Mobile zoned/exponential LAF screen: a new concept in ultra-clean air technology for additional operating room ventilation

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Summary: A mobile screen (0.5 x 0.4 m) producing ultra-clean exponential LAF (air-flow central zone 0.6 m/s and peripheral zone 0.4 m/s) was investigated as an addition to conventional turbulent/mixing operating room ventilation. The evaluation was performed during strictly standardized sham operations reflecting conditions during major surgery. The study consisted of a pilot experiment designed to give high counts of sedimenting aerobic colony forming units (cfu). In a second main study, recording dust particles, air-borne and sedimenting aerobic cfu, the screen was associated with optimal operating room clothing.

In the pilot experiment the use of the screen resulted in a substantial reduction of sedimenting bacteria from 3835–4940 to 0–390 cfu/m²/h. In the main study, the use of the additional LAF reduced the surface contamination from 416–329 to 7–78 cfu/m²/h up to 1.6 m from the screen (P = 0.001–0.0001). Measured in the wound area the screen reduced the air counts of bacteria from 9–14 to 0.2–0.4 cfu/m³ (P = 0.008–0.0001) and a marked reduction of air-borne dust particles was recorded (P = 0.007–0.009).

In conclusion, the additional mobile LAF screen reduced the counts of aerobic air-borne and sedimenting bacteria-carrying particles as well as dust particles to the levels gained with complete ultra-clean LAF room ventilation. Thus, the screen might prove a valuable addition to operating room ventilation as well as in other areas where asepsis is essential.

Keywords: Operating room; laminar air flow; clothing; colony counts; microbiology; particle counts.

Introduction

A major factor in surgical site infection (SSI) is bacterial contamination of the operating room (OR) air either directly contaminating the wound or indirectly by contaminated sterile equipment.1,2 The origin of this contamination predominantly is contaminated skin scales shed by the surgical team.3–5 There are three ways to reduce this contamination. The first is OR ventilation to dilute and evacuate the contamination. The second is operating clothing enclosing the personnel to reduce spread of skin scales to the OR air. The third is to kill organisms either by ultraviolet light in the OR or after contamination using antibiotics.6,7

The first of these has resulted in development of ultra-clean laminar air flow (LAF) systems for ventilation of operating rooms (operating box).8–11 This is used mainly for implant surgery and is costly and requires space for installation.

A new method introducing a mobile screen supplying ultra-clean exponential LAF has been developed. The system is designed to work independently as an addition to basic OR ventilation and contains
a HEPA filter as well as enclosed UVC-light for bacterial control.

The purpose of the present study was to evaluate the novel mobile screen supplying ultra-clean exponential LAF as an addition to conventional turbulent or mixing OR ventilation.

**Methods**

**Operating room (OR) and ventilation systems**

All experiments were performed in the same OR. The air streams in both systems were tested using smoke. Illumination was provided using two streamlined cross-shaped operating lights positioned at 45° to minimize disturbance of the airflow.

**OR ventilation**

The OR was equipped with a conventional turbulent or mixing ventilation system (16 air changes/h, temperature 20°C) supplying filtered outdoor air to the OR using a positive (plenum) pressure and an inclined perforated screen at the ceiling along one side wall and evacuated at the opposite side at floor level.

**Additional LAF unit**

In half the experiments in addition to the basic OR ventilation a mobile unit producing ultra-clean exponential LAF was introduced (TOUL Hospital AB, Västerås, Sweden). The LAF unit consisted of a stainless steel box on wheels equipped with a fan and High Efficiency Particulate Air Filter (HEPA type MGEA 600) and closed ultraviolet light (UVC 254 nm). The OR air was sucked into the box, filtered and sterilised before passing through a tube to a movable screen (Figure 1). The screen (0.55 × 0.4 m) had a central zone of air flow at 0.6 m/s and a peripheral zone with 0.4 m/s producing zoned or exponential air-flow preventing entrainment of OR air outside the LAF. The screen was placed at the foot-end of the OR table with the air-flow directed along the table (Figure 2).

