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# The Thermal Comfort Properties of Reusable and Disposable Surgical Gown Fabrics

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## Abstract

Surgical gowns are worn to protect both patients and the surgical team from contamination during an operation. They were initially manufactured from cotton fabrics, while modern gowns use various types of woven and non-woven fabrics. The purpose of this study was to evaluate the thermal comfort properties of the different fabrics that are used in the manufacture of surgical gowns. Eight commercially available surgical gown fabrics were evaluated in this study. Three of the fabrics were nonwoven (Spunlace, SMS, Spunbond), and five of the fabrics were woven (100% cotton; 50% polyester – 50% cotton; 65% polyester –35% cotton; 66% polyester – 33% cotton – 1% carbon; 99% polyester – 1% carbon). The thermal conductivity, thermal absorption, and thermal resistance values were measured with Alambeta thermal comfort testing equipment. The thickness of each of the fabrics was measured to investigate the correlation between thermal resistance and thickness. The data obtained from this research were evaluated statistically.

Key words: surgical gown, thermal comfort, woven, nonwoven, thermal resistance, thermal conductivity.

## *Termofiziološke lastnosti udobnosti kirurških oblačil za enkratno in večkratno uporabo*

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## Izvleček

*Kirurška oblačila se uporabljajo za zaščito pacientov in kirurške ekipe pred okužbo med samo operacijo. Prvotno so bila izdelana le iz bombažnih tkanin, danes pa se za njihovo izdelavo uporabljajo različne vrste tkanin in netkanih tekstilij. Namen te raziskave je bila ocena termofizioloških lastnosti udobnosti različnih tekstilij, ki se uporabljajo za izdelavo kirurških oblačil. Analiza je bila izvedena na osmih kirurških oblačilih, ki so dostopna na tržišču; na treh netkanih tekstilijah (Spunlace, SMS, Spunbond) in petih tkaninah (100 % bombaž, 50 % poliester – 50 % bombaž, 65 % poliester – 35 % bombaž, 66 % poliester – 33 % bombaž – 1 % ogljikova vlakna, 99 % poliester – 1 % ogljikova vlakna). S preskuševalno opremo za določitev termofizioloških lastnosti Alambeta so bile določene toplotna prevodnost, absorpcija toplote in toplotna upornost tekstilij. Izmerjena je bila debelina tekstilij in določena korelacija med debelino in toplotno upornostjo. Rezultati meritev pridobljeni v okviru raziskave so bili statistično obdelani z analizo sipanja (ANOVA).*

*Ključne besede: kirurška oblačila, termofiziološko udobje, tkanine, netkane tekstilije, toplotna upornost, toplotna prevodnost.*

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## 1 Introduction

Gowns are used widely in healthcare facilities as part of personal protective equipment to minimize both the passage of microbes to surgical patients and the exposure of healthcare providers to infectious agents, especially blood borne pathogens such as the human immunodeficiency virus (HIV), the hepatitis B virus, and the hepatitis C virus. Modern technology allows gowns to be constructed of many materials. Healthcare facilities should understand the characteristics of the ideal gown or drape, and make their purchase decisions by balancing health and safety concerns with economic, environmental, and comfort issues [1].

