Air contamination during hip and knee arthroplasties

Horizontal laminar flow randomized vs. conventional ventilation

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In a randomized study 90 patients, operated on with a total hip or knee arthroplasty, were allocated to 1 of 3 different regimes, all including a reinforced single-use operating gown: (1) horizontal laminar flow ventilation and conventional clothes (cotton shirts and trousers) for all staff members, (2) horizontal laminar flow ventilation and occlusive garments (Klinidress) and (3) conventional ventilation and occlusive garments.

Volumetric air sampling gave a low mean number of colony-forming units (< 10 cfu/m^3) in the vicinity of the wound in all 3 groups. Laminar ventilation, with or without occlusive staff garments, resulted in less air contamination compared to conventional ventilation. During knee arthroplasty, the use of occlusive clothes in the laminar ventilation room, further reduced the number of airborne, bacteria-carrying particles to around 1 cfu/m^3. No such reduction was seen during hip arthroplasty.

We conclude that hip and knee arthroplasties can be performed in operating theaters with conventional ventilation when occlusive staff garments are used. However, laminar air flow ventilation in knee surgery, preferably in combination with occlusive garments, resulted in a substantially lower air contamination and should be preferred.

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To prevent peroperative infections a low air contamination in the operating room is of the utmost importance (Lidwell et al. 1982, 1987). We report the combined effects of occlusive clothing and 2 types of ventilation, horizontal laminar and conventional, on air contamination.

Patients and methods

45 primary hip replacements and 45 primary knee arthroplasties for primary arthrosis were randomly allocated to 1 of 3 regimes, according to instructions in a sealed envelope. The different regimes were: 1) horizontal laminar flow ventilation and cotton shirts and trousers for all personnel in the operating theater, 2) horizontal laminar flow ventilation, while all staff members wore occlusive garments (Klinidress, Mölnlycke, Sweden) and 3) conventional ventilation and occlusive garments for all staff members. Due to a technical error, 1 patient with a knee arthroplasty in the conventional ventilation group had to be excluded.

In all 3 regimes, nonwoven gowns (Mölnlycke, Sweden) were used by the sterile team. The lower sleeves and the front of those gowns contain a layer of impermeable polyethylene film. Double gloves were used. The 2 operating rooms were located next to each other. One of them had a conventional ventilation system with 17–20 changes of air per hour and the air passed through a prefilter and a microfilter (Micretain 7 D-1000, Camfil, Trosa, Sweden) retaining 95 percent or more of particles larger than 0.5 µm. The other room had a horizontal laminar air flow outlet with approximately 530 air-changes per hour and a HEPA-filter (Ultramare AB, Bromma, Sweden) retaining 99.99 percent or more of particles larger than 0.5 µm. The filtered, horizontal, bacteria-free air stream, passed across the operative field from the patient's feet towards the head. The operating team stood beside the operation site and the anesthesiologist further downstream, behind the patient's head.

Only the first operation that took place that day in the operating room was included in the study. At all operations, disposable impermeable laminate Mölnlycke drapes with self-adhesive edges were

Table 1. Patient and operation data. Median (range)

	1 Laminar air ventilation + Cotton clothes (n 30)	2 Laminar air ventilation + Occlusive clothes (n 30)	3 Conventional ventilation + Occlusive clothes (29)
Hip arthroplasty			
Age	72 (61–84)	75 (62–85)	76 (70–86)
Men/women	4/11	3/12	4/11
No. of staff in the theater	7 (6–7)	6 (6–7)	6 (5–7)
Duration of operation (min)	100 (66–140)	85 (72–167)	86 (61–185)
No. of times door was opened	2 (0–7)	2 (1–7)	2 (0–6)
Knee arthroplasty			
Age	77 (44–84)	71 (59–79)	73 (55–82)
Men/women	5/10	4/11	6/8
No. of staff in the theater	7 (6–8)	7 (6–8)	7 (6–7)
Operation time (min)	110 (72–162)	95 (75–137)	110 (90–140)
No. of times door was opened	2 (0–14)	2 (0–5)	2 (0–6)

used. The operation area was covered with an incision drape.

