Comparison of laminar and mixing airflow pattern in operating rooms of a Norwegian hospital

GUANGYU CAO
Norwegian University of Science and Technology, Trondheim, Norway

ANDERS MOSTRØM NILSSEN
Norwegian University of Science and Technology, Trondheim, Norway

HANS MARTIN MATHISEN
Norwegian University of Science and Technology, Trondheim, Norway

YIXIAN ZHANG
Chongqing University, China

KAI XUE
Chongqing University, China

LIV-INGER STENSTAD
St. Olavs hospital, Norway

ANDREAS RADTKE
St. Olavs hospital, Norway

JAN GUNNAR SKOGÅS
St. Olavs hospital, Norway

Abstract

At present, laminar airflow (LAF) systems and mixing ventilation (MV) systems are two commonly used ventilation solutions for operating rooms (ORs) to ensure the required indoor air quality. Recent studies have shown that there is little difference in the prevalence of surgical site infection (SSI) between LAF systems and MV systems. The objective of this study was to compare the performance of a LAF system and a MV system in ORs at St. Olavs hospital, Norway. In this study, all experimental measurements were conducted in real ORs at St. Olavs hospital in Trondheim, Norway. The results showed a wide range of air distribution patterns in the surgical microenvironment with both systems. Under operating conditions, the thermal plume from a lying patient and surgical staff may change the local airflow distribution in the surgical microenvironment in the OR with LAF. This indicates that MV may be a robust way to deliver airflow under disturbed conditions. This study suggests that the performance of LAF and MV needs to be evaluated regularly under real surgical procedures in Norwegian hospitals.

Introduction

Surgical site infection (SSI), which are the most common hospital-acquired infections, leads to a big burden for the patient and an increased cost for the society. Among other factors, the air quality of operating rooms (ORs), especially the surgical microenvironment (see **Figure 1**), plays an important role to prevent the development of surgical site infections (SSIs). One previous study shows that an improved indoor environment of a hospital building can reduce costs associated with airborne illnesses by 9% – 20% [1]. At present, both laminar airflow (LAF) systems and mixing ventilation (MV) systems are commonly used in ORs to ensure the required indoor air quality. **Figure 1** shows sketches of an operating theatre with a mixing system and a laminar airflow system.

Recent studies have shown that there is little difference in the prevalence of SSI between the designs of an LAF system and an MV system. The recently published WHO guideline suggests that LAF systems should not be used to reduce the risk of SSI for patients undergoing total arthroplasty surgery, but the conclusion is disputed and based on conditional recommendation, low to very low quality of evidence [3]. In fact, ORs contains numerous transient phenomena that may cause significant changes to the time resolved indoor air distribution patterns. Multiple studies have investigated how different factors affect the efficiency of the two different ventilation systems. **Table 1** summarizes these findings.

The reason for these controversial results and conflicting guidance is the lack of scientific understanding of the dynamic distribution in the surgical microenvironment (see **Figure 1**) in ORs under operating conditions. The objective of this study was to compare the performance of LAF systems and MV systems in terms of airflow distribution in the surgical microenvironment in ORs at St. Olavs hospital.