**Sham surgery**

To compare bacterial and dust particle contamination with and without the mobile LAF screen, an experimental model with strictly standardised sham operations was chosen. The model has been described in detail and consisted of a simple pilot experiment designed to yield high counts of bacterial surface contamination. This was followed by a main study where the screen was challenged with optimal OR clothing.

The experimental model used in the main study consists of three phases. With the OR empty (only one person performing the sampling (10 min) was present in the room). During preparation (10 min) the operating table was dressed with a disposable non-woven sterile sheet (Möllycke Health Care AB) and the members of the surgical team were dressed and positioned in the room. During surgery (30 min) the surgical team every minute performed a 15 s routine of standardized movements and commands mimicking the oral and physical activities during a 2-h major orthopaedic operation. In the pilot experiment only the surgical phase was used.
Operating team and clothing

The pilot experiment was done on a separate occasion. In the main study the sham operations were performed over two days by the same mock team. The team consisted of six individuals. Four acted as the operating team and one as anaesthetist and one as circulating nurse.

In both parts of the study the whole team wore basic operating theatre clothing in the form of shirts tightly fitted around arms and trousers tightly fitted around the ankles, all made of nylon and cotton (30/70 domestic Mercan P-3467), sterile gloves (Biogel Regent Medical UK) and facemasks (special Mölnlycke Health Care AB Sweden). In the pilot experiments this was supplemented with a small cap as head cover. In the main study the surgical team in addition used sterile gowns (standard C) and a surgical hood helmet model (Glenn) covering the neck, reaching out on shoulders and well tucked under the sterile gown all from (Mölnlycke Health Care AB, Sweden). All clothing was changed before each experiment.

Sampling methods and experimental set up

Aerobic bacteria were studied using agar plates incubated for 48 h at 37°C before counting the number of bacteria-carrying particles, i.e., colony forming units (cfu). The two control plates not exposed to the air used in each experiment were all without contamination.

Air counts of bacteria

The number of cfus in the air was measured only in the main study with an MD8 Air Sampler (1 m³/10 min) using gelatine membrane filter (AKA AB) transformed to 9 cm/diameter agar plates (Figure 2). The air was measured during five 10-min periods, before preparation (10 min), during preparation (10 min) and during sham surgery (3 × 10 min).

Bacterial sedimentation rates

Surface contamination was studied using 14 cm diameter agar plates Columbia II Agar Base (BBL) enriched with 5% horse blood (Figure 2). Four plates were placed outside the surgical zone but at the same level as the operating table and were exposed during main study to air during 40 min both during preparation (10 min) and during sham surgery (30 min). In the pilot experiment, the only exposure time was during surgery. The other plates were placed in the instrument area (0.30 m from screen), in the wound area (0.75 m from screen) and patient area (1.10–1.60 m from screen).

Air counts of dust particles

Dust particles were sampled in the wound area with a laser particle sampler (Met One Model 217 Inc OR
USA capacity 0.028/m³/min). The sampler recorded particles sized >0.5–5 and >5 μm during 1 min in the middle of each 10 min during the experiments. During sham surgery, physical activity was avoided during measurements.

Statistics

In the main study the type of ventilation was randomized to morning and afternoon. SPSS was used for statistical calculations and differences between means were analyzed with Mann–Whitney U-tests. The relations between sedimenting and air-borne cfu as well as the relations between air-borne cfu and dust particles were studied using regression analyses. \( P < 0.05 \) was chosen as a significant difference.

Results

Pilot study

Bacterial sedimentation rates

The use of the LAF screen with ultraclean exponential air streams markedly reduced the surface contamination (cfu/m²/h) with bacteria-carrying particles in the ‘instrument’, ‘wound’ and ‘patient’ areas compared with the experiment not using the screen (Table I). With the screen no contamination was registered in the ‘instrument’ and ‘wound’ areas. In the periphery of the operating room no major difference in sedimenting cfus could be seen using the extra LAF or not.

