

# Some aspects of protective efficacy of surgical clothing systems concerning airborne microorganisms based on results from measurements in a dispersal chamber and during surgical procedures

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**The main source of airborne microorganisms in an operating room is the staff and the patient. In order to reduce airborne bacteria-carrying particles from the staff, it is important that the surgical team wears a functional clothing system. This paper compares results from measurement studies of the protective efficacy, i.e. the source strength, of different surgical clothing systems. The studies were performed in a dispersal chamber and during ongoing surgery. The results show that the fabric of the clothing system, the level of the staff activity (high or low) and the use of knee-length boots or not, have considerable influence on the source strength, i.e. microbial air cleanliness in the operating room.**

**Key words:** Surgical clothing system, colony-forming units, airborne microorganisms, dispersal chamber, ultraclean air operating rooms.

## Introduction

The hospital environment is contaminated by microorganisms and some of them are antibiotic resistant. The number of airborne bacteria-carrying particles in the operating room is considered as an indicator of the risk of infections to the patient undergoing surgery susceptible to infections. To reduce surgical site infection, it is desirable to keep the bacteria-carrying particles at a low number in the operating room air, especially during orthopaedic prosthetic surgery. The main source of microorganisms in an operating room is normally the personnel and the patient. The surgical staff wear clothing systems suitable for an ultraclean air environment. Several studies have been performed to investigate and determine the protective efficacy, i.e. source strength, of surgical clothing systems both in dispersal chambers and during ongoing surgery in operating rooms<sup>1-10</sup>. The source strength is described here as the mean value of the number of airborne bacteria-carrying particulates per second emitted from one person.

The purpose of this paper is to compare data of the protective efficacy of surgical clothing systems, i.e. source

strength, between results from a dispersal chamber and during ongoing surgery. The activity level of the staff can play a role. Furthermore, the paper compares data of the protective efficacy (source strength) of the clothing system when persons are using shoes and textile knee-length boots over the shoes, respectively.

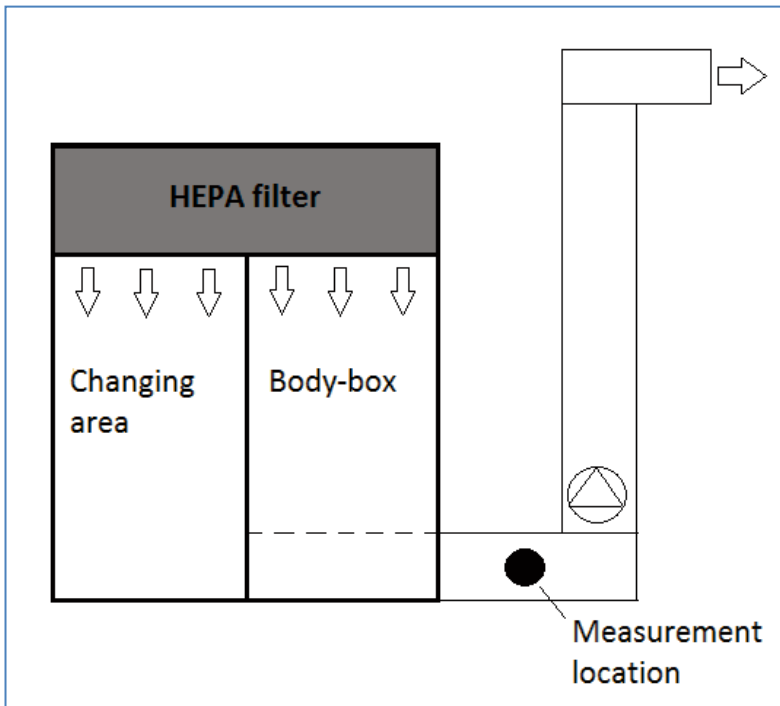
## Materials and methods

### Apparatus

Airborne viable particles were collected using a slit-to-agar sampler, FH3<sup>®</sup>, and sieve sampler, MAS-100<sup>®</sup>. The sampling periods for the two instruments were 10 minutes. The sampling volume per period becomes 0.5 m<sup>3</sup> for the FH3<sup>®</sup> sampler and 1 m<sup>3</sup> for the MAS-100<sup>®</sup> sampler. The two samplers in comparison to the other impaction samplers have been discussed by Ljungqvist and Reinmüller<sup>11,12</sup> and Romano *et al*<sup>13</sup>. Both instruments have a d<sub>50</sub>-value (cut-off size) less than 2 μm and were operated according to the manufacturers' instructions. Thus, the results from the two samplers are comparable.

