Journal of Hospital Infection xxx (2018) 1–8

Available online at www.sciencedirect.com

Journal of Hospital Infection

journal homepage: www.elsevier.com/locate/jhin

Effect of mobile laminar airflow units on airborne bacterial contamination during neurosurgical procedures

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ARTICLE INFO

Article history:
Received 16 November 2017
Accepted 20 March 2018
Available online xxx

Keywords:
Operating room
Laminar airflow
Colony counts
Neurosurgery

SUMMARY

Background: Surgical site infections (SSIs) after neurosurgery are potentially life-threatening and entail great costs. SSIs may occur from airborne bacteria in the operating room, and ultraclean air is desired during infection-prone cleaning procedures. Door openings and the number of persons present in the operating room affect the air quality. Mobile laminar airflow (MLAF) units, with horizontal laminar airflow, have previously been shown to reduce airborne bacterial contamination.

Aim: To assess the effect of MLAF units on airborne bacterial contamination during neurosurgical procedures.

Methods: In a quasi-experimental design, bacteria-carrying particles (colony-forming units: cfu) during neurosurgical procedures were measured with active air-sampling in operating rooms with conventional turbulent ventilation, and with additional MLAF units. The MLAF units were shifted between operating rooms monthly. Colony-forming unit count and bacterial species detection were conducted after incubation. Data was collected for a period of 18 months.

Findings: A total of 233 samples were collected during 45 neurosurgical procedures. The use of MLAF units significantly reduced the numbers of cfu in the surgical site area ($P < 0.001$) and above the instrument table ($P < 0.001$). Logistic regression showed that the only significant predictor affecting cfu count was the use of MLAF units (odds ratio: 41.6; 95% confidence interval: 11.3–152.8; $P < 0.001$). The most frequently detected bacteria were coagulase-negative staphylococci.

Conclusion: MLAF successfully reduces cfu during neurosurgery to ultraclean air levels. MLAF units are valuable when the main operating room ventilation system is unable to produce ultraclean air in infection-prone clean neurosurgery.

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https://doi.org/10.1016/j.jhin.2018.03.024
0195-6701/

Introduction

Surgical site infections (SSIs) are defined as infections that occur within 30 days after surgery, or within one year in patients receiving implants. SSIs are classified according to whether they involve the incision area or organ/spaces. Incisional SSIs are further divided into superficial (involving skin or subcutaneous tissue) or deep SSIs (involving fascial, muscle or other deeper tissues) [1]. There are several exogenous (procedure-related) factors that influence the risk of SSI. One important factor is the microbiological quality of the air in the operating room, since airborne microbes may contaminate the wound by direct sedimentation, or indirectly by contaminated surgical instruments [1].

Deep neurosurgical SSIs most usually presents as meningitis, subdural empyema, bone flap osteomyelitis and/or brain abscess, which entails high morbidity and are potentially life-threatening [2,3]. Previously studies have shown that coagulase-negative staphylococci (CoNS), *Staphylococcus aureus* and *Propionibacterium* species are the most frequently offending organisms in SSIs after neurosurgical procedures [2,3]. When costs associated with SSI from a hospital perspective were evaluated between high-volume surgical specialties, the greatest mean cost was found among neurosurgery patients [4]. Most neurosurgical procedures are classified as infection-prone clean surgeries since artificial implants are used, and ultraclean air ($\leq$10 colony-forming units (cfu) per m^3) in the operating room is desired.

Airborne contamination is related to the dispersal of skin particles from the persons present in the operating room. Each person releases $\sim 10^4$ particles per minute when walking, whereof 10% carry viable micro-organisms [5]. Thus, the more people in the operating room, the more bacteria-carrying particles in the air [6]. Door openings in the operating room defeat the positive air pressure and allow possibly contaminated air to flow in, resulting in unacceptable numbers of airborne cfu during surgery [7,8].

Operating-room air ventilation with laminar airflow ceiling canopy reduces the airborne cfu, and is predominantly used in orthopaedic procedures. However, these systems are expensive to install, and studies have failed to produce convincing evidence of decreasing SSI rates [9]. Mobile laminar airflow (MLAF) units significantly reduce airborne cfu in experimental studies [10,11], as well as during surgical procedures [12,13]. Although the consequences of SSI after neurosurgical procedures often are severe and sometimes life-threatening, no previous studies have been undertaken to assess the effectiveness of MLAF during neurosurgical procedures.

The aim in this study was to assess the effect of MLAF units on airborne bacterial contamination during neurosurgical procedures.

Methods

The study was conducted at a neurosurgical operating suite at a University Hospital in Stockholm, and a quasi-experimental design was used, shifting MLAF units monthly. Table I shows characteristics of the operating rooms, Table II the use of MLAF units, and samples collected. All operating rooms were equipped with turbulent ventilation with air supply in the ceiling and exhaust air devices close to the floor.

