrobial agents.

The need to enhance the infection-free environment in hospitals by using protective textiles and antimicrobial wound dressings that are discussed in this chapter would be a valuable subject for the reader to understand the multidisciplinary areas of medicine and smart textiles. The tests, standards, and benchmark values for surgical gowns, drapes, and clean air suits highlighted are a ‘ready reference’ for the reader.

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