

# Review of ventilation systems in operating rooms in view of infection control

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## REVIEW OF VENTILATION SYSTEMS IN OPERATING ROOMS IN VIEW OF INFECTION CONTROL

M A Melhado<sup>(1)</sup>, J L M Hensen<sup>(1)</sup>, M Loomans<sup>(2)</sup>

<sup>1</sup>Center for Building and Systems, Technische Universiteit Eindhoven, The Netherlands  
e-mail: m.d.a.melhado@bwk.tue.nl

<sup>2</sup>Nederlandse Organisatie voor toegepast-natuurwetenschappelijk onderzoek (TNO), Netherlands

**ABSTRACT:** The Postoperative Infection Rate (PIR) generally depends on factors such as the type of surgery, the cleanliness of equipment, medical procedures, and the level of microorganisms in the immediate and surrounding environments. Another major factor to consider is the quality of the air in the operating room (OR). The aim of this paper is review different ventilation systems in order to evaluate the of infection control (IC). This review consists of a literature review and observations in OR.

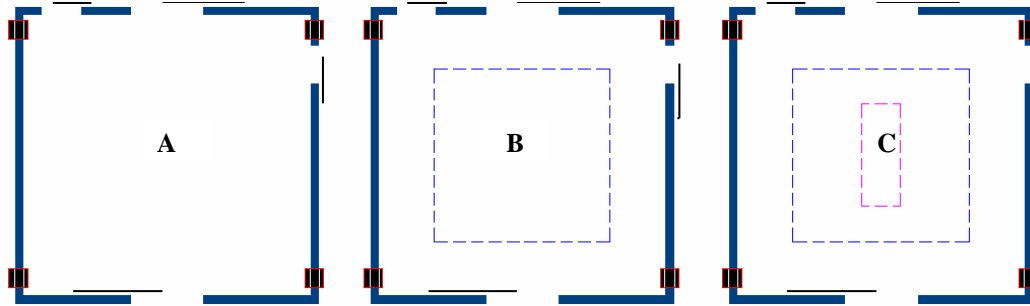
The objective is to assist design engineers in developing more efficient ventilation systems, and to help stakeholders in choosing the “best” system for the particular type of surgery they need to perform. The practical result will be that security aspects of IC will be strengthened, which should lead to lower PIR.

Key words: Indoor air quality, infection control, operating room, ventilation system

### 1. INTRODUCTION

Many countries suffer high postoperative infection rates (PIR) in their hospitals, especially in developing countries. In Brazil, for example, 15% PIR was reported while in Europe and USA the highest PIR was 5%. (OSPA and OMS, 2001, PREZIES, 2004, and CDC, 2003, respectively). The incidence of PIR depends on many variables, including the type of operating room (OR) ventilation system and the type of surgery performed.

The ventilation system is responsible for keeping good indoor air quality (IAQ) and also for ensuring infection control in the OR, i.e. to protect the patient from becoming infected. In accordance with (ASHRAE, 2002) the IAQ of a space is determined by the level of indoor air pollution and other characteristics, including the air temperature, relative humidity and air speed. Pollutants in an OR include aerosols and anaesthesia gases. A significant consideration is that different types of ventilation systems have different designs, dimensions, applicability and resultant airflow dynamics. According to (Friberg et al., 2003), in some cases the ventilation system can decrease the percentage of infection. Some types of ventilation systems improve infection control, because they provide airflow dynamics that “divide” the OR in different zones, ensuring different protection levels. The examples shown in Figure 1 are: one zone (example A), two zones (example B) and three zones (example C) – this also it is reported by (Mora, English and Athienitis, 2001). Previous studies (Mora, English and Athienitis, 2001, Friberg B, 1998, and Mermarzadeh and Manning, 2002) reported satisfactory results using ventilation systems which resulting in three zones the OR.



**Figure 1.** Zones defined in accordance with the type of ventilation system

The type of surgery also has a significant influence on the PIR. In some types of surgery, for example implant and orthopedic surgeries, the patient has a great chance of contracting a postoperative infection. An important point is that each particular surgery will determine various details in the OR, for example, the amount, the type and the use of people and equipment. The type surgery will also determine the layout of the OR. That influence in the infection control.