Surgical gowns must act as a barrier between the sources of infection and the user, and must also demonstrate good wearing-comfort. The latter is important for the surgeon who often has to wear the surgical gown for several hours while doing complicated work [2]. Surgical gowns are fabricated from either multiple or single-use materials. These two basic types of products each have advantages and disadvantages. From the late 19th century to the 1970s, hospital sheeting used cotton muslin as the primary fabric. During this era, three fabrics were commonly used. All-cotton muslin (140 thread-count muslin) is a loosely woven fabric that is soft, absorbent, drapeable, and extremely porous. Since it is readily permeable, this material does not possess any liquid-resistance capability. Furthermore, it tends to abrade easily and generate lint. Blended sheeting (180 thread-count percale), consisting of polyester and cotton, has permanent press qualities, but otherwise exhibits performance similar to muslin. Finally, T280 barrier (175 to 280 thread-count), a tightly woven cotton or polyester-and-cotton blended fabric, was the first reusable fabric with a water-repellent chemical finish. However, resistance to liquid penetration diminishes with repeated wash cycles. In the 1980s, new surgical textiles with improved, multiple-use protective qualities were developed. Advances in these materials included more consistent barrier properties, reduced flammability, low lint generation, and extended durability. Two broad groups of products encompass all the known varieties currently available. The first is polyester sheeting which consists of a tightly woven fabric made of continuous-filament synthetic yarn that is chemically finished. The second includes composite materials consisting of combinations of woven or knitted fabrics engineered to obtain enhanced performance characteristics by laminating or coating them with various types of films that provide increased protection against strikethrough of liquids and microorganisms. Single-use surgical gowns are most commonly made of nonwoven materials independent of, or in combination with, materials that offer increased protection from liquid penetration (e.g., plastic films). Nonwoven fabrics are manufactured from various forms of natural (e.g., wood pulp, cotton) and synthetic fibers (e.g., polyester, polyolefin) that can be engineered to achieve desired properties through the use of special fiber types, bonding processes, and fabric finishes. The three most commonly used nonwoven fabrics for surgical gowns are: Spunlace, a hydroentangled material often consisting of wood pulp and polyester fibers; Spunbond/Meltblown/Spunbond, a fabric consisting of three thermally or adhesively bonded layers (Spunbond provides the strength, Meltblown provides the barrier); and wet-laid, a nonwoven fabric consisting of wood pulp, or a blend of polyester and wood-pulp fibers. The fibers are suspended in water to obtain a uniform dispersion, and are then separated from the slurry by draining the water through a fine mesh screen. Chemical treatments can be used to improve liquid penetration resistance [1].

Disposable gowns allow for rapid disposal of contaminated textiles, reduce laundry costs, and can be donned and doffed quickly in locations such as Emergency Rooms. Nonwoven disposables are not as heavy as reusables and are, therefore, cooler [3].

The term comfort is defined as either "the absence of unpleasantness or discomfort," or "a neutral state compared to the more active state of pleasure." There is general agreement that the movement of heat and water vapour through a garment are probably the most important factors in clothing comfort. Comfort is considered a fundamental property when a textile product is valued. The comfort characteristics of fabrics mainly depend on the structure, types of raw material used, weight, moisture absorption, heat transmission, and skin perception. Clothing has a large part to play in the maintenance of heat balance as it modifies the heat loss from the skin surface, in turn resulting in the secondary effect of altering the moisture loss from the skin [4].

Thermal properties are among the most important features of textiles. For instance, thermal insulation determines the elementary function of garments. Most of the studies hitherto carried out are devoted to measurements of static thermal properties such as thermal conductivity, thermal resistance, and thermal diffusion. Thermal insulation is a very important factor for estimating apparel comfort for the user [5]. The thermal properties of clothing materials, which relate to user-comfort, depend on the heat transfer between a dressed body and the environment. The thermal resistance of a clothing system represents a quantitive evaluation of how good the clothing is at providing a thermal barrier to the wearer [11].

The heat transfer resistance of a fabric is of critical importance to its thermal comfort. In studying the thermal insulation properties of garments during wear, it is reported that thermal resistance to the transfer of heat from the body to the surrounding air is the sum of three parameters:

(i) the thermal resistance to the transfer of heat from the surface of the material,
(ii) the thermal resistance of the clothing material, and
(iii) the thermal resistance of the air interlayer [4].

## 2 Material

In this research, eight commercially available surgical gown fabrics were evaluated. Five of the fabrics were woven (100% cotton; 50% polyester – 50% cotton; 65% polyester – 35% cotton; 66% polyester – 33% cotton – 1% carbon; 99% polyester – 1% carbon) and three of the fabrics were nonwoven (Spunlace, SMS, Spunbond).

Spunlace is a hydroentangled material often consisting of wood pulp and polyester fibers. SMS (Spunbond/Meltblown/Spunbond) is a kind of nonwoven fabric consisting of three thermally or adhesively bonded layers. Spunbond fabrics are produced by depositing extruded, spun filaments onto a collecting belt in a uniform random manner, followed by bonding of the fibers. The fibers are separated during the web-laying process by air jets or electrostatic charges. The collecting surface is usually perforated to prevent the air stream from deflecting and carrying the fibers in an uncontrolled manner.

The technical parameters of the selected woven and nonwoven fabrics can be seen in Table 1 and Table 2, respectively.

