

# Zoned vertical ultraclean operating room ventilation

## A novel concept making long side walls unnecessary

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We evaluated a novel concept of High Efficiency Particulate Air (HEPA)-filtered vertical Laminar Air Flow (LAF) for operating room ventilation, designed to be used without side-walls. The LAF-unit has a central zone with an airflow of 0.4 m/s and a peripheral zone with an airflow of 0.2 m/s. The design provides an exponential downflow of air resembling an upside-down trumpet mouth and it was claimed to prevent entrainment of peripheral contaminated air. The unit was evaluated with regard to elimination of particles with focus on bacteria-carrying particles (colony-forming units = cfu) during rigidly standard-

ized sham operations. Three different lengths of walls/enclosures (short-ending 2.0 m, medium 1.0 m and long 0.2 m above the floor) were tested. It provided a high degree of bacteriological cleanliness (0.05–4 cfu/m<sup>3</sup> of air and 7–64 cfu/m<sup>2</sup>/h surface contamination) and its efficiency was proved to be independent of the length of the enclosures.

We conclude that the novel zoned ultraclean vertical LAF unit is versatile, as it allows for omitting long side-walls, without compromising bacteriological safety.

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In a large multicenter study of hip and knee replacements, a linear correlation was defined between bacterial counts in the operating room air and the postoperative deep infection rate (Lidwell et al. 1983). In order to reduce bacterial air contamination in operating rooms, vertical or horizontal Laminar Air Flow (LAF) systems equipped with High Efficiency Particulate Air (HEPA) filters producing ultraclean air (<10 cfu/m<sup>3</sup> air) were introduced in the 1960s (Charnley 1964). To prevent contaminated peripheral air from being deflected into the ultraclean zone, the designs of the vertical systems have traditionally included walls enclosing the core of ultraclean air, creating an operating box (Lidwell et al. 1982, Howarth 1985). The enclosure is a drawback for the operating team, as it reduces the versatility of the operating room and has, in fact, discredited vertical LAF. To solve this problem, Howarth (1985) proposed a novel concept of vertical LAF producing a radically outward flow from the perimeter of the ultraclean zone. The air was directed by special canopies producing an exponential flow resembling an upside-down trumpet mouth. The system was claimed to prevent peripheral air entrainment without the use of extra side-walls but, to our knowledge, has not been properly evaluated with regard to bacteriological efficiency during surgery.

We evaluated a similar novel construction of a vertical ultraclean LAF system without side-walls. It was designed to prevent entrainment of peripheral air by using a ceiling with a higher airflow in a central zone and a lower flow in a peripheral zone. To challenge the concept its bacteriological efficiency was investigated when the unit was equipped with side-walls/enclosures of three different lengths around the ultraclean air supply.

### Methods

An experimental model using 15 strictly standardized sham operations was chosen. The model has earlier been described in detail and only information relevant to this study is given (Friberg et al. 1996).

### Ventilation system

The size of the operating room was 5.4 × 7.3 × 3.1 m. The HEPA filtered vertical airflow was supplied through a ceiling consisting of perforated stainless steel cassettes (OPTICEIL 2000. ABB, Airtech AB Stockholm, Sweden). In the 2.4 × 2.4 m central area above the operating table, the perforations comprised 30% of the surface producing an airflow of 0.4 m/s

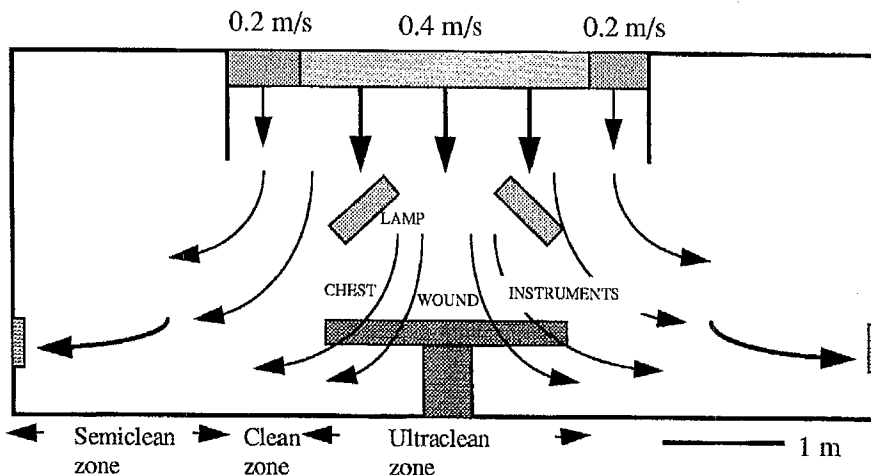


Figure 1. The exponential airflow in the zoned vertical LAF unit with a short enclosure.

