Chapter

A New Approach to Surgical Gowns

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Abstract

Emerging diseases such as Ebola hemorrhagic fever, hepatitis B, hepatitis C, SARS, and most recently the Covid 19 epidemic have increased the importance of hygiene in the world, bringing the need for personal protective equipment (PPE) to the forefront. An important part of PPE in healthcare is surgical gowns, which are worn by doctors and nurses in the operating room to serve a dual function of preventing the transmission of microorganisms and body fluids from surgical staff to patients and from patients to staff. This chapter presents the history and importance of surgical gowns. The factors to be considered in the selection of surgical gowns are discussed. The model characteristics and fabric properties of surgical gowns currently on the market and the environmental impact of reusable and disposable gowns are outlined. Finally, shortcomings in available gowns are discussed, a new knitted surgical gown design is introduced, and recommendations are given in the final section. The chapter provides broad coverage of surgical gowns for both experienced readers and those new to the field.

Keywords: Surgical gown, reusable, disposable, design analysis, performance characteristics, environmental effect

1. Introduction

As a result of the Covid-19 epidemic, the importance given to hygiene has increased in the world, thus the necessity of personal protective equipment (PPE) has come to the fore. The type of PPE that should be used in the health field varies depending on three factors:

- the body part at risk (e.g. face, legs, hands) and type of exposure (e.g. pressure, liquids, droplets, aerosols),
- the amount of exposure to blood or body fluid (i.e., large volumes of fluid with a few drops)
- possible duration of exposure (i.e. short exposure such as initiation of an intravenous route or long exposure such as cardiothoracic surgery) [1].

An important part of PPE in the field of health; it forms surgical gowns that are worn by healthcare professionals to prevent the transfer of blood, body fluids and other potentially infectious materials and to help maintain the integrity of the sterile field. These gowns are the second most frequently used PPE item after gloves in this area [2–4].

Surgical gowns are defined by the United States (USA) Food and Drug Administration (FDA) as: "Equipment intended to be worn by operating room staff during surgical procedures to protect both the surgical patient and operating room staff from the transfer of microorganisms and bodily fluids" [5]. Surgical gowns are the most important part of the surgical clothing system that covers a large part of the body, and besides protection, they also affect the comfort condition of the healthcare personnel and thus the operational success [6].

Surgical gowns have been used by healthcare professionals for more than a century. Although these gowns are considered the leading item of protective equipment today, surgical gowns and clothing were not used regularly in the surgical profession until the 1800s. At that time, surgeons performed their operations in an auditorium or amphitheater-style rooms, in rooms where the operation would be performed in the center and where the audience would sit in the surrounding seats. Surgeons typically wore street clothes and sometimes wore something similar to a butcher's apron to protect their clothes from stains. In fact, surgeons in those years typically performed surgeries with bare hands and non-sterile surgical instruments and supplies. In the late 1800s, after Joseph Lister's pioneering research, the carbolic acid solution was used to sterilize surgical instruments, surgical cuts and dressings to prevent gangrene and other infections. In 1867 he published numerous articles on "Antiseptic Surgery Practice" describing these procedures and also encouraged surgeons to wear clean gloves and wash their hands before and after surgery. However; surgical gowns and other protective equipment did not see wide use until much later. Advances in the knowledge of antisepsis and infection until the 1940s led to the use of antiseptic dressings and surgical gowns. In 1952, when William C. Beck warned the surgical circles that these gowns lost their bacterial barrier property while wet, researches on developing materials in this area increased.

Surgical gowns used from the late 19th century until the 1970s; It is made from a loosely woven, readily permeable, reusable fabric known as cotton muslin fabric. Three types of fabric were commonly used at that time. All-cotton muslin (140 thread muslin); it is a soft, absorbent, draped and highly porous, loosely woven fabric. Because it is easily permeable, this material does not have any liquid resistance properties. It also tends to wear easily and create lint. It is a blended layered (180 thread) polyester and cotton blend fabric that has a permanent print quality but otherwise performs similar to muslin. Finally, it is the first reusable fabric with a water-repellent chemical coating, a tightly woven cotton or polyester/cotton blend fabric (with 175–280 threads). However, with repeated washing cycles, it has been shown that resistance to liquid penetration is reduced in this fabric [7].

While initially worn surgical garments were white to emphasize cleanliness; the combination of bright lights, white rooms, and white clothing caused eye strain on surgeons and staff. For this reason, the use of white surgical gowns and other clothing used in the early days has been abandoned and hospitals have started to use various shades of green and blue surgical clothing. As surgical procedures progressed during the twentieth century, surgical garments saw more use and improvement, but the biggest increase in surgical garment use did not occur until the 1980s. The Occupational Safety and Health Administration (OSHA) [8] introduced a rule in 1991 to minimize the risk of healthcare workers acquiring blood-borne pathogens. This rule required employers to provide appropriate personal protective equipment (PPE) to healthcare workers. It is stated that the AIDS epidemic has a lot to do with this [9].

