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Assessment of Textiles for Use in Operating Theatres with Respect to the Thermal Comfort of Surgeons

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Abstract
Materials used to manufacture surgical clothing ensembles are characterised by high barrier-properties protecting surgeons and patients against germs. However, medical clothing made of those materials should not induce thermal stress. Such an uncomfortable sensation experienced by surgeons can decrease their psychomotor skills and, at the same time, adversely influence the way an operation procedure is carried out. The objective of this paper is to present a problem which affects the majority of surgeons: the too high thermal insulation of medical clothing ensembles, which results in thermal stress experienced by this professional group.

Key words: *medical protective clothing, thermal insulation, thermal manikin, medical standards.*

Introduction

Medical clothing for personnel working in an operating theatre must be made of materials resistant to the permeation of blood and other body liquids, as well as to germs transferred by them. Moreover it has to meet the requirements of the PPE (Personal Protective Equipment) directive [1] and harmonised Standard EN 13795 1-3 [2 - 4]. The aforementioned standard, in annex A [2], mentions the need of assessing materials and medical clothing also in terms of ensuring thermal comfort, i.e. "surgical clothing should be designed in a manner which will minimise physiological stress related to work in this type of clothing". Furthermore, the standard points to the need for carrying out an assessment of thermal resistance, air permeability, water steam-resistance and flexibility. However, no concrete values of the parameters mentioned are given.

One of the establishments which deals with the testing of medical clothing is the Hohenstein Institute, Germany. Scientists from this Institute introduced a certificate called the Hohenstein Quality Label 'Breathability", which is granted to medical clothing whose steam water resistance, measured on a skin model compliant withStandard EN 31092 [5], is below 17 m^{2}Pa/W. This value was set on the basis of experiments conducted by Bartels [6], which established a correlation between the steam water resistance of barrier material and the maximum temperature of the environment at which the user continues to experience thermal comfort. Apart from steam water permeation, the thermal comfort of the user of medical clothing depends, above all, on the thermal insulation and its adjustment to environmental conditions existing in an operating theatre during a surgical operation. Thermal insulation tests performed at the Central Institute of Labour Protection – National Research Institute on surgical clothing ensembles in the past years, selected in accordance with WHO recommendations and the requirements of EN ISO 9001 [7], showed that their thermal insulation lies within the limits: 0.54 ± 0.01 clo - 0.95 ± 0.01 clo [8]. At the same time, it was determined that surgeons will experience thermal comfort when the temperature in an operating theatre amounts to 20 - 24 °C and their clothing is composed of shoes, cotton socks and a surgical ensemble made of nonwoven fabric, similar to cotton, containing viscose fibres of good air and water steam permeability. Likewise, thermal comfort can also be achieved in the temperature range of 16 - 20 °C, when the surgical outfit includes the above-mentioned garment in combination with a thermoplastic 2-layered hygienic surgical gown, a made of nonwoven fabric and polypropylene foil, which is liquid-proof.

Due to the fact that medical clothing made of cotton material is being gradually taken out of use and in light of the need signalled in the standard [2] to search for assessment methods which take into account the thermal comfort of medical clothing, the authors of this paper decided to conduct their own tests. Contrary to the testing of materials carried out by the Hohenstein Institute, the authors performed tests on full ensembles of medical clothing. Objective research results were supplemented by an analysis of the physiological parameters of surgeons as well as their subjective assessment.

Objective of the study

the main goal of this study was to assess the thermal insulation of modern materials used in manufacturing medical clothing in the context of thermal comfort experienced by surgeons wearing a full clothing ensemble. Furthermore, in order to confirm our considerations, it was decided to conduct a case study – a physiological examination of surgeons using selected clothing ensembles in real-life surgery – a urological procedure. Due to the difficulty of carrying out a medical examination during real-life surgery, the number of subjects was limited to 2 surgeons.

Material and methods

in order to examine the thermal insulation of surgical gowns against the requirements of thermal comfort, the thermal parameters were tested in operating theatres. Thermal insulation was measured for selected ensembles of medical clothing, and next the results were compared with guidelines on the thermal insulation required to achieve thermal comfort when performing work in an operating theatre.

