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Thermal Comfort Properties of Cotton and Nonwoven Surgical Gowns with Dual Functional Finish

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Abstract. The purpose of this study was to evaluate thermal comfort properties of surgical gowns made of dual functional finish cotton and nonwoven fabrics which have barrier properties of blood and micro-organism. Four types of surgical gowns, which were made of nonwoven fabrics with finish or without and were made of cotton with finish or without, were tested. The thermal insulations of four surgical gowns were measured with thermal manikin. Subjective experiments on thermal comfort, skin temperature and clothing microclimate were conducted. Six male subjects, between 26 and 28 years age old, participated in the wear trials tests. Typical activities for surgeons in the operation theater were simulated during the experimental sessions. Air temperature in a climate chamber was kept at 22°C and its humidity was 60%RH. Air velocity was controlled at less than 0.15 m/s. Inner radiant temperature was almost equal to the air temperature. Basic thermal insulation of the dual functional finished nonwoven surgical gown was 0.87 clo, which was slightly higher than that of untreated (0.84 clo). However, the skin temperature of the subject wearing a dual functional finished surgical gown was significantly lower at $P<.05$. When the subject wears the dual functional finished gown, the amount of sweating was less than that when wearing untreated. Microclimate temperature and humidity of dual functional finished surgical gown were lower than untreated and it was statistically significant. There was no significant difference in subjective humid and overall comfort sensation between finished and untreated ones. Thermal sensation of dual functional finished one was significantly different from untreated one only during the first exercise. The results of this study indicate that the dual functional finish surgical gown allowed heat to be transferred from the skin of subject to the atmosphere better than untreated. The nonwoven surgical gown showed no difference in comfort properties from cotton one.

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Keywords: surgical gown, thermal comfort, nonwoven, thermal insulation, dual functional finish

Introduction

Surgical gowns have been worn to protect patients from surgical staff and objects during an operation. They were conventionally manufactured from cotton woven fabrics. However, Beck and Collette (1952) noted severe limits to the worthiness of the conventional gowns being used by surgeons. In addition, blood routinely covers gowns during surgery and it often contaminates surgeons' undergarments and skin. Hence, surgical gowns not only have to protect the patient from surgical staff, but also have to protect the surgical team from a patient's infectious blood and other body fluids (Smith and Nichols, 1991). In many hospitals, there has been a transition from the conventional cotton woven gown to one made of nonwoven or film coated fabrics which have barrier properties. However, the choice of gown was determined mainly by considerations of comfort and cost (Schwartz and Saunder, 1980). Many operating room personnel still prefer the traditional cloth gowns which they consider more comfortable, cooler, and more durable.

In a normal situation, human beings can restore a correct balance of heat exchange by modifying the environment. In an operating room, however, this ability is lessened. Once a surgeon wears a sterile gown and gloves at the operating table, she/he cannot remove them even if she/he feels too warm. This warmth can be experienced even though the room temperature is 20-23°C and relative humidity is 40-60% (Schlegel et al., 1988). Moreover the heat accumulated because of the lack of skin evaporation, which may be actually dangerous. Therefore, surgical gowns should provide sufficient heat transfer characteristics that the skin surface temperature remains within comfortable range. Comfort should be an essential, since the surgeon should be freed of the work necessary to overcome the limitations of his accomplishment, if he is to expend his physical reserves in accomplishing the objectives of his activity. In addition, there must be sufficient flexibility to provide comfort during activity, as well as the ability to form the material into gowns, caps, and other items (Beck and Carlson, 1963).

Several studies have been carried out concerning the efficiency of surgical gowns. Schwartz and Saunders (1980) compared the degree of microbial penetration into woven and nonwoven surgical gowns and paid attention to such practical considerations as comfort in choosing a surgical gown for the operating room. They demonstrated that a woven gown cannot serve as a barrier to microbial migration, however spunlaced nonwoven found somewhat better acceptance than that of woven. Most of the reports concerning the surgical gown (Beck, 1981; Schwartz and Saunder, 1980; Smith and Nichols, 1991) dealt with the barrier materials, but little is known about how the barrier materials affect thermal comfort. Moreover, the comfort properties of the surgical gown have been overlooked in material design, so the surgeon's gown still poses a problem.

We conducted experiments to develop new materials for the surgical gown which have antimicrobial and blood repellent properties by dual functional finish with antibiotic and fluorochemical. The dual functional finished fabrics showed a high reduction rate in the number of colonies and little blood penetration (Cho and Cho, 1995). Thus, it is necessary to examine the objective and subjective thermal comfort properties of these surgical gown materials. The purpose of this study is to investigate the thermal comfort aspects of these surgical gowns. This study was conducted to evaluate the effect of dual functional finish on thermal resistance of surgical gowns using thermal manikin and to investigate subjective thermal comfort sensation and microclimate inside clothing.