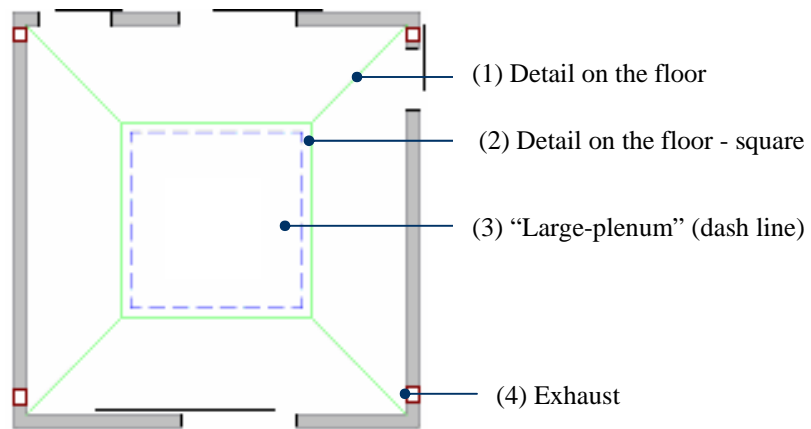
This paper describes and then evaluates different types of ventilation systems. It considers the airflow dynamic, the layout of the OR in accordance with the type of surgery, and the infection control. The structure of this paper consists of an introduction, methods, results and discussion, and conclusion.

## 2. METHODS

In order to investigate the infection control in accordance with the types of ventilation system and surgery, three things were done: First, academic literature were reviewed; Second, observations of Ors were performed; and Third, interviews with a surgical team and with supporting technical staff were carried out. The purpose of the literature review was to get an overview of how and where different types of ventilation systems were used, and to assess how successful they were in managing the security aspects of infection control. The objective of the interviews with the surgical team was to establish some details about the medical procedure, the limitations of the ventilation system used, and the routines performed in the surgery. The interview with the technical support was conducted in order to understand the power and limitations of the equipment and lights, however, this will be not discussed in this paper. The observations in ORs were recorded on a specially designed form.

The observation of the ORs also had two objectives. The first was to establish how the previously mentioned variables (i.e. the position of the surgical team, the instruments and operating table, and the patient in the OR during the surgery) are dealt with in the real world, as opposed to in the literature. The observed surgeries were performed in the same OR which was equipped with a “Large-plenum” ventilation system. It was evaluated whether or not this ventilation system was suitable for the type of surgery both in terms of coverage of the patient, instruments, operating table and staff, and in the control of relevant security aspects of infection control such as temperature, humidity, air velocity, etc.

The second objective was to “test” the applicability of the special form used to evaluate the infection control, and to determine what questions are most important to consider in future observations. All observed surgeries were orthopaedic (three hip surgeries, hand, ulna, clavicle, foot, tibia and femur) and therefore they used the same layout of the OR. The surgeries took place over three days and the surgical teams were not the same in all surgeries. The observed OR was divided into two zones, as can be seen in Figure 2. The area of each operating room is 36 m<sup>2</sup> (6x6 m). Zone 1 is the space where the patient, the surgeons and their auxiliary and the instrument table should be. Outside this square (2) is Zone 2, occupied by the surgical support staff (anesthesiologist, nurses and technical). The exhausts are located in the four corners, as represented in the figure (4). The diffuser of the Large Plenum ventilation system is smaller than the zone delineated on the floor, as represented by the “dashed line”.



**Figure 2.** Schematic drawing of the observed operating room

### 3. RESULTS AND DISCUSSIONS

The literature review was carried out in order to get a clearer picture of how different ventilation systems have been used in different situations, and how successful their use has been in terms of dealing with the security aspects of infection control in the OR. In order to create a clearer picture and to allow a comparison of the different ventilation systems, four separate questions were considered: 1) Which (type of) countries use which systems? 2) Which systems are used for which type(s) of surgery? 3) How many zones each system can create? 4) How successful is each system at dealing with infection control? The ventilation systems that were evaluated are the Conventional ventilation system, the Plenum and the Laminar Air Flow (LAF), and some combining systems. Each system will be discussed below in line with questions raised above.

#### COVENTIONAL

Conventional (mixing) ventilation systems are used in ORs in old hospitals, which the majorities are located in developing countries. These systems are normally used for general surgeries, for example, Abdominal Surgery. These systems define only one zone

in the OR and present turbulent airflow dynamic. The use of this system is not a good option for the OR, mainly in surgeries Class I (ASHARE, 2001), because of turbulence insurance the air is not clean in the area of the patient and on the table of instruments.