Additionally the physiological parameters of surgeons were assessed during the performance of surgery in a given clothing ensemble.

Microclimate measurements

The microclimate in an operating theatre was tested with the use of MM-01 microclimate meters, located near a surgeon (measurement points 1 and 2). The tests were performed during the real time of a surgical procedure. Measurements were

Figure 1. Thermal manikin wearing ensembles of surgical gowns (A – surgical underwear and ensemble A, B – surgical underwear and ensemble B; C - surgical underwear and ensemble C; D - surgical underwear and ensemble D).

made in 2 operating theatres (A and B) of the Specialised Hospital in Warsaw, which has environmental conditions compliant with Polish regulations [9].

Measurements of the microclimate parameters were determined by the PVM index (which represents the overall thermal sensation). PVM is described with the following values: -3 cold, -2 cool, -1 slightly cool, 0 – neutral, +1 slightly warm, +2 warm, +3 hot. Thermal comfort ranges within the limits -0.5 < PMV < +0.5 [11]

Testing ensembles of surgical clothing

Four clothing ensembles and one underwear ensemble used with surgical gowns were selected for the purpose of this study (***Figure 1***). They represented typical disposable medical clothing manufactured according to the requirements of EN ISO 9001 [7] and EN 13795 [2 - 4]:

- *Ensemble A* - barrier surgical gown for multiple use, worn during standard risk operations, made of polyester cloth with the addition of carbon fibre. The gown's critical area (front and sleeves) is made of liquid proof fabric of higher resistance (weight 300 g)
- *Ensemble B* - barrier surgical gown for multiple use, worn during high risk operations, made of polyester cloth with the addition of carbon fibre on the back. The gown's critical area (front and sleeves) is made of laminate with a PTFE (polytetrafluorethylene) membrane
- *Ensemble C* – cotton surgical gown for single use (in theory, whose use is discontinued, yet it is still worn in operating theatres)
- *Ensemble D* - lead surgical apron, Pb 0.5 mm, used to make x-ray pictures (mass 3.349 kg).

The surgical underwear applied in all the test variants was identical - made of polyester cloth with coal fibre, ensuring humidity absorption from the skin's surface.

Thermal insulation measurements

All the experiments were performed on a thermal manikin and took place in a walk-in climatic chamber. The thermal insulation of the ensembles was determined on a thermal stand, a stationary manikin type TM 3.2/R110, named 'Diana', [8]. Measurements were taken in accordance with Standard EN ISO 15831 [10]. Each measurement was repeated three times with the assumption that the climatic chamber had the following environmental parameters: air temperature (t_a) 20 ± 0.1 °C, air velocity (v_a) 0.4 ± 0.05 m/s, and relative humidity (RH) 45 ± 1%. All the measurements were taken at 1-second intervals, and subsequently a 1-minute average value was calculated and recorded. The results were constantly displayed to help evaluate the steady state.

Table 1. *Physical characteristics of the subjects. (*A_{Du} Body area by Hardy and DuBois [13]).*

Parameter	Subject 1	Subject 2
Weight, kg	81	103
Height, m	1.78	1.80
A_{Du}*, m^2	1.99	2.22
Age, years	38	45

Case study with the participation of surgeons

In the case study experiments in an operation theatre, two surgeons were subjected to experiment. Both men were in a good physical state, the physical characteristics of which are presented in ***Table 1***.

Measurements of the surgeons' skin temperature were taken at 4 measurement points (a sensor closely fastened to the skin's surface) as well as measurements of the temperature and humidity between the skin of the subject and his clothing (sensors were place on the stand 2 mm away from the skin's surface) (***Figure 2***). The experiments were performed with the use of a HygroLab2 (manufactured by Rotronic AG) and cardio monitor FX 2000 (manufactured by Emtel). The testing procedure was approved by the Committee for Research Ethics.

Each surgeon took part in the experiment four times, i.e. in each of the four clothing ensembles:

- surgical underwear, cotton gown (C) and lead gown (D)
- surgical underwear and cotton gown (C)
- surgical underwear and polyester gown (A)
- surgical underwear and polyester gown (B).