Methods

Clothing

Four experimental surgical gowns were made for this study. Two of the surgical gowns were made with untreated cotton (CU) and spunlaced nonwoven fabrics (SU), and the other two were made with dual functional finished fabrics with fluorochemical and antibiotic (CT, ST). Fig. 1 shows the experimental surgical gown which is same as a surgical gown commonly used in an operating room, but the length is slightly shorter than conventional ones. The physical characteristics of experimental clothing are given in Table 1. The clothing was stabilized in a climate chamber before each experiment.

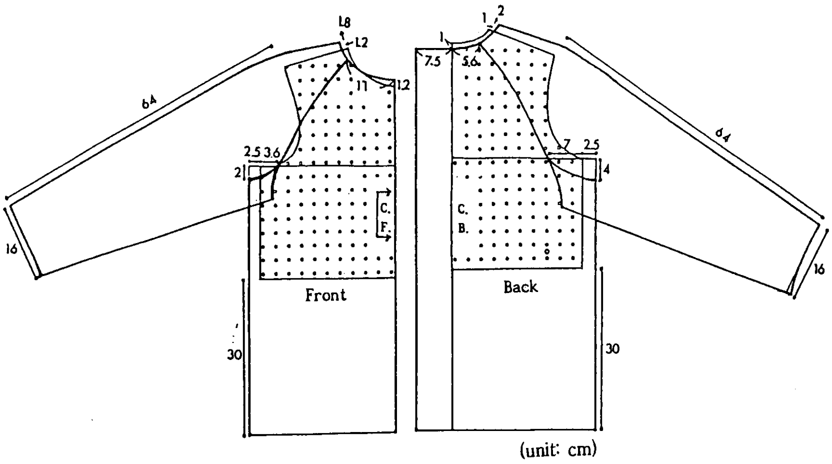


Fig. 1. Structure of experimental clothing.

Table 1 Characteristics of experimental clothing

Clothing	Fabric	Dual functional finish	Thickness (mm)	Weight (g/m^2)	Air permeability (ft^3/ft^2. min)	Water vapour permeability (mg/cm^2. 24 hr)	Flexural rigidity (mg/cm)
CT	Cotton 100% Muslin	Finished	0.40	180	70.38	13.14	10.46
CU	Cotton 100% Muslin	None	0.41	200	85.73	11.82	68.04
ST	Woodpulp/polyester 55/45% spunlaced nonwoven	Finished	0.34	71	46.98	13.51	2.32
SU	Woodpulp/polyester 55/45% spunlaced nonwoven	None	0.35	63	59.34	15.89	22.66

Thermal resistance of clothing

The thermal resistance of experimental clothing was measured by using a thermal manikin with controlled skin surface temperature. The manikin was composed of 16 body parts and heating element was placed at the outer surface of the manikin (Tanabe et al., 1994). Fig. 2 is a picture of the thermal manikin wearing experimental clothing (named Anne). Each part is controlled separately to approximate the skin temperature distribution of a human being and measured by a computer outside the manikin. The manikin with a surgical gown ensemble composed of under wear, scrub suit and surgical gown was exposed in a climate chamber at Ochanomizu University. In the climate chamber operative temperature was controlled at 22 ± 0.1°C, and humidity was at 60 ± 2%RH. Air velocity in the climate chamber was less than 0.15 m/s, which was the same as that in an operating room. Inner radiant temperature was equaled to the air temperature. After steady state condition was confirmed, the electric consumption and skin temperature were monitored every one minute. At the same time air temperatures and globe temperature were recorded. Mean of measured values during five minutes were used for the further analysis. The basic clothing insulation value (*Icl*) was calculated from the following equations. Equation (4) is introduced by McCullough et al. (1985).