2. Performance features required in surgical gowns

Surgical gowns are worn by doctors and nurses in the operating room to fulfill a dual function of preventing the transfer of microorganisms and body fluids from the surgical staff to the patient as well as from patient to staff [10]. These gowns, which are used to protect the surgical team, must have some protective properties. Most of the performance requirements for surgical gowns are clearly stated in the standards. Performance characteristics required from these aprons can be listed as follows:

- It must be resistant to the penetration of blood and other body fluids as required by its intended use (gown materials should contain protective barriers to minimize the passage of microorganisms, particles and fluids),
- It should be designed considering liquid repellency, liquid impermeability, air permeability and similar properties,
- It must be resistant to tears, punctures and abrasions,
- It must have an acceptable level of quality (i.e. no holes, tears, etc. in the garment),
- It must be made of materials suitable for the sterilization method/methods (e.g. radiation, steam and ethylene oxide),
- It must be resistant to fire (i.e. gowns chosen for use must be consistent with accepted flammability standards that will provide the safest environment for patients and healthcare professionals),
- It should contribute to maintaining the user's desired body temperature, that is, have the ability to maintain an isothermal environment for the user,
- It should not generate dust and fly or allow them to pass through,
- It should fit tightly but does not restrict movement.
- In general, it should be free from toxic ingredients and allergens,
- It should be soft and flexible, light, which does not cause discomfort during use,
- It must be large enough to allow full closure at the back,
- It should be of sufficient arm length to prevent exposure of the sleeve outside of the sterile glove,
- It should have an appropriate cost–benefit ratio, that is, it should not be a priority in the cost selection process,
- It should also meet some ergonomic requirements. It should be comfortable and functional, have sufficient freedom of movement and adapts to changes in heat and sweat when necessary,

- Surgical gowns should be ankle-long, the design of the collars and straps should not disturb the person wearing the garment and should not restrict the person's movements,
- It should provide high wearing comfort, should not lose its protection performance as a result of repeated washing and sterilization processes,
- As hospitals only stock in limited quantities, they should be designed to fit a variety of body shapes and sizes with a limited size range,
- It should help to protect the sterile area required in the operating room,
- It should be easy to donning and doffing without contamination,
- Whether single or reusable, the garment must be durable enough to maintain its intended useful life,
- The integrity of the garment must be preserved [9, 11–16].

Each of these characteristics can be measured in one or more "standardized" tests. These standardized tests have been developed by various organizations such as the American Society for Testing and Materials (ASTM; e.g. ASTM F-1670, ASTM F-1671), the American Textile Colorists and Chemists Association, the Health Industry Manufacturers Association, and the National Fire Prevention Association.

For the structural requirements of surgical gowns, structural analysis is performed first to evaluate the design features of existing products and to characterize the market. Comfort issues with product design are particularly alarming, as comfort is a critical product requirement for surgical gowns. While comfort is somewhat dependent on the permeability and flexibility of the fabric, it has a design effect. Researches done; emphasizes the sustainability of reusable gowns as they are more cost-effective throughout their life cycle in terms of production costs, waste and carbon footprints [17–19].

3. Design analysis of surgical gowns

Today, different gowns are designed to handle different surgeries. **Figure 1** shows the front and the back of a simple disposable surgical gown. The model and cost of aprons vary depending on the amount of protection provided.

The successful production of functional apparel products is a matter of a disciplined, structured approach to design and development. An effective, integrated approach proceeds through researching the design problem, defining design requirements and critical analysis of those requirements before arriving at a design solution [14].

Plumlee and Pittman [14] carried out a design analysis of 13 disposable and 2 reusable surgical gowns. They devised an analysis strategy to evaluate whether surgical gowns were of appropriate size. With this analysis, the model features of the surgical garments were examined and measurement analyzes were made. Kilic et al. conducted a study to determine the model characteristics of functional surgical suits to be worn in the surgical setting. For this purpose, samples were taken from surgical clothes used in hospitals in Izmir and design analysis was applied to these clothes. As a result of this analysis, suggestions were made about the model features and dimensions of surgical suits [20].

