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Influence of disturbances on bacteria level in an operating room

Henrik Brohus*, Mikkel L. Hyldig, Simon Kamper and Ulla M. Vachek

Aalborg University, Denmark

**Corresponding email: hb@civil.aau.dk*

SUMMARY
In operating rooms great effort is manifested to reduce the bacteria level in order to decrease the risk of infections. The main source of bacteria is the staff and the patient, thus, the resulting bacteria concentration is roughly speaking a combination of the ventilation system and the emission from the occupants. This study investigates the influence of two main disturbances in an operating room namely the door opening during the operation and the activity level of the staff. It is found that the frequent door opening in this case does not cause significant transport of air from outside the operating room to the wound area of the patient. However, a significant influence of the activity level on the bacteria emission and concentration is found. Counting the number of persons in an operating room to estimate the bacteria source strength is not sufficient, the corresponding activity level must be considered, too.

KEYWORDS
Bacteria level, Operating room, People's activities, Emission sources, Exposure assessment

INTRODUCTION
In operating rooms great effort is manifested to reduce the bacteria level in order to decrease the risk of infections. Post-operative infections prolong the stay at the hospital and generate extensive costs for health services and society apart from the personal inconvenience of the patient.

The main source of bacteria is the staff and the patient. The bacteria may be transported from the sources to the wound by several routes either directly or indirectly via instruments or the room air (Whyte, 1988). The room air is a main transport route which is the concern of the present work.

The resulting bacteria concentration in the room air is roughly speaking a combination of the ventilation system and the emission from the occupants. Operating rooms are equipped with installations with the purpose of reducing airborne bacteria like ventilation with high air change rates and over-pressurized rooms. Proper ventilation removes most of the bacteria and maintains a sufficiently low concentration around the wound and the operating staff. At the same time pressure differences between the operating room and the surroundings may prevent infiltration from less clean external environments.

The total emission of airborne bacteria is not only a function of the number of occupants in the operating room; it depends heavily on activity level, sex, clothing, etc. However, only few investigations are available that quantifies the influence (Whyte, 1988; VDI, 1996; Tinker and Roberters, 1998; Segadal et al., 2001).

In order to design the ventilation system and determine for instance the necessary air change rate and a proper air distribution principle the local bacteria concentration must be assessed as a function of the contaminant sources and the ventilation. Most often this assessment does not consider the influence of disturbances and occupant behaviour inside the operating room (Brohus et al., 2006).

This study investigates the influence of disturbances in an operating room by means of tracer gas measurements and bacteria measurements. A typical operating room usually applied for heart surgery is chosen for the investigations. Two kinds of disturbances are considered namely the door opening during the operation and the activity level of the staff.

METHODS

To investigate the two kinds of disturbances a typical Danish operating room for heart surgery is chosen for a field investigation, see Figure 1. The investigated operating room, Operating Room 9, is located in the central part of the hospital to avoid any influence from the outdoor climate. The room is connected to a wash room used by the staff and the patient to enter the room and an ultra clean hall where additional equipment is located for instance the heart-lung machine.

