Effects of Forced Air Warming on Airflow around the Operating Table

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ABSTRACT

Background: Forced air warming systems are used to maintain body temperature during surgery. Benefits of forced air warming have been established, but the possibility that it may disturb the operating room environment and contribute to surgical site contamination is debated. The direction and speed of forced air warming airflow and the influence of laminar airflow in the operating room have not been reported.

Methods: In one institutional operating room, we examined changes in airflow speed and direction from a lower-body forced air warming device with sterile drapes mimicking abdominal surgery or total knee arthroplasty, and effects of laminar airflow, using a three-dimensional ultrasonic anemometer. Airflow from forced air warming and effects of laminar airflow were visualized using special smoke and laser light.

Results: Forced air warming caused upward airflow (39 cm/s) in the patient head area and a unidirectional convection flow (9 to 14 cm/s) along the ceiling from head to foot. No convection flows were observed around the sides of the operating table. Downward laminar airflow of approximately 40 cm/s counteracted the upward airflow caused by forced air warming and formed downward airflow at 36 to 45 cm/s. Downward airflows (34 to 56 cm/s) flowing diagonally away from the operating table were detected at operating table height in both sides.

Conclusions: Airflow caused by forced air warming is well counteracted by downward laminar airflow from the ceiling. Thus it would be less likely to cause surgical field contamination in the presence of sufficient laminar airflow. **(ANESTHESIOLOGY 2018; 128:79-84)**

HYPOTHERMIA delays healing and predisposes patients to wound infections. Maintaining normothermia during surgery reportedly reduces the incidence of surgical site infection, improves wound healing, and hastens discharge from the hospital.[1–3] Forced air and conductive patient warming systems are widely used to prevent unintentional hypothermia during surgery. However, there is a possibility that forced air warming (FAW) systems cause convection flows in the operating room (OR).[4]

The ventilation system in the OR is designed to maintain constant air quality by eliminating airborne particles. Special ventilation systems supplying filtered air at positive pressure are required in the OR. Approximately 20 air changes/h are necessary to dilute microorganisms generated in the operating room and to exclude ingress from surrounding areas.[5] A laminar airflow (LAF) system is thought to be a useful ventilation system, and thus it is recommended for preventing surgical site infection in the OR. However, LAF has not been recommended for performing orthopedic implantation in the Centers for Disease Control and Prevention/Healthcare Infection Control Practices Advisory Committee guidelines.[5] LAF systems also require high investment costs and operating expenses compared with conventional ventilation systems.[6]

What We Already Know about This Topic

- Forced air warming systems are effective at maintaining body temperature during surgery
- It has been suggested that forced air warming systems may disturb the air environment of the operating room, contributing to airborne contamination to the surgical site

What This Study Tells Us That Is New

- The airflow caused by forced air warming is well counteracted by downward laminar airflow from the ceiling

There are concerns that convection flows caused by FAW could disrupt LAF and impede its ability to prevent surgical site contamination. Some surgeons request that FAW devices are not activated until the patient has been fully prepared and draped—or even that they not be used at all.[7] Whether FAW increases the risk of surgical site infection is a matter of continuing debate.[7,8]

A variety of techniques, including particle count,[4,9] bacterial colony count[10–12] and illuminated neutrally buoyant detergent bubble count,[13,14] have been used to examine the influence of FAW on surgical site infection, but the changes in OR airflow caused by FAW in the presence or absence of LAF have

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This article is featured in "This Month in Anesthesiology," page 1A. This article has a video abstract. Authors wish to include the following note at proof: Please be aware of a recent (posted August 30, 2017) communication from the U.S. Food and Drug Administration about the use of forced air thermal regulating systems. See https://www.fda.gov/Safety/MedWatch/SafetyInformation/SafetyAlertsforHumanMedicalProducts/ucm574053.htm.

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not been reported. The purpose of this study was to evaluate changes in OR airflow caused by FAW, with or without LAF.

