THERMO-PHYSIOLOGICAL BEHAVIOR OF SINGLE USE SCRUB SUITS USING A THERMAL MANIKIN

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ABSTRACT

In operationg room, the health professionals are exposed to stress situations that can influence their physical and psychological performance. The thermal properties are an important requirement for the best performance of OR medical clothing, that plays a crucial role in thermal comfort of the user, that involve the regulation of heat and mass transfer between a clothed body and the environment. This study evaluates thermal comfort of medical clothing under specified conditions. Twelve types of non-woven single-use scrub suits were tested. The experiments were conducted on a thermal dry manikin that simulates human body to measure the heat loss from manikin surface and determine clothing thermal insulation The total clothing insulation, I_T (m^2.°C/W), is used to define the insulation from the skin surface to the environment. Thermal insulation of scrub suits show statisticaly significant differences between them. SS7 and SS9 have the the lower and higuer values of total isolation of 0.23 m^2.°C/W and 0.14 m^2.°C/W, respectively.

Key Words: Scrub suit, thermal comfort, thermal manikin, thermo-physiology

1. INTRODUCTION

Scrub suits are known as traditional uniform worn by healthcare staff and, inside the operating room (OR) it is used under the surgical gown and frequently denominated as "pajamas" that consists of pants and shirt [1,2]. Scrub suits produced with non-woven fabrics, according with the Association of Operating Room Nurses [3], promote high-level of cleanness and hygiene within the practice setting in the operating room (O.R.). Inside of OR, thermal comfort of medical clothing apparel is a very important parameter, since the lack of comfort can lead to thermal stress that influence the physic and psychological conditions of the surgeon, as the ability to maintain constant vigilance and concentration of which, the correct surgical procedure is dependent. Thermal comfort of the user of medical apparel depends on thermal insulation and its adjustment to the environmental conditions in the operating room during the surgery, among many other factors like design, size and fabric characteristics [4]. The overly insulating, and very low absorbent, medical clothing apparel result in the increase of skin temperature inducing a higher accumulation of humidity between staff skin and clothing, which can decrease psychophysics conditions of surgeons. For health professional can achieve thermal comfort, the mean skin temperature should be between 33 °C and 34 °C and sweating or chills should not occur. Studies have determined that surgeons experience thermal comfort when OR temperature is between 20 °C and 24 °C and if their clothing ensemble were consisted by shoes, cotton socks, nonwoven surgical clothing with viscose fiber and good air and water vapor permeability [5].

To measure the thermal insulation of garments and clothing ensemble a thermal manikin is the better equipment to use, and it is already a work instrument in other studies [4-7] since it´s considered one of the most useful tools for evaluating thermal comfort of overall clothing systems. It not only enable time-effective and accurate tests to carry out, but it also makes recreating measurement conditions possible, as well as to simulate heat exchange at particular segments of the manikin. Still, such a test result is a compromise between simplicity, low

costs and a real representation of all the processes influencing heat balance, which reflect in the clothing thermal insulation value [7].

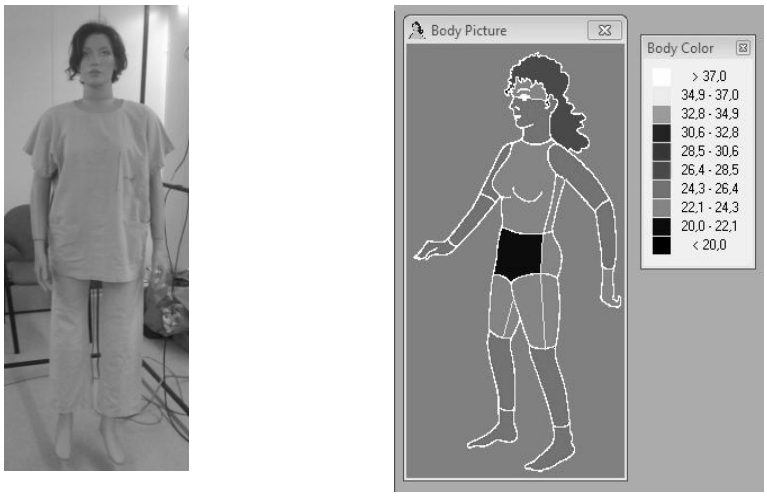
The aim of this study was to evaluate thermal comfort of medical clothing made of non-woven fabric.