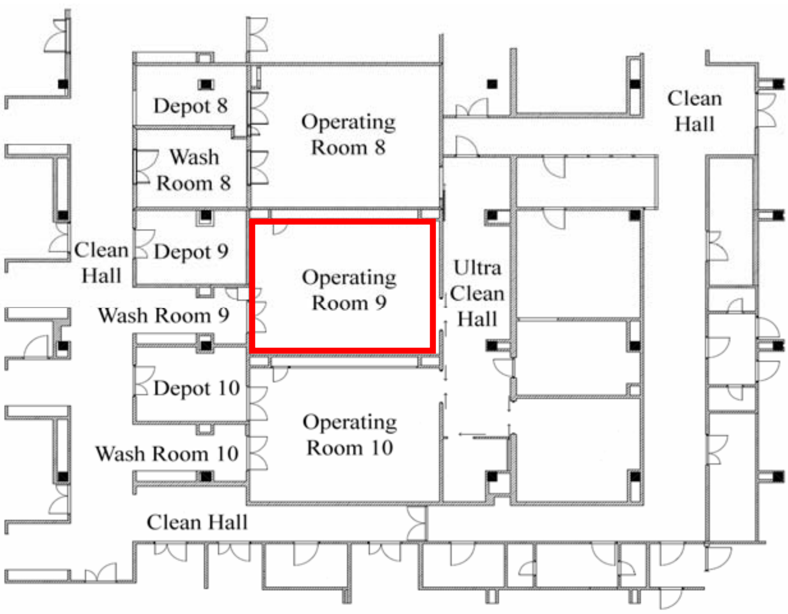

Figure 1. Location of Operating Room 9 at Aalborg Hospital in Aalborg, Denmark.

Figure 2 illustrates typical location and clothing of the staff doing heart surgery. The staff during a bypass operation usually comprises surgeon, assistant surgeon, scrubnurse, floor nurse, perfusionist (operating the heart-lung machine), anesthesia doctor and anesthesia nurse. However, the number of occupants may vary due to the need to get equipment outside the room, transportation of blood for testing, and due to complications demanding additional staff. Thus, the number of occupants and bacteria emission sources may vary throughout an operation.

The equipment of the operating room is listed in Figure 3 and the overall characteristics as to size and ventilation is mentioned in Table 1. The operating room is ventilated by mixing ventilation with a relatively high air change rate partly to maintain a low bacteria concentration and partly to ensure an efficient mixing to avoid local areas with high concentration levels.

Figure 2. Photos from a typical heart surgery operation in Operating Room 9. Left: Scrubnurse, surgeon and assistant surgeon. Centre: Scrubnurse and floor nurse. Right: Perfusionist and anesthesia staff.

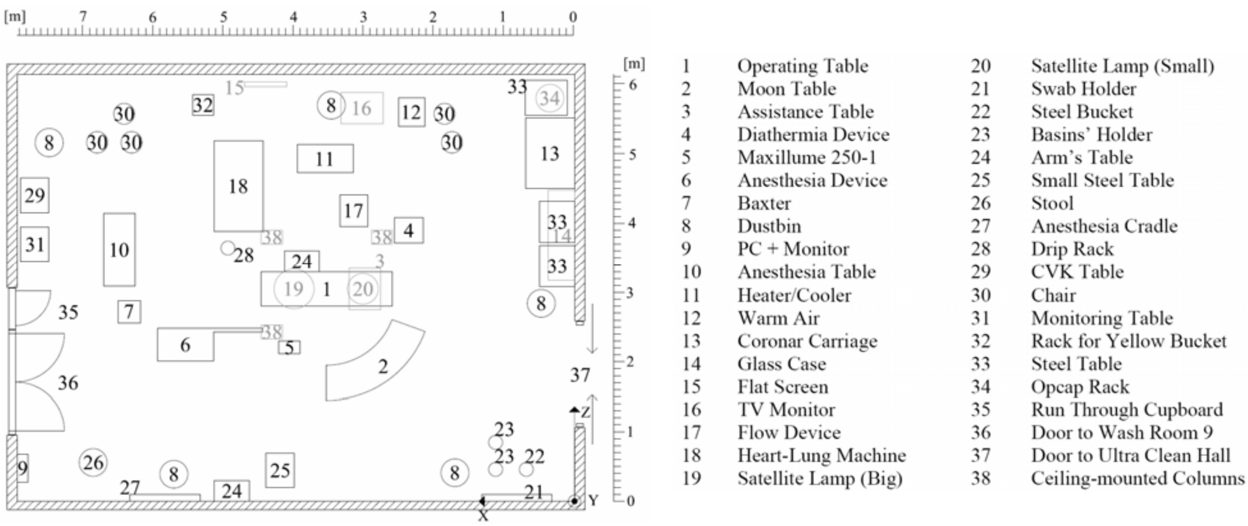

Figure 3. Equipment inside Operating Room 9.