Materials and Methods

This study was performed in an OR in Kyushu University Hospital, Fukuoka, Japan. The OR is equipped with a vertical LAF system supplied by an independent air conditioning unit (air handling unit GV-7; Sinko Industries Ltd., Japan). The volume of the OR was 102.7 m^3 (floor space: 34.22 m^2, ceiling height: 3.0 m). The capacity of the air conditioning unit of this OR was planned as total supply air of 6,000 m^3/h to achieve International Standards organization cleanliness class 6, resulting in 58.4 air changes/h. The total area of the outlet high efficiency particulate air filter of LAF was 3.535 m^2; thus the mean outlet airflow velocity was planned as 47.1 cm/s.

We measured the airflow speed and direction caused by FAW in the absence or presence of LAF using three-dimensional ultrasonic anemometer. A 3M Bair Hugger (model 750; 3M Health Care, USA) with upper-body blanket model 522 or lower-body blanket model 585 was used as the FAW device, with the warming temperature set to 38°C. The Bair Hugger supplies approximately 48 cubic feet/min (23 L/s) of warmed air to the blanket. The laminar airflow operating temperature in the OR was 20 to 23°C, and the OR thermostat was set to 25°C.

Three-dimensional Measurement of Airflow

An upper-body manikin was placed in the supine position on the operating table and covered with a lower-body warming blanket and a general surgical drape. A manikin was used for these recordings due to the prolonged measurement time (fig. 1A). A three-dimensional ultrasonic