*Table 2: Technical parameters of the nonwoven fabrics*

| Fabric No | Type of Fabric | Mass per unit area (g/m$^2$) |
|---|---|---|
| 1 | Spunlace | 78 |
| 2 | SMS | 50 |
| 3 | Spunbond | 45 |

## 3 Method

All the measurements were completed in a controlled laboratory environment of about 23°C and 55% relative humidity. Five samples were tested for each fabric type to obtain the thermal comfort properties. In total, 40 measurements were made according to the EN 31092 standard. The thermal conductivity, thermal absorption, and thermal resistance values were measured with an Alambeta, and the thickness values were measured with a Shirley Digital Thickness Gauge [9]. The measuring head temperature of the Alambeta was approximately 32°C in all cases. The measuring head contains a copper block which is eletrically heated to 32°C, thereby simulating human skin temperature. The temperature is controlled by a thermometer connected to the regulator. The lower part of the heated block

*Table 1: Technical parameters of the woven fabrics*

| Fabric No | Type of Fabric | Mass per unit area (g/m$^2$) | Yarn count (tex) | | Density (threads per cm) | |
|---|---|---|---|---|---|---|
| | | | Weft | Warp | Weft | Warp |
| 1 | 100% Cotton | 185 | 30 | 31 | 18 | 41 |
| 2 | 50% Polyester – 50% Cotton | 125 | 13 | 13 | 30 | 50 |
| 3 | 65% Polyester – 35% Cotton | 110 | 13 | 13 | 32 | 48 |
| 4 | 66% Polyester – 33% Cotton –1% Carbon | 132 | 20 | 21 | 41 | 59 |
| 5 | 99% Polyester – 1% Carbon | 89 | 17 | 16 | 40 | 56 |

is equipped with a direct heat flow sensor. The sensor measures the thermal drop between the surfaces of a very thin, non-metallic plate using a multiple differential micro-thermocouple. This sensor is 0.2 mm thick and, on contact with a subject of a different temperature, reaches the maximum heat flow, $q_{max}$, in 0.2 seconds. Thus, it simulates the human skin, which is approximately 0.5 mm thick and whose nevtron ends, located in the middle, also take 0.1–0.3 seconds to reach $q_{max}$ when heated [12]. The thickness measurements were made according to the EDANA 30.5 standard [10]. Ten samples were tested for each fabric types.

Thermal conductivity: The coefficient of specific thermal conductivity ($\lambda$) represents the amount of heat which passes through a unit length per unit time and creates difference in temperatures of 1 K [6].

The measurement result of thermal conductivity is based on equation (1):

$$\lambda = \frac{Q}{F_T \frac{\Delta T}{h}}, \text{ Wm}^{-1}\text{ K}^{-1} \qquad (1)$$

where:
$Q$ – amount of conducted heat
$F$ – area through which the heat is conducted
$\Delta T$ – temperature change
$h$ – fabric thickness

Thermal resistance: Thermal resistance is a quantity specific to textile materials or composites which determines the dry heat flux across a given area in response to a steady applied temperature gradient [7]. The lower the thermal conductivity, the higher the thermal resistance.

Thermal resistance is related to fabric thickness by equation (2):

$$R = \frac{h}{\lambda}, \text{ m}^2\text{ KW}^{-1} \qquad (2)$$

where:
$h$ – fabric thickness
$\lambda$ – thermal conductivity

Thermal absorption: Thermal absorption characterizes ‘warm-cool’ feelings, and represents the amount of heat absorbed for a difference in temperatures of 1 K over a unit area per unit time (and results from heat accumulating in a volume unit). Indoors, we experience colder temperatures while wearing material with a high absorption capacity Black clothing has a higher absorption coefficient, and we feel hotter while wearing it outside. [6].