Table I
Characteristics of operating rooms

Characteristic	Operating room		
	1	2[a]	3
Size (m^3)	153	175	173
Air changes/hour	14.9	21.7	15.2

[a] Closed from July 2015 due to reconstruction.

The additional MLAF units consisted of Operio and SteriStay (Toul Meditech AB, Västerås, Sweden). Each unit consists of a table, a high-efficiency particulate air (HEPA) filter, and a laminar airflow (LAF) screen (0.6 × 0.45 m). Ambient air is passed through the HEPA filter and the LAF screen, which produces a turbulence-free airflow that pushes potentially contaminated air forwards, away from the sterile zone with an airflow velocity of 0.4–0.5 m/s (400 m^3/h). The single-use LAF screen has a unique bar code, that is recorded in the control system of the equipment, to ensure proper use. The HEPA filter should be replaced every 2000 h. The airflow is locally distributed and has no impact on the regular ventilation system. Operio works as a mayo stand with the LAF screen over an integrated foldable instrument tray, and should be directed towards the surgical site, aiming to keep the sterile integrity over the surgical site and instruments. The airflow is efficient up to 120 and 50 cm width, provided that the airflow is not blocked by equipment or staff. SteriStay is an instrument table with the LAF screen at one of the short sides, with a table work surface of 1.33 × 0.6 m. The airflow of SteriStay is pressed against a larger area, thus spreading the clean airflow for a greater length compared to Operio.

Surgical team

In neurosurgery, the surgical team generally consists of one or two surgeons, one scrub nurse, one circulating nurse, one nurse anaesthetist and/or one anaesthetist. Each member of the surgical team was dressed in a reusable Mertex P-3477 clean air suit, disposable surgical hoods that were tucked into the neckline, disposable facemasks, private socks and shoes. The surgeons and the scrub nurse were in addition using single-use sterile gowns.

Baseline sampling for pre-study conditions

Baseline sampling was conducted to assess pre-study conditions with the conventional turbulent ventilation concerning cfu/m^3, numbers of staff, and door openings. Data were collected during 11 neurosurgical operations, collecting 55 samples. The cfu results from the baseline sampling were approximately normally distributed and ranged 6–59 cfu/m^3 (mean: 23.6; standard deviation: 13.1). Numbers of staff ranged 6–10 (median: 8; interquartile range (IQR): 6–8) and door openings 0–4 (median: 2; IQR: 1–2) and were not normally distributed. Since the baseline sampling did not differ from the sampling in the study, nor in the types of neurosurgical procedures, the baseline cfu samples were included in the results.

Sampling methods

Active air sampling was performed according to Swedish guidelines during neurosurgical procedures; in ordinary condi-

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Table II

Characteristics of operating rooms, placement of mobile laminar airflow (MLAF) units, number of surgical procedures and number of agar samples during the data collection period Q4

Sampling month/site	Operating room (OR)								
	1			2[a]			3		
	No. of procedures	MLAF used[b]	Agar samples/ sampling site	No. of procedures	MLAF used[b]	Agar samples/ sampling site	No. of procedures	MLAF used[b]	Agar samples/ sampling site
January 2015	0	No		2	No		2	No	
Surgical site			0			0			0
Instrument table			0			0			0
Peripheral in OR			0			10			10
February	2	No		3	No		2	No	
Surgical site			0			0			0
Instrument table			0			0			0
Peripheral in OR			10			15			10
March	2	No		1	Yes		1	Yes	
Surgical site			0			2			2
Instrument table			0			2			2
Peripheral in OR			10			2			2
April	1	Yes		1	Yes		1	No	
Surgical site			2			2			2
Instrument table			2			2			2
Peripheral in OR			2			2			2
May	1	No		1	Yes		1	Yes	
Surgical site			2			2			1
Instrument table			2			2			1
Peripheral in OR			2			2			1
June	0	Yes		1	Yes		0	No	
Surgical site			0			2			0
Instrument table			0			2			0
Peripheral in OR			0			2			0
July	1	No		0	No		1	Yes	
Surgical site			1			0			2
Instrument table			1			0			2
Peripheral in OR			2			0			2
August	1[c]	Yes		0	No		0	No	
Surgical site			3			0			0
Instrument table			2			0			0
Peripheral in OR			2			0			0
September	1[c]	No		0	No		1[c]	Yes	
Surgical site			2			0			3
Instrument table			1			0			2
Peripheral in OR			1			0			2
October	1[c]	Yes		0	No		1[c]	No	
Surgical site			3			0			1
Instrument table			2			0			1
Peripheral in OR			2			0			1
November	1[c]	No		0	No		1[c]	Yes	
Surgical site			2			0			3
Instrument table			1			0			2
Peripheral in OR			1			0			2
December	1[c]	Yes		0	No		1[c]	No	
Surgical site			3			0			1
Instrument table			2			0			1
Peripheral in OR			2			0			1
January 2016	1[c]	No		0	No		1[c]	Yes	
Surgical site			2			0			3
Instrument table			1			0			2
Peripheral in OR			1			0			1