2. MATERIALS AND METHODS

Twelve SMS (Spunbond/Meltblown/Spunbond) non-woven scrub suits from different commercial brands named as SS01 to SS12 were tested. Table 1 shows some characteristics, weight, thickness and air permeability, of these scrub suits
The thermal insulation of clothing was measured using a thermal manikin (Figure 1) with controlled skin surface temperature. This thermal manikin has a woman's body; its size and configurations are similar to an adult woman. It´s divided in 20 thermally independent sections and only sense dry heat transfer. Thermal manikin, positioned 0.1 m from the floor, kept standing with their legs and arms held in vertical position without any motion. The skin temperature was set, and during the test period maintained at 33 ± 0.1 °C. The tests were conducted at ambient conditions characteristic of an operating theatre, 20 °C ± 2 °C and 50% Rh.

Table 1. Characteristics of tested clothing

Scrub suit	Weight (g/m²)	Thickness (mm)	Air permeability (l/m²/s)
SS1	36	0.24	723.2
SS2	45	0.27	835.4
SS3	36	0.25	636.8
SS4	35	0.25	735.6
SS5	37	0.25	573.8
SS6	49	0.36	1824
SS7	37	0.27	521
SS8	36	0.25	858.8
SS9	43	0.33	3954
SS10	38	0.28	792
SS11	37	0.29	925.4
SS12	35	0.26	464



a b

Figure 1. Thermal manikin: photo of thermal manikin dressed with a scrub suit used on tests (a) and software body picture of thermal manikin and color legend of body segments temperature (b)

Data acquisition started after achieving stationary conditions and did not take more than 60 min. During the acquisition period, the heat flux and the skin temperature of each body part record every minute.

Total thermal insulation I_T (m².°C/W), is used to define the insulation from the skin surface to the environment. It was calculated according to global method, Equation 1, where T_{sk} [°C] is the mean skin temperature, T_0 [°C] is the room temperature, $\dot{Q}_s$ [W/m^2] the sensible heat flux of the manikin and f_i the relationship between the surface area of segment i of the manikin [8]. This is the general formula for defining the whole body resistance and the one that best fits the definition of thermal insulation expressed [9]. Furthermore, global method is less susceptible to significant variations to calculate thermal insulation.

$$I_T = \frac{\sum_i (f_i \times \bar{T}_{sk,i}) - T_0}{\sum_i (f_i \times \dot{Q}_{s,i})} \quad (1)$$

The effective clothing insulation (I_{cle}), consisting of the difference between I_T and I_a are calculated by the Equation 2, considering I_a is measured by operating the manikin nude:

$$I_{cle} = I_T - I_a \quad (2)$$

3. RESULTS AND DISCUSSION

Heat loss from body segments of manikin using different scrub suits can be seen in Figure 2. As expected, higher heat loss occurs in non-clothing segments, like hands, forearms and feet. Scull has the lower heat loss once that hair are thermal insulator, back side and pelvis also have lower value and they are attributed to t-shirt and trousers overlapping.