The microbial growth medium for all tests was standard tryptic soy agar (TSA) in 90 mm Petri dishes. The TSA plates

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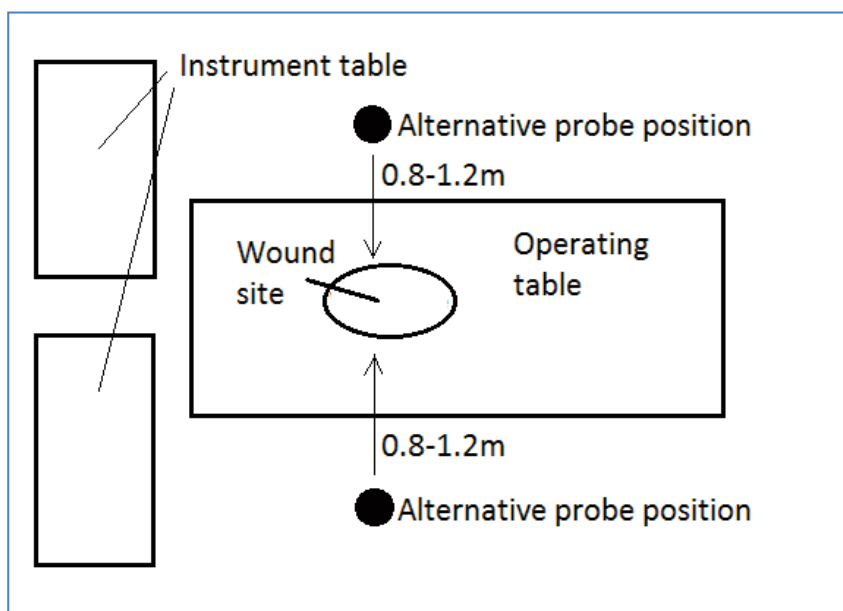


**Figure 1.** Principal arrangement of dispersal chamber (body-box).

were incubated for not less than 72 hours at 32°C followed by not less than 48 hours at room temperature. After incubation, the number of colony-forming units (CFUs) were counted and recorded as aerobic CFUs/m<sup>3</sup>.

### Dispersal chamber

Tests in the dispersal chamber have been carried out to evaluate a surgical clothing system of mixed material and two olefin surgical clothing systems with textile hoods, one with shoes and the other system with textile knee-length boots over the shoes. Concentration of airborne bacteria-carrying particles as aerobic CFUs were measured in the exhaust air of the dispersal chamber,



**Figure 2.** Principal arrangement of the alternative placement of the sampling probes beside the operating table.

where the air is turbulently mixed, by using the FH3<sup>®</sup> slit sampler, see Ljungqvist and Reinmüller<sup>3,7</sup> and Romano *et al*<sup>10</sup>. The principal arrangement of the dispersal chamber is shown in **Figure 1**.

During the measurements the male test subjects performed standardised cycles of movements that included arm movements, knee bends and walk in place at a set speed. These movements are, in principle, comparable with those described in IEST-RP-CC003.4<sup>14</sup>. Prior to each cycle of movement, the test subject stood still to avoid the influence of particle generation from the previous test cycle. The evaluated clothing systems each had five test subjects performing the standardised cycles of movements four times<sup>3,7</sup>. The activity level in the dispersal chamber is considerably higher than that of orthopaedic surgery.

### Operating rooms

The measurements were performed in operating rooms at a hospital in the Stockholm area. The tests were performed during ongoing orthopaedic surgery in operating rooms, where the air movements could be characterised as turbulent mixing, i.e. the dilution principle is applicable. The supply air was high efficiency particulate air (HEPA)-filtered with air volume flows of about 0.6–0.9 m<sup>3</sup>/s, which give about 17–20 air changes per hour.

The surgical clothing systems used during the surgical procedures were the same clothing systems used during the dispersal chamber tests. All present staff (5–8 persons) in the operating rooms wore clothes made from the same material during each surgical procedure.

The measurements were performed either with the FH3<sup>®</sup> slit sampler or with the MAS-100<sup>®</sup> sieve sampler. The probe of the two air samplers was situated just beside the operating table with a distance of approximately 0.8–1.2 m to the wound site at two alternative locations depending on the position of the surgical team. The sampling probe was positioned just above the operating table 1.2 m above the floor. **Figure 2** shows the principle arrangements of the location of the sampling probe.