Results

Results of experiments on the thermal environment in an operating theatre

On the basis of the measurements made in two operating theatres, the PMV index was specified at two measurement locations corresponding to those where the surgeons stood at the operating table (1 and 2) in two operating theatres (A and B) of the hospital (***Table 2***). The PMV was calculated on the basis of the programme available in the ISO 7730 standard [14]. The PMV index values calculated for surgeons wearing each of the test surgical clothing ensembles showed that their

Table 2. Air parameters in operatiing theatres (t_a – ambient temperature, RH – relative humidity, v_a – air velocity).

Operating theatre	Measurement point	t_a, °C	RH, %	v_a, m/s
A	1	22.9	54.6	0.1
	2	24.6	66.0	0.0
B	1	22.9	54.6	0.0
	2	24.6	66	0.0

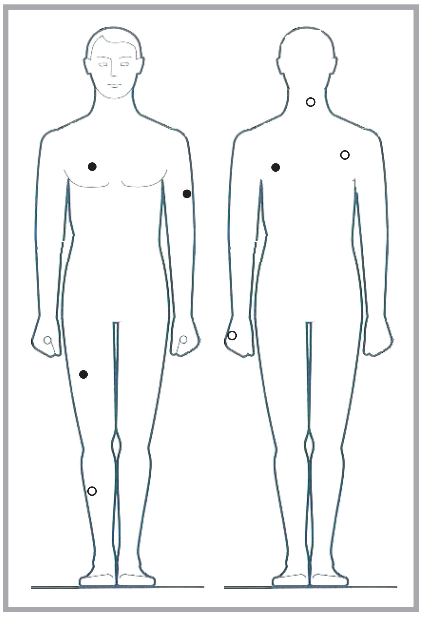

Figure 2. Distribution of sensors for the measurement of skin temperature (o – t_{skin}) *as well as the temperature and humidity in the area between the clothing and the body* (• – t_s, *and* RH_s).

thermal sensation is defined at a PMV level ranging between +0.75 and +1.25. From this, it follows that surgeons assess the thermal environment from "slightly warm" to "warm". As for the patient on which surgery was performed, the PMV index amounted to -2 ('cool' thermal sensation). The results obtained showed that limiting control to thermal environment parameters only does not ensure the patient nor medical personnel thermal comfort at the same time. For this reason the only possibility of providing a surgeon with thermal comfort is to select the properties of the clothing he/she uses in an appropriate manner.

Figure 3 presents a graph with values of the PMV index determined on the basis of the thermal insulation of the clothing ensemble used. These values were established considering the arithmetic mean of the air parameters measured for the operating theatres. On the basis of the graph, it can be observed that approaching conditions considered comfortable is only possible in the case of surgical clothing within the value range of 0.028 m²K/W and 0.124m²K/W

Results of tests on the thermal insulation of surgical clothing

The results of tests examining the thermal insulation of the given clothing ensembles (surgical underwear and gown) and surgical underwear are presented in ***Table 3***. It can be concluded that the insulation value of particular ensembles of surgical underwear and surgical gowns are comparable, with the highest insulation value being noted in the case of the cotton gown ensemble. Furthermore It was noted that the thermal insulation of surgical underwear and lead gowns is lower than ensembles with other surgical gowns, which would indicate that a lead gown constitutes some sort of load for the surgeon's body, which is only due to its weight (3.3 kg) and not because of its high insulation. The results have also demonstrated that the highest insulation is possessed by surgical underwear used under all types of surgical gowns.