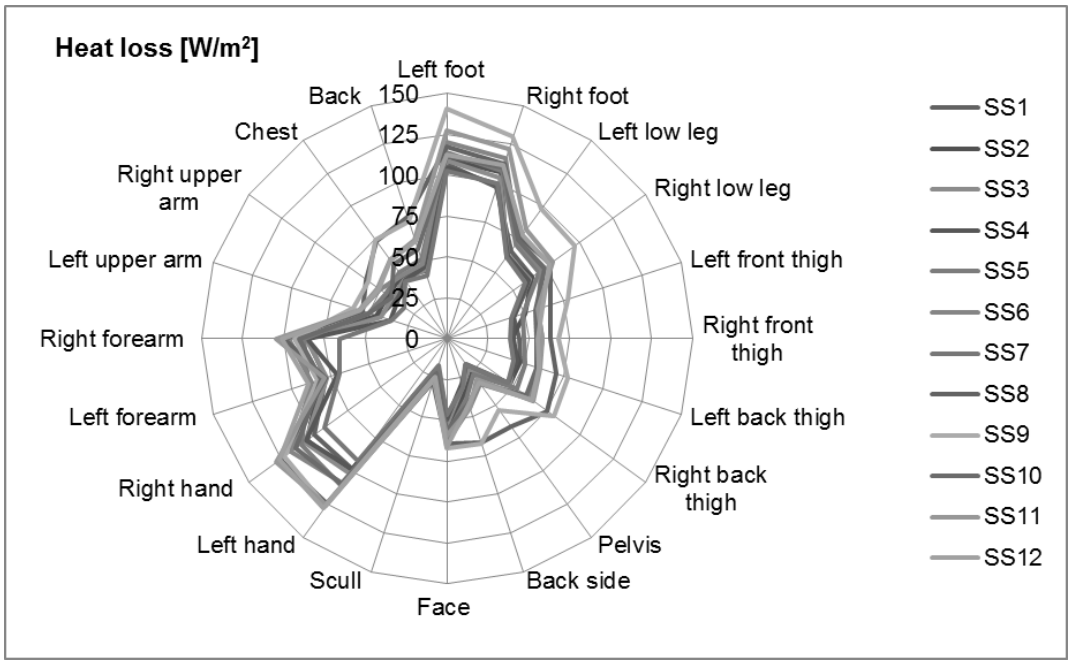


Figure 2. Heat loss from body section of manikin dressed with SS

The Table 2 shows total values of heat loss ($\dot{Q}_s$), total clothing thermal insulation (I_T) and effective clothing insulation (I_{cle}) from nude manikin and all tested scrub suits. In Table 2 can be seen that when thermal manikin is nude, the heat loss ($\dot{Q}_s$) has the highest value, 88.28 W/m^2 and, consequently, lower thermal insulation, 0.13 m^2.°C/W, because there is no barrier to heat propagation from manikin surface to environment. When thermal manikin is dressed with scrub suit, heat loss maximum decrease is around 39% and the minimum is 5% corresponding to the lower value of total heat loss measured attributed at SS7, with 53.81 W/m^2, and the higher is from SS9, with and 83.89 W/m^2, respectively. The heat loss can be closely relate to thermal insulation and they are inversely proportional parameters, in this way through heat loss values, total (I_T) can be calculated. To heat loss values of SS7 and SS9 we have the corresponding values of total isolation of 0.23 m^2.°C/W and 0.14 m^2.°C/W, respectively. SS8 have thermal insulation value very close from SS9, around 0.15 m^2.°C/W. Despite of SS9 being the scrub suit with higher thickness value, 0.33 mm , its thermal insulations is lower when compared with other scrubs, this can be explained by higher value of air permeability that allow a better heat exchanges between skin surface to environment.
When the effect of air layer thermal insulation is removed (I_{cle}), clothing thermal insulation decreases but show the same behaviour, Table 2.

Thermal insulation of clothing can also be express in Clo. The higher the value of Clo, the greater is thermal insulation. Clo value of one is defined as the amount of clothing required to a human being at rest to be comfortable at room temperature of 21 °C [6]. Following this, SS9 is the scrub suit with lower clo value and SS8 the clo value closer to that one that are defined as termically comfortable.

A statistical study was made and was concluded that the differences between scrub suits are statistically significant ($p < 0.5$) which means that thermal differences between scrub suits will be perceived by the user.

Table 2. Mean values of total heat loss, total and effective insulation of the 12 clothing tested on thermal manikin

Clothing	$\dot{Q}_s$	I_a/I_T		I_{cle}	
	W/m²	m².°C/W	Clo	m².°C/W	Clo
Nude	88.28	0.13	0.87	n.a.[a]	n.a.[a]
SS1	59.39	0.21	1.41	0.08	0.54
SS2	61.12	0.20	1.38	0.08	0.51
SS3	59.13	0.21	1.43	0.08	0.57
SS4	57.18	0.22	1.48	0.09	0.61
SS5	65.25	0.19	1.28	0.06	0.41
SS6	70.00	0.18	1.19	0.05	0.32
SS7	53.81	0.23	1.56	0.10	0.69
SS8	79.02	0.15	1.01	0.02	0.15
SS9	83.89	0.14	0.95	0.01	0.08
SS10	67.67	0.18	1.22	0.05	0.35
SS11	74.10	0.16	1.11	0.04	0.24
SS12	72.98	0.17	1.13	0.04	0.26

[a] not applied. Once I_{cle} is the effective clothing insulation, it is not applied to undressed manikin.

3. CONCLUSION

Thermal manikins provide a good estimate of the total dry heat loss from the body and the distribution of heat flow over the body surface; these measures were used to describe the thermal characteristics of clothing. Clothing thermal insulation differences are statistically significant ($p < 0.5$) which means the user will perceive thermal differences between scrub suits.

To overcome thermal stress situations of health professionals, surgical clothing needs to satisfy some requirements; they should be comfortable, breathable, keep the user in cool conditions and allow heat changes between the body and environment. In our study SS8 and SS9 had the better performance in keeping the thermal comfort, clo values closer to that one that are defined as termically comfortable.

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