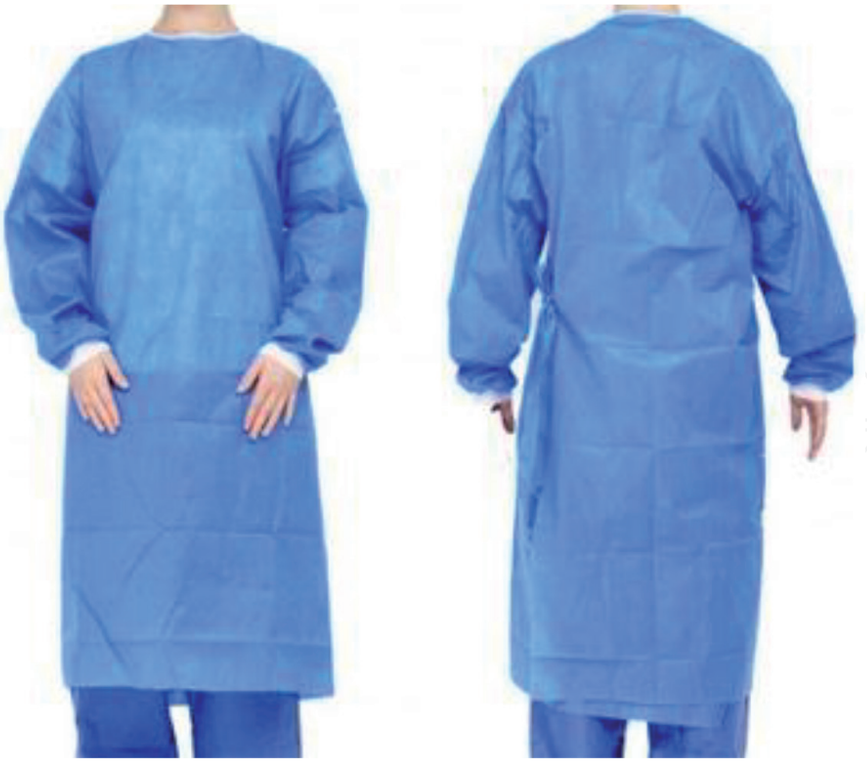

Figure 1.
Front and back of a surgical gown.

The model characteristics (size-sleeve length, closure properties, etc.) and fabric properties of surgical gowns worn in surgical settings vary according to the characteristics specified in the technical specifications of the Ministry of Health. **Figure 2** includes various surgical gowns.

3.1 Sleeves and cuffs

In general, there are two different kinds of sleeves in the gowns sold in the market at present: Raglan sleeves and set-in sleeves. A raglan sleeve, which can be identified by the diagonal seam line from the neckline to the armpit, is the most common type of sleeve used in surgical gowns [21]. Another type of sleeve construction found in many garments is commonly referred to as a set-in sleeve. The set-in sleeve is more difficult to construct and offers less freedom of movement

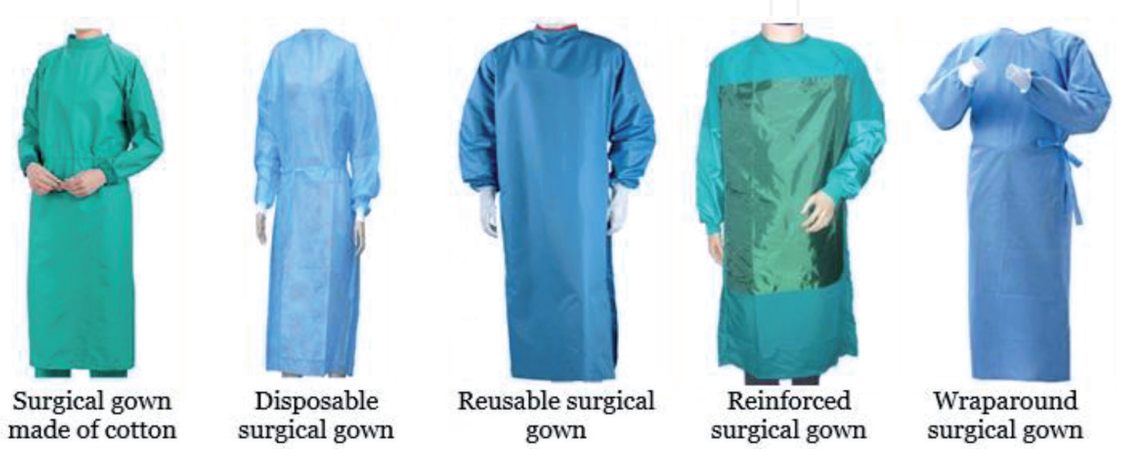

Figure 2.
Various surgical gowns.

for the wearer. The set-in sleeve is tight and results in high garment pressure in the armpit.