(ultraclean zone). In a 0.6 m wide zone around this area, the perforations were only 13% of the surface resulting in an air velocity of 0.2 m/s (clean zone). The remaining part of the operating room contained the air outlets in the lower part of the corners (semiclean zone). The different air velocities result in an outward or exponential flow of sterile air from the ultraclean towards the clean and semiclean zones (Hillerbrant and Ljungqvist 1990) (Figure 1). The air streams were verified with smoke. Illumination was provided by two streamlined cross-shaped operating lights (55 cm diameter) angled at 45° and positioned to minimize disturbance of the airflow.

The LAF unit was tested equipped with side-walls/enclosures of three different lengths surrounding the air supply ceiling (short-ending 2.0 m, medium 1.0 m and long 0.2 m above the floor). Each length of enclosure was investigated using 5 sham operations.

#### Operating team and clothing

The sham operations were performed during 1 week by the same mock-team consisting of 6 persons (2 women). 4 acted as the surgical team in the ultraclean zone, 1 as anesthetist in the clean zone and 1 as circulating nurse in the semiclean zone. The whole team used complete disposable clothing, consisting of a shirt with open short sleeves and trousers tightly fitted around the ankles, both made of laminated paper and polyester fiber (55/45%) (Fabric 450 Surgikos®) plus a face mask (Surgikos®) and a surgical hood (Barrier) tucked down under the shirt (all from Johnson & Johnson). In addition, members of the surgical team were wearing sterile gowns (Surgikos®) and sterile gloves. All garments were changed between each experiment.

#### Procedure and sampling

Before preparations, only one person performing the sampling was present in the room. During preparation, the operating table was dressed with a sterile barrier incision sheet (Fabric 450, Johnson & Johnson) and the surgical team was dressed and positioned in the room. During sham surgery the surgical team once each minute performed a 15-sec routine of standardized movements and commands mimicking the oral and physical activities during a 2 h major orthopedic procedure. The anesthetist performed the same activity as the surgical team and, in addition, performed a standardized walking scheme in the semi-clean zone.

Bacteria-carrying particles, i.e., human skin scales carrying bacteria (colony-forming units, cfu) in the air and on surfaces were studied using blood agar plates (14 cm diameter, Columbia Agar Base, BBL) enriched with 5% horse blood. Before exposure to the operating room air, any agar surface contamination was eliminated by exposing all plates to a bactericidal dose of ultraviolet light during 1 minute. The 2 control plates not exposed to air used for cultures in each experiment were always negative. The air contamination was measured using 2 slit samplers (Casella & Co Ltd., London, England, capacity 0.7 m<sup>3</sup>/min, equipped with agar plates) placed in the "wound" area and close to the "instrument" table, respectively, during five 10-min periods (before preparation 10 min, during preparations 10 min and during sham surgery 3 × 10 min). The sedimenting cfus outside the enclosure were studied, using 4 agar plates placed at the same level as the operating table and exposed to the air both during preparation (10 min) and sham surgery (30 min). The bacterial settling on the chest of

Table 1. The air contamination with bacteria-carrying particles during sham surgery in the zoned vertical LAF unit equipped with different walls/enclosures. Means and (SD) are given

Sampling period and area	Air counts (cfu/m <sup>3</sup> )		
	Short wall (n 5)	Medium wall (n 5)	Long wall (n 5)
Before preparation	0.2 (0.2)	0.1 (0.1)	0.2 (0.1)
During preparation			
Wound	4.0 (3.3)	0.9 (0.2)	1.1 (0.7)
Instruments	0.9 (0.4)	0.9 (0.5)	0.6 (0.3)
During surgery			
Wound	1.3 (0.5)	1.1 (0.6)	0.8 (0.3)
Instruments	2.3 (1.1)	2.3 (1.1)	1.2 (0.9)

No significant differences between wall lengths or sampling sites were recorded. For reference, 20-100 cfu/m<sup>3</sup> were recorded in a conventionally-ventilated operating room during identical sham surgery (Friberg et al. 1996).

Table 2. Sedimentation of bacteria-carrying particles during sham surgery in the zoned vertical LAF unit equipped with different walls/enclosures. Means and (SD) are given

Sampling area	Air counts (cfu/m <sup>3</sup> )		
	Short wall (n 5)	Medium wall (n 5)	Long wall (n 5)
Outside LAF	653 (170)	780 (180)	864 (365)
Inside LAF			
Patient chest	64 (35)	51 (26)	58 (32)
Wound	39 (51)	38 (51)	64 (40)
Instruments	26 (38)	19 (38)	7 (13)

No significant differences between wall lengths were recorded. For reference, 500-2900 cfu/m<sup>3</sup> were recorded in a conventionally-ventilated operating room during identical sham surgery (Friberg et al. 1996).

Table 3. Particle counts in the wound area during sham surgery in the zoned vertical LAF unit equipped with different walls/enclosures. Means and (SD) are given

Particle size (µm)	Particles per m <sup>3</sup>		
	Short wall (n 5)	Medium wall (n 5)	Long wall (n 5)
> 0.3	2084 (3531)	1377 (2331)	1978 (5156)
> 5.0	141 (212)	247 (388)	247 (742)
> 10.0	106 (141)	177 (283)	177 (586)

No significant differences between wall lengths were recorded. For reference, 8500 particles > 10.0 µm were recorded in a conventionally-ventilated operating room during identical sham surgery (Friberg et al. 1996).

the "patient" (4 plates), in the "wound" area (2 plates) and on the "instrument" table (4 plates) were studied only during sham surgery (30 min.).