Thermal absorption can be expressed by equation (3):

$$b = \sqrt{\lambda \cdot \rho \cdot c}, \text{ Ws}^{1/2}\text{ m}^{-2}\text{ K}^{-1} \qquad (3)$$

*Table 3: The mean values of thermal conductivity, thermal absorption, and thermal resistance for all fabric types*

| Types of Fabrics | Thermal Conductivity ($\text{Wm}^{-1}\text{ K}^{-1}$) | Thermal Absorption ($\text{Ws}^{1/2}\text{m}^{-2}\text{K}^{-1}$) | Thermal Resistance ($\text{m}^2\text{ KW}^{-1}$) |
|---|---:|---:|---:|
| Spunlace | 0.03258 | 116.20 | 0.00961 |
| SMS | 0.02766 | 111.00 | 0.01077 |
| Spunbond | 0.02558 | 88.20 | 0.01216 |
| 100% Cotton | 0.05200 | 208.40 | 0.00794 |
| 65% Polyester<br>35% Cotton | 0.03770 | 167.80 | 0.00737 |
| 50% Polyester<br>50% Cotton | 0.03870 | 137.80 | 0.01037 |
| 66% Polyester<br>33% Cotton<br>1% Carbon | 0.03890 | 151.40 | 0.00851 |
| 99% Polyester<br>1% Carbon | 0.03300 | 203.20 | 0.00372 |

where:
$\lambda$ – thermal conductivity,
$\rho$ – fabric density,
c – the specific heat of the fabric.

## 4 Results

The mean values of thermal conductivity (Wm$^{-1}$ K$^{-1}$), thermal absorption (Ws$^{½}$m$^{-2}$ K$^{-1}$), and thermal resistance (m$^2$ KW$^{-1}$) for woven and nonwoven fabrics can be seen in Table 3. The mean values of thickness for all fabrics are listed in Table 4.

*Table 4: The mean thickness values for all fabrics*

| Types of Fabrics | Mean Thickness (mm) |
|---|---|
| Spunlace | 0.55 |
| SMS | 0.40 |
| Spunbond | 0.38 |
| 100% Cotton | 0.41 |
| 65% Polyester<br>35% Cotton | 0.28 |
| 50% Polyester<br>50% Cotton | 0.40 |
| 66% Polyester<br>33% Cotton<br>1% Carbon | 0.33 |
| 99% Polyester<br>1% Carbon | 0.13 |

## 5 Statistical Evaluation and Discussion

In this section, the aim is to test several hypotheses by applying a one-way analysis-of-variance procedure (ANOVA) to the data given in Table 11 in order to determine if there is any difference among the fabric types with respect to thermal resistance values [8]. The selected value of significance level (α) for all statistical tests in the study was 0.05. We have 8 different values (treatments) of a single factor (fabric) that we wish to compare. The thermal resistance values say $y_{ij}$ represents the *j*th observation taken under treatment *i*. Here, $i = 1, 2, \ldots, 8$ represents fabric type (Spunlace, SMS, Spunbond, 100% cotton; 50% polyester – 50% cotton; 65% polyester –35% cotton; 66% polyester – 33% cotton – 1% carbon; and 99% polyester – 1% carbon, respectively).

$$y_{ij} = \mu + \tau_i + e_{ij} \qquad \text{(Model 1)}$$

where $\mu$ is overall mean strength, $\tau_i$ is the effect of *i*th fabric type, and $\varepsilon_{ij}$ is a random error component. In this one-way analysis-of-variance model, $r_i$ denotes the number of observations at *i*th level of the factor. The appropriate hypotheses are

$$H_0 : \tau_1 = \tau_2 = \ldots = \tau_7 = 0 \,;\, H_1 : \tau_i \neq 0 \text{ for at least one } i.$$

If the null hypothesis is true, then it can be concluded that fabric types do not significantly affect the mean thermal resistance. The Minitab (Release 13.20) statistical software package was used to conducting these tests.

ANOVA table of thermal resistance for Model 1 can be seen in Table 5.

In Table 5, $H_0$is rejected (<α), and the small *P* value indicates that fabric type has a statistically significant effect on the thermal resistance value.

According to Figure 1, the main effects diagram for thermal resistance, it is evident that the 65% polyester – 35% cotton woven fabric has the lowest thermal resistance value, while Spunbond nonwoven fabric has the highest value.