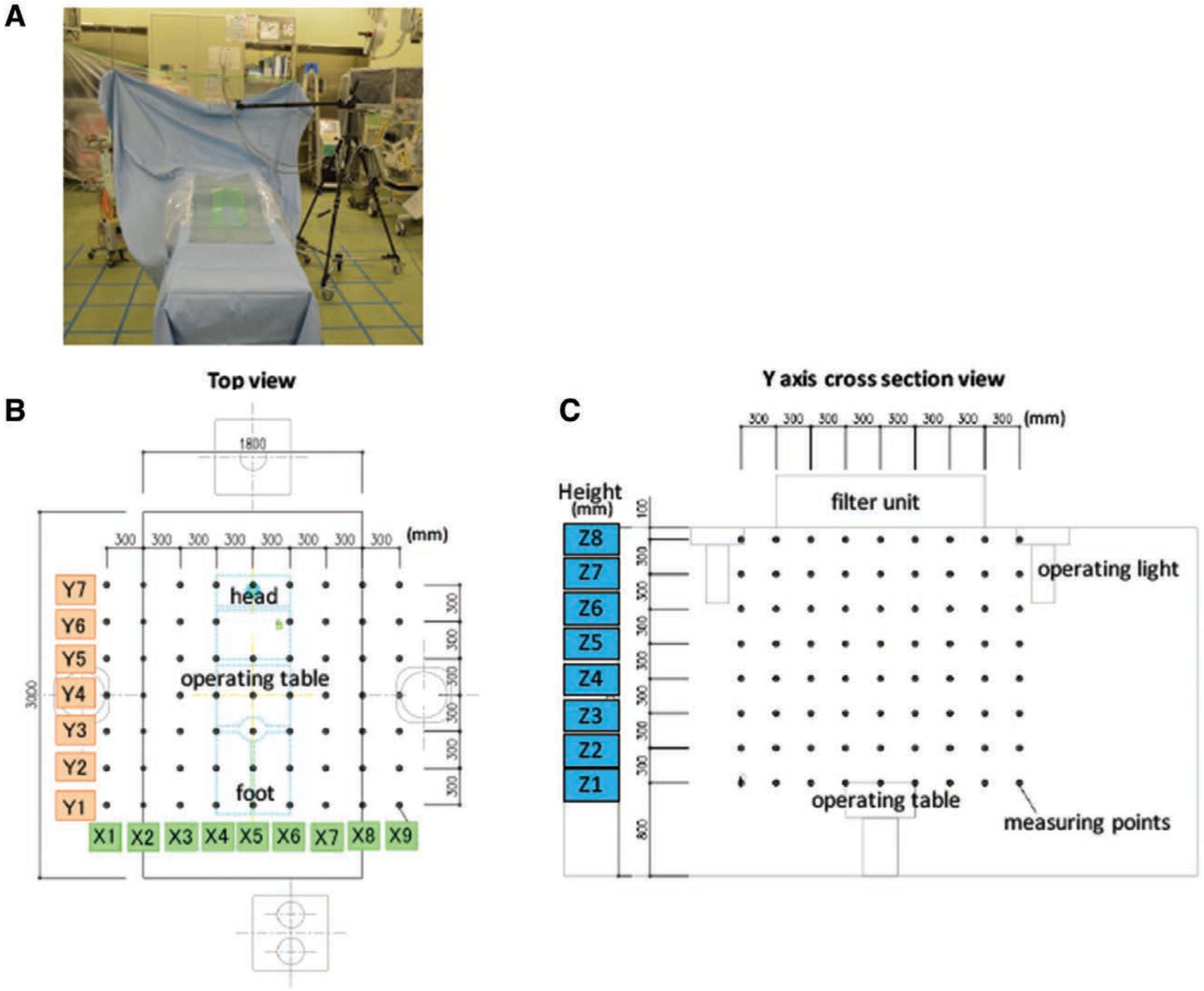


Fig. 1. Experimental setup and airflow measurement points. (*A*) An upper-body manikin was placed supine on the operating table and covered with a warming blanket and a general surgical drape. The floor was marked with tape every 300 mm. (*B*) View from above. There were nine measurement points on the *x* axis (X1–X9, where X5 was the center). There were seven measurement points on the *y* axis (Y1–Y7, where Y4 was the center). (*C*) View from the head of the operating table. There were eight measurement points on the *z* axis (Z1–Z8, where Z1 was 800 mm from the floor). All measurement points were 300 mm apart.

anemometer (model WA-790; Sonic Corporation, Japan) and airflow analyzing software (WASP-007N; Sonic Corporation) were used to measure airflow at a total of 504 points in every 300-mm interval; there were nine points in the side-to-side axis (*x* axis; the middle sagittal plane lay at point X5), seven points in the head-to-toe axis (*y* axis; the head lay at point Y7), and eight points in the vertical axis (*z* axis; point Z1 lay 800 mm from the floor at the height of the operating table; fig. 1, B and C). The results are indicated as the ranges (minimum – maximum) of the measurement area.

Visualization of Airflow

An adult volunteer lay supine on the operating table and was covered by lower- or upper-body warming blanket and a general surgical drape suitable for abdominal surgery or total knee arthroplasty. To observe the airflow, particles in the air were illuminated using smoke and laser light. The special harmless smoke of fine particles (approximately 10 μm in diameter) was created from a glycol-based solvent and water using a portable vapor generator (Porta Smoke, PS-2005; Dainichi Co., Japan). This smoke was illuminated by a laser light sheet source (Parallel Eye H; Shin Nippon Air Technologies Co., Ltd., Japan). Smoke was created on a sheet of laser light while the air conditioning was stopped, and changes in the smoke after the FAW and the LAF were activated were observed and recorded. We conducted these studies for 1 or 2 days each. These studies include data from one trial, and recording time length was about 12 h each. These studies were performed another day in the same room. This study was observational, and no formal statistical analyses were conducted.

