The addition of a mobile ultra-clean exponential laminar airflow screen to conventional operating room ventilation reduces bacterial contamination to operating box levels

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Received 2 December 2002; accepted 24 March 2003

\textbf{KEYWORDS}
Operating room; Laminar airflow; Clothing; Colony counts; Microbiology; Surgery; Groin hernia; Implant

\textbf{Summary} A mobile screen producing ultra-clean exponential laminar airflow (LAF) was investigated as an addition to conventional turbulent/mixing operating room (OR) ventilation (16 air changes/h). The evaluation was performed in a small OR (50 m\textsuperscript{3}) during 60 standardized operations for groin hernia including mesh implantation. The additional ventilation was used in 50 of the operations. The LAF passed from the foot-end of the OR table over the instrument and surgical area. Strict hygiene OR procedures including tightly woven and non-woven OR clothing were used. Sedimentation rates were recorded at the level of the patients’ chests (\(N = 60\)) (i.e. the air had passed the surgical team) and in the periphery of the OR. In addition bacterial air contamination was studied above the patients’ chests in all 10 operations without the additional LAF and in 12 with the LAF. The screen reduced the mean counts of sedimenting bacteria (cfu/m\textsuperscript{2}/h) on the patients’ chests from 775 without the screen to 355 (\(P = 0.0003\)). The screen also reduced the mean air counts of bacteria (cfu/m\textsuperscript{3}) above the patients’ chests from 27 to 9 (\(P = 0.0001\)). No significant differences in mean sedimentation rates (cfu/m\textsuperscript{2}/h) existed in the periphery of the OR where 628 without and 574 with screen were recorded. During the follow-up period of six months no surgical site infections were detected. In conclusion when the mobile LAF screen was added to conventional OR ventilation the counts of aerobic airborne and sedimenting bacteria-carrying particles downstream of the surgical team were reduced to the levels achieved with complete ultra-clean LAF OR ventilation (operating box).

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\textbf{Introduction}

It is generally accepted that the main factor causing surgical site infection (SSI) after clean operations is
bacterial contamination of the operating room (OR) air, predominantly caused by contaminated skin scales shedded from the surgical team.\textsuperscript{1-5} To prevent this, clothing enclosing the personnel is worn to reduce the spread of skin scales to the air. In addition, proper OR ventilation is important in order to dilute and evacuate the contamination. Normally, conventional OR ventilation has 16–20 air changes/h resulting in turbulent or mixed airstreams. The importance of ventilation has resulted in the development of ultra-clean laminar airflow (LAF) systems (operating boxes).\textsuperscript{6-9} Operating boxes are mainly used for implant surgery. They are costly and require space for installation, which is often difficult or impossible to provide in existing premises.

A new concept in the form of a mobile screen supplying ultra-clean exponential LAF has been developed. The system is designed to work independently or in addition to conventional ventilation. In experimental situations using sham operations the screen was recently found to achieve bacterial counts equivalent to those accepted for operating boxes.\textsuperscript{10-12}

The purpose of the present study was to evaluate, in actual surgery, the effect of the novel mobile screen as an addition to conventional turbulent or mixing OR ventilation on aerobic bacterial air and surface counts.

\textbf{Methods}

\textbf{Surgery}

Sixty groin hernia operations were performed in the same room during a three-week period. Strict hygiene routines were used. The surgical technique included a mesh implant (Prolene 6 $\times$ 12 cm, Johnson & Johnson) to reinforce the fascial structures. Local anaesthetic was used in 50 of the 60 operations, in addition to the basic OR ventilation, a mobile unit producing ultra-clean exponential LAF was introduced (TOUL Hospital AB, Västerås, Sweden). During one week the use of the additional ventilation was randomised. Systemic antibiotic prophylaxis was not used. The study was approved by the local ethics committee.

Comparing the operations with and without the LAF screen, there were no significant differences in factors with possible influence on bacterial contamination in the OR (Table I).