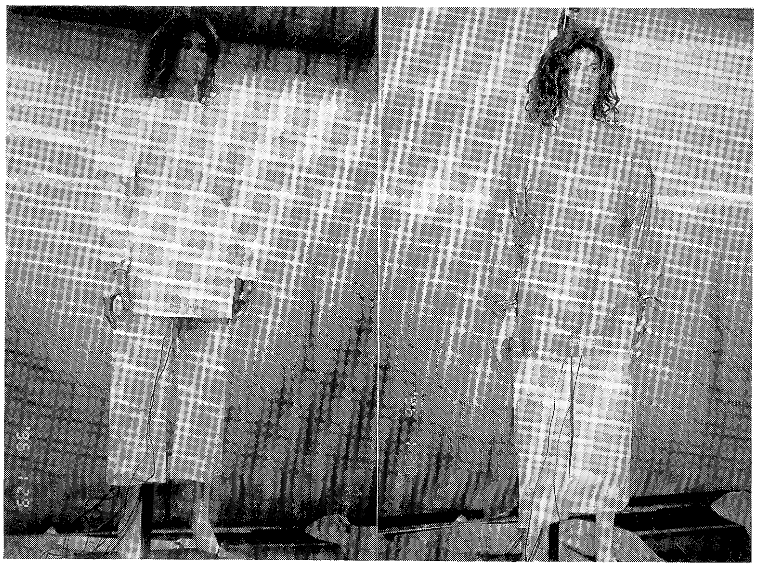
$$It = (ts, cl - to)/0.155\ Qt \qquad (1)$$
$$Ia = (ts, n - to)/0.155\ Qa \qquad (2)$$
$$Icl = It - Ia/fcl \qquad (3)$$
$$fcl = 1 + 0.3\ Icl \qquad (4)$$

Where,
- *Ia*: thermal resistance of air layer on skin surface (clo)
- *Icl*: basic clothing insulation (clo)
- *It*: total clothing insulation (clo)
- *Qa*: sensible heat loss from skin surface at nude (W/m^2)
- *Qt*: sensible heat loss from skin surface (W/m^2)
- *fcl*: clothing area factor (−)
- *to*: operative temperature (°C)
- *ts*: mean skin surface temperature (°C)
- *cl*: with clothing (suffix)
- *n*: at nude (suffix).

Subjective experiments

Six volunteers, healthy male subjects, between 26 and 28 years age old, participated in this study. Each subject attended two experiments. The physical characteristics of the subjects are described in Table 2. Scheffe's paired comparison method was used with surgical gowns as presented in Table 3. All subjects wore cotton 100% knit under pants, scrub suit (100% cotton woven fabric, short sleeved and colorless T-shirt and pants, loose, fitted at waist), socks (ankle length), and experimental surgical gown. The clothing worn by each subject was the same type of clothing worn by operating room personnel.

Before the experiment, the subject was acclimatized in a climatic chamber for 1 hour. During this time the subject was dressed in experimental clothing and then thermistor and humidity sensor (Takara Thermistor, THP B3) were attached. The subjects followed a pattern of



(dual functional finished cotton surgical gown) (dual functional finished nonwoven surgical gown)

Fig. 2. Picture of thermal manikin with experimental clothing made with cotton and nonwoven fabrics.

Table 2 Physical characteristics of subjects

Subject	Age (years)	Height (cm)	Weight (kg)	Skin surface area (m^2)
S1	26	170	60.55	1.70
S2	26	173	62.89	1.75
S3	26	170	57.61	1.66
S4	28	172	63.48	1.75
S5	26	167	60.45	1.68
S6	26	170	62.50	1.72
Mean	26	170	61.24	1.71

Table 3 Experimental design

	Clothing			
Subjects	CT	CU	ST	SU
S1	X	X		
S2		X		X
S3		X	X	
S4	X			X
S5	X		X	
S6			X	X

Table 4 Subjective comfort sensation scales

Sensation rate	Thermal	Humidity	Comfort
1	cool	very dry	very comfortable
2	neutral	dry	comfortable
3	slightly warm	slightly dry	slightly comfortable
4	warm	indifferent	indifferent
5	slightly hot	slightly moist	slightly uncomfortable
6	hot	moist	uncomfortable
7	very hot	very moist	very uncomfortable

exercise and rest transients consisting of 30-min quick walking (7.0 km/h) on a motor-driven treadmill (EX I), 10-min rest in a chair (RE I), 15-min quick walking (EX II), and 10-min rest in a chair (RE II). The exercise rate in walking was 6.1 met and the relative (per kg body weight) oxygen uptake of subject during walking was 21.3 ml/(kg.min). When the assumed energy metabolism of the walking and resting period is added, total energy expenditure can be estimated at 249 W/m^2. This work load was chosen as a typical mean time and work rate of actual operating (Fanger, 1982).

Skin temperature and clothing microclimate were monitored every minute during the experiment. Six skin thermistors were attached to the subject's: 1-forehead; 2-chest; 3-forearm; 4-thigh; 5-leg; 6-back. Mean skin temperature (t_{sk}) was calculated by averaging the temperature using the fellow formula: t_{sk}={9.8 (forehead) + 32.8 (chest) + 19.6 (forearm) + 17.2 (thigh) + 20.6 (Leg)} × 1/100 (Kurata, 1954). The microclimate temperature and humidity inside clothing were measured at the chest and back by thermistor and humidity sensors. They were attached on inner layer surface of scrub suit to be placed in same distance from skin.