This type of ventilation system can present different disposition on the ceiling and some times also on the walls.

## PLENUM

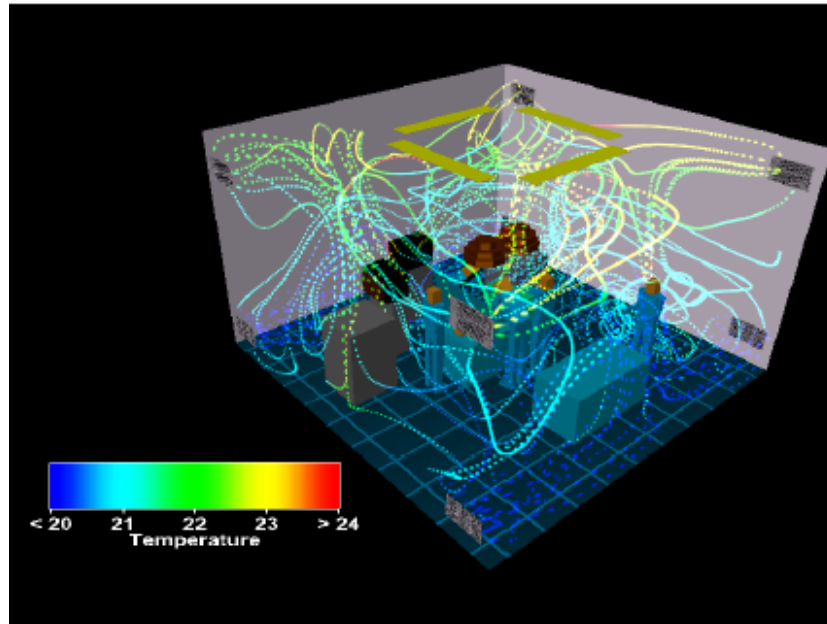
Plenum ventilation systems are used in some countries, including the Netherlands they are the most common system in use in ORs. These ventilation systems have been used for different types of surgery. There are different types of Plenum used in the Netherlands: Plenum (1.2mx2.4m and 2.4mx2.4m), Large-plenum (3.0mx3.0m), 3T-plenum and the orthogonal plenum. The 3T plenums and large plenums present the state-of-the-art for newly built or (to be) renovated operating theatres, which have presented satisfactory results in environmental control. The Large-plenum divides the OR in two zones while the 3T-plenum in three thermal zones and two zones of protection.

## LAMINAR AIRFLOW

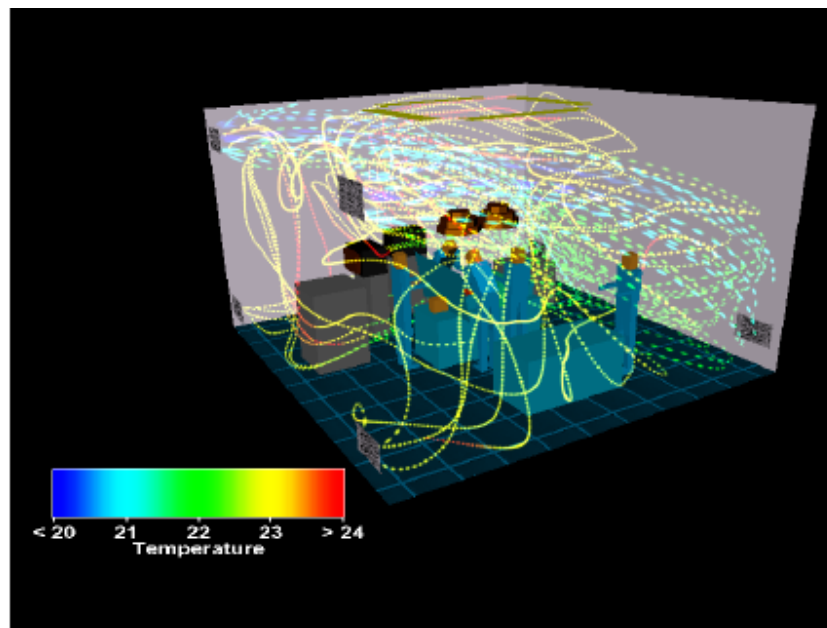
This type of ventilation systems are used in all word, and are recommended for environments which require ultra-clean air, including ORs Class I (ASHRAE, 2001). The Class I involve the orthopaedic, transplant, and other specialised surgeries, isolation rooms, areas of people with burns and laboratories. To have Class I characteristics these ventilation systems are combined with the use of the high-efficiency particulate air filters (HEPA), and a low and uniform velocity. This system, if used alone, can divide the ORs in two zones. There are two types of LAF system, the horizontal and the vertical. The horizontal LAF was developed to overcome the problems associated with vertical airflow. However, the horizontal supply air in ORs usually is disrupted by the surgical team (Dharan and Pittet, 2002). The vertical LAF is more effective in OR than the horizontal, because the clean air is supplied directly over the operating table, and also more effective in accordance with some studies, for example, by (Lidwell, 1982, Friberg, 1998, McCarthy et al, 2000, and Technology Assessment Team, 2001). In accordance with critical review and studies made by (Friberg, 1998), the Ultra clean air system ensures the potential of protection for the patient. The LAF may divide the OR in one zone or in two zones, in accordance with the design of the diffuser. For example, a full ceiling diffuser defines only a zone. Alternatively, examples other cases with diffuser smaller divide the OR in two zones.