Table 1. Operating Room 9 characteristics

Room size	7.95 m x 6.1 m x 3 m [length x width x height]
Room volume	145.5 m^3
Air change rate	15 h^{-1}
Pressure difference	~ 10 Pa (over pressure)
Ventilation principle	Mixing ventilation using one slot diffuser (6.2 m x 0.3 m) and two exhaust openings, all three located in the wall plane $z = 6.1$ m.

Two setups are applied to examine the two kinds of disturbances. First, the influence of frequent door opening is investigated using tracer gas measurements and partly person simulators (not a real operation), see Figure 4. Next, the bacteria emission during a real operation is investigated (Figure 5).

Door opening

Even though door opening during an operation must be reduced as much as possible (due to hygienic requirements and hospital policy) it is found that up to approximately 100 door openings during one operation may occur. This figure clearly surprised the staff after being told. To investigate infiltration from the surroundings tracer gas measurements are undertaken. Due to hygienic considerations a setup is applied in this case using a thermal manikin (simulating the patient) and the real persons partly replaced by person simulators (heated cylinders) as shown in Figure 4. A tracer gas source simulating bacteria emission is located in the Wash Room 9 outside the door to the operating room. Tracer gas concentration measurements are made in the wash room, around the wound and in the exhaust air from the operating room, see Table 3.