In order to assess the total amount of sweat (w_1) secreted in the course of the experiment, the subjects were weighed in the nude before and after the experiment with an accuracy of ± 5 g. The amount of sweat entrapped at the end of the experiment in the surgical gown and scrub suit was calculated as the weight difference before and after the experiment (w_2). For estimating evaporative heat loss from skin surface (E_{sk}) of subject, total latent heat loss (E) and evaporative heat loss from respiration (E_{res}) were calculated from the amount of sweat evaporated from skin and rate of metabolic heat production (M). E_{sk} was calculated from the following equations (ASHRAE, 1993):

$$E_{sk} = E - E_{res}$$

$$E = (w_1 - w_2) * h_{fg}$$

$$E_{res} = [0.0173M\,(5.87 - Pa)]/A_D$$

where,

A_D: surface area of nude body (m^2)
E: total latent heat loss (W/m^2)
E_{res}: evaporative heat loss from respiration (W/m^2)
E_{sk}: evaporative heat loss from skin (W/m^2)
Pa: water vapour pressure in ambient air (kPa)
h_{fg}: heat of vaporization of water (kJ/kg)
w: amount of sweat (g)

The subjective rating of the thermal, humidity and comfort sensation were obtained during the experiment. The subjects answered at 5-min intervals using 7 point scales of subjective sensation as shown in Table 4. The scales were placed in front of the treadmill and answers were recorded by the assigned number.

The results of both the objective and subjective data were statistically tested using a statistic program (SAS) for personal computer. Analyses of variance (ANOVA F-test) and Duncan's multiple range test were applied for the data of skin temperature, clothing microclimate and subjective sensation.

Results

Thermal resistance of experimental clothing

Thermal resistance of the experimental clothing are

Table 5 Thermal resistance of experimental clothing

Clothing	ts (°C)	Qt (W/m^2)	to (°C)	Ia ; It (clo)	Icl (clo)
CT-Ensemble	33.5	55.8	22.1	1.32	0.82
CU-Ensemble	33.5	57.1	22.1	1.29	0.78
ST-Ensemble	33.5	53.4	22.2	1.37	0.87
SU-Ensemble	33.5	55.4	22.0	1.34	0.84
Nude	31.4	95.1	22.0	0.64	-
Scrub suit	32.1	65.4	22.1	0.98	0.43
Under wear	31.6	90.3	22.1	0.68	0.07

presented in Table 5. The basic clothing insulation (*Icl*) of CT was 0.82 clo, which was slightly higher than that of CU (0.78 clo). The basic clothing insulation of ST was 0.87 clo, which was slightly higher than that of SU (0.84 clo). The difference in basic clothing insulation value between dual functional finished and untreated for nonwoven and cotton were very similar as 0.04 clo for cotton and 0.03 clo for nonwoven. Regardless of finish, the nonwoven surgical gown ensemble showed slightly higher basic clothing insulation than cotton. The basic clothing insulation of the scrub suit and underwear were 0.43 clo and 0.07 clo respectively.

Skin temperature

The mean skin temperature (t_{sk}) of three subjects for each clothing ensemble was plotted in Fig. 3. The trend of mean skin temperature curves of surgical gowns were very similar. However, start values of the mean skin temperature were different from each other, so the changes of mean skin temperature from initial value were shown in Fig. 4. This took place at different rates depending on the surgical gowns at P<.01. The average mean skin temperature of the subjects wearing ST decreased during EX I and they were much lower than those of the subjects wearing SU. The t_{sk} of CT was lower than that of CU during EX II and RE II, even though those of CT were nearly same as those of CU during first exercise (EX I). The surgical gown/period, exercise and rest, interaction were statistically significant at P<.01. It indicated that over a protocol time period, there was a time related difference among the surgical gowns.

Fig. 5 shows the skin temperature at back ($t_{sk\text{-}b}$) for each clothing ensemble of three subjects. The skin temperature at back were higher than t_{sk} and their rate of change according to exercise and rest was greater. The skin temperatures at back were significantly lower with wearing CT and ST than those with CU and SU.