(Mermarzadeh and Manning, 2002) made a comparative study of OR ventilation systems. They evaluated the LAF, Unidirectional, conventional and nonaspirating and displacement diffuser types in order of contaminant deposition on an OR and back table. These ventilation systems presented some different parameters, for example, the volume flow rate for each ventilation system. This study objectives to evaluate various parameters, for example, the effects of ventilation flow rate, diffuser type and location, supply temperature and exhaust location. The methodology used was numerical simulation. In Figures 3 and 4 it is possible to observe the airflow in two ORs using conventional ventilation. The difference between Figure 3 and Figure 4 are the number and position of the diffuser's of supply air. This research considered important analyses in terms of infection control. It showed results that identified the LAF ventilation system

as the best performance in OR with some care. Another advantage of the LAF was that it results in better ventilation effectiveness. Figure 5 (Mermarzadeh and Manning, 2002) shows a laminar supply with conventional exhaust.



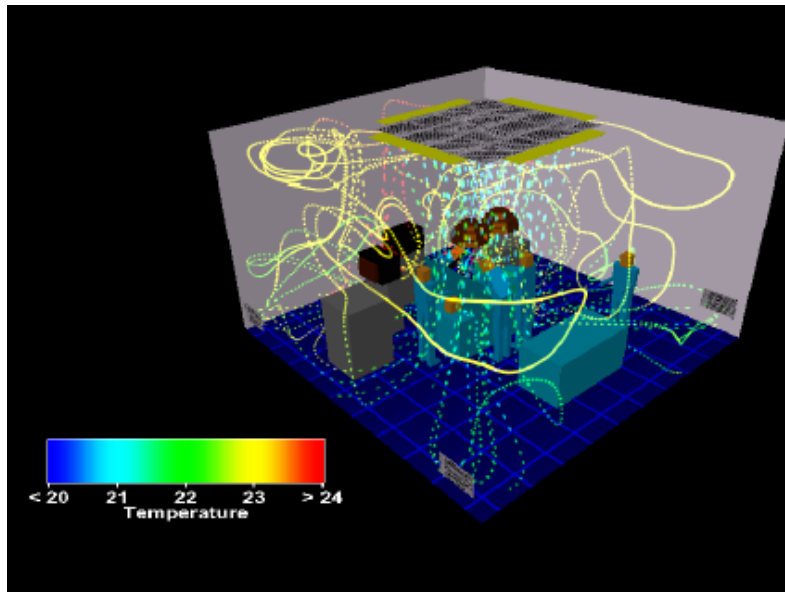
**Figure 3.** Airflow and temperatures in an OR with conventional ventilation systems (Mermarzadeh and Manning, 2002)