Results

Three-dimensional Airflow Measured by Anemometry

At the X5 cross-section, an upward airflow of 39 cm/s was detected in the presence of FAW just above the manikin's head, and a continuous 9 to 14-cm/s convection flow from head to foot was observed along the ceiling (fig. 2), both of which were counteracted by laminar airflow (fig. 3). In other areas, no meaningful airflow was detected, particularly above the operating table. The airflows at the head and ceiling created by FAW were counteracted by laminar airflow of 38 to 45-cm/s outlet speed, which produced a

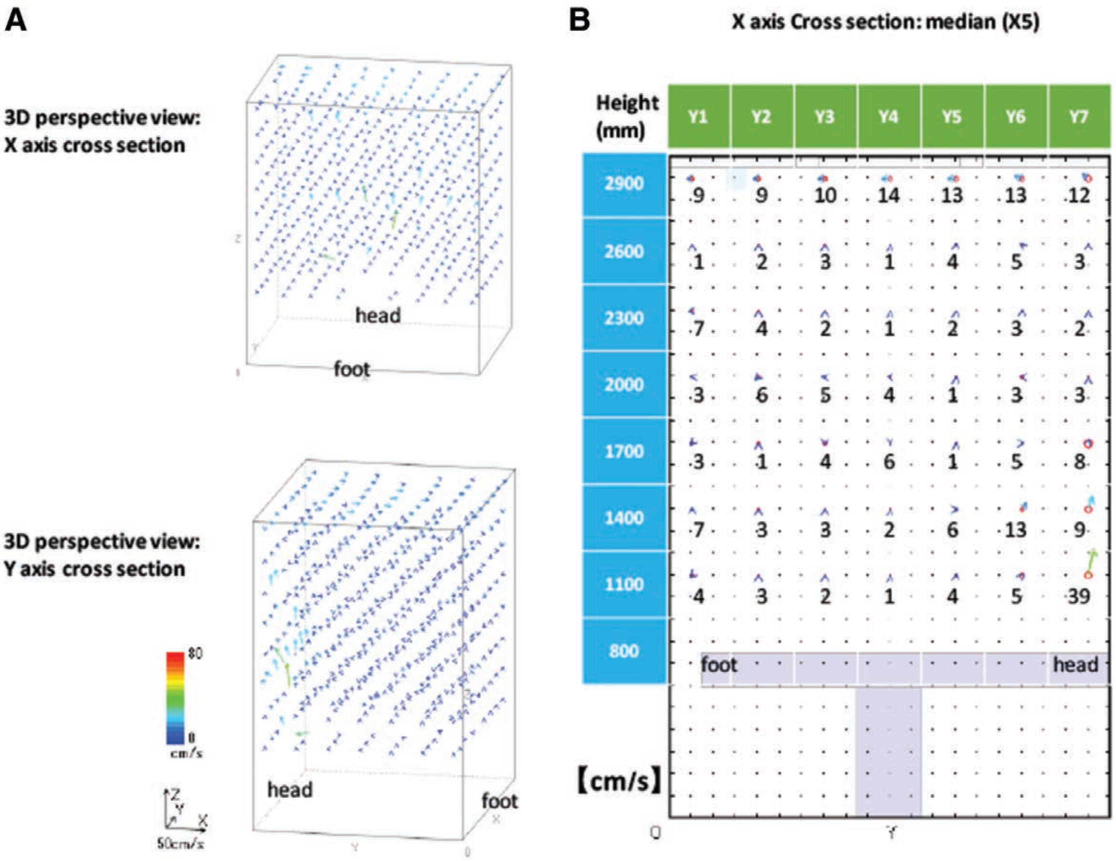
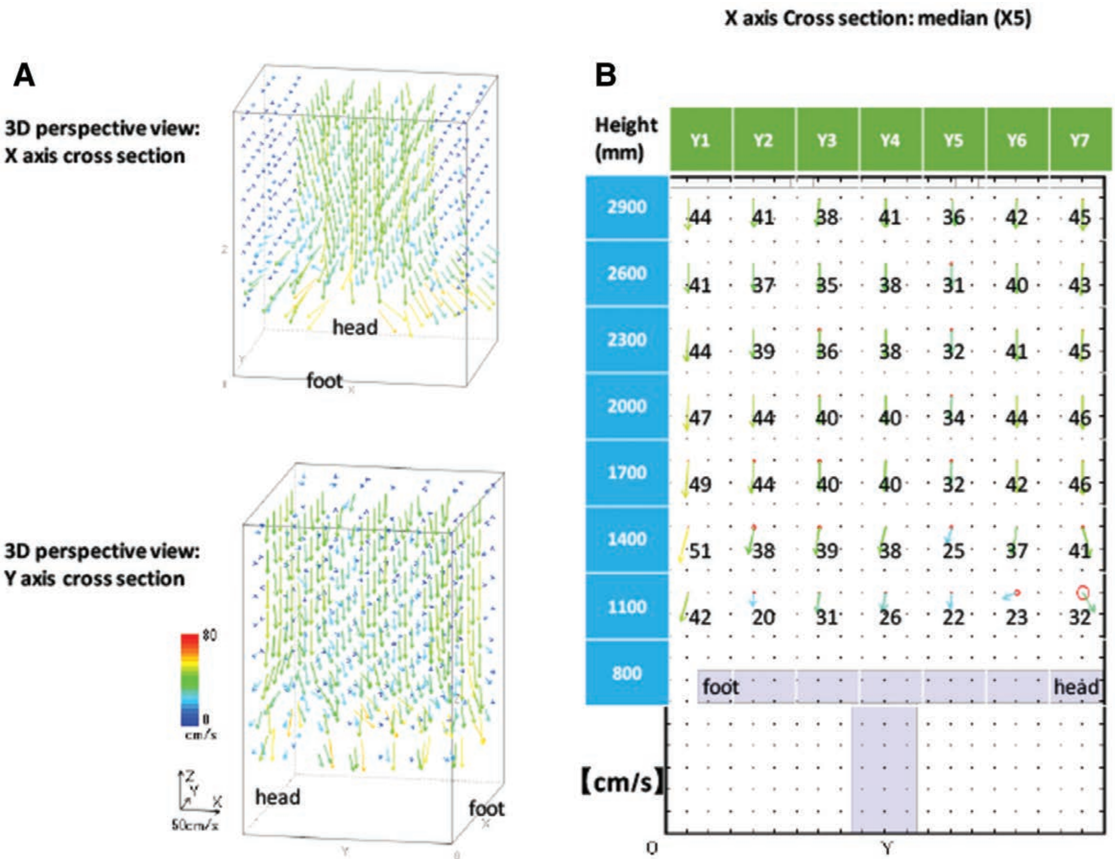