\textbf{OR and ventilation systems}

A relatively small (2.5 m $\times$ 3.4 m $\times$ 6 m = 50 m$^3$) OR, originally designed for endoscopic examinations, was used due to a need to expand the facilities for open surgery. The OR was originally equipped with a conventional turbulent/mixing ventilation system (16 air changes/h). The filtered outdoor air was supplied through two diffusers in the ceiling over the OR table and evacuated via the ceiling at both ends of the room. Illumination was provided using one operating lamp angled to minimize disturbance of the airflow. The airstreams, tested by smoke, provided an appropriate direct flow towards the OR table.

The additional LAF unit consisted of a box equipped with a fan, a 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 sterilized before passing through a tube to a movable screen. The screen (0.5 $\times$ 0.4 m) had a central zone of airflow at 0.6 m/s and a peripheral zone with 0.4 m/s producing zoned or exponential airflow preventing entrainment of OR air outside the LAF (shown by smoke tests). The screen was placed at the foot-end of the OR table with the airflow directed over the instrument table, surgical area and towards the head of the patient (Figure 1).

\textbf{Surgical team and clothing}

The whole team wore basic tightly woven 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). Head cover consisted of facemasks (special Mölnlycke Health Care AB, Mölnlycke, Sweden) and surgical hood helmet model (Glenn, Mölnlycke) covering the neck and extending onto the shoulders. In addition, the

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure1.png}
\caption{Schematic illustration of the study (top view). The broken arrows illustrate the exponential airflow. Filled circles = sedimentation plates; AS = air sampler located 30 cm above the sedimentation plate on the patient’s chest.}
\end{figure}
surgeon, scrub nurse and assistants used sterile non-woven gowns (standard C, Mölnlycke), and sterile gloves (Biogel Regent Medical UK). The hood was well tucked down under the sterile gown.

Sampling methods

The sedimentation of aerobic bacteria-carrying particles, i.e. colony-forming units (cfus), was studied during all operations using 14 cm diameter agar settle plants containing Columbia II Agar Base (BBL) enriched with 5% horse blood. One sterile plate was placed on the patients chest 1.4 m from the LAF screen and one in the periphery of the OR at the same level as the operating table. Both plates were exposed during surgery (Figure 1). The number of aerobic cfus in the air was measured with a MD8 air sampler (1 m³/10 min) using a gelatine membrane filter (AKA AB, Sweden) transferred to a 9 cm diameter agar plate. The sampler was located 20 cm above the settle plate on the patients chest (Figure 1). Air counts were studied in 12 operations using the LAF and in all 10 operations without LAF support. On each occasion the mean value of three 10 min sampling periods was used.

The agar plates were incubated for 48 h at 37°C before counting before counting the number of cfus.

Statistics

SPSS (Statistical Package for Social Sciences) was used for statistical calculations and differences between means were analysed with Mann-Whitney U-tests. Relationships between individual variables were studied by linear regression analysis. \( P > 0.02 \) was chosen to denote non-significant difference.

Results

Compared with operations without the screen, the surface counts on the chest of the patient (i.e. the airflow had passed the surgical team) were reduced with the LAF screen to a level acceptable for operating units with ultra-clean laminar ventilation \( (P = 0.0003) \). In the periphery of the OR no difference was found using the LAF screen (Table II). The control plates not exposed to the air used for each operation were all without contamination.

No correlation existed between surface contamination on the chest of the patient and in the periphery of the OR when the LAF screen was used \( (P = NS, r^2 = 0.02) \). Without the screen a strong relationship was found between the two sampling areas \( (P = 0.008, r^2 = 0.61) \).

Compared with conventional OR ventilation the LAF screen reduced the air contamination downstream of the surgical team by 68\% \( (P < 0.0001) \) to a level below the accepted limit for operating units with ultra-clean laminar ventilation, i.e. <10 cfu/m³ (Table II).

With the screen the nonsignificant ratio between sedimenting and airborne cfus in the wound area was 29/1 \( (N = 12, P = ns, r^2 = 0.04) \). Without the screen a significant correlation existed with a ratio of 28/1 \( (N = 10, P = 0.02, r^2 = 0.5) \).