**Figure 4.** Airflow and temperatures in an OR with conventional ventilation systems (Mermarzadeh and Manning, 2002)

(Buchanan and Dunn-Rankin,1998), simulated two ventilation systems: cross-flow and “impinging-flow”. The cross-flow presented airflow moved horizontally over

the operating table, and the particles were lifted toward the ceiling by strong air currents and then carried to the outlet and removed. In this case the heating source had a little effect in the airflow. The impinging flow was opposed by rising natural convection currents caused by the heating loads that prevented the inlet air from properly ventilating the surgical site and its distribution in the room. Cross-flow was more efficient in the contaminant removal than impinging flow. The results showed that surgical team, patient and lights had great effect on the airflow due heat loads, which had a significant influence in the transport of air contaminants. Other papers also reported these effects in LAF, Unidirectional and Plenum ventilation systems, mainly which present vertical air supply. (Scherrer, 2003, Friberg, 1998, Mukhaiber and Turner, 2004, and Dhara and Pittet, 2002).



**Figure 5.** Airflow and temperature in an OR, resulting of a laminar supply (Mermarzadeh and Manning, 2002)

(Wanner et al., 1980), evaluated ORs equipped with a LAF “modern” (“Greenhouse”) and with a so called “germ-stop wall”. The second system consisted of glass wall with an opening to move in the patient, and which divided the OR in two zones. The first Zone is cleaner than Zone 2, which attend, respectively, the surgical team and another anaesthesiologist and other support staff. The second system reported great results on control of bacteria levels.

The LAF also had significant impact on postoperative infection rate, when combined with other ventilation systems, for example, the Helmet Aspirator System. However, a disadvantage of the body exhaust gowns is the reduced working conditions – freedom of movement, weight, etc. These results were reported in (Friberg et al., 2001, and Lidwell et al., 1987) cited in (Friberg, 1998) and (Technology Assessment Team, 2001). Otherwise, some studies reported a reduction, not significant, to the count of aerobic airborne and sedimenting bacteria-carrying particles in the OR using a mobile LAF screen in addition to conventional (mixing) ventilation system. These same levels were achieved with a LAF with HEPA filters. (Friberg et al., 2003, Napolitano, 2004 and Pasquarella et al. 2003). This subject needs to be investigated in details, because some

studies presented different comments for a same type of ventilation system for the same types of surgeries.

### COMBINED SYSTEMS

In this topic, some question will not be answered because literatures searched do not present all the information.

Other types of ventilation systems were evaluated and compared in the study of (Friberg et al., 1996). The ventilation systems were: “Floormaster” with the supply air from the floor and exhaust through the ceiling, and the Plenum with the diffuser of supply air inclined and in a wall, while the exhaust at floor level. The conclusions were “that an upward displacement system will lead to increased counts of airborne and sedimenting bacteria and thus increase the risk of postoperative infection in comparison with convention operating room ventilation systems”.

Two types of ventilation systems used in Brazil and in other countries are the Unidirectional ventilation system in addition the Linear System. These systems combined define three zones in the OR – Zone 1 (ultra clean) stay the patient, Zone 2 the surgeon, auxiliary nurse and instrument tables, and Zone 3 the anesthesiologist, the circulating nurse and other support staff. The Linear system here “works” like a barrier, dividing the Zone 2 from Zone 3. This barrier does not permit that the less clean air enter in the Zone 2, therefore ensuring satisfactory protection for the instrument table. Hospitals that used these systems in OR have reported lower infection rate. These combined systems are represented in the Figures 6.