Fig. 2. Three-dimensional airflow direction and speed at the *x*-axis cross-section in the absence of laminar airflow. (*A*) Airflow caused by forced air warming in the absence of laminar airflow. (*Upper*) 3D perspective view at the *x*-axis cross-section. (*Lower*) 3D perspective view at the *y*-axis cross-section. (*B*) Airflow direction and speed at the cross-section of the *x*-axis (X5) caused by forced air warming in the absence of laminar airflow.



Height (mm)	Y1	Y2	Y3	Y4	Y5	Y6	Y7
2900	44	41	38	41	36	42	45
2600	41	37	35	38	31	40	43
2300	44	39	36	38	32	41	45
2000	47	44	40	40	34	44	46
1700	49	44	40	40	32	42	46
1400	51	38	39	38	25	37	41
1100	42	20	31	26	22	23	32
800	foot						head

Fig. 3. Three-dimensional airflow direction and speed at the *x*-axis cross-section in the presence of laminar airflow. (*A*) Airflow caused by forced air warming in the presence of laminar airflow. (*Upper*) 3D perspective view at the *x*-axis cross-section. (*Lower*) 3D perspective view at the *y*-axis cross-section. (*B*) Airflow direction and speed at the cross-section of the *x* axis (X5) caused by forced air warming in the presence of laminar airflow.

downward airflow from the ceiling to the operating table (fig. 3B).