When the LAF screen was used there was no significant correlation between bacterial sedimentation rate (cfu/m²/h) at the patients’ chest or in the periphery of the OR and the factors registered during the operation, i.e. OR team members, male:female ratio, number of door openings, order of operation during the day and duration of operation. Without the screen a significant correlation existed only between OR team members and an increase in the sedimentation rate both at the chest area \( (P = 0.01, r^2 = 0.54) \) and in the periphery of the OR \( (P = 0.002, r^2 = 0.7) \). The correlations are illustrated in Figure 2.

No significant correlation was found between the above parameters and bacterial air contamination (cfu/m³) above the patients’ chest regardless of whether the screen was used or not.

Normal skin flora only was cultured from the sample plates. Findings were dominated by

### Table I  Distribution of factors with possible influence on bacterial contamination in the operating room (OR) with and without the laminar airflow (LAF) screen

<table>
<thead>
<tr>
<th>Factors possibly influencing bacterial OR contamination</th>
<th>With LAF screen ( N = 50 )</th>
<th>( P )-value</th>
<th>Without LAF screen ( N = 10 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>OR team members</td>
<td>5.7 (0.8)</td>
<td>ns</td>
<td>6.3 (0.7)</td>
</tr>
<tr>
<td>Male:female ratio in OR team</td>
<td>0.7 (0.4)</td>
<td>ns</td>
<td>0.7 (0.2)</td>
</tr>
<tr>
<td>Number of door openings</td>
<td>1.9 (1.5)</td>
<td>ns</td>
<td>1.4 (1.4)</td>
</tr>
<tr>
<td>Order of operation during day</td>
<td>2.4 (1.1)</td>
<td>ns</td>
<td>1.8 (0.8)</td>
</tr>
<tr>
<td>Duration of operation (min)</td>
<td>84 (19)</td>
<td>ns</td>
<td>84 (19)</td>
</tr>
</tbody>
</table>

Means and SD are given.
coagulase-negative staphylococci in addition to Micrococcus and Corynebacterium species. During the six months follow-up period no SSIs were detected.

**Discussion**

Under experimental conditions a mobile ultra-clean LAF screen with exponential airflow was shown to reduce OR bacterial contamination to the levels achieved by complete ultra-clean laminar OR ventilation systems, i.e. operating boxes. This prompted us to study the effect of the screen on bacterial OR contamination in 50 of 60 consecutive groin hernia operations using mesh implantation. The ultra-clean air, directed over the instruments and surgical area, was used as an addition to conventional mixing ventilation.

The reason for studying the effect of the screen during these operations was that they had to be performed in a room originally designed for endoscopic examinations due to lack of ORs. The room is supplied with air at a rate of 16 air changes/h but because of the small size of the room (50 m³) the volume of air to dilute and remove contamination is relatively small. To improve the basic conditions strict hygiene procedures were used. The efficiency of modern operating garments in reducing bacterial contamination is well documented, and consequently the surgical team used modern tight operating clothing including square hoods extending onto the shoulders. The hoods were used to minimize dispersal of skin scales from the upper part of the body at the neck area.

In the operations without the additional screen the clothing used in combination with strict hygiene resulted in a relatively low bacterial surface and air contamination on and above the patients chest (mean 27 cfu/m³ and 775 cfu/m²/h). The addition of the screen significantly reduced both types of bacterial contamination to levels comparable with the suggested upper limits for complete ultra-clean LAF units, i.e. 10 cfu/m³ and 350 cfu/m²/h. It must be noted that this result was achieved although the measured points were located downstream of the surgical team for practical reasons. In the experimental study that preceded this clinical study the contamination in the 'wound area' was 10 times lower than downstream of the 'surgical team'. Thus, in this clinical study the contamination was presumably even lower in the instrument and wound areas. As in the earlier experimental situation the additional ventilation did not influence surface contamination in the periphery of the OR.