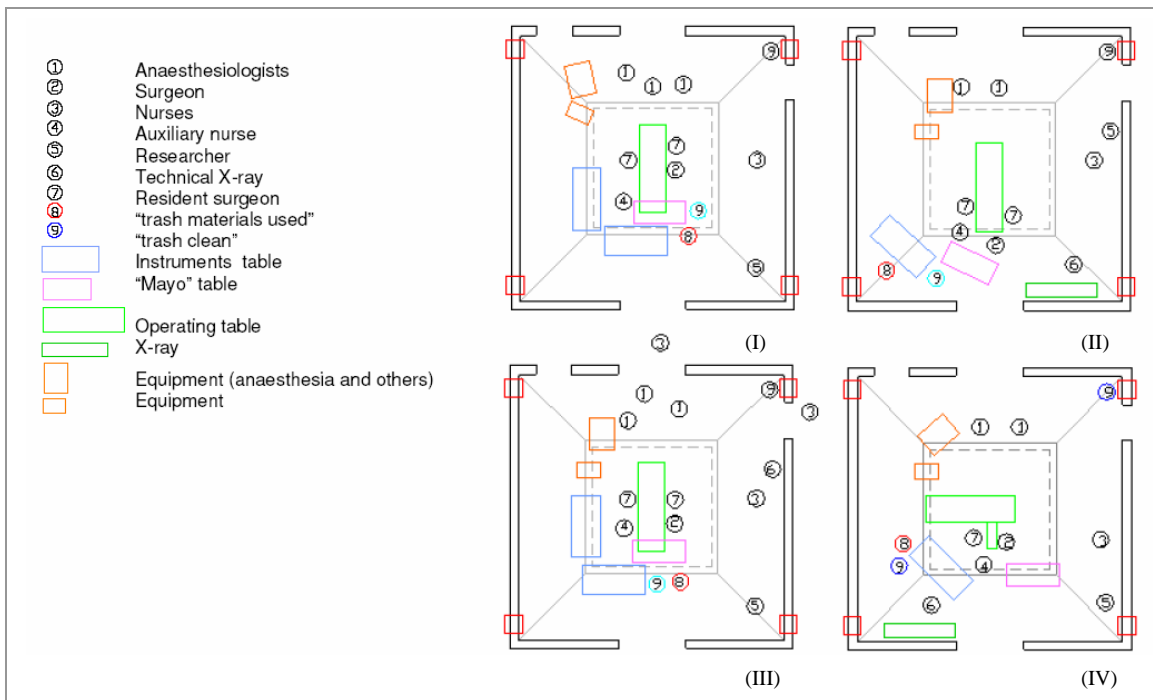


**Figure 6.** Example of Unidirectional and linear systems (TROX do Brazil, 1992 - reported by Melhado, M. 2003)

Reporting the results in visits in OR, it was observed the high complexity involved in this subject, and that it is very difficult to control some variables. In different types of surgery it was observed different layouts. However, in the hip surgeries (OR I and III) the layout of table instruments, position of the operating table, light and people were similar. In all surgeries the instrument table had out if the Zone 1, or in some case between Zone 1 and Zone 2. In all surgeries the anesthesiologist, anesthesiologist residents, nurses and other people stay in Zone 2. In the Figure 6 you can see four examples of layouts and surgeries, in which the security aspects of infection control were



not kept for the instrument table and for the patient. The “mayo” table usually was in Zone 1. However, in the cases that the surgeon need more space because the type of surgery, or when it was used the X-Ray, this table was kept between Zone 1 and Zone 2, or totally in the Zone 2. All equipment was kept in the limit Zone 1 in the majority of the surgeries. The position of these can result in disturbed airflow dynamic of the supply air. The people positions are represented in the Figure 6 through numbers: anaesthesiologist and respective residents (1), surgeon (2), nurse (3), auxiliary nurse (4), researcher (5), technical X-ray (6), resident surgeon (7), and the other number representing the trashes (8 and 9). The “trashes” always were located closer the instrument table. The “trash”, closer from the doors, always it was in this corner and covering the exhaust. The position of the people and instrument table changed in accordance with the type of surgery.



**Figure 6.** Examples of layout observed during some surgeries

## CONCLUSION

The purpose of this paper was to make a comparative of different ventilation systems. The literature shows that the LAF (vertical) is the most efficient system in terms of infection control. Satisfactory results were also reported in the Large-plenum and Unidirectional x Linear systems. However, it was verified that this efficiency is affected by the heat load in the OR, which, in turn, is affected by the amount and type of equipment, people and lights used. Other variables may also affect the efficiency, for example, the movement of people in the OR, and the occurrence of open doors.

The observations in ORs permitted to see how difficult it is to manage the security aspects of infection control during the surgery, independent of the type of ventilation

system used. Usually the instrument table is not kept in an ultra clean zone, which decreases the level of protection against contaminants on the instruments.

The different ventilation systems should be used in different types of surgery, taking into account the different number and type of equipment, lights and people that are necessary. There is a great need for further research in this area. One very important task is to make a review of all the ventilation systems used in reality, and to evaluate their real efficiency. This would permit designers and engineers to develop more efficient ventilation systems, and to clarify to consumers the behaviour of the products. Of course, the primary advantage would be that improved knowledge in this area would lead to improvements in the security aspect of infection control in ORs.

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