In the Y4 cross-section, FAW caused a 14-cm/s convection flow from head to foot along the ceiling (fig. 4A), but no other meaningful flows were detected. This flow was counteracted by laminar airflow of 38 to 41-cm/s outlet speed, which again produced an area of downward air current 600 mm wide on either side of the center of the operating table (fig. 4B). Although the downward airflow reduced to 26 to 29 cm/s just above the operating table, air speeds of 34 to 56 cm/s were detected on both sides of the operating table at the height of the operating table (800 mm from the floor).

Visualization of Airflow Caused by Forced Air Warming

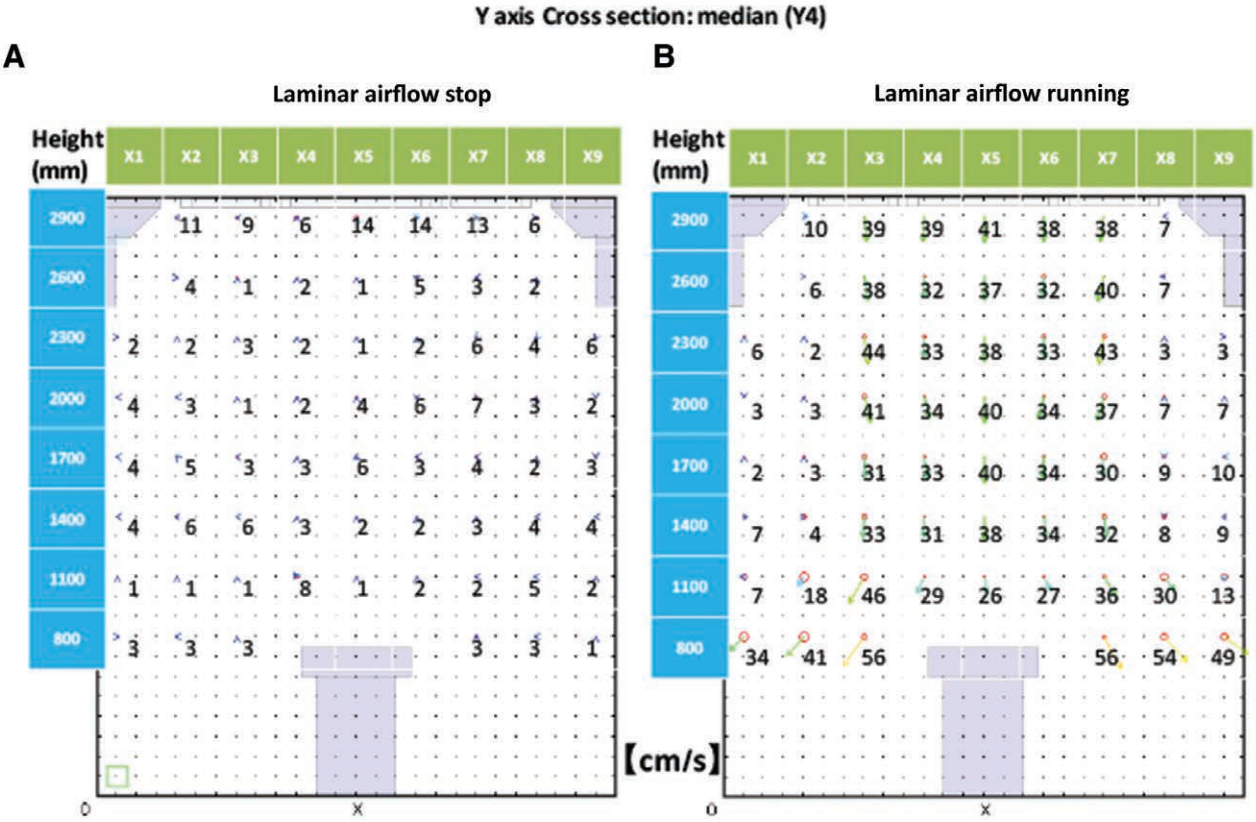
There was no meaningful airflow without forced air warming or laminar airflow (fig. 5A). FAW produced an upward airflow around the manikin's head and a continuous convection downward and footward flow around the body (fig. 5B). There was no convection flow around the side of the operating table and no upward flow from the floor (fig. 5B).