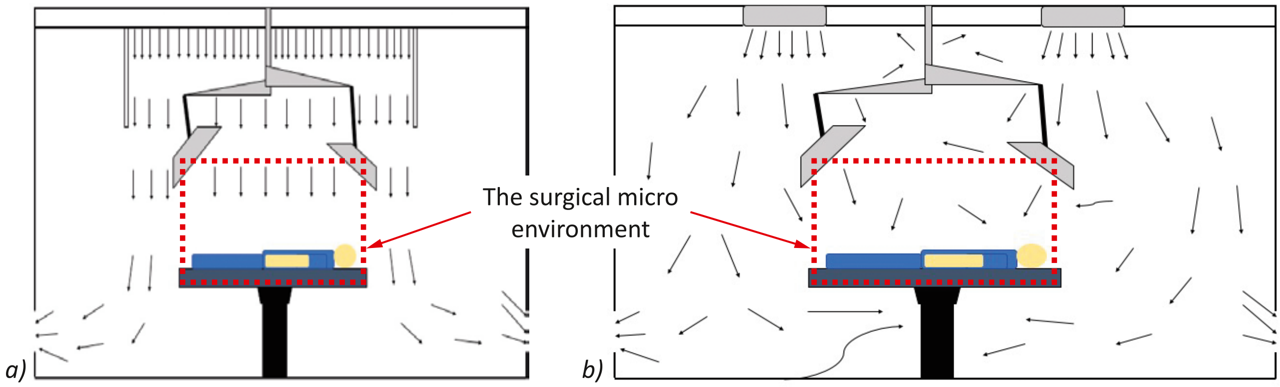


Figure 1. Principle of ventilation systems in operating rooms: a) a vertical laminar system, b) a mixing ventilation system. [2]

Table 1. *A comparison of LAF and MV. [4]*

Aspects	LAF	MV
Position of the operation table and the sterile operating team	Very important. Has specific borders between the sterile zone and the surroundings.	Not so important. Designed to provide equal conditions in the entire room.
Type and position of the lamps	Very important [5]. It was identified that the positioning of lamps is crucial to the airflow distribution near the patient.	Less important. Mixing airflow will dilute the contamination concentration in the whole operating room.
Operating staff clothing system	Very important. To great extent determines staff source strength.	Very important. To great extent determines staff source strength [6].

Methods

Experimental setup

In this study, all measurements were conducted in two ORs at St. Olavs hospital in Trondheim, Norway. The OR with an LAF has an area of 56 m² with 11 m² of laminar airflow zone, which is surrounded by 1.1 m long partial walls (see **Figure 2**). During the experimental measurements, the ventilation system was operated with full load, and the room temperature was commonly set to 22°C. During the experiments, the supply air temperature was 20 ±1°C. The designed supply air in the orthopedic OR with LAF was 10 580 m³/h: comprising 4 280 m³/h of outdoor air and 6 300 m³/h of recirculated air. A male thermal manikin was used to simulate a patient in an operating room. The detailed description of the thermal manikin can be found in Cao et al. (2018) [7].

The OR with an MV system was equipped with four ceiling-mounted diffusers. For the exhaust, there were two wall-mounted exhaust outlets and one near the ceiling. The OR with MV had an area of 59.7 m². The set-point temperature of the theatre was 22.0°C in all scenarios. The supply airflow rate was 3 700 m³/h, and the exhaust airflow was 3 600 m³/h. During measurement, an adjustable stand was used to carry the anemometers. Five anemometers were aligned on the stand with a separation of 10 cm. The stand was placed at three different positions above the operating table: pelvis, waist and chest. At each cross-section, measurements were performed at six heights: 5, 10, 15, 20, 25, and 30 cm above the surface of the location. The heights of the measurement point were selected to present relative to the human body, which does not have equal heights at each part of the body surface.