*Table 5: ANOVA table for thermal resistance*

| Source | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| Fabric Types | 7 | 0.0000916 | 0.0000131 | 22.43 | 0.000 |
| Error | 32 | 0.0000187 | 0.0000006 | | |
| Total | 39 | 0.0001102 | | | |

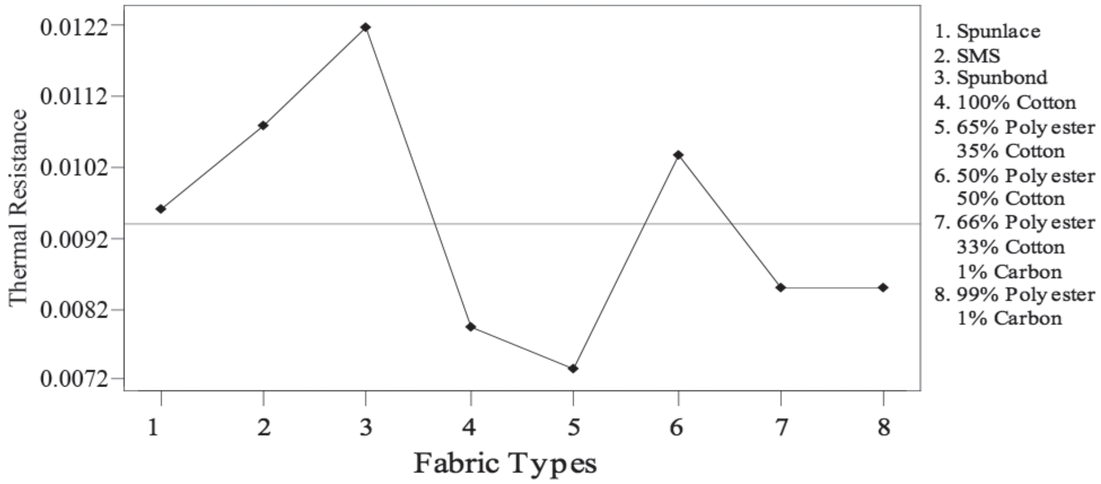

*Figure 1: Thermal Resistance as a function of Fabric Type.*

### Simple Linear Regression Analysis for Thermal Resistance and Thickness

In this section, the correlation between thermal resistance and fabric thickness of surgical gown fabrics was explored, and a simple linear regression model was used to explain the relationship between these parameters.

It is supposed that the true relationship between $y$ (thermal resistance) and $x$ (thickness) is a straight line, and each observation, $y_i$, can be described by the following model

$$y_i = \beta_0 + \beta_1 x_i + \varepsilon_i \qquad i=1, 2, \ldots, n \qquad \text{(Model 2)}$$

where the intercept ($\beta_0$) and the slope ($\beta_1$) are unknown constants, and $\varepsilon$ is a random error with a mean of zero and a variance of $\sigma^2$.

The sample correlation coefficient between thermal resistance and thickness was computed as 60%. It indicates that there is a positive relationship between thermal resistance and thickness, and it justifies the assumption of linearity in model (2). Thus, if the data in Tables 11, 12, and 13 are used to determine the relationship between thermal resistance and thickness, the fitted simple linear regression model below is obtained.

$$y = 0.00270 + 0.0170x$$

The hypotheses that relates to the significance of regression are given below:

$$H_0: \beta_1 = 0$$
$$H_1: \beta_1 \neq 0$$

These hypotheses were tested using an analysis-of-variance procedure. The result of this procedure is given in Table 6. Since the $P$ value is less than α, we reject $H_0$ and conclude that $\beta_1 \neq 0$. In other words, there is a significant linear relationship between the thermal resistance and thickness.

## 6 Conclusion

The clothing-comfort of reusable or disposable surgical gowns is an important parameter for the surgical team who often has to wear the surgical gown for

*Table 6: ANOVA table for thermal resistance and thickness values*

| Source | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| Regression | 1 | 0.00015142 | 0.00015142 | 56.96 | 0.000 |
| Error | 38 | 0.00010102 | 0.00000266 | | |
| Total | 39 | 0.00025244 | | | |

several hours while doing complicated work in operation room. For the best thermal comfort properties, the fabrics of the surgical gowns, both reusable and disposable, must have low thermal resistance values. The results of this research show that woven fabrics have better thermal conductivity properties. Specifically, 65% polyester – 35% cotton and 100% cotton fabrics have the lowest thermal resistance values. According to this result, it is possible to say that these kinds of fabrics can be selected for use in reusable surgical gowns. Alternately, the disposable surgical gowns, made with Spunlace nonwoven fabrics, are preferable for long-duration operations.

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