Zoned exponential, vertical and horizontal ultra-clean laminar airflows

No differences in bacteriological efficiency

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We compared the novel zoned exponential ultra-clean operating room ventilation, needing no extra side-walls with the traditionally used ultra-clean air systems having vertical or horizontal laminar airflow, but requiring extra side-walls. The three units were evaluated with regard to elimination of particles with focus on airborne and sedimenting bacteria-carrying particles (colony forming units, cfu) during rigidly standardized sham operations. Although minor differences were recorded inside the ultra-clean airflows, the three systems were comparable with regard to bacteriological efficiency and ensured a low air and surface contamination (0.05–4 cfu/m^3 and 7–72 cfu/m^2/h, depending on the site of sampling).

We conclude that all three systems fulfilled well the criteria for ultra-clean air (< 10 cfu/m^3), but that exponential airflow is the most versatile alternative, as additional side-walls around the operating area can be omitted.

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To prevent deflection of bacteriologically contaminated peripheral air into the ultra-clean zone the traditional vertical and horizontal laminar airflow (LAF) designs have included extra side-walls creating an operating box (Charnley 1964a, b, Charnley and Eftekhar 1969, Charnley 1972, Lindberg 1973, Lidwell et al. 1982, Lidwell 1983). The drawbacks of such enclosures are decreased space and versatility of the operating room. Howorth (1985) described a system producing an exponential LAF, preventing entrainment of contaminated peripheral air. We showed that a similar system, with zoned air inlet producing exponential LAF airflow, was equally efficient, with regard to elimination of bacteria-carrying particles, whether or not equipped with extra walls (Friberg et al. 1996a).

We have now compared the zoned exponential LAF without side-walls with the traditional vertical and horizontal LAF systems with side-walls, having regard to elimination of particles with focus on bacteria- carrying particles.

Methods

For the evaluation, we chose strictly standardized sham operations, recently described in detail (Friberg et al. 1996 a and b).

Ventilation systems

The air streams in the ultra-clean LAF systems were verified with smoke. The team strictly respected the directions of the ultra-clean airflows and aseptic areas.

Exponential LAF (n 5): The zoned exponential LAF (Opticeil 2000, ABB, Airtech AB, Stockholm, Sweden) was equipped with a short screen ending 2.0 m from the floor (Figure 1).

Vertical LAF (n 5): The zoned system was equipped with four side walls/enclosures ending 0.2 m above the floor (Figure 2). The walls redirected the exponential airflow into a traditional vertical LAF.

Horizontal LAF (n 4): The cross-flow unit (Enviramedic, Ultramare AB, Stockholm, Sweden), equipped with two side-walls, was installed in a conventional plenum pressure ventilated (16.5 air changes/h) operating room (Figure 3).

Statistics

Means and standard deviations are given. Differences between mean values were compared, using the Mann-Whitney U-test and $p < 0.05$ was chosen as a significant difference.

Results

Air contamination with bacteria-carrying particles be-

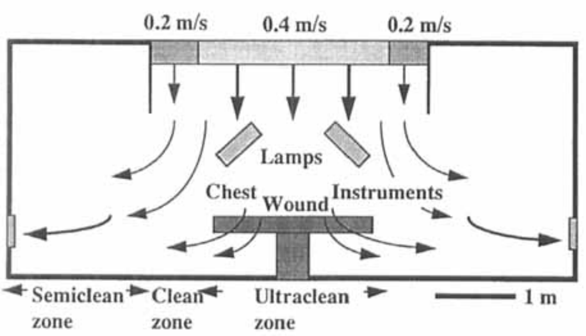

Figure 1. Side view of the zoned exponential LAF unit.

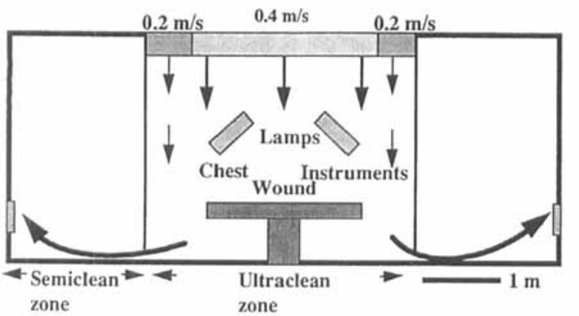

Figure 2. Side view of the vertical LAF unit.

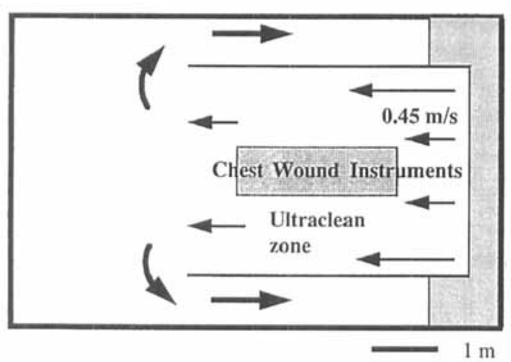

Figure 3. Top view of the horizontal LAF unit.

fore preparations for surgery, when only minimal activity occurred in the operating room, was extremely low and all three ventilation systems provided an almost sterile atmosphere. During preparations, the mean air contamination increased slightly, but with no differences between the airflows. During sham surgery, the wound area air counts were slightly higher in the horizontal flow than in the vertical LAF unit while, at the instruments, it was lower in the horizontal than in the exponential and vertical units. During surgery, in the horizontal flow the air in the wound area was more contaminated than in the instrument area (Table 1).

Surface contamination of bacteria-carrying particles in the LAF revealed no differences between the airflows at any sampling site. In the vertical unit, the instrument area was less surface-contaminated than the wound and chest areas. The rate of sedimenting cfus outside the LAF was higher in the exponential and vertical units than in the horizontal airflow (Table 2).