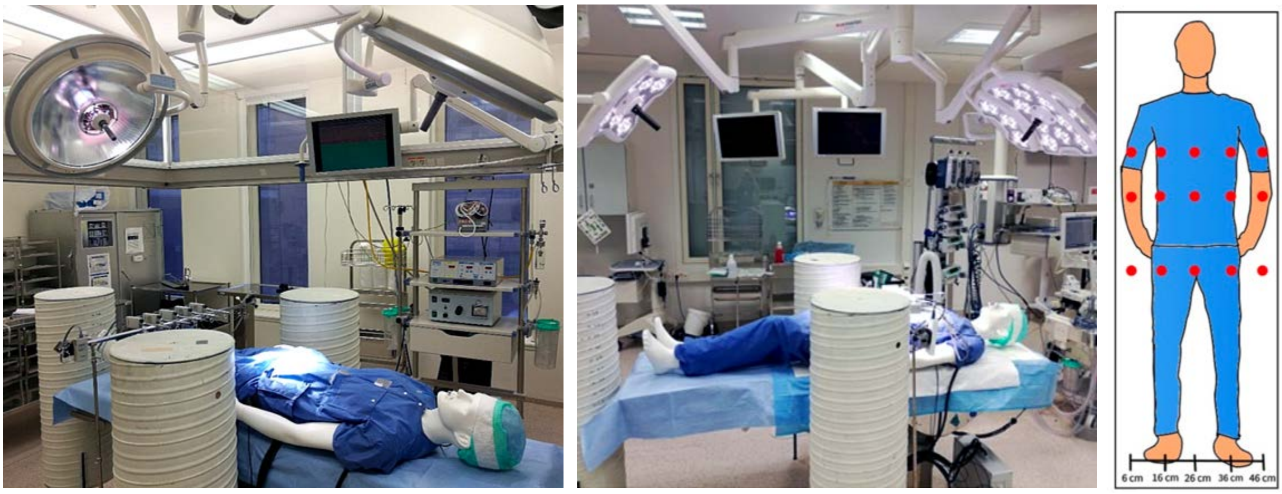
In this study, two scenarios (see **Table 2**) that include four different cases, were investigated. Scenario 1 (cases 1-2) measured the airflow distribution in these ORs with only an operating table as a reference case. Scenario 2 (cases 3-4) measured the airflow distribution in the ORs with a lying patient. Operating lamps were put away from the measurement zone.

Table 2. Scenarios of the experimental measurements.

Scenarios	Cases	Number of patients	Ventilation mode