Air counts of dust particles

In the ‘wound’ area and compared to the experiment without the screen the addition of laminar air flow reduced the number of airborne dust particles/m³ > 5 μm by a factor of 3.5 and for particles > 0.5–5 μm by a factor of 2.6 (Table I).

Main study

Air counts of bacteria

Using the LAF screen, the air contamination with cfu/m³ in the wound area before sham surgery, during preparations and during surgery was minimal and well below the accepted limit for operating units with ultraclean laminar ventilation, i.e., < 10 cfu/m³. Compared to experiments without the screen the additional ventilation significantly

\( (P = 0.008–0.0001) \) reduced air contamination during the phases of activity by a factor of 22–70 (Table II).

Bacterial sedimentation rates

In all areas important for surgery the additional screen significantly \( (P = 0.001–0.0001) \) reduced the surface contamination to a level well under the limit for what is acceptable for operating units with ultraclean laminar ventilation, i.e., < 350 cfu/m²/h. In the periphery of the operating room no difference was found using the LAF screen or not. The results are given in Table III.

Surface to air ratio (SAR)

With screen the relation between sedimenting and air-borne colony forming units in the wound area was 33/1 \( (P = 0.77, \, r^2 = 0.03) \). Without screen the relation was 24/1 \( (P = 0.055, \, r^2 = 0.76) \).

Type of cultured bacteria

The cultured bacteria colonies were mainly coagulase negative staphylococci and micrococcus.

Table I. Sedimenting bacteria-carrying particles (cfu/m²/h) and air counts of dust particles/m³ in the two pilot experiments, with and without an additional LAF screen, using ultraclean exponential air streams. For particle counts means (standard deviations) of ten measurements are given

<table>
<thead>
<tr>
<th>Variable and sampling site (distance to screen in m)</th>
<th>With screen</th>
<th>Without screen</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sedimenting bacteria (cfu/m²/h)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Instruments (0.30)</td>
<td>0</td>
<td>3835</td>
</tr>
<tr>
<td>Wound (0.75)</td>
<td>0</td>
<td>3835</td>
</tr>
<tr>
<td>Patient (1.10)</td>
<td>390</td>
<td>4940</td>
</tr>
<tr>
<td>Periphery (&gt; 2)</td>
<td>715</td>
<td>520</td>
</tr>
<tr>
<td>Particle air count/m³</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wound (0.75)</td>
<td>383 (336)</td>
<td>1346 (361)</td>
</tr>
<tr>
<td>&gt; 0.5–5 μm</td>
<td>10396 (4218)</td>
<td>26846 (2380)</td>
</tr>
</tbody>
</table>

Table II. The air contamination (cfu/m³) in the wound area (0.75 m from screen) with bacteria-carrying particles during sham surgery with and without an additional LAF screen with ultraclean exponential air streams. Means (standard deviations) and significant differences between groups are given for five replicate measurements

<table>
<thead>
<tr>
<th>Air counts cfu/m³</th>
<th>With LAF screen</th>
<th>P-value</th>
<th>Without LAF screen</th>
</tr>
</thead>
<tbody>
<tr>
<td>No activity</td>
<td>0.2 (0.5)</td>
<td>0.04</td>
<td>1.6 (1.1)</td>
</tr>
<tr>
<td>Preparations</td>
<td>0.4 (0.5)</td>
<td>0.008</td>
<td>8.8 (2.6)</td>
</tr>
<tr>
<td>During surgery</td>
<td>0.2 (0.6)</td>
<td>0.0001</td>
<td>14.0 (4.9)</td>
</tr>
</tbody>
</table>

(P = 0.008–0.0001)
Air counts of dust particles
Using the LAF screen the air contamination with dust particles/m³ in the wound area before sham surgery, during preparations and during surgery was minimal and compared to experiments without the screen the additional ventilation significantly ($P \leq 0.009 \pm 0.007$) reduced this air contamination (Table IV).