Since surgical gowns are worn over the scrubs, it is extremely important that they provide freedom of movement. The necessary comfort and freedom of movement are achieved by raglan sleeves as they create a large area in the armpit and provide more fit for the shoulder and arm [21–23]. In addition, raglan sleeves make donning and doffing easier compared to set-in sleeves because the deep armholes of raglan sleeves make it easier to reach into the sleeves when donning [21].

The sleeve edges were trimmed with a wrist cuff. Generally, three different types of cuffs are used, elastic cuffs around the wrist (disposable), knit cuffs made of cotton or cotton-polyester blend (disposable and reusable), and thumb loops (disposable and reusable) [3]. **Figure 3** contains different cuff designs.

According to the ANSI/AAMI PB70 classification, cuffs are not considered a critical area, so the material used on the cuff does not necessarily have barrier protection. In order to eliminate the strike-through through the cuffs, surgical gloves are worn pulled up over the cuffs so that the cuffs must fit snugly. One of the latest solutions to keep the gown wrist in place are thumb loops [3, 14].

3.2 Neck closures

The necklines of the gowns are closed in various ways: Tie, snaps, and hook and loop neck closures, all of which provide some adjustability for fit. The different types of closures are shown in **Figure 4**.

The most commonly used method is the tie back closure. The back contains a tie band at the neckline edge and another inside the neckline near the shoulder. The corresponding ties are located outside the left back piece, near the shoulder or at the edge [14]. The reusable surgical gowns made of slippery materials tend to slide down when worn. The back tie(s) can sometimes become loose, which would cause the surgical gown to slide down slightly and make the medical staff feel

Figure 3.
Different cuff designs.

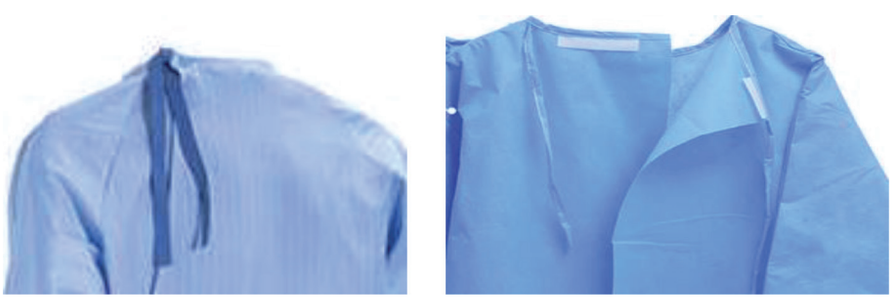

Figure 4.
Different closure types.

uncomfortable [24]. For this reason, Chang et al. [24] proposed a new combined tie fastening method for the reusable surgical gowns with two tie straps to prevent the tendency of the surgical gowns to loosen and slide down.

Snap fasteners provide closure of the gown neckline. The right back includes two male snap components, while the female components are located near the neckline of the left back. The snap components are spaced 1–1.5 inches apart to provide four adjustment options and flexibility in fit. Closer spacing of the snaps allows for more precise adjustment of the neckline area [14].

Some gowns with hook and loop neck closures are made for easy adjustability. This type of neck closure allows for easy adjustment of the neckline to fit a variety of sizes. The look components of the tape are located at the neckline of the left back. The corresponding hook component is located on the right back piece. Hook and loop closures offer great ease, flexibility, and accuracy in neckline fit, but often cause discomfort to surgical staff as hair is easily caught in the closure [3, 14].

It has been observed that reusable surgical gowns are subjected to heavy washing and sterilization steps after each use and various difficulties are encountered in models with hook and loop and snap fasteners. Due to the rough surface of the hook and loop fastener, it is difficult to clean its surface, it can be deformed quickly, and its outer surface can cause linting. In addition, the hook and loop can get caught in the garment during the washing process, which can cause damage. On the other hand, snaps can damage both the garment and the machine during wash and sterilization cycles. If the snap is damaged, it is unlikely that it can be repaired. There is also the possibility that the snap will not provide the desired degree of closure. So there is a risk that the gown will be tight/loose for the user. Since the tie is made from the fabric structure of the gown or a more durable fabric, there are no problems during washing and sterilization. It also ensures a complete closure for people of different sizes and avoids the problem of loose/tight fit.

3.3 Sizing/fit

Sizing/fit is also one of the features that is critical to surgeon protection and comfort. Gowns must allow the surgeon adequate freedom of movement, fit a variety of body shapes and sizes, and be easy to put on and take off without contaminating the worker or the workplace. Poorly fitting gowns can cause blood to easily get on the skin or other clothing [3].