S1	case 1	0	LAF
	case 2	0	MV
S2	case 3	1	LAF
	case 4	1	MV

Instruments

The AirDistSys 5000 system with five omnidirectional anemometers was used to measure the velocity and temperature of the airflow near the operating table. The velocity range of the SensoAnemo 5100 LSF omnidirectional anemometers is 0.05 – 5.00 m/s with an accuracy of ±0.02 m/s ±1.5% of readings. The recording time for each measurement row was set to 3 minutes.



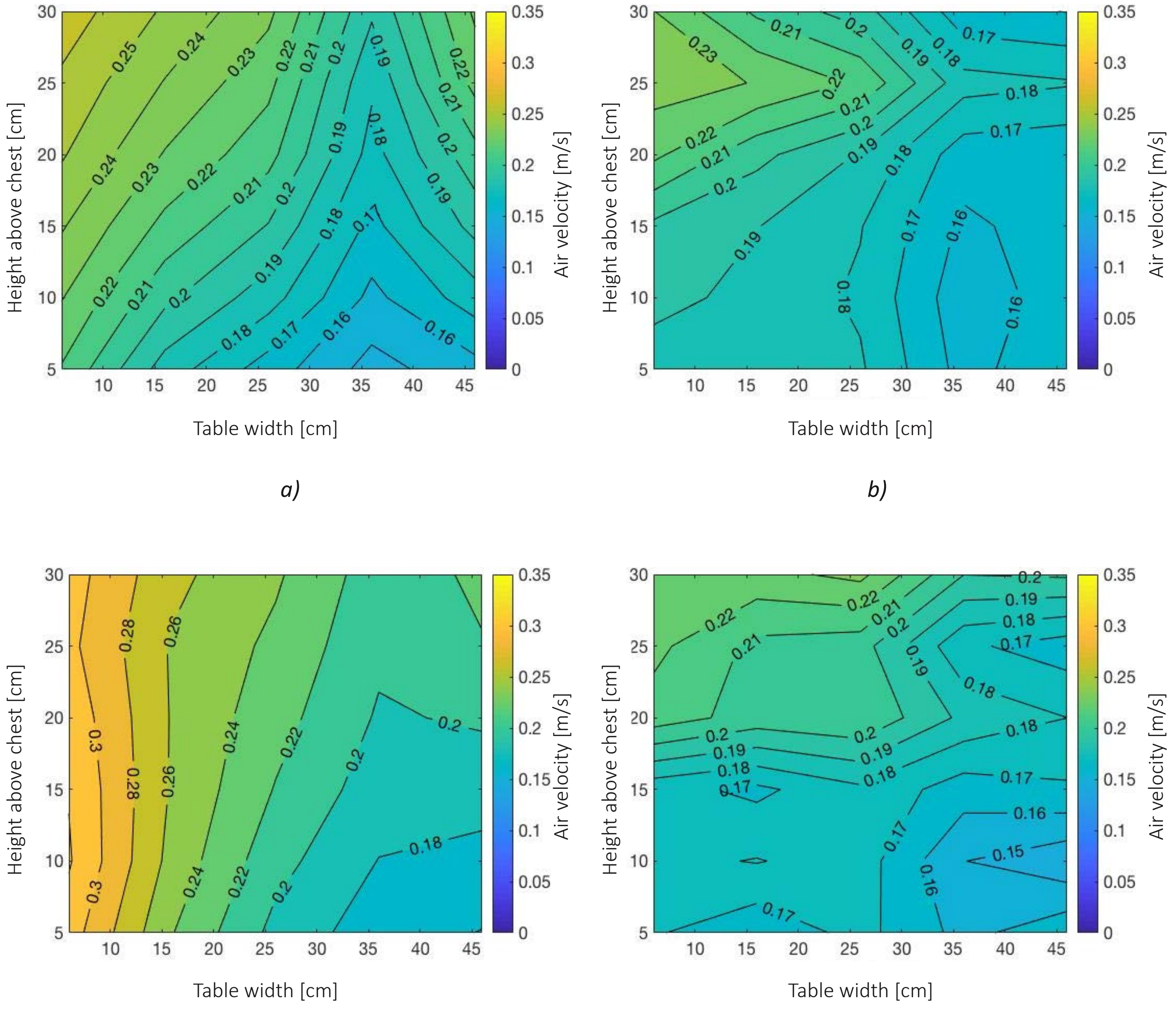
a) b) c)