Clothing microclimate

The microclimate temperatures at chest ($t_{cl\text{-}c}$) and at back ($t_{cl\text{-}b}$) of surgical gowns were presented in Figs. 6 and 7. The trend of $t_{cl\text{-}b}$ curves was similar to that of skin temperature (see Fig. 5), but that of $t_{cl\text{-}c}$ was different

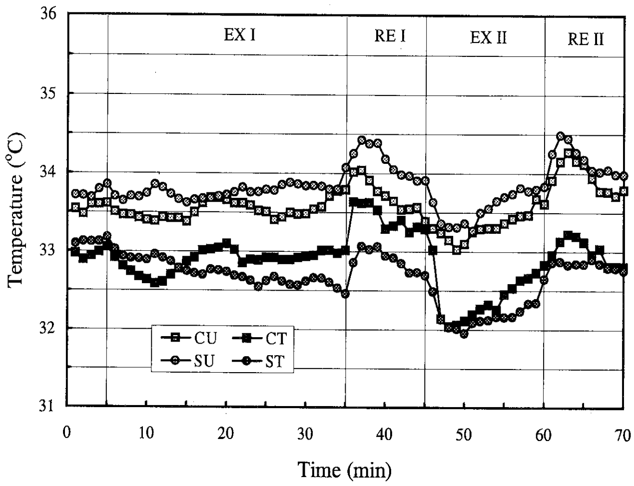


Fig. 3. Mean skin temperature of three subjects during exercise and rest for four experimental clothing. CU: Untreated Cotton, CT: Dual Functional Finished Cotton, SU: Untreated Nonwoven, ST: Dual Functional Finished Nonwoven, EX I: First Exercise Period, EX II: Second Exercise Period, RE I: First Rest Period, RE II: Second Rest Period.

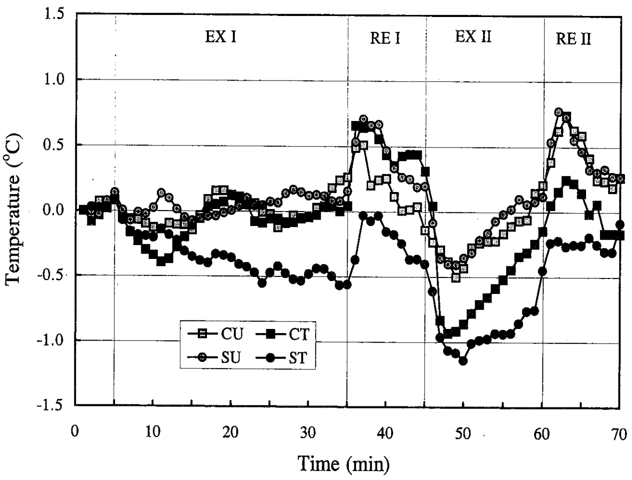


Fig. 4. The difference of mean skin temperature of three subjects during experiment. Abbreviations, see Fig. 3.

from its skin temperature. The microclimate temperature at chest and at back with CT were significantly lower than that of CU during EX I at P<.05. The microclimate temperature with ST was significantly lower than that with SU at back through all periods and at chest except EX I. There is no significant difference of $t_{cl\text{-}b}$ between CU and SU. The microclimate temperature of ST was lower than that with CT at P<.05.

Microclimate humidity (H_{cl}) of the surgical gown ensemble at chest was presented in Fig. 8. Hcl of four surgical gowns showed similar patterns of change. At the beginning of EX I microclimate humidity was at the range of 25 to 40%RH. When the exercise began, H_{cl} continued to increase very steeply for 15 to 20 minute, and it

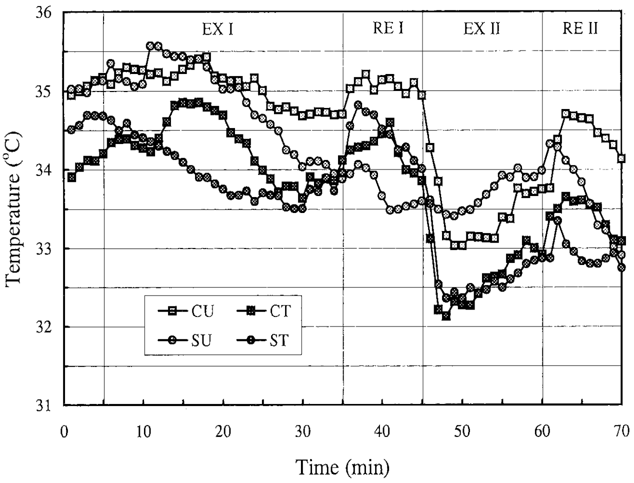


Fig. 5. Skin temperature of three subjects at back during exercise and rest for four experimental clothing. Abbreviations, see Fig. 3.