Nowadays, surgical gowns are made with different size options (medium, large, extra-large, etc.) in addition to the universal fit (one size fits all). One-size-fits-all gowns are designed to fit a range of people with different sizes. However, they are usually not efficient for surgeons and are too large. The CDC recommends that multiple gown types and sizes be available in a healthcare facility to ensure adequate coverage for staff.

3.4 Stitches-seam

The characteristics of the seams of surgical gowns determine the overall performance of the product as a barrier to the spread of microorganisms. The seam provides a barrier against particulate, liquid, and gas/vapor, as well as potential chemical resistance and a biological barrier [22].

Traditional sewing with needles and threads is the most widely used method to join textiles together. Most of the reusable gowns are partially joined using traditional stitches and seams, usually a 401 double-thread chain stitch with a simple superimposed seam. Exceptions to this generalization include a reusable gown assembled with a lapped seam structure and two parallel rows of 401 stitches [14].

A low stitch density is used to minimize puncturing of the fabric and needle holes to avoid loss of barrier effect. Traditional sewing is not preferable in the manufacture of reinforced surgical gowns or some critical zones, such as sleeve seams, as needles can leave holes and cause seam leakage, leading to loss of barrier effect of the gowns [22, 25].

Eryuruk et al. [26] found that in traditionally sewn garments with membrane reinforcement, water can penetrate through the seams due to the needle holes in the fabric, which poses a risk to medical personnel in real-life use of the garment. To prevent this, the seams need to be sealed or a new joining technique based on welding such as ultrasonic welding can be used to create a fully sealed seam. Ultrasonic sewing is even more preferred than other conventional sewing methods in the manufacture of nonwoven based products. By using ultrasonic welding, seams with high waterproof properties can be obtained [25, 27, 28].

Mistik et al. compared the tensile properties of ultrasonic, lock and chain sewing methods. In their study, woven fabric was used, and the result of their study shows that the tensile properties of ultrasonic sewing were lower than traditional sewing methods [27]. Eryuruk et al. [29] compared bond strength and permeability properties of ultrasonically welded nonwoven fabrics with traditional sewing techniques. They found that ultrasonic welding technique is a suitable method for joining layers in the manufacture of surgical gowns, with acceptable bonding strength. Moreover, no water penetration was observed in the ultrasonically welded joints of the membrane-reinforced fabrics [26].

As a result, it can be said that while traditional sewing methods are preferred for reusable gowns, ultrasonic welding gives better results for disposable gowns. Although the seam strength values obtained in traditional sewing are high, the ultrasonic welded seams show higher performance in terms of liquid impermeability.

4. Fabrics used in surgical gowns

The surgical gowns on the market are made of different fabrics and a variety of fibers to reduce microbial contamination of the incision and protect the surgical staff from infection. These gowns are classified as “disposable/single-use” or “reusable/multi-use/multiple”. These two basic types of each product have advantages and disadvantages in terms of protection, maintenance, comfort, cost and environmental impact. Within each of these categories, there are significant differences in design and performance characteristics [3, 30–32].

Reusable gowns, typically made of 100% cotton, 100% polyester, or polyester/cotton blends, are tightly woven plain weave fabrics; after each use, they are laundered, sterilized, and packaged for reuse. They can generally be used for 50 or more washing and sterilization cycles. Reusable gowns meet several requirements, such as comfort, drapability, good tensile strength, steam permeability, and steam sterilizability. While reusable surgical gowns are desirable for their comfort, their protectiveness is a critical factor. The pore size is large enough to allow fluid or viruses to pass through, thus providing no barrier effect until or unless a specific measure is taken [3, 30, 33–36].

Disposable surgical gowns and drapes are usually made from nonwovens alone or in combination with materials that provide greater protection against fluid penetration (e.g., plastic films). Nonwoven fabrics are made from various forms of natural fibers (wood pulp, cotton) and synthetic fibers (polyester, polyolefin) that can be adjusted to desired properties through specific fiber types, bonding processes, and fabric finishing. There are a variety of nonwoven fabrics of all types,

including hydroentangled, bonded, stitched, and laminated nonwovens, which vary in quality depending on the manufacturer's intended use. The three most commonly used nonwovens for surgical gowns and drapes are: Spunlace, a hydroentangled material often composed of wood pulp and polyester fibers; Spunbond/Meltblown/Spunbond, a fabric composed of three layers thermally or adhesively bonded together; and Wet-laid, a nonwoven fabric composed of wood pulp or a blend of polyester and wood pulp fibers [1, 30, 37].