Figure 2. Experimental setup: a) photo of the operating room with a LAF; b) photo of the operating room with an MV; c) location of measurements. [4]

Results

Measured air velocity distribution over an empty operating table - Scenario S1

Figures 3 a-d show the velocity distribution above an empty operating table in ORs with LAF and MV. **Figures 3a** and **3b** show the velocity contours above the chest of the patient in ORs with LAF and MV, respectively. With the LAF system, the velocity above the chest position is 0.15 – 0.26 m/s, which is similar to the velocity distribution with the MV. The velocity contours in the LAF system show a downward airflow pattern, and the velocity contours in the OR with MV shows a side-blow (from left to right) airflow pattern. **Figures 3c** and **3d** show the velocity above the waist position in two ORs with the LAF and the MV, respectively. In the OR with LAF, the minimum value is 0.18 m/s, and the maximum is 0.32 m/s. The results show that the velocity distribution varies in these two systems. The airflow distribution in the OR with LAF resembles a stratified airflow with decreasing velocity when it approaches the operating table. The velocity distribution in the MV system is more similar at different positions.



a)

b)

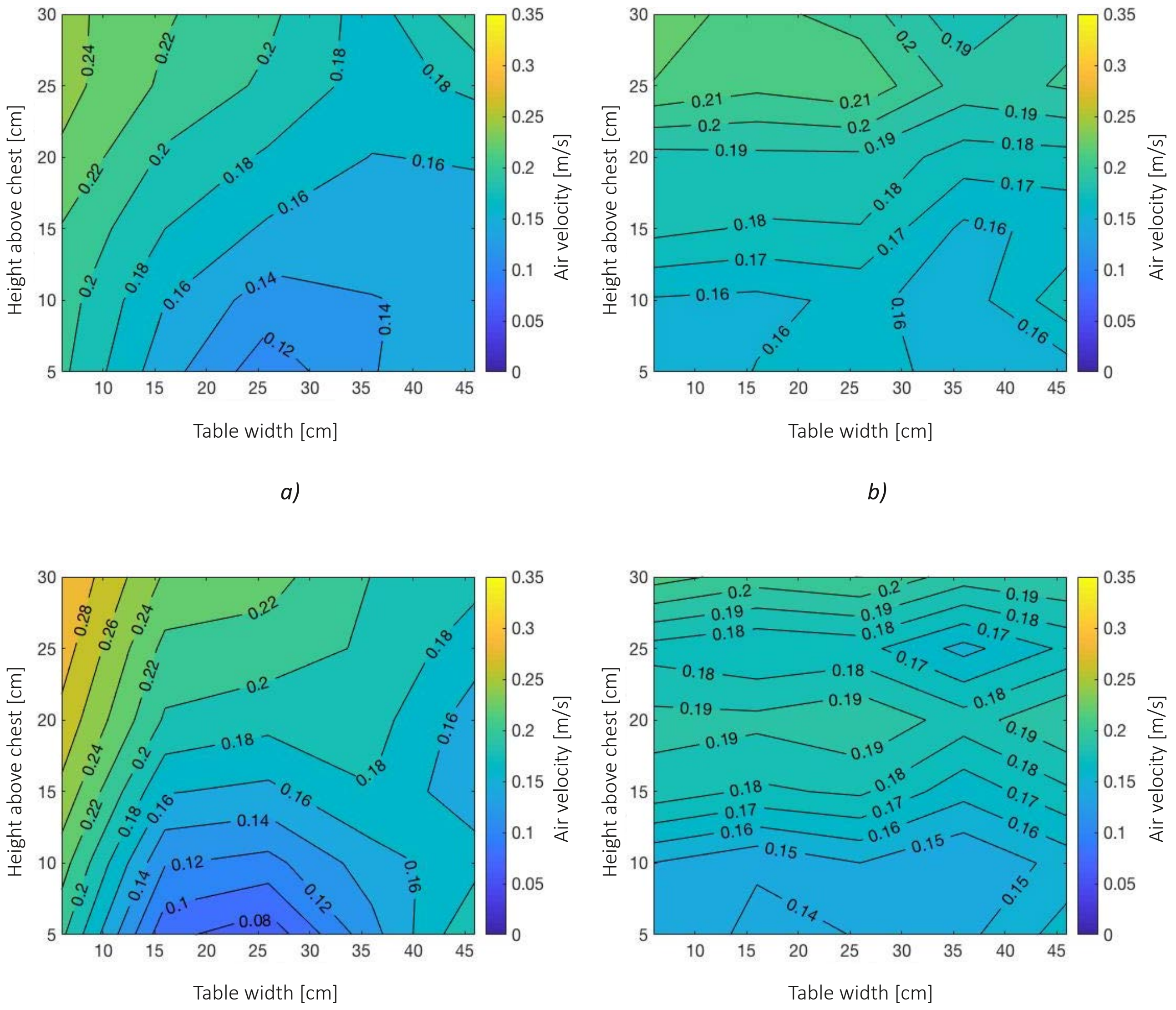
c)

d)

Figure 3. Measured velocity contours above operating table in ORs with LAF and MV – scenario S1 including case 1 and case 2: a) above the chest position with an LAF system; b) above the chest position with an MV system; c) above the waist position with an LAF system; d) above the waist position with an MV system.

Measured air velocity distribution over one patient - Scenario S2

Figures 4 a-d show the velocity distribution above a lying patient in ORs with LAF and MV. **Figure 4a** and **4b** show the velocity contours above the chest of the patient in ORs with LAF and MV, respectively. With the LAF system in **Figure 4a**, the velocity above the chest position was 0.12 – 0.24 m/s. The velocity near the patient was notably low (0.12 m/s) because of the thermal plume generated by the patient. **Figure 4b** shows a similar distribution with the MV system, which generated a slightly higher velocity zone (0.16 m/s) notably near the chest. **Figure 4c** shows the velocity distribution above the waist in the OR with LAF. It shows that the velocity near the patient became even lower above the waist, 0.08 m/s. The plume-like airflow distribution may be caused by the rising thermal plume from the patient. As **Figure 4d** shows, the velocity measured above the waist varies between 0.14 – 0.20 m/s, which is similar to that in **Figure 4b**, which was measured above the chest.



a)

b)

c)

d)

Figure 4. Velocity contours above a lying patient in ORs with LAF and MV – scenario S2 including cases 3 and 4: a) above the chest position with an LAF system; b) above the chest position with an MV system; c) above the waist position with an LAF system; d) above the waist position with an MV system.