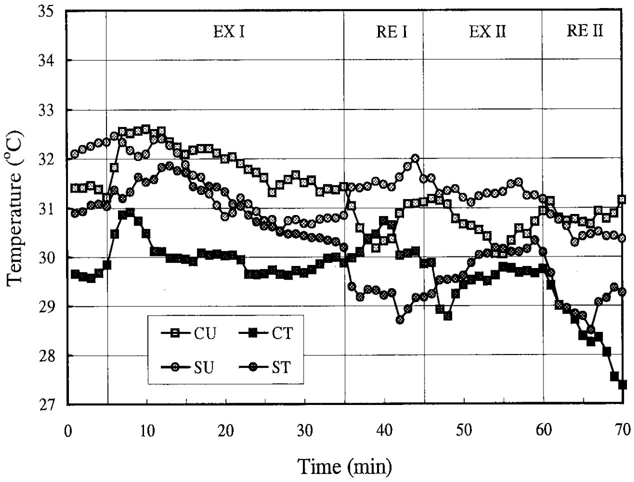


Fig. 6. Clothing microclimate temperature change at chest during exercise and rest four experimental clothing. Abbreviations, see Fig. 3.

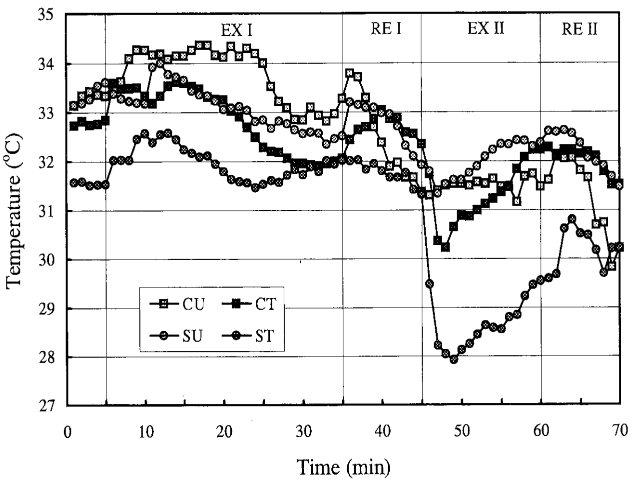


Fig. 7. Clothing microclimate temperature change at back during exercise and rest four experimental clothing. Abbreviations, see Fig. 3.

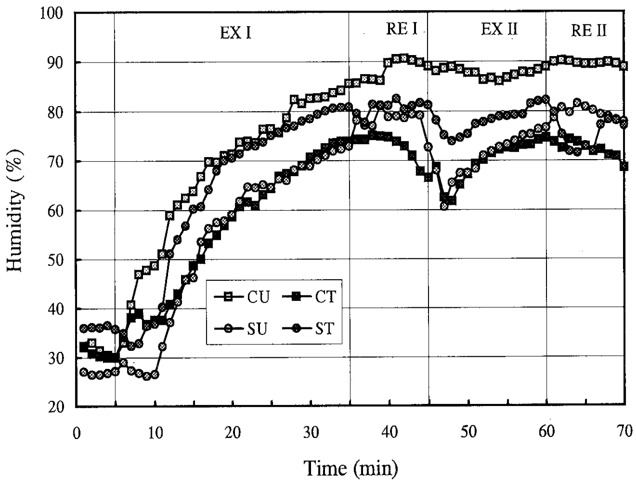


Fig. 8. Clothing microclimate humidity change at chest during exercise and rest four experimental clothing. Abbreviations, see Fig. 3.

reached over 60%RH regardless of surgical gown. However, the difference of H_{cl} among surgical gowns was significant at P<.01. H_{cl} of CT was significantly lower than that of CU during all exercise and rest periods. During exercise period H_{cl} of ST was higher than that of SU, but during rest period that of nonwoven surgical gowns (ST and SU) did not show any significant differences. Through the whole test period H_{cl} of CU was much higher than that of ST.

Evaporative heat loss and the amount of sweat retention by experimental clothing

The total amount of sweat secretion of the subject and amount of sweat retention by experimental clothing during the experiment are described in Table 6. The total amount of sweat was lower in subjects wearing CT and ST than that in subjects wearing CU and SU. The amount of sweat entrapped in the scrub suit was more with the cotton surgical gown than that with the nonwoven, although subjects wore the same cotton scrub suit. The amount of sweat entrapped in the surgical gown was more in CU than in CT. It was very small with nonwoven surgical gowns. The evaporative heat loss from skin surface (E_{sk}) was a little more in subject wearing CU than in subject wearing CT. E_{sk} of ST was slightly less than that of SU. The evaporative heat loss from skin surface was about 60-50% of metabolic heat production for cotton surgical gown and was about 45-50% of metabolic heat production for nonwoven.