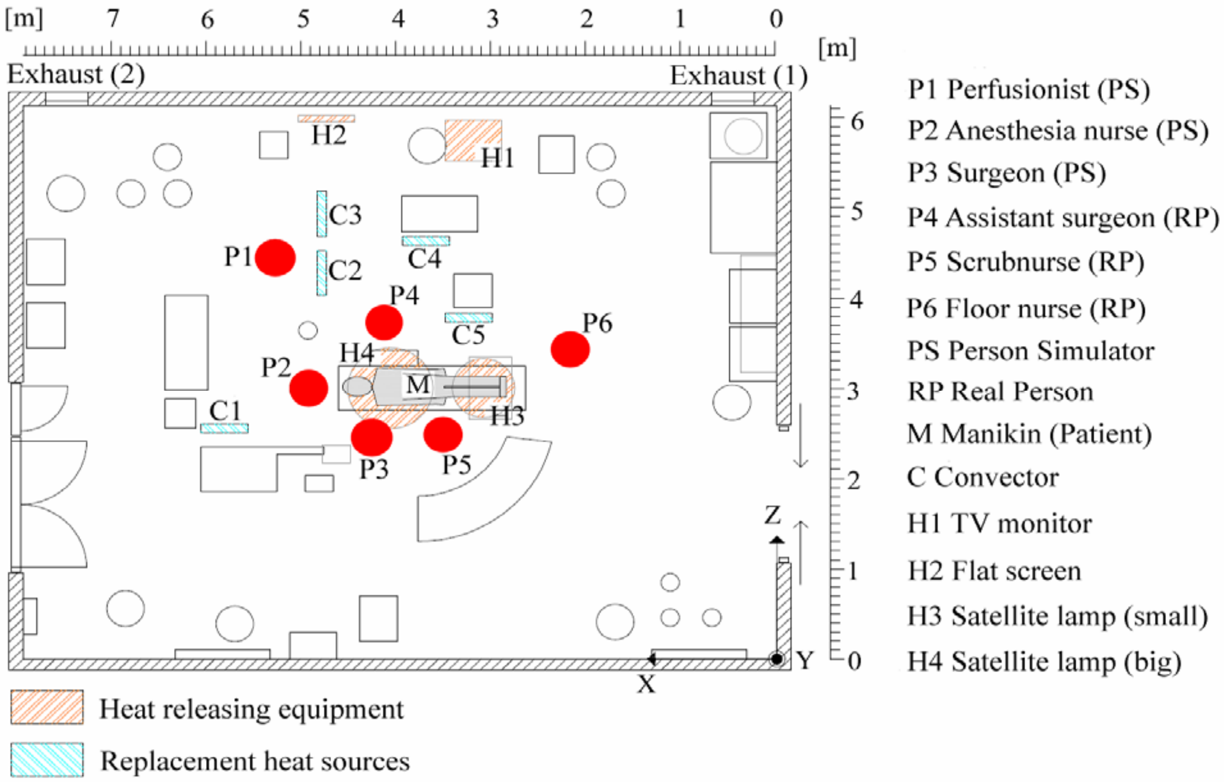

Figure 4. Measurement setup in case of tracer gas measurements (investigation of door opening).

Initially steady-state conditions are obtained followed by one hour of measurements without door opening. Then the wash room door is operated once per minute in an hour. The reason for including only the wash room in the traces gas measurements is that it is assumed to be a worst case because the bacteria level is supposed to be lower in the ultra clean hall.

Apart from tracer gas measurements extensive smoke visualisation is performed observing a person entering the room through both the wash room door as well as the door facing the ultra clean hall.

Activity level during operation

To investigate the influence of the activity level of the staff during an operation, spatial and temporal bacteria concentration levels are measured using two slit samplers, see Figure 5. Two real operations are applied namely a bypass operation and an operation treating a post-infection, respectively. The measurement locations are listed in Table 2.

To get an idea of the local bacteria concentration level throughout the operation room, i.e. the spatial distribution, measurements at up to seven different locations are performed. Due to limited measuring equipment the measurements are not performed at the same time. To investigate also the time and activity dependence, i.e. the temporal distribution, continuous measurements are performed for one specific location in the operating area throughout the entire operation ranging from the preparation phase before the patient arrives until after the patient leaves the room.

Figure 5. Left: Slit sampler Biap CDII applied for bacteria measurements during the operations. Centre and Right: Operation of slit sampler using extension pipes.

Table 2. Bacteria measurement locations (coordinate system in Figure 3)

Measurement point	Location	
	Coordinates (*x*, *y*, *z*) [m]	Description
S1	(7.5, 0.5, 6.1)	Exhaust Opening 2 (centre)
S2	(0.5, 0.5, 6.1)	Exhaust Opening 1 (centre)
S3	(11.9, 2.7, 0.7)	Wash Room 9
S4	(-0.3, 4.1, 0.7)	Ultra Clean Hall
S5	(3.2, 1.1, 1.9)	Above Moon Table
S6	(3.6, 1.1, 3.0)	Above Operating Table
S7	(2.4, 1.1, 3.7)	Inside Operation Area

RESULTS

The results from the tracer gas measurements on door opening are presented in Table 3.

Table 3. Tracer gas concentration measurements investigating door opening

Location and status for door operation	Mean value [ppm][2,3]	Standard deviation [ppm]
Door closed (duration 1 hour)		
- Wound (*x*, *y*, *z*) = (3.85, 1.29, 3.1) m	0.56	0.12
- Exhaust (*x*, *y*, *z*) = (7.475, 0.51, 6.1) m	0.44	0.12
- Wash Room 9 (*x*, *y*, *z*) = (8.59, 1.3, 2.56) m	29.94	10.66
Door opening (duration 1 hour)[1]		
- Wound	1.32	0.18
- Exhaust	1.25	0.13
- Wash Room 9	23.71	5.93

1: During “door opening” the door is operated once per minute.
2: Tracer gas: N_2O (tracer gas source located in Wash Room 9).
3: Equipment: Brüel & Kjær Multipoint Sampler and Dozer type 1303 and Brüel & Kjær Multigas Monitor type 1302.

Tables 4 and 5 present the bacteria concentration measurements from Operation Room 9 during two operations focusing on spatial and temporal distribution, respectively. Finally, Figure 6 is the time-dependent net bacteria emission from the occupants in the operation room based on the bacteria concentration in the operating area, the number of occupants, and the air change rate assuming fully mixed conditions.