Dust particles were sampled in the "wound" area, using a laser particle sampler (Met One Model 217 Inch, 481 California Avenue, Grants Pass, OR 97526, capacity 0.028 m<sup>3</sup>/min). The sampler recorded particles sized >0.16, >0.3, >0.5, >1.0, >5 and >10 µm during 1 minute in the middle of each 10-min period of the experiment. During sham surgery, physical activity was avoided while particle measurements were made.

### Statistics

The lengths of walls/enclosures surrounding the ultraclean air supply were randomized between the experiments. Differences between means were analyzed with the Mann-Whitney U-test and  $p < 0.05$  was chosen as a significant difference.

### Results

Air contamination with bacteria-carrying particles before preparation, during preparation and during sham surgery was minimal and well below the accepted limit for operating units with so-called ultraclean, i.e., <10 cfu/m<sup>3</sup>. The length of the side-walls/enclosures had no significant influence on the air counts at any sampling site (Table 1).

The sedimentation rate of bacteria-carrying particles was generally 10-20-fold higher outside than inside the LAF unit. The length of the walls/enclosures had no influence on the bacterial sedimentation rates at the different sampling sites in the unit ("patient" chest, "wound", instrument table). Comparing sample sites inside the LAF enclosure, the surface contamination was numerically lower on the instrument table than at the patient's chest and wound area. This difference was statistically significant only when long walls were used (Table 2).

Air contamination with particles was minimal and no differences were seen between the different wall lengths/enclosures, irrespective of particle size. The wound area counts for particle sizes relevant to HEPA filter function and the sizes of the typical colony-forming units are given in Table 3.

### Discussion

The zoned vertical laminar airflow (LAF) unit produced ultraclean air, i.e., <10 cfu/m<sup>3</sup> (Whyte et al. 1983a) with low air and surface counts of bacteria-carrying particles and total particle air counts without any differences related to the length of the walls/enclosures of the airflow. This is in contrast to earlier

reports where extra side-walls around the ultraclean airflow were shown to increase the bacteriological efficacy of vertical LAF units (Lidwell et al. 1982). The probable reason for the difference is that the outward directed airstreams produced by the zoned/exponential airflow unit prevent entrainment of contaminated air. The fact that our LAF unit has air outlets placed in the lower corners of the operating room instead of at the ceiling might contribute to the favorable results.

The numbers of surface counts of bacteria were generally lower at the instruments than at the "patient's" chest and in the "wound" areas, but the difference was significant only when long walls were used. A probable explanation is that the majority of persons inside the ultraclean air were closer to the "patient" and "wound" areas than to the instrument table. This leads to the question whether air or surface counts or both should be used to evaluate operating room hygiene. Air counts have been used by most workers (Lidwell et al. 1983) but Taylor and Bannister (1993) suggested that sedimentation plates may offer a better assessment of bacterial fall-out into a surgical wound. From our study we can only conclude that there is no obvious correlation between air counts and sedimentation of bacteria. On the other hand, if the unit is properly used, our results suggest a standard for surface contamination in vertical LAF units of about 100 cfu/m<sup>2</sup>/h.

It has been recommended that body exhaust suites should be used in ultraclean vertical LAF (Taylor and Bannister 1993). Our findings show that adequate disposable garments will result in a very low and standardized degree of bacterial contamination, which also was proven by Whyte et al. (1983b). In this context, it must be pointed out that contamination from the neck area probably is of importance in a vertical LAF and that, as in this study, hoods well tucked in under the surgical gown are an important feature (Håeri et al. 1980).

Our experimental model using sham operations, designed to mimic a major (2 h) orthopedic procedure, has earlier been used in several studies (Friberg and Friberg 1994, Friberg et al. 1980, 1996). In general, it has been found to generate bacterial dispersal rates equivalent to those reported for real surgery performed during similar conditions (Whyte et al. 1983b, Hambraeus 1988, Ahl et al. 1995). There are several advantages with an experimental model (Friberg et al. 1996). One is that the strict standardization of individuals, speech, and physical activity will give rather constant bacterial dispersal rates from the team, resulting in small standard deviations that will reduce the number of experiments required for a study. Secondly, the behavior of the team during real procedures

not only results in more variable dispersal rates but also introduces the risk of bias, i.e., that the behavior is stricter during a study than during routine work. In other words, in clinical practice bacteria dispersal may be greater and bacteria-preventing measures studied less efficacious than during studies. The third reason is ethical, because all new equipment should be evaluated before being used in clinical practice.

In conclusion, the concept of the zoned vertical LAF system claimed to prevent entrainment of peripheral contaminated air was supported by our data. The present development of vertical LAF units making additional walls inside the operating room unnecessary seems promising and will make the units more versatile, without compromising patient safety from a bacterial point of view.

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