Relation between air count of cfus and dust particles
Fifteen sets of measurements were made during surgical activity with, and 15 without the screen. Each 10 minutes air-borne cfu were correlated with the corresponding measurements of dust particles (0.5–5 μ and >5 μ). No significant correlation ($r^2 = 0.01–0.03$) was found with or without the screen. When both ventilations were considered together significant correlation ($P = 0.001$, $r^2 = 0.71–0.74$) existed between both sizes of dust particles and airborne bacterial contamination. The equations for the linear regression were for dust particles $0.5–5 \mu = 106.19 \text{cfu/m}^3 + 196.3$ and for $>5 \mu = 0.7283 \text{cfu/m}^3 + 0.919$.

Discussion
The novel mobile ultra-clean LAF screen with exponential airflow was first tested in a simple pilot experiment designed to give high counts of sedimenting aerobic cfu. The result form the pilot study prompted us to a main study using optimal OR clothing. With regard to ethical considerations the LAF screen was evaluated in experimental situations with sham operations earlier proved to reflect actual activity during major surgery.12

In the pilot experiment, the extra screen was challenged with a situation where the team members did not use operating gowns, just small head caps and face masks. Without the screen, this resulted in a very high surface contamination with bacteria-carrying particles. The contamination was almost totally eliminated when the screen was used.

In the main study, optimal operating clothing in the form of squire hood reaching out on shoulders and disposable non-woven gowns was used. It can be noted that in the experiments without the screen this clothing resulted in a very low bacterial air and surface contamination. In fact, the contamination in the wound area during surgery was just above the suggested acceptable limits for ultra-clean LAF units, i.e., 10 cfu/m³ and 350 cfu/m²/h.13,14 Also in this situation the addition of the screen significantly reduced both types of bacterial contamination to very low levels comparable to those found in different types of complete ultra-clean LAF units. The screen proved to supply the operating table with ultra-clean air in the areas studied, i.e., up to a distance of 1.6 m from screen.

Supplementing conventional OR ventilation with clean-air spot ventilation is not new (e.g., Weiss Technik GMBH D-6301 Reiskirchen Germany). However, this has not been shown to be as efficient as complete LAF units and is today a method not generally used. A problem with extra spot ventilation with uniform air flow is the entrapment of OR air from outside the extra air stream. We tested a similar screen to the one described here supplying uniform air flow. This screen could only supply ultra-clean air up to a distance of 0.5 m and smoke tests clearly showed inflow of OR air into the ultra-clean air stream. The exponential airflow produced by a

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### Table III
Sedimentation of bacteria-carrying particles during sham surgery with and without an additional LAF screen with ultraclean exponential air streams. Means (standard deviations) and significant differences between groups are given for five replicate measurements

<table>
<thead>
<tr>
<th>Sampling site (distance to screen in m)</th>
<th>With screen</th>
<th>P-value</th>
<th>Without screen</th>
</tr>
</thead>
<tbody>
<tr>
<td>Instruments (0.30)</td>
<td>65 (92)</td>
<td>0.001</td>
<td>416 (228)</td>
</tr>
<tr>
<td>Wound (0.75)</td>
<td>7 (29)</td>
<td>0.0001</td>
<td>364 (201)</td>
</tr>
<tr>
<td>Patient 1 (1.10)</td>
<td>61 (67)</td>
<td>0.0001</td>
<td>329 (176)</td>
</tr>
<tr>
<td>Patient 2 (1.60)</td>
<td>78 (52)</td>
<td>0.0001</td>
<td>416 (130)</td>
</tr>
<tr>
<td>Periphery (&gt; 2)</td>
<td>309 (185)</td>
<td>ns (0.9)</td>
<td>314 (204)</td>
</tr>
</tbody>
</table>

### Table IV
The air contamination with dust particles $> 5 \mu$ and $> 0.5–5 \mu$ in the wound area (0.75 m from screen) during sham surgery with and without a mobile LAF screen with ultraclean exponential air streams. Means (standard deviations) and significant differences between groups are given for five replicate measurements