Table 4. Bacteria concentration, spatial distribution

Tuesday 20.12.05	Bypass operation	
Measuring point	Time	Bacteria concentration [cfu/m^3]
S1[1]	10:00	29
S2[1]	10:25	50
S3[1]	8:57 & 12:27	154 (mean value of 115 and 194)
S4[1]	9:30 & 11:58	48 (mean value of 47 and 48)
S5[1]	11:35	57
S6[1]	11:10	45
S7[2]	7:00 – 13:25[2]	39 (std.dev. 21; min. 9; max. 108)
Wednesday 21.12.05	Operation treating a post-infection	
Measuring point	Time	Bacteria concentration [cfu/m^3]
S6[1]	11:00	9
S7[3]	7:16 – 10:42[3]	7 (std.dev. 8; min. 0; max. 34)

1: Sampling time 20 minutes

2: Sampling time 10 minutes for each measurement (a total of 36 measurements)

3: Sampling time 5 minutes for each measurement (a total of 28 measurements)

Table 5. Bacteria concentration, temporal distribution

Tuesday 20.12.05, Measuring point S7 (Inside operation area, see Table 2)				
Time	Concentration [cfu/m^3][6]	No. of persons	Door openings (Wash Room)	Door openings (Ultra Clean Hall)
7:00 - 7:30	47	5.00	0	4
7:30 - 8:00[1]	26	3.44	11	5
8:00 - 8:30[2]	15	3.64	11	5
8:30 - 9:00	46	5.00	5	9
9:00 - 9:30[3]	47	9.00	20	10
9:30 - 10:00	34	9.50	1	13
10:00 - 10:30	29	10.00	4	6
10:30 - 11:00	28	10.00	1	2
11:00 - 11:30	56	11.25	0	4
11:30 - 12:00	47	10.00	1	5
12:00 - 12:30[4]	19	6.50	0	8
12:30 - 13:00[5]	64	8.50	8	4
13:00 - 13:30	47	Not registered	Not registered	Not registered

Main actions during operation: 1: Preparation 7:30, 2: Patient arrives 8:10,
3: Operation starts 9:20, 4: Operation ends 12:30, 5: Patient leaves 12:50.
6: Sampling time 30 minutes

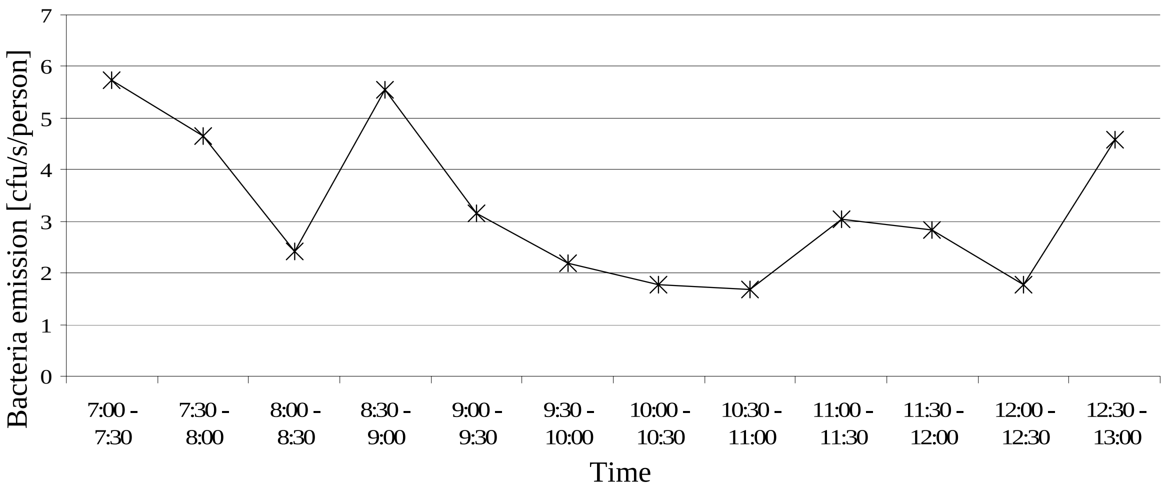

Figure 6. Bacteria emission from occupants during operation Tuesday 20.12.05.