The Influence of Laminar Airflow

LAF counteracted the airflows produced by FAW (fig. 5C). There was no stagnant air under the laminar airflow (fig. 5C).

Discussion

This is the first report of airflow speed and direction caused by FAW with or without laminar airflow. We found upward airflow by the head at 39 cm/s, slight airflow (9 to 14 cm/s) from head to toe along the ceiling, and no airflow around the table (fig. 3). Laminar airflow of 38 to 45 cm/s outlet speed was barely affected by FAW (fig. 4). The reduction in laminar airflow to 20 to 31 cm/s just above the operating table is assumed to be caused by the contact of the flow with the surgical drapes (fig. 4). We were surprised to find a downward and footward convection flow above the body in the airflow visualization study (fig. 5B), which was not recognized in the flow measurement study. It was understood that airflow of minimal detectable speed was not recognized as a meaningful airflow in the three-dimensional airflow measurement study, whereas even such a fine current was detected as continuous particle movement in the airflow visualization study. Laminar airflow produced airflows down and away from



A Laminar airflow stop

Height (mm)	X1	X2	X3	X4	X5	X6	X7	X8	X9
2900		11	9	6	14	14	13	6	
2600		4	1	2	1	5	3	2	
2300	2	2	3	2	1	2	6	4	6
2000	4	3	1	2	4	6	7	3	2
1700	4	5	3	3	6	3	4	2	3
1400	4	6	6	3	2	2	3	4	4
1100	1	1	1	8	1	2	2	5	2
800	3	3	3				3	3	1

B Laminar airflow running

Height (mm)	X1	X2	X3	X4	X5	X6	X7	X8	X9
2900		10	39	39	41	38	38	7	
2600		6	38	32	37	32	40	7	
2300	6	2	44	33	38	33	43	3	3
2000	3	3	41	34	40	34	37	7	7
1700	2	3	31	33	40	34	30	9	10
1400	7	4	33	31	38	34	32	8	9
1100	7	18	46	29	26	27	36	30	13
800	34	41	56				56	54	49

Fig. 4. Airflow direction and speed at *y*-axis cross-section. Airflow direction and speed at the cross-section of the *y* axis (Y4) caused by forced air warming in the absence (*A*) or presence (*B*) of laminar airflow.