Additional materials in the form of coatings, reinforcements, laminates or plastic films are often added to reusable and disposable products to improve their performance in terms of barrier resistance, absorbency and slip resistance. For some surgical gowns and drapes, the barrier properties of one layer of a material may not be sufficient for the application; in these cases, additional materials are often added in the form of additional layers of material, coatings, reinforcements, or laminates. Rutala and Weber [1] provide the following categorization of reinforcement approaches: reinforced fabric (second fabric layer to reinforce base materials); impermeable fabric with liquid repellent finish; layered fabric with a highly resistant membrane between two layers; and fabric reinforced with liquid-proof protection membrane. These approaches improve the protective performance of gown materials, but whether they address the thermal comfort of wearers is questionable. Membranes and coatings tend to compromise wearer comfort [1].

These two basic types of products each have advantages and disadvantages. Criteria for the selection of gowns and drapes include protection of medical personnel and patients from surgical site infections or nosocomial infections, barrier efficacy, clothing comfort, cost effectiveness, and environmental life cycle analysis. Moreover, the appropriate gown should be selected according to the duration of surgery and surgical status [1, 7, 18, 34].

The reusable gowns are mostly preferred by the clinicians due to their comfort, color etc. Disposable gowns are generally perceived by them as "paper-like" gowns and they do not want to wear them. Reusable gowns are also preferable in terms of tear resistance and liquid absorption. Independent studies have found that the use of disposable gowns can be 4–10 times more expensive than reusable materials on a per benefit cost basis. The potential problems with reusable surgical items can be listed as: perception of lower barrier protection, actual loss of barrier properties due to wear, abrasion and degradation of the fabric during laundering and sterilization, uneven consistency of the product when reprocessed multiple times [34, 38, 39].

The disposable gowns are used only once so there is no concern of damage to the barrier due to reprocessing and the product quality is very uniform. These gowns offer the advantage that hospitals can quickly dispose of the contaminated textiles, they reduce the cost of laundering, and they can be donned and doffed quickly in a place like the emergency room. In addition, nonwoven fabrics can prevent almost all possible strike-through of blood and body fluids. While disposable textiles are often perceived as having protective advantages over reusable textiles, there are some problems that arise with disposable textiles. For one, they tend to tear and break. Also, due to their barrier properties to liquids, the textiles are not permeable to air and moisture, making them uncomfortable to wear, especially during prolonged surgeries. Disposable gowns and drapes often receive negative feedback from surgeons and OR technicians due to thermal comfort and size issues. Finally, inexpensive disposables also tend to shed more particles than reusable ones, which in turn increases cleaning and maintenance costs [34, 38–40].

So, in conclusion, the gown type should be selected according to the different expectations of the users, the different operating environment conditions and the duration of operation. In the study where Behera and Arora made a general assessment, they stated that high density reusable synthetic fibers which are beneficial in

terms of comfort and have adequate barrier performance should be preferred for high-risk surgical procedures with bleeding and disposable gowns with low barrier performance and lower comfort performance should be used for less risky procedures.

5. Environmental effects of reusable and disposable surgical gowns

The environmental impact of surgical gowns has had an increasing influence on the decision-making process in recent years. As environmental issues have become increasingly important, the environmental impacts of surgical gowns are discussed in this section.

Climate change and other environmental threats have become more prominent in recent years. As a result, environmental sustainability has gained much importance in many sectors. As one of the most polluting industries in the world, sustainability issues have received much attention in the textile and apparel industry. Textile and apparel products impact the environment at every point of the product life cycle, from fiber extraction to disposal (which is referred to as cradle to grave) and threaten our planet and its resources through the consumption of energy, chemicals, and water [41–44]. The textile industry causes significant environmental impacts throughout the life cycle of textile products.

Environmental sustainability, which considers the trade-off between economic productivity and environmental impact, should be an important perspective in business decisions. It refers to the ability of something to continue to exist without disturbing the ecological balance of the earth. Environmental sustainability in business refers to longevity, but in terms of what natural resources the production process relies on, how the resources are used and replenished, the overall impact of the final product on the environment, and where the product ends up after it is disposed of. Many tools and indicators have been developed to assess and benchmark the environmental impact of different systems. Life cycle assessment (LCA) is an environmental management tool that is increasingly used to understand and compare how a product or service is provided "from cradle to grave". The technique quantifies the environmental impact of a product, service or commodity at each stage of the Life Cycle, from raw material sourcing through manufacturing, distribution, use, potential reuse/recycling and then final disposal [29, 43, 45–47].

Furthermore, each operation or process unit within a stage is included. For each process within a stage, inputs (raw materials, resources, and energy) and outputs (emissions to air, water, and solid waste) are calculated. These inputs and outputs are then aggregated across the Life Cycle [47].