Air contamination with dust particles in sizes relevant to those of typical bacteria-carrying particles and to HEPA filter function was lower in the exponential and vertical units than in the horizontal unit (Table 3). In general, the air contamination with dust particles was 100 to 1000-fold higher than with bacteria-carrying particles

Discussion

Although minor differences between the ultraclean exponential, vertical and horizontal LAF systems were recorded, they provided a bacteriologically comparable air quality fulfilling well the criteria for ultra-clean operating rooms, i.e., < 10 cfu/m^3 (Whyte et al. 1983).

During surgery, the horizontal flow resulted in slightly higher bacterial air counts in the wound area than did the vertical flow. This is consistent with the finding that air contamination in the wound area with dust particles in sizes comparable to those of the bacteria-carry-

Table 1. Air contamination with bacteria-carrying particles during sham surgery in the exponential, vertical and horizontal LAF units. Mean (SD)

Sampling period and area	Air counts cfu/m^3		
	Exponential (n 5)	Vertical (n 5)	Horizontal (n 4)
Before preparation	0.2 (0.2)	0.2 (0.1)	0.1 (0.2)
During preparation			
Wound	4.0 (3.3)	1.1 (0.7)	3.1 (3.0)
Instruments	0.9 (0.4)	0.6 (0.3)	0.8 (0.4)
During surgery			
Wound	1.3 (0,5)	0.8 (0.3)	1.9 (0.3)
Instruments	2.3 (1.1)	1.2 (0.9)	0.05 (0.03)

The number of cfus found in the wound during surgery were higher (p = 0.01) in the horizontal flow than in the vertical unit while at instruments it was lower (p = 0.01) than in the exponential and vertical units. During surgery in the horizontal flow, the wound was more contaminated than in the instrument area (p = 0.02).
For reference, 20–100 cfu/m^3 were recorded in a conventionally ventilated operating room during identical sham surgery (Friberg et al. 1996b).

Table 2. Sedimentation of bacteria-carrying particles during sham surgery in the exponential, vertical, and horizontal LAF units. Mean (SD)

Sampling area	Sedimentation (cfu/m²/h)		
	Exponential (n 5)	Vertical (n 5)	Horizontal (n 4)
Outside LAF	653 (170)	864 (365)	90 (53)
Inside LAF			
Patient chest	64 (35)	58 (32)	72 (106)
Wound	39 (51)	64 (40)	32 (37)
Instruments	26 (38)	7 (13)	32 (45)

Inside the LAF, no significant differences were recorded between the air flows. In the vertical unit, the instrument area was less contaminated than the wound and chest areas ($p = 0.03$–0.01). Outside the LAFs the number of cfus was higher in the exponential and vertical units than in the horizontal air flow ($p = 0.01$). For reference, 500–2900 cfu/ m^2/h were recorded in a conventionally ventilated operating room during identical sham surgery (Friberg et al. 1996b).

Table 3. Particle counts in the wound area during sham surgery in the exponential, vertical and horizontal LAF units. Mean (SD)

Particle size (µm)	Particle per m³		
	Exponential (n 5)	Vertical (n 5)	Horizontal (n 4)
> 0.3	2084 (3531)	1978 (5156)	27426 (18413)
> 5.0	141 (212)	247 (742)	1153 (307)
>10.0	106 (141)	177 (586)	929 (285)

The number of particles was lower in the exponential and vertical than in the horizontal air flow unit ($p = 0.03$–0.01). For reference, 8500 particles >10.0 µm were recorded in a conventionally ventilated operating room during identical sham surgery (Friberg et al. 1996b).

ing particles also was higher in the horizontal than in the exponential and vertical flows. This is consistent with several studies comparing vertical and horizontal LAFs with regard to bacterial contamination and postoperative infection rate (Whyte et al. 1973, 1983, Salvati et al. 1982, Lidwell et al. 1987, Bischoff et al. 1994). On the other hand, the horizontal system had slightly lower air counts than the exponential and vertical units in the instrument area. This reflects the fact that in the horizontal flow the instrument table was placed close to the HEPA filter wall and that team members were not allowed to pass in the space between the wall and the instruments. As contaminated instruments have been considered a more important route of transfer of bacteria into the wound than direct airborne contamination, our result here instead points in favor of the horizontal system (Charnley 1964a, Ritter et al. 1976, Whyte et al. 1982).

The surface contaminations inside the ultra-clean areas were similar in all three LAF systems. The large differences in surface contamination between inside and outside the ultra-clean areas in the exponential and vertical LAFs stress the importance of using the systems correctly. In our opinion, instrument table set-up, gowning and gloving should not be done outside the ultra-clean airflow. Outside the ultra-clean zone, the horizontal airflow yielded lower counts than the other units. A possible explanation is that, unlike in the exponential and vertical units, the horizontal unit was placed in an operating room with conventional mixing ventilation.

In conclusion, the zoned exponential, vertical and horizontal LAF units proved to be equally efficient and showed a high degree of bacteriological cleanliness. It must be pointed out that performing surgery in ultra-clean air is a very delicate task, needing special skills, and training of all staff on how to respect the aseptic area. Ultra-clean air cannot be expected to compensate for poor operating room practices (Mc Quarrie et al. 1990, Taylor and Bannister 1993). A LAF system must ensure an aeromicrobiologically clean zone in which various types of major surgery can be carried out, without imposing changes of procedure or restriction of movements or in access. As the exponential airflow allows for omission of extra sidewalls, we regard this system to be the most versatile in clinical use.

Acknowledgments

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