Discussions

Effects of surgical lamps on airflow distribution

This study only presents the measurement results in ORs without the use of surgical lamps, which may affect the airflow pattern significantly. One earlier study reported the measured air velocity profiles formed under the surgical lights and without lights for different heights [7] (shown in **Figure 5**). The edges of lights are highlighted with dashed lines of the same matching color that is used for the velocity profiles. The turbulent airflow formed behind lights is illustrated by the gap formed between the yellow marked points representing velocities measured without lights and the points measured under different surgical lights – marked by blue, red and green colors. The mean value of the velocities measured under surgical lights were 0.07 m/s under light mo. 1 (blue), 0.07 m/s for light mo. 2 (red) and 0.06 m/s for light mo. 3 (green). The measured air velocity was over 0.25 m/s without the effect of surgical lamps.

Turbulence intensity in the surgical microenvironment with MV and LAF

In addition to airflow distribution, another previous study investigated the turbulence intensity in the surgical microenvironment with an MV and an LAF [4]. **Figure 6 a-b** show the measured air turbulence

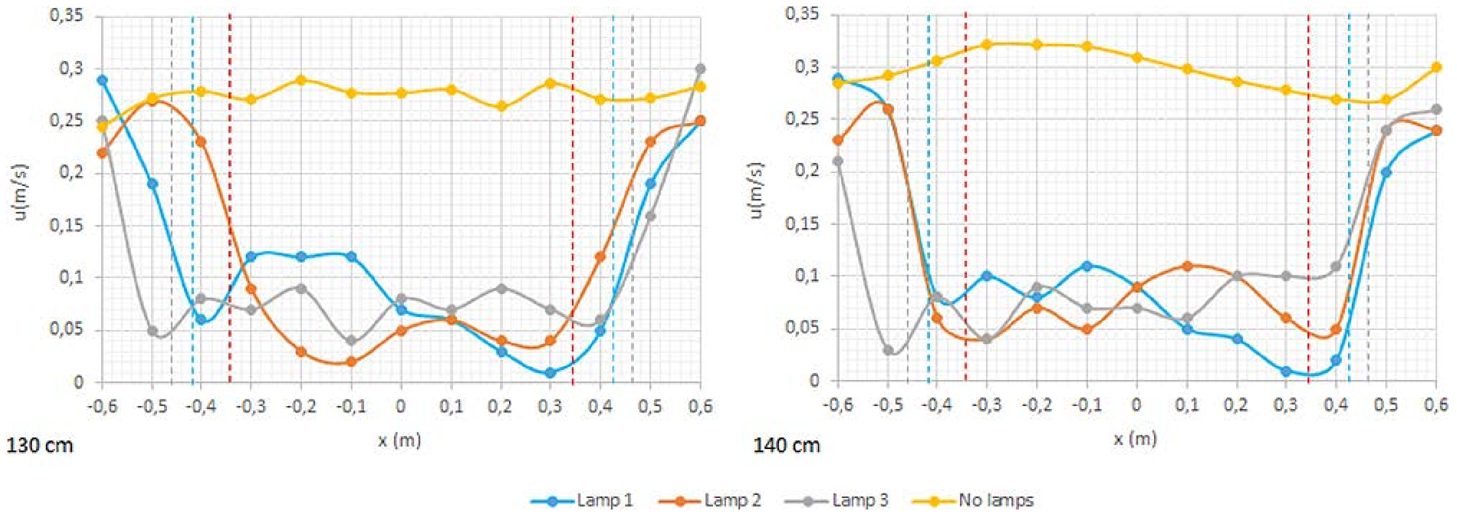
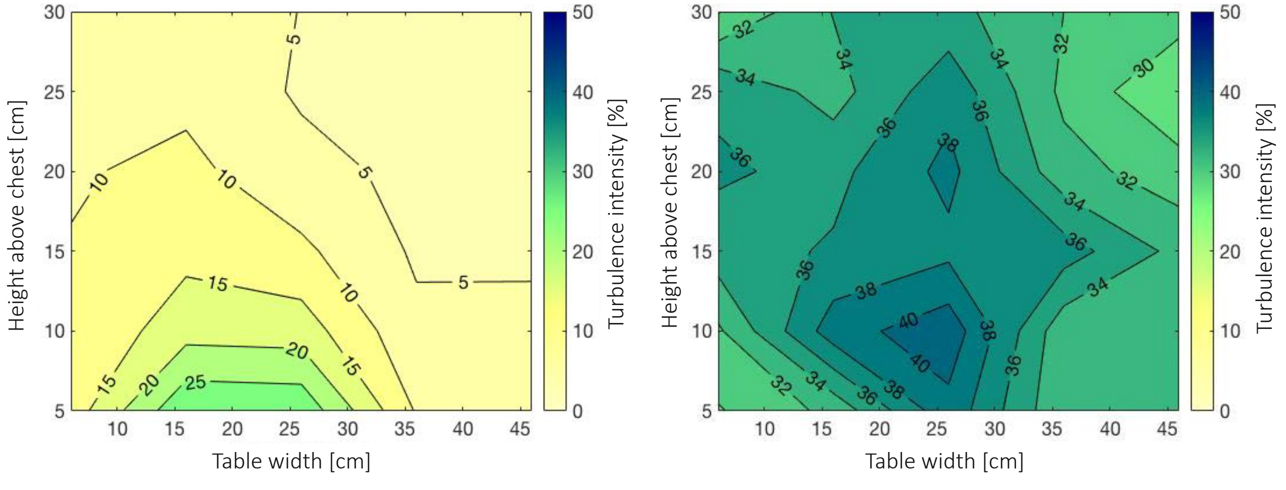