From a material life cycle perspective, reusable textiles have the advantage of a longer life span, they can withstand more than 50 commercial laundering cycles and therefore offer an additional saving to the user and the environment. In the case of reusable gowns, the final products are biodegradable when cotton or biodegradable polyester fibers such as polylactic acid (PLA) are the main components. The reusable textiles are used more frequently and therefore offer significant environmental advantages over disposable materials in terms of waste. However, these processes require more labor and facilities for washing and sterilizing and may contribute to water pollution. They also generate more volatile organic compounds as air emissions [1, 35, 39].

On the other hand, disposable products consume more raw materials and energy and generate more solid waste than reusable products. Moreover, disposable materials release more toxic compounds such as dioxins and mercury into the environment during the disposal process. In addition, disposable gowns require a larger inventory. Most of the air emissions (nitrogen oxides, sulfur oxides, and particulate

matter) from the manufacturing and transportation of both types of products result from energy production; therefore, the disposable products generate more energy-related air emissions. These types of air emissions are associated with air pollution that leads to acid rain [1, 35, 39].

Both disposable and reusable gowns have an impact on the environment that has been evaluated by researchers. Vozzola et al. analyzed all activities from the extraction of fossil materials from the earth to the end-of-life disposal of reusable and disposable surgical gowns. The results of the study showed that choosing reusable gowns instead of disposable gowns reduced the energy consumption of natural resources (64%), greenhouse gas emissions (66%), blue water consumption (83%) and solid waste generation (84%). In addition, the reusable surgical gown system was found to consume approximately 83% less water (blue water) than the disposable surgical gown system. This result differs from some published information indicating that reusable garments are more water intensive [48].

Comparative life cycle studies by McDowell, Carre, Van den Berghe and Zimmer, and Overcash compared the manufacturing, sterilization, and transportation of reusable and disposable surgical gowns. All of these studies found that reusable textile systems had a significantly better environmental profile than disposable systems. Reusable gowns were found to produce lower environmental impacts in terms of global warming, photochemical oxidation, eutrophication, carcinogens, land use, water consumption, solid waste and fossil fuels. In general, disposable gowns had higher impacts in most categories because of the environmental impacts associated with gown production for each gown use. In a study also found that when these disposable products were replaced with reusable products, there was an average 64.5% reduction in surgical waste generated [40].

The European Textile Services Association (ETSA) reviewed the environmental impact of reusable and disposable surgical gowns in a LCA study considering a number of environmental impact categories. In the overall comparison, reusable products were found to have a lower negative environmental impact [49].

Another study conducted by American Reusable Textile Association (ARTA) and International Association for Healthcare Textile Management (IAHTM) found that reusable surgical gowns were significantly better for the environment than disposable gowns in areas such as energy consumption, water use, greenhouse gas emissions, and waste management. The study found that choosing reusable isolation gowns instead of disposable alternatives reduces the environmental footprint by; 28% lower energy consumption of natural resources, 30% lower greenhouse gas emissions (measured as CO2 emissions), 41% lower total water consumption (blue water), 93–99% lower waste generation in the healthcare facility [50, 51].

In summary, both disposable and reusable gowns and drapes have an impact on the environment. However, the existing literature on comparative studies for surgical gowns and drapes generally concludes that reusable textiles result in a lower environmental impact than disposable textiles. Comparing the two systems above, reusable gowns have advantages over disposable gowns in terms of natural resource consumption, waste generation, emissions and sustainability.

6. Shortcomings in available gowns, the design of knitted surgical gowns and recommendations

Garments used in the surgical environment are available in the market as single-use and multi-use. As mentioned before, reusable surgical garments are more preferable in terms of tensile strength, liquid absorption and bacterial protection performance. At the same time, they provide more comfort to the user because they

are breathable. However, although the procurement processes of single and reusable products are simultaneous, the reusability of reusable products makes these products more advantageous due to the increasing needs in the field of health in today's conditions.

Sun Tekstil San. ve Tic. A.S. and Ekoten Tekstil San. ve Tic. A.S. in the study carried out by the companies within the scope of cooperation; the development of knitted fabric structures with different constructions produced from functional fiber structures, which will replace the woven fabrics used in the production of reusable surgical gowns according to the state of the art, that provide high wearing comfort in accordance with different types of surgical operations, do not lose their protection performance as a result of repeated washing and sterilization processes, and this reusable surgical gowns have been produced using functional fabric structures. Surgical garments have been developed by using knitted fabric structures in order to increase wearing comfort, breathability and comfort features. Thanks to the knitted fabric of the fabric used in clothing, it has an advantage over woven fabrics in terms of lightness and flexibility. The use of knitted fabric structures in the production of surgical clothing and the use of knitted fabric structures developed in different constructions from functional fibers in different parts of the garment have created the innovative aspect of the study.