The idea of supplementing conventional OR ventilation with clean-air spot ventilation is not new (e.g. the system manufactured by Weiss Technik GMBH D-6301 Reiskirchen Germany). A problem with extra-spot ventilation with uniform airflow is the entrapment of OR air from outside the extra airstream. This is avoided in the current design with exponential airflow. The exponential airflow produced by a higher velocity airstream in the central part of the screen than in the peripheral

### Table II

<table>
<thead>
<tr>
<th>Aerobic bacterial contamination</th>
<th>With LAF screen</th>
<th>P-value</th>
<th>Without LAF screen</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface contamination (cfu/m²/h)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>On chest of patient</td>
<td>N = 50</td>
<td>0.0003</td>
<td>N = 10</td>
</tr>
<tr>
<td>Periphery of OR</td>
<td>355 (269)</td>
<td></td>
<td>775 (304)</td>
</tr>
<tr>
<td>Air contamination (cfu/m³)</td>
<td>N = 12</td>
<td>ns</td>
<td>626 (267)</td>
</tr>
<tr>
<td>Above chest of patient</td>
<td>8.9 (4.8)</td>
<td>&lt;0.0001</td>
<td>27.4 (9.9)</td>
</tr>
</tbody>
</table>

Means and (SD) and significant differences are given.

![Figure 2](image-url)  
**Figure 2** The relationship between number of OR team members and surface counts at the patient’s chest and in the periphery of the OR in the operations performed without the additional ultra-clean LAF screen. •, on pat. chest; ■, OR periphery; ——, on pat. chest; ----- OR periphery.
part results in an air pressure gradient giving an airflow fanning out in the remaining part of the OR. This graded outflow of air efficiently prevent in-flow of OR air into the ultra-clean air. The principle is a well-documented technique used in operating box air technology where the exponential airflow makes extra walls in the OR unnecessary.\textsuperscript{7,8,10} As in full-scale operating boxes no relationship between surface and air contamination of bacteria-carrying particles was found when the screen was used.\textsuperscript{10,12,19} Without the screen a correlation existed, which is in accordance with the results from previous studies of conventional/mixing OR ventilation, with a ratio in the range of that reported previously.\textsuperscript{10,20} 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.\textsuperscript{12,21,22} Our results further support the view that surface contamination is a better indicator of bacterial contamination when an ultra-clean LAF is used.\textsuperscript{12}

The evaluation of different factors that could possibly influence bacterial contamination only revealed that, in the operations without the screen, an increased number of OR personnel produced a marked increase in surface contamination rates both in the chest area and in the periphery of the OR. No such correlation was found with the additional ventilation. The increase in surface counts is possibly enhanced by the fact that, in the small OR used, the basic OR ventilation resulted in a comparatively small volume of air to dilute and remove contamination in spite of 16 air changes/h. This is in accordance with Luckraz and Treasure\textsuperscript{23} who also reported that bacterial contamination escalated in an OR with conventional/mixing ventilation when the number of OR team members increased.\textsuperscript{23}

Six months after surgery no SSIs was recorded. The incidence of SSI reported after groin hernia surgery varies from 1 to 9\%.\textsuperscript{24–27} The comparatively small number of patients studied here makes any conclusion regarding the effect of the additional ultra-clean air on the SSI rate impossible.

In conclusion, the additional mobile ultra-clean LAF screen reduced the counts of aerobic airborne and sedimenting bacteria-carrying particles during groin hernia implant surgery to the levels achieved with complete ultra-clean LAF OR ventilation units (operating boxes). A complete ultra-clean LAF OR unit is expensive and can be cumbersome or even impossible to install in existing premises without extensive rebuilding. The mobile LAF screen can be seen as a valuable addition to OR ventilation technology, and in situations with insufficient ventilation or clothing facilities the screen is an easily applied tool to reduce bacterial contamination in critical aseptic areas.

References


17. Scheibel JH, Jensen I, Pederson S. Bacterial contamination