DISCUSSION

Influence of door opening

The high number of door openings observed during several operations is obviously a source of concern. Thus, it is important to have an indication of the importance in terms of potential bacteria transport from the neighbouring rooms to the operation room and eventually the patient's wound where it may cause infections.

The results presented in Table 3 reveal that there is a significant increase in the tracer gas concentration from the background level, where the door is closed, to the case of frequent door opening. This fact indicates that there may certainly be transported bacteria from the wash room to the wound in case of frequent door opening despite the over-pressurized operating room.

The main reason, which is clearly observed by smoke visualisation, is that a person entering the room via the door entrains and transports a certain amount of air especially in the wake behind the body. This amount of air transported from the neighbouring room depends on the behaviour of the person (especially the speed of the movements and the way the door is operated). After entering the room this amount of air is diluted and only a small fraction may finally reach the operation area.

Thus, even though it is found that bacteria transport does occur, the substantial dilution in the operation room dictates that usual hygienic requirements will not be jeopardised unless high bacteria concentration prevails in the neighbouring rooms.

Influence of activity level during operation

The influence of the activity level on bacteria emission during an operation is important for several reasons. Firstly, in order to provide guidance on proper occupant behaviour to minimize infection risk and, secondly, to estimate bacteria emission source strength for optimum design of the ventilation system. Furthermore, robustness of the ventilation system to account for the inevitable disturbances is relevant to consider (Brohus et al., 2008).

An important overall result is that significant variation in terms of space and time is found. This variation is not only due to variation in number of occupants (i.e. bacteria sources). It depends also on the local ventilation effectiveness and the activities of the staff.

It is found that throughout the two operations the bacteria level ranges from 0 to approximately 200 cfu/m^3, however, most often in the interval of 20 to 60 cfu/m^3. This means that the bacteria concentration level satisfies the present Danish recommendations of maximum 200 cfu/m^3 and the Norwegian and Swedish requirement of 100 cfu/m^3.

If the two operations are compared it is evident that the first operation (bypass) shows significantly higher bacteria levels than the other (treatment of post-infection). This corresponds well with observed activity levels that are observed to be considerably higher for the first operation.

To investigate the direct influence of the activity level the net bacteria emission per person is approximated based on measured bacteria concentration in the operation area and the number of persons. In this approximation it is assumed that the room air is fully mixed, see Figure 6. Furthermore, it is assumed that all bacteria initially caught by the slit sampler are also counted. Both assumption are to some extent violated depending on the specific case, thus, the results are subject to some uncertainty. The local concentration in the operation area can be both higher and lower than in case of fully mixed conditions. The slit sampler may collect only approximately 50 % of all bacteria (Möller, 2002). Based on those limitations the results presented in Figure 6 may be interpreted to an emission rate in the interval of 3 - 10 cfu/s/person highly dependent on the activity level.

CONCLUSIONS

It is found that frequent door opening in this case does not cause significant transport of air from outside the operating room to the wound area of the patient. Small amounts of air from the neighbouring rooms may reach the wound, however, unless the bacteria concentration in the neighbouring room is high this is not assumed to violate the hygienic guidelines.

A significant influence of the activity level on the bacteria emission and concentration is found. Counting the number of persons in an operating room to estimate the bacteria source strength is not sufficient, the corresponding activity level must be considered, too. It is estimated that the occupants in the operating room have a net emission rate varying in the range of 3 – 10 cfu/s/person depending on the activity level.

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