### Clothing systems

The surgical clothing systems used were one common system of mixed material and two systems made of synthetic fibre, olefin. During surgical procedures, the surgeon and the surgical nurse wore an additional disposable sterile coat over the surgical clothing system.

### Mixed material clothing system

The common clothing system is of mixed material consisting of 69% cotton, 30% polyester and 1% carbon fibre. The weight is 150 g/m<sup>2</sup>. The clothing system was evaluated after being laundered up to approximate 50 times. In addition, the test subjects were wearing disposable head covering, sterile face mask, sterile gloves, clean but not sterile cotton socks and clean but not sterile open shoes.

### Olefin clothing system

The fabric olefin consists of 98% olefin and 2% carbon fibre. The blouse with cuffs at arms and neck, and trousers with cuffs at the wrists were laundered about 20 times, but not antimicrobial treated. The weight is 125 g/m<sup>2</sup>. Textile hoods with cuffs at the face and buttons below the chin (laundered about 20 times), sterile disposable face-masks and disinfected gloves were also worn. None of the tested components were sterilised. The difference between the two olefin clothing systems is the footwear. One clothing system had clean socks of cotton and disinfected plastic shoes while the other system had textile knee-length boots over the shoes. The textile knee-length boots with zip at the back of the leg were laundered approximately 10

times. Photos of the different clothing systems are shown in **Figures 3–5**. **Figure 6** shows the surgical team dressed in the olefin surgical clothing system with knee-length boots.

### Source strength

With the assumption of no leakage into the operating room and the HEPA filters having efficiency close to 100%, the simplest possible expression, which is applied on the dilution principle, describes the source strength, protective efficacy of surgical clothing system (outward particle flow).

$$q_s = c \cdot Q/n \quad (1)$$

- where  $q_s$  = Source strength; total particulates (number/s), bacteria-carrying particles (CFU/s)  
 $c$  = Concentration; total particulates (number/m<sup>3</sup>), bacteria-carrying particles (CFU/m<sup>3</sup>)  
 $Q$  = Total air flow (m<sup>3</sup>/s)  
 $n$  = Number of persons present (number)



**Figure 3.** Surgical clothing system of mixed material, 69% cotton, 30% polyester and 1% carbon fibre.



**Figure 4.** Olefin surgical clothing system, blouse and trousers.



**Figure 5.** Olefin surgical clothing system, textile hood and textile knee-length boots.



**Figure 6.** The surgical team dressed in the Olefin surgical clothing system with knee-length boots.

There is only one person during the tests in the dispersal chamber, why  $n = 1$  in Equation (1). The source strength is described as the number of total or viable airborne particulates per second emitted from one person. Data are given as mean values based on several persons dressed in specific clothing systems. The source strength, which is in this paper limited to the mean value of the number of aerobic CFUs per second from one person, is a valuable tool in describing the protective efficacy of clothing systems against bacteria-carrying particles (Ljungqvist and Reinmüller<sup>3</sup>).

**Table 1.** Source strength mean values of aerobic CFUs from dispersal chamber tests with five test subjects dressed in clothing system of mixed material (69% cotton, 30% polyester and 1% carbon fibre).

Test subject	Source strength (CFUs/s)	
	Mean value*	Minimum–maximum*
1	2.5	1.5–4.0
2	7.5	6.0–8.5
3	10.1	7.0–12.5
4	8.6	8.0–10.5
5	10.3	6.5–15.0
Grand mean value	7.8	Not applicable

\* Numbers are given to one decimal place.

**Table 2.** Source strength mean values of aerobic CFUs from dispersal chamber tests with five test subjects dressed in olefin clothing system with textile hood. Additionally, open plastic shoes (sandals) were worn with or without textile knee-length boots.

Test subject	Source strength (CFUs/s)*	
	Without boots	With boots
1	1.4	1.2
2	0.7	0.2
3	3.1	0.8
4	2.4	0.6
5	3.8	2.3
Grand mean value	2.3	1.0
Minimum–maximum	0.7–3.8	0.2–2.3

\* Numbers are given to one decimal place. Source strength values are calculated from data given by Ljungqvist and Reinmüller<sup>15</sup>.

**Table 3.** Concentration of aerobic CFUs and estimated source strength for clothing system of mixed material during different orthopaedic operations with high staff activity during ongoing surgery in operating rooms with turbulent mixing air.