Comparison of the results obtained with ***Figure 3*** revealed that clothing ensembles currently used are characterised by too high insulation values in relation to the value required for maintaining thermal comfort. The highest thermal value is possessed by surgical clothing worn under a surgical gown; therefore, for thermal comfort to be achieved, it is necessary to decrease the insulation value of surgical underwear to ca. 0.08 m²K/W

Case study experiments

Figures 4 - 6 show differences in the physiological parameters of both surgeons (mean skin temperature, mean temperature and humidity in the space between the skin and the inner layer of the clothing, as well as the perspiration rate) when performing surgical treatment in four clothing ensembles. The highest increase in the mean skin temperature during an operation was observed with surgeon 1 wearing surgical underwear and a cotton gown (C), whereas with surgeon 2 this occurred during an operation conducted in a polyester gown. The highest increase in the mean temperature in the area between the skin and clothing was observed when surgeon 1 performed an operation wearing surgical underwear and a cotton gown (C), whereas with surgeon 2 this occurred during surgery in surgical underwear and a polyester gown (B). The highest increase in mean humidity in the area between the skin and clothing was observed when surgeon 1 performed surgical treatment using surgical underwear and a cotton gown (C), whereas with a surgeon 2 this occurred during an operation in surgical underwear and a cotton gown together with a lead apron (C and E).

Following these findings, it can be concluded that the objective maximum thermal discomfort experienced by surgeon 1 occurred when performing surgical treatment in a cotton gown (C) and was slightly smaller in a medical clothing ensemble with a polyester gown equipped with a PTFE membrane (B). As regards thermal comfort, it was maintained during the performance of surgery in a polyester gown (A). With regard to surgeon 2, the highest thermal discomfort level appeared during an operation performed in a polyester gown with a PTFE membrane (B); it was smaller in a cotton gown (C). Under none of the experiment variants was thermal comfort achieved with surgeon 2. In the case of both surgeons, a considerable increase in humidity in the area between the skin and clothing was noted, attributed to insufficient sweat transfer from the surface of the surgeon's body.

The results of the case study revealed no major difference in the clothing ensembles examined. However, they have confirmed the need for further study into the thermal comfort of surgeons performing surgery in protective clothing. Furthermore, the results have shown weak points in the clothing structure e.g. a considerable increase in the mean skin temperature by almost 2 °C and in the humidity between the skin and clothing by 40%. This information should be used by clothing

Table 3. *Thermal insulation for given ensembles of surgical clothing (thermal insulation nomenclature of EN ISO 15831).*

Type of clothing	Thermal insulation, m²K/W	
	parallel	serial
Surgical underwear + polyester gown (ensemble A)	0.151	0.202
Surgical underwear + polyester gown (ensemble B)	0.160	0.218
Surgical underwear + cotton gown (ensemble C)	0.166	0.231
Surgical underwear + lead gown (ensemble D)	0.149	0.193
Surgical underwear	0.123	0.154

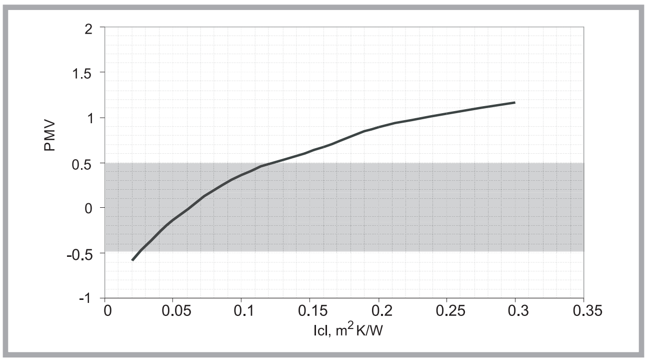

Figure 3. Changes in the PMV index with respect to the thermal insulation values of clothing ensembles (grey field marks the thermal comfort zone).

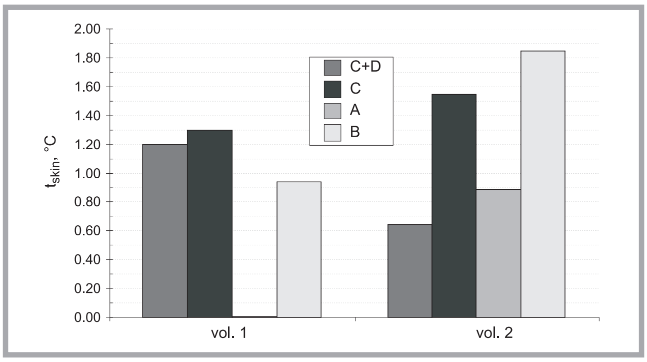

Figure 4. Increase in the mean skin temperature of a surgeon (t_{skin}) during a surgical operation for each variant of the experiment.