The operations were performed by all staff surgeons. Peroperative antibiotics (cloxacillin 1 g × 3 i.v.) and bone-cement (Palacos®, Schering-Plough, Belgium) was used. For all knee and hip arthroplasties in the conventional ventilation group, cement with gentamicin was used. In hip replacement, a posterior approach and a Charnley, Stanmore or Bimetric implant was used, according to the preference of the surgeon. Knee replacements were performed using an AGC tricompartmental (n 38) or an Oxford unicompartmental (n 6) knee prosthesis.

Records were kept of the patient's age and sex, as well as the number of persons in the operating room, the duration of the operation and the number of peroperative times the door was opened (Table 1). All wounds healed without any sign of infection. The occlusive garment was convenient to wear and well accepted by all staff members.

Sampling technique

Air was sampled at the beginning, in the middle and at the termination of the operations, at 2 sites, using 2 different samplers. 1 Casella slit sampler MK2 (Casella Co Ltd, London, England), with a capacity of 700 L/min, was placed in the periphery of the operating theater with conventional ventilation or in the periphery, outside the zonal ventilation area, in the theater with laminar airflow. The sampler was run for three 4-minute periods. Another Casella slit sampler, modified to a capacity of 900 L/min and run for three 10-minute periods, was placed close to the operation area at the side of the operation table, thus sampling air passing the operation field and the surgeon. It was run in parallel with the other sampler. Both samplers took in air 1 meter above the floor. Blood agar plates were used.

Sampling from the uncovered skin preoperatively, and from the surface of the Steridrape at the end of each operation, was performed using a plastic applicator with a moist sampling pad made of polyvinyl alcohol (PVA) foam (Mölnlycke). Bacteria on the surfaces were picked up by doing 5 double-strokes with the pad in a board-frame measuring 5 × 10 cm (Hambraeus et al. 1990).

Wound-sampling was performed before closure of the wound. 5 sterile PVA pads, 4 × 7.5 cm, were allowed to absorb fluid to their full capacity.

At the end of the operation, the gloved fingertips of the surgeon and his assistant were gently pressed against the surfaces of 2 blood agar plates.

Laboratory technique

All blood agar plates from the air samplers and gloved fingertips were incubated at 37 °C for 24 h. All bacteria were counted and identified by standard techniques (Bergey 1984). No attempt was made to isolate anaerobic bacteria.

All PVA pads were treated in a Stomacher 400 (Seward Medical, London, England) and cultured on blood agar by the method of Hoborn and Nyström (1985). Penicillinase (Genzyme Biomedicals Ltd, Biodisk AB, Sweden) was added to the homogenization fluid.

Statistics

The Student's t-test was used and $P < 0.05$ was considered significant. Calculations were performed on the logarithms of the results.

Table 2. Air contamination (cfu/m^3) in the central area, i.e., close to the operation field, and in the periphery of the operation theater, at the beginning, in the middle and at the end of the operations (time 1–3). Arithmetic means

Arthroplasty:	Hip			Knee		
Group[a]	1 (n 15)	2 (n 15)	3 (n 15)	1 (n 15)	2 (n 15)	3 (n 14)
Central						
Time 1	1.5	0.9	4.3 [cd]	2.9	1.0 [b]	6.1 [cd]
Time 2	2.1	2.8	6.4 [cd]	4.2	1.0 [b]	7.2 [cd]
Time 3	2.1	4.4	7.2 [cd]	3.5	1.3	5.4 [cd]
Periphery						
Time 1	1.6	0.6 [b]	5.1 [cd]	2.3	1.1	7.0 [cd]
Time 2	1.0	0.8	7.6 [cd]	1.4	0.6 [b]	8.8 [cd]
Time 3	1.6	1.0 [b]	11.0 [cd]	1.2	1.2	9.6 [cd]

[a] see Table 1
[b] superior results in group 2 compared with group 1 ($P < 0.05$)
[c] inferior results in group 3 compared with group 1 ($P < 0.05$)
[d] inferior results in group 3 compared with group 2 ($P < 0.05$)

Results

The horizontal laminar air-flow ventilation system resulted in a reduction of air contamination compared to conventional ventilation and occlusive clothes, both during hip and knee arthroplasties (Table 2). When occlusive clothes were used in the laminar air-flow ventilation theater, a further reduction in air contamination was seen outside the zonal ventilation area both in hip and knee surgery. In the central area, close to the operation field, this occurred only in knee surgery.