Figure 5. Measured mean velocity profiles with and without the effect of surgical lamps at different heights in ORs. [8]



a)

b)

Figure 6. Air turbulence intensity contours above a lying patient surrounded by three surgical staff with the use of two surgical lamps: a) above the waist position with an LAF system; b) above the waist position with an MV system. [4]

intensity distributions above a lying patient surrounded by three surgical staff with the use of two surgical lamps. **Figure 6a** shows measured turbulence intensity in an OR with an LAF. The values range from 5 to 20% at 15 cm above the body surface. While the highest values, 20 to 25% are encountered within 10 cm from the body surface. **Figure 6b** shows the measured contours of air turbulence intensity in the operating room with MV, which varies from 30% to 40% above the waist of the simulated patient. These results indicate that air turbulence intensity level of supply airflow from LAF is much lower than from MV. This was caused by the mixing processed of supply air and ambient air in operating rooms in the surgical microenvironment.

Conclusion

The air distribution in operating rooms may significantly change under real operation conditions with various disturbance, including surgical facilities, internal heat sources, patients, surgical staff and various monitors. A common feature of the airflow pattern in ORs with either LAF or MV is that the velocity contours are drastically changed from each cross-section, which indicates the combined effect of surgical facilities and the thermal plume of the patient and surgical staff. However, the surgical lamps appear to have a greater effect on the velocity with an LAF system than with an MV system. This study provides evidence that the airflow velocity in the surgical microenvironment shows a wide range of patterns with an LAF system and an MV. The thermal plume from a lying patient may change the airflow distribution in the surgical microenvironment more in the OR with an LAF than with an MV system. This study suggests that the performance of LAF and MV need to be evaluated under different surgical procedures in Norwegian hospitals. Further studies are needed to clarify how these different airflow patterns will influence the development of SSIs. More experiments using tracer gas need to be performed to investigate the effect of MV and LAF on the heat and mass transfer in the surgical microenvironment. ■

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