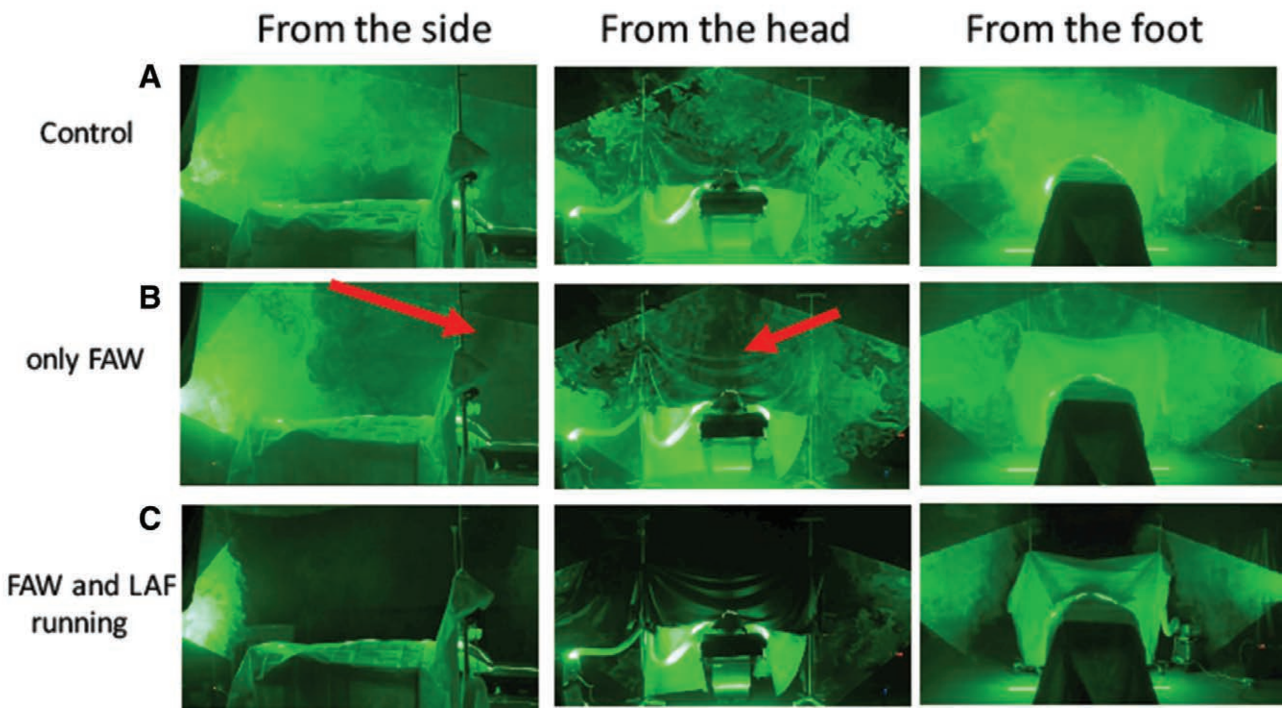


Fig. 5. Photographs of airflow visualization study (side, head, and foot view). (*A*) Airflow without forced air warming (FAW) or laminar airflow (LAF). (*B*) Airflow with FAW but without LAF. The *red arrow* indicates the upward air current caused by FAW. (*C*) Airflow with FAW and LAF. (*Left*) View from the side of the operating table. (*Center*) View from the head of the operating table. (*Right*) View from the foot of the operating table.

the manikin's body that were higher than the outlet speed (56 cm/s; fig. 4B). We were not able to detect any upward airflows from the floor to the side of the operating table in the presence of FAW (fig. 5B). Even if FAW at higher temperatures was able to entrain an upward airflow,[14] we judge that this would be counteracted by downward laminar airflow. It may also be possible that stagnant air lying outside the area of laminar airflow could be entrained toward the surgical site by human motion. For this argument, the capacity and position of air intakes for the laminar airflow is important. Although air intakes were located in each of the four corners around the floor of our OR, stagnant air was detected.

Our study had several limitations. First, the surgical lights were not positioned as they normally would have been during surgery. Second, we did not simulate the movement of surgical, nursing, and other OR staff during the study. Both might interfere with LAF. It has been suggested in a meta-analysis study that LAF actually may increase infection risk, presumably by pushing bacterial particulates from the faces of surgeons and scrub nurses right into the surgical wound.[15,16] However, Oguz *et al.*[17] reported that the absence of unidirectional LAF and longer duration of surgery increased bacterial counts and that FAW systems had no significant influence on the airborne bacterial counts at six standardized locations during minor orthopedic surgery. This report has suggested that human motion might have little effect on airborne contamination to surgical wounds and that LAF might be worthwhile to prevent surgical site infections. Third, we did not examine the influence of FAW temperature setting. It was reported that excess heat (43°C) from FAW resulted in the disruption of ventilation airflows over the surgical site because the release of excess thermal energy can establish temperature gradients that impede the downward flow of ultra-clean air.[13,14] This temperature setting might provide different results from our study and previous studies. However, we believe that this study brings important findings, because our airflow measurement study is an innovative technique compared with previous studies. Further research will be needed to characterize the influence of FAW on laminar airflow in an active, fully equipped OR. In the meantime, we should give careful considerations to LAF setting and the positions of the operating table and LAF system.

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Competing Interests

The authors declare no competing interests.

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