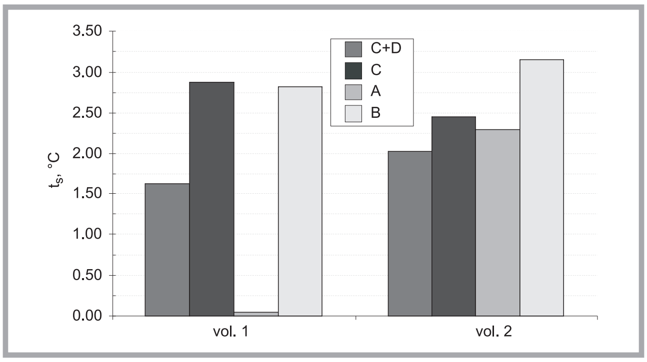

Figure 5. Increase in the mean temperature in the area between the skin and inner layer of a surgeon's clothing (t_s) during a surgical operation for each variant of the experiment.

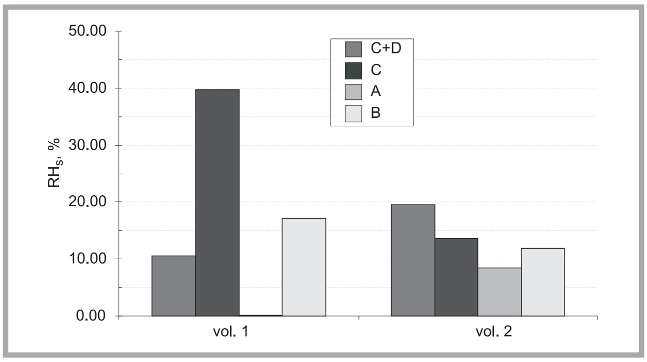

Figure 6. Increase in mean humidity in the area between the skin and inner layer of a surgeon's clothing (RH_s) during a surgical operation for each variant of the experiment.

designers as a guideline when creating new types of protective garment.

Conclusions

It is crucial that surgical clothing protect the surgeon and patient from infecting each other. It follows that the key parameters which need to be observed, in compliance with Standard EN 13795 [2 - 4], include the following features: germ-resistance, pollen-resistance, cleanliness, liquid-resistance, and material resistance to bagging and stretching. It should also be borne in mind that surgical work is performed in a high air temperature environment, requiring psycho-physical fitness.

On the basis of the experiments conducted, the following conclusions were drawn:

1. The clothing ensembles tested are characterised by too high thermal insulation in relation to the value required for maintaining thermal comfort conditions. The highest thermal insulation is characterised by surgical underwear made of polyester cloth with carbon fibre, which, in theory, was supposed to be characterised by high humidity absorption.
2. Air parameters are not appropriate to ensure the surgeon and patient thermal comfort at the same time. Comfort conditions for the surgeon can be achieved only when surgical clothing insulation has a value within a range of 0.028 m^2K/W (0.18 clo) and 0.124 m^2K/W (0.8 clo).
3. On the basis of the results of the physiological parameters of surgeons in this case study, it was determined that in all the types of clothing ensembles tested, the skin temperature as well as the temperature and humidity in the area between the skin and clothing would increase.
4. The most negative assessment of the thermal environment was noted during experiments in a cotton gown and lead gown protecting against X-rays (used more and more often due to the development of minimally-invasive surgical techniques).

The results obtained leave no doubt that work which is performed in medical clothing made of latest technology materials entails considerable thermal discomfort for a surgeon. The unduly high insulation of medical clothing ensembles and too low absorption of surgical inner clothing result in an increase in skin temperature, which also induces a high accumulation of humidity in the area between the skin and clothing, which can result in a worsening of the psycho-physical condition of surgeons.

Given that the correct course of a surgical procedure depends, to a large extent, on the surgeon's mental condition, inter alia, on their ability to maintain constant vigilance and concentration [12], the elimination of cotton gowns was an important step towards improving safety in an operating theatre. However, as our experiments have shown, medical clothing ensembles made of modern materials can still bring about the risk of thermal stress.

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