Operation number	Operating room		CFU concentration		Source strength* (CFUs/s)
	Air flow (m <sup>3</sup> /s)	Number of persons	Mean value (CFUs/m <sup>3</sup> )	Minimum–maximum (CFUs/m <sup>3</sup> )	
1	0.63	8	43.0	31–67	3.4
2	0.63	6	20.0	14–24	2.1
3	0.71	8	51.5	23–90	4.6
4	0.93	6	40.0	13–52	6.2
5	0.93	6	30.5	11–39	4.7

Source strength grand mean value\*: 4.2

\* Source strength values are given to one decimal place.

**Table 4.** Concentration of aerobic CFUs and estimated source strength for clothing system of mixed material during different orthopaedic operations with low staff activity during ongoing surgery in operating rooms with turbulent mixing air.

Operation number	Operating room		CFU concentration		Source strength* (CFUs/s)
	Air flow (m <sup>3</sup> /s)	Number of persons	Mean value (CFUs/m <sup>3</sup> )	Minimum–maximum (CFUs/m <sup>3</sup> )	
1	0.63	6	15.0	8–25	1.6
2	0.66	7	31.0	20–47	2.9
3	0.66	7	22.5	16–33	2.1
4	0.71	7	38.5	18–54	3.9
5	0.54	7	8.0	6–10	0.6
6	0.54	7	10.0	5–16	0.8
7	0.54	5	6.0	5–7	0.6

Source strength grand mean value\*: 4.2

\* Source strength values are given to one decimal place.

## Results

### Dispersal chamber

Source strength mean values of aerobic CFUs from dispersal chamber tests with five test subjects are given in **Tables 1** and **2**. **Table 1** shows the results when the test subjects were dressed in a clothing system of mixed material (69% cotton, 30% polyester and 1% carbon fibre), while **Table 2** shows the values when the test subjects were dressed in the olefin clothing systems with textile hood, with and without textile knee-length boots. The air volume flow in the body-box part of the dispersal chamber was 0.23 m<sup>3</sup>/s during all tests. **Table 2** shows that the reduction of the number of aerobic CFUs with boots compared to without boots is about 57%.

### Ongoing surgery

**Tables 3** and **4** show concentrations of aerobic CFUs and estimated source strengths for the clothing system of mixed material during different orthopaedic operations

with high staff activity (**Table 3**) and low staff activity (**Table 4**) during ongoing surgery in operating rooms with turbulent mixing air. High staff activity occurred during ongoing hip joint surgery and low staff activity was during other orthopaedic surgery when the staff were almost standing still.

**Tables 3** and **4** show that the source strength mean value during low staff activity is 43% of that of high staff activity. Furthermore, **Table 3** shows that during high staff activity (hip joint surgery) the source strength mean value is calculated to 4.2 CFUs per second. This is in agreement with data given from hip joint surgery by Tammelin *et al*<sup>5</sup>.

Comparison between source strength data from **Tables 1, 3** and **4**, shows that the source strength mean value during surgical procedures during high staff activity is 54% of the dispersal chamber mean value, while during low staff activity the source strength mean value is 23% of the dispersal chamber mean value.

**Table 5** shows the concentration of aerobic CFUs and estimated source strength during ongoing orthopaedic surgery in an operating room with turbulent mixing air

**Table 5.** Concentration of aerobic CFUs and estimated source strength during ongoing orthopaedic surgery in an operating room with turbulent mixing air and an airflow of 0.71 m<sup>3</sup>/s. The surgical team was dressed in olefin clothing systems with textile hood, and private shoes with and without textile knee-length boots. Measurements were performed during three operations and the sampling time of airborne CFUs was 10 minutes per sample.

Air sample number	Without boots			With boots		
	Number of persons	Concentration (CFUs/m <sup>3</sup> )	Source strength* (CFUs/s)	Number of persons	Concentration (CFUs/m <sup>3</sup> )	Source strength* (CFUs/s)
1	6	4	0.5	5	<2	<0.3
2	6	10	1.2	5	<2	<0.3
3	6	10	1.2	5	2	0.3
4	6	14	1.6	5	6	0.9
5	5	12	1.7	–	–	–
Mean value	5.8	10	1.2	5	<3	0.4

\* Source strength values are given to one decimal place.

**Table 6.** Summary of results achieved for the source strength for different surgical clothing systems in a dispersal chamber and during ongoing orthopaedic surgery.