<table>
<thead>
<tr>
<th>Particle size and sampling period</th>
<th>With screen</th>
<th>P-value</th>
<th>Without screen</th>
</tr>
</thead>
<tbody>
<tr>
<td>$&gt; 5 \mu$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No activity</td>
<td>0</td>
<td>ns (0.1)</td>
<td>28 (38)</td>
</tr>
<tr>
<td>Preparations</td>
<td>7 (16)</td>
<td>0.007</td>
<td>1119 (358)</td>
</tr>
<tr>
<td>Surgery</td>
<td>2 (16)</td>
<td>0.007</td>
<td>424 (89)</td>
</tr>
<tr>
<td>$&gt; 0.5–5 \mu$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Empty</td>
<td>317 (437)</td>
<td>0.009</td>
<td>45549 (19440)</td>
</tr>
<tr>
<td>Preparations</td>
<td>472 (369)</td>
<td>0.009</td>
<td>68584 (15315)</td>
</tr>
<tr>
<td>Surgery</td>
<td>324 (258)</td>
<td>0.009</td>
<td>66317 (11546)</td>
</tr>
</tbody>
</table>

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A higher velocity of the air stream in the central part of the screen than in the peripheral part results in an air pressure gradient giving an airflow deviating out in the rest of the OR. This graded outflow of air efficiently prevents inflow of OR air into the ultra-clean air. This principle is a well-documented technique used in operating box air technology where the exponential air flow makes extra walls in the OR unnecessary.9,10,16

The use of the optional closed UVC-light can be questioned as the Structure of the HEPA filter used in this mobile unit is quite sufficient to eliminate bacterial contamination in the OR environment. Using UVC-light can of course be of value to reduce contamination by viruses and could also be seen as an extra insurance if filter control and maintenance is neglected.

No relation between surface contamination and air contamination of bacteria carrying particles was found when the screen was used. Without the screen a weak correlation existed with a ratio in the range earlier demonstrated in similar experimental conditions.17 Recently the use of bacterial air counts as the most reliable indicator for the risk of contamination of sterile areas in the OR environment has been questioned by several authors.17–19 Our results further support the view that surface contamination is a better indicator of bacterial contamination in the OR and especially so when an ultra-clean air flow is used.17

The efficiency of modern operating garments in reducing bacterial contamination is well documented.5,8,20–24 However, the level of contamination found here was very low and about half that found earlier in similar experiments.12 Compared with earlier experiments, the difference in clothing consisted of a tight fit around the upper arm of the working dress and a surgical hood reaching the shoulders and worn under an operating gown. Although, not proven here, these changes in clothing designed to prevent the known risk for dispersal of skin scales from the upper part of the body at the neck area seem to be of importance for an optimal function of modern operating clothing.

In OR surroundings dust particle counts are generally accepted as a method of assessing filter efficiency but have not been shown to reflect bacterial air contamination.25 Also in this study no correlation between particle counts and airborne cfus was found when the experiments with and without the additional ventilation were studied separately. However, when the two different conditions were considered together a strong correlation existed between the two parameters indicating that in a specific situation particle counts can give an estimate of the efficiency of a ventilation system in reducing bacterial air contamination. A similar result has been reported in a study of air contamination in different ventilation conditions in a laboratory.26

In conclusion, the additional LAF screen reduced the counts of aerobic airborne and sedimenting bacteria-carrying particles as well as dust particles to the levels gained with complete ultra-clean LAF OR ventilation units (operating box). In implant surgery operating boxes are today widely used for prevention of airborne bacterial contamination to wound and sterile equipment. A complete ultra-clean LAF OR unit is expensive and needs a building that have room for the large ventilation unit, air ducts and filter ceiling or wall in the OR. This is often cumbersome or impossible in existing premises without extensive rebuilding. In this situation the mobile LAF screen can be seen as a valuable addition to operating room ventilation technique used as a complement to existing conventional OR ventilation. Especially in situations with insufficient ventilation and/or clothing facilities the screen might prove to be an easily applied tool to reduce the risk for surgical site infection.

References