Table 6 Total amount of produced sweat and amount of sweat entrapped at the end of the experiment in the scrub suit

	Clothing			
	CT	CU	ST	SU
Total amount of produced sweat (g)	460	539	417	453
Amount of sweat entrapped in scrub suit (g)	35.14	32.80	16.82	15.16
Amount of sweat entrapped in surgical gown (g)	7.86	17.47	0.47	1.44
Evaporative heat loss from skin surface (W/m^2)	123	147	117	129

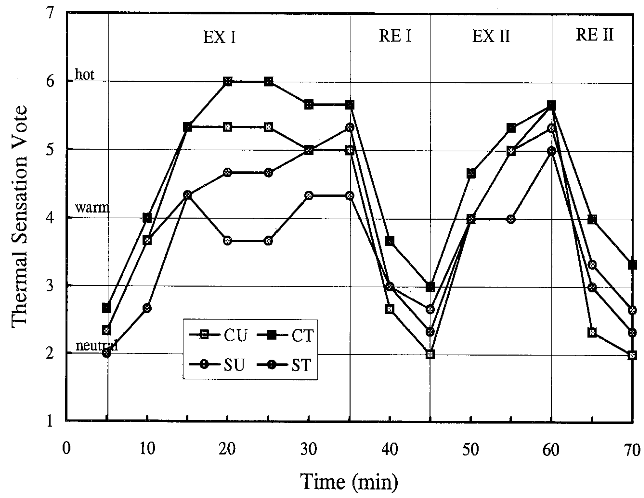


Fig. 9. Subject thermal comfort sensations change during exercise and rest four experimental clothing. Abbreviations, see Fig. 3.

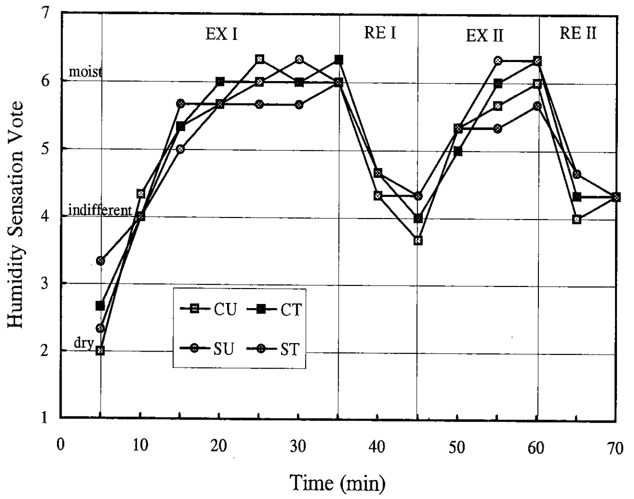


Fig. 10. Subject humidity comfort sensations change during exercise and rest four experimental clothing. Abbreviations, see Fig. 3.

Subjective comfort sensation

Figs. 9-11 show the trends of comfort sensation vote of subjects. Thermal, humid and overall comfort sensations showed similar patterns of change during exercise and rest periods. However, they showed slightly different patterns from those of skin temperature and clothing microclimate. Where the exercise was stopped skin temperature and clothing microclimate temperature suddenly rose, but the comfort sensation went down. At the beginning of EX I, the subjects reported neutral (2.0-2.7), dry (2.0-3.3) and slightly comfortable (3.0-3.7). The difference of humidity and overall comfort sensations were not significant at $P<.05$. The thermal sensation vote was significant different by clothing types. For EX I the nonwoven surgical gown (ST, SU) were estimated to be significantly less hot than cotton (CT, CU). For rest periods CU was estimated significantly hotter than the other surgical gowns at $P<.05$.

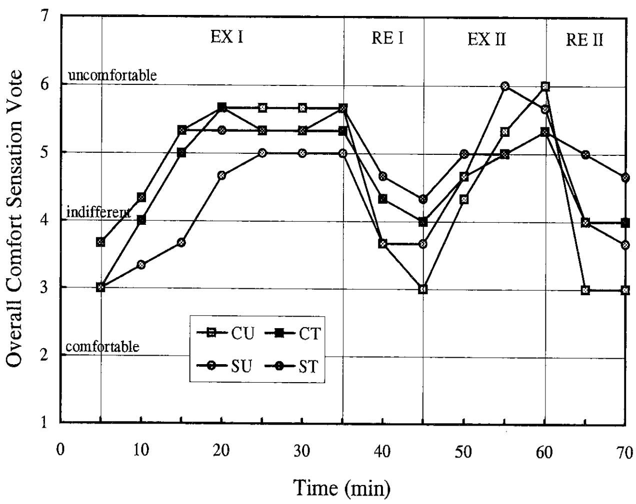


Fig. 11. Subject overall comfort sensations change during exercise and rest four experimental clothing. Abbreviations, see Fig. 3.