With this study, knitted fabrics of different constructions were developed by using different fiber structures, thus the production of surgical garments with improved protection and comfort properties was achieved. In the production of fabrics; cotton, polyester, cotton-polyester, cotton-polyester-carbon fiber blends and nilite, coolmax, tencel, etc. fibers are used to increase the comfort feature. Antistatic thread is used to prevent static electricity of the fabrics. With these yarn raw materials, fabrics with a single jersey knit structure were obtained and the characteristics of these fabric structures regarding performance and comfort were compared with each other. As a result of the tests, it has been observed that 100% cotton fabric gives worse results than other fabrics in relation to moisture transmission, thermal resistance and size stability in washing. The rubbing fastness and pilling values of the tencel/cotton blend fabric are very low in terms of usage. When the results were examined, it was seen that 100% Coolmax and 100% Nilit fabrics are advantageous in terms of comfort properties such as moisture transmission and thermal resistance. In addition, the results of moisture transmission, bursting strength and size stability in washing of 100% polyester and 99% -1% polyester-carbon fabrics were better than other fabrics. It is seen that it has the best results after 100% Coolmax and 100% Nilit fabrics in terms of thermal resistance. Although the test results of the micro-polyester fabric seem good, due to its fast moisture absorbing structure, its moisture transmission properties are quite low. Dimension change properties of 65–34–1% polyester-cotton-carbon blended fabric in washing gave worse results than Nilit, Coolmax, polyester and polyester-carbon fabrics. Comfort features are very important in surgical garments. In the literature, the expected value for comfort from fabrics in terms of moisture management performance properties is above 0.4. For this reason, it has been observed that 100% Coolmax, 100% Nilit, 100% Polyester and 99–1% polyester-carbon fabrics provide these values, while other fabrics are poor in terms of moisture management in terms of comfort. For this reason, fabric structures with these 4 different raw materials have been selected for lamination.

Multiple film structures (PTFE, microporous PU film, hydrophilic PU film and ether-based polyester film) were used to use the surgical gowns obtained with the study for multiple purposes. The advantages provided by each film structure in terms of its technical properties also vary. In order to make the barrier properties of the film structures more effective, dot lamination studies were carried out with reactive

polyurethane adhesive as 2-layer (Fabric + Film) and 3-layer (Fabric + Film + Fabric) together with the fabric structures of the films. Due to the insufficient test and sterilization resistance of the 2-layer structures, the lamination studies of the 3-layer structures were continued. However, different performance criteria were met with the different film structures used in the studies. Adhesives with high resistance to sterilization were preferred in studies on film structures with different performance properties.

After lamination processes, antibacterial finishing process to give antibacterial properties to the fabrics, water repellent finishing that is resistant to washing at high temperatures to give water repellency and membrane coating to increase the protection feature.

In order to determine the physical-mechanical, protection and comfort properties of the fabrics produced; thickness, liquid repellency, liquid impermeability, bursting strength, linting, porosity and microorganism permeability were investigated. At the same time, bending strength, air permeability, thermal resistance and water vapor resistance tests were applied to determine the clothing comfort properties of the fabrics. The sterilization strength of the products obtained was also examined. These tests to be applied to fabric structures also shed light on the tests applied in EN 13795 and PB70 standards, which are a requirement for surgical gowns.

Along with these; the designs of the existing surgical gowns were examined, and in line with the interviews with surgeons, new designs were created for different types of operations (intense fluid, low fluid, etc.), that can be easily put on and taken off and provide body movement comfort.

It has been observed that the 3-layer laminated fabric structure obtained with the knitted fabric design and film lamination within the scope of the study has fulfilled both the comfort and protection parameters with the test studies. In the light of this information, it was decided to use a film laminated knitted fabric structure in the entire surgical gown. In this way, the protection and barrier feature of the user is not only specific to the body and arms of the user, but a protection that covers the whole body will be provided. The fact that the fabric structure is extremely light in weight will not create a weight on the user in terms of comfort.

Surgical garments developed; It will be used as personal protection equipment to minimize the transmission of viruses to patients and the exposure of healthcare personnel to pathogens, especially blood-borne pathogens. Within this scope, there is no product in which knitted fabric structures are used in the production of surgical garments in the international market. In this respect and according to the advantages it provides compared to reusable woven fabrics, surgical garments have been obtained from knitted fabric that stands out in the market.

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