Although the mean values of the number of airborne particles were within the proposed limits for ultraclean air (≤ 10 colony-forming units (cfu)/m^3) in all 3 groups, during hip arthroplasty at least 1 central sample was above 10 cfu/m^3 in 4/15 of the operations in the conventional ventilation group, compared with only 1/15 in each of the 2 laminar ventilation groups. In knee arthroplasty, 1 sample from the central area was above 10 cfu/m^3 in 4/14 of the operations in the conventional ventilation group, compared to 2/15 in the laminar ventilation group when occlusive clothes were not used, and none when occlusive clothes were used.

The bacteria found were, as expected, mainly *Bacillus* species, *Staphylococcus epidermidis* and other coagulase negative staphylococci (CNS). One important exception, however, was a patient with coxarthrosis, where *Staphylococcus aureus* was found both in the air (2–4 cfu/m^3) and on the skin (around 150 colonies per 50 cm^2) preoperatively.

Cultures from the skin before final preoperative skin disinfection were positive, mainly CNS including *S. epidermidis*, in 9/45 patients with coxarthrosis and in 14/44 patients with gonarthrosis.

Cultures from the incision drape, wound and fingers were positive only occasionally, and no differences between the clothing/ ventilation groups were found.

Discussion

It has been proposed that the average number of bacteria-carrying particles in the air should not exceed 10 cfu/m^3 in an operating room with an acceptable ultraclean air (Whyte et al. 1983a).

Already in 1985 Bergman et al. (1985) showed, in surgery for idiopathic scoliosis, that ultraclean air could be achieved if a polypropylene coverall was worn in a conventionally ventilated operation theater. Our results show that ultraclean air can be achieved close to the operation field also in hip and knee replacement surgery performed in a conventionally ventilated operation theater when occlusive garments are used by all persons in the operating room. At the termination of the operation, the bacterial counts in the periphery, however, were higher than at the wound site. This was probably because of the movements of staff members in the perifery.

Air contamination levels below 1 cfu/m^3 can be achieved with laminar airflow in combination with total body exhaust gowns (Lidwell et al. 1982, Whyte et al. 1983b). Ultraclean air enclosures, however, are expensive, and total body exhaust gowns

with helmets are inconvenient and make communication difficult. Equally good results have been reached when other more convenient occlusive clothes, in combination with laminar airflow ventilation, were used (Whyte et al. 1983b).

Vertical laminar airflow is said to be preferred to enclosures with horizontal flow (Whyte et al. 1973, 1983b, Lidwell et al. 1987). However, the number of cfu/m^3 found in our study compares well with results presented for vertical airflow ventilation (Whyte et al. 1983b, Blomgren et al. 1990).

In a large retrospective study, Salvati et al. (1982) found an increased infection rate of 1.4–3.9 percent when total knee replacements were performed in a horizontal unidirectional filtered airflow system compared with those in a conventional ventilation room. This increased infection rate was explained by the position of the operating team periodically interfering with the laminar airflow. However, we were able to show a significant reduction in air contamination close to the operation field in the horizontal laminar ventilation room, as compared to the conventional ventilation room.

In the laminar ventilation flow, a tendency to higher cfu in the center where activity is high was seen. This is probably explained by disturbance of the laminar flow by the operating team (Taylor and Bannister 1993). Due to the high number of air-changes the air contamination in the periphery is constantly kept at a low level.

Blomgren et al. (1990) found a further reduction in air contamination when occlusive clothes were also used with a vertical air flow ventilation system. Such a reduction was only seen during knee arthroplasty in our study, achieving mean values of air contamination around 1 cfu/m^3 and, probably most important, revealing no single sampling value above 10 cfu/m^3.

Probably due to the filtration and rapid air turnover in the laminar air ventilation room, an increase in air contamination over time was not noticed during the operation, a tendency seen in the periphery in the conventionally ventilated room.

In conventionally ventilated operating rooms, approximately 95 percent of deep infections have been reported to be caused by airborne microorganisms, but with fewer than 5 cfu/m^3 of air, routes of contamination other than air predominate (Lidwell et al. 1987). If ultraclean air, expressed as less than 10 cfu/m^3, is set as a golden standard for the acceptable microbiological air contamination, our results indicate that total hip and knee replacements can be performed in a conventionally ventilated operating room, in combination with the use of occlusive clothes. If, on the other hand, 1–2 cfu/m^3 results in substantially fewer infections, which is not proven, laminar flow ventilation is necessary.

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