Discussion

The thermal insulation of the surgical gowns (clo value) increased by dual functional finish and it was higher in nonwoven than cotton. The thermal insulation of clothing is dependent upon their specific design, fitness, and fabric characteristics, particularity air space between skin and clothing. Since the surgical gowns used in this study have same design and fitness, their inherent fabric characteristics would have an effect on thermal insulation. The increase of thermal insulation, however, was very little.

In this study, the physical condition of subjects, weight, height, and age, were limited intentionally to minimize the physiological difference between subjects. Even though internal variations in the physiological response are unavoidable in this experimental field (Vokac et al., 1971), the patterns of reactions to exercise and rest were alike. The amount of sweating was less when the subjects wear dual functional finished surgical gowns than when wearing untreated. The evaporative heat loss from skin was somewhat different according to surgical gowns. But it was very little. The amount of evaporative heat loss from skin was about 50% of metabolic heat production.

The skin temperature of subjects wearing dual functional finished surgical gown was lower than that of untreated one, which was more clear for exercise period than for rest. The difference of skin temperature indicates a higher rate of heat loss from the skin with the dual functional finished surgical gown than with the untreated one. However, the thermal resistances of surgical gowns were almost same. The heat loss by evaporation of sweat contributed greatly to the total heat loss from the skin. Evaporative heat loss is markedly enhanced by forced ventilation of the clothing due to the rhythmical movements of body and limbs when walking (Vokac et al., 1973). The air and water vapour permeabilities of dual functional finished fabrics was a little different from that of untreated, and its difference has little effect on skin temperature. With dual functional finish, cotton muslin and nonwoven were more drape and less stiff than untreated and it could partly contribute to the convective and evaporative heat losses by bellow ventilation.

Although the untreated cotton surgical gown showed significantly high microclimate temperature and the nonwoven surgical gown showed lower microclimate temperature, the comfort sensations were not significant difference. The thermal sensation showed significant difference same as microclimate temperature only during first exercise. Skin temperature as an index of warmth or discomfort experienced has been widely used but has the disadvantage of being influenced by sweating. Further, the presence of moisture is highly important in a subjective assessment of comfort (Hollies et al., 1979). The subjects produced sweat during the first exercise and the microclimate humidity was over the climate chamber's relative humidity.

The cotton muslin having a high density, 140 over, was used as surgical gown material conventionally and the spunlaced nonwoven is used recently as materials of disposable one. The surface of nonwoven was more compact and smooth than that of cotton muslin even though nonwoven was light and thin. Dual functional finish was done to impart barrier properties of blood and micro organism to surgical gown materials using fluorochemical and antibiotic. The fluorochemical reduced the surface tension of the fabrics and provide blood repellency and it was effective to treat fabric having compact and plane surface. The dual functional finished nonwoven had excellent blood repellency. (Cho and Cho, 1995).

Conclusions

This study was undertaken to estimate thermal comfort properties of surgical gowns made with dual functional finished cotton and nonwoven fabrics. Basic clothing insulation was measured with thermal manikin. Skin temperature, clothing microclimate and subjective comfort sensation were monitored by the subjects clothed in surgical gown during intermittent activity. The wear trial was performed in a climate chamber at 22°C, 60%RH and air movement less than 0.15 m/s, which was the same condition as an operating room.

The dual functional finished surgical gown showed slightly higher thermal insulation than untreated and nonwoven had higher thermal insulation value than cotton. However, the differences were very little. The amount of sweating of subjects was less when wearing dual functional finished than when wearing untreated. The evaporative heat loss from skin was about 50% of metabolic heat production and was slightly less in dual functional finished surgical gowns than in untreated. The skin temperature of the subject wearing a dual functional finished surgical gown was significantly lower. Microclimate temperature and humidity of dual functional finished surgical gown was lower. The clothing shape worn on subjects was different because dual functional finished fabrics was more drape than untreated. There was no significant difference in subject comfort sensation, even though the difference of the skin temperature and microclimate. Thermal sensation was different significantly only for first exercise.

The dual functional finish surgical gown allowed heat to be transferred from the skin of subject to the atmosphere better than untreated. Dual functional finished nonwoven has better barrier properties of blood than cotton muslin. Therefore, the finding of this study suggest that dual functional finished nonwoven would be a functional and comfortable material for surgical gown.

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