Clothing system	Source strength (CFUs/s)	
	Dispersal chamber	Ongoing surgery
Mixed material (69% cotton, 30% polyester and 1% carbon fibre)	7.8	4.2 (high activity) 1.8 (low activity)
Olefin without knee-length boots	2.3	1.2 (high activity)
Olefin with knee-length boots	1.0	0.4 (high activity)

\* Source strength values are given to one decimal place.

**Table 7.** Calculated total air volume flows needed in an operating room with turbulent mixing air and with the mean value concentration of 5 CFUs/m<sup>3</sup> during ongoing hip joint surgery, when the operating team of six persons has different surgical clothing systems. Dispersal chamber values are reduced by 50% to be equivalent to values from hip joint surgery.

Clothing systems	Data related to dispersal chamber tests		Data related to hip joint surgery	
	Source strength* (CFUs/s)	Air flow* (m <sup>3</sup> /s)	Source strength* (CFUs/s)	Air flow* (m <sup>3</sup> /s)
Mixed material	3.9	4.7	4.2	5.0
Olefin without boots	1.2	1.4	1.2	1.4
Olefin with boots	0.5	0.6	0.4	0.5

\* Source strength values are given to one decimal place.

and an air flow of 0.71 m<sup>3</sup>/s. The surgical team (5–6 persons) were dressed in olefin clothing systems with textile hood, with and without textile knee-length boots. Measurements were performed during three operations and the sampling time of airborne CFUs was 10 minutes per sample.

**Table 5** shows that the reduction of the number of aerobic CFUs with boots compared to without boots is about 67%. Even if the number of measurements is limited, the results indicate that the reduction during ongoing surgery is in the same range as in dispersal chamber tests.

## Discussion and conclusion

In **Table 6**, a summary of achieved results is shown. The results show, as a first approximation when using source strength data from dispersal chamber tests, that during ongoing orthopaedic surgery the source strength mean value at high and low staff activity is about half and a quarter of the mean values obtained in the dispersal chamber tests, respectively.

This is in agreement with results from Ljungqvist *et al.*<sup>8</sup>, where a comparison between different clothing systems are tested during ongoing hip joint surgery as well as in the dispersal chamber.

When the air movements are turbulent mixing, the dilution principle is applicable, i.e. Equation (1) is valid. The concentration of bacteria-carrying particles calculated from Equation (1) is the theoretical mean value during ongoing surgery from incision to wound closure.

The total air flow necessary can be calculated if the theoretical mean value of bacteria-carrying particles is determined and the number of people in the room and

their source strength is known. In this case, the Equation (1) becomes:

$$Q = n \cdot q_s / c \quad (2)$$

In the following example, some estimations are given with Equation (2).

### Example

The calculated total air flow necessary in an operating room with turbulent mixing air and the mean value of the bacteria-carrying particle concentration should be 5 CFUs/m<sup>3</sup>, when the operating team has different kinds of surgical clothing systems during hip joint surgery. The operating team consists of six persons, all with the same surgical clothing system. Source strength data from dispersal chamber tests and from ongoing surgery should be used, see the summary in **Table 6**.

The source strength mean value of a specific clothing system from operating room measurements during hip joint surgery (high staff activity) is about half the mean values obtained in the dispersal chamber tests. With source strength values from **Table 6** and data given in the example above, the total air flow can be calculated with the aid of Equation (2). The results are given in **Table 7**.

**Table 7** shows that the reduction of necessary air flow volume with boots compared to without boots is about 60%, which is comparable with the reduction values of aerobic CFUs.

Reinmüller<sup>16</sup> describes tests in an aseptic filling room for pharmaceutical production, where the operators were dressed in cleanroom coveralls with hoods. The effect of knee-length boots compared to normal cleanroom shoes was evaluated. When knee-length boots were used, a

reduction of airborne particles and aerobic CFUs of approximately 90% was achieved. The high reduction with cleanroom clothing might depend on the cleanroom operator being better covered than a person with surgical clothing.

The calculations in **Table 7** show that chosen clothing systems play an important role in the level of theoretical necessary air volume flows. If the mixing of the air is incomplete, it will be necessary to have higher air flows than that estimated by the dilution principle, Equation (2), in order to achieve the required level of cleanliness. A dispersal chamber test can be a valuable tool in the development of new clothing systems and the estimation of the protective efficacy.

In summary, in operating rooms for surgery susceptible to infections, the selection of clothing systems for the operating room personnel should no longer only be considered in terms of comfort but also in terms of patient safety.

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