(*continued on next page*)

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Table II (*continued*)

Sampling month/site	Operating room (OR)								
	1			2[a]			3		
	No. of procedures	MLAF used[b]	Agar samples/ sampling site	No. of procedures	MLAF used[b]	Agar samples/ sampling site	No. of procedures	MLAF used[b]	Agar samples/ sampling site
February	1[c]	Yes							
Surgical site			2	0	No	0	1[c]	No	2
Instrument table			1			0			1
Peripheral in OR			1			0			1
March	1[c]	No		0	No		1[c]	Yes	
Surgical site			2			0			2
Instrument table			1			0			1
Peripheral in OR			1			0			1
April	1[c]	Yes		0	No		1[c]	No	
Surgical site			3			0			2
Instrument table			2			0			1
Peripheral in OR			2			0			1
May	1[c]	No		0	No		1[c]	Yes	
Surgical site			2			0			3
Instrument table			2			0			2
Peripheral in OR			1			0			2
June	1[c]	Yes		0	No		1[c]	No	
Surgical site			1			0			2
Instrument table			2			0			1
Peripheral in OR			2			0			1

[a] Closed from July 2015 due to reconstruction.
[b] MLAF units used comprise both Operio and SteriStay.
[c] Bacterial species identification performed.

tions with turbulent ventilation and using additional MLAF units (both Operio and SteriStay were used at all procedures during sampling) [14]. An SAS Super ISO 100 impactor air sampler (PBI International, Milan, Italy) was used to collect airborne microorganisms. The SAS Super ISO meets the international standard of measurements, ISO 14698-1, for biocontamination control, and aspirates air in a constant flow rate of 1 m^3/10 min through a perforated plate, impacting particles on to a surface of agar medium. Sampling was conducted at three locations during each operation; peripheral in the operating room, in a radius of $\leq$0.5 m from the surgical site and above the instrument table. The sampling position within $\leq$0.5 m of the surgical site area could not be standardized since each operation was unique in terms of patient position and the varying needs and positions of surgical equipment. When sampling for bacterial species identification in a radius of $\leq$0.5 m from the surgical site using Operio MLAF, samples were collected both in the Operio airflow and outside the airflow. During sampling within the sterile zone, the air sampler was prepared with sterile drapes, and the sampling was conducted using sterile gown and gloves. For all surgical procedures, the time from incision to closure of the wound exceeded 45 min, allowing at least three consecutive measurements to be taken. Procedures with primarily infected patients were excluded.

Tryptose soy agar (TSA) 55 mm plates were used when only cfu count was performed, and blood agar plates with 5% sheep blood when additional bacterial species identification was performed. The TSA agar plates were incubated three days at 32 $\pm$ 1°C and two days at 22 $\pm$ 2°C, and the blood agar plates were incubated two days at 35 $\pm$ 1°C before bacterial count. The results were expressed in cfu/m^3. The agar plates were sent the same day for incubation and cfu counts: the TSA agar plates to a microbiological laboratory at Research Institutes of Sweden, and the blood agar plates to the laboratory of clinical microbiology at the Karolinska University Hospital for incubation, bacterial species identification, and cfu counts. Species differentiation was not performed. The medical records in patients who underwent the surgical procedures were reviewed for detection of SSIs within one year after the procedures.

The study was approved by the Regional Ethical Review Board, Stockholm, Sweden (2014/1609-31/1, 2015/67-31).

Data analysis

Statistical analyses were performed with SPSS (Statistical Package for Social Sciences) version 22 (IBM SPSS Statistics, Armonk, NY, USA). The sample size was based on a power calculation, using data from the baseline measurements; a reduction from 23 to 10 cfu/m^3 (ultraclean air), with a statistical power of 80% and an alpha value of 0.05, showed that at least six samples were needed.

Data were not normally distributed and non-parametric tests were used. Comparisons were made between measure points of agar plates, sampled within the MLAF flow and plates outside the MLAF flow. Mann–Whitney *U*-test was used for comparisons of numbers of cfu, door openings, and maximum numbers of persons in the operating room between groups. Logistic regression was used to analyse potential predictors of cfu counts. Colony-forming units were dichotomized into ultraclean/not ultraclean air with a threshold of 10/11 and was the dependent variable; the use of MLAF units, door openings,

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and numbers of persons were explanatory variables. $P < 0.05$ was considered significant throughout.

Results

Colony-forming units

Active air-sampling was performed during 45 neurosurgical procedures, 26 with conventional turbulent ventilation and 19 with additional MLAF units. A total of 233 agar samples were collected, whereof 99 were collected in operating rooms using MLAF units and 134 in operating rooms with solely the conventional turbulent ventilation. The majority ($N = 39$) of the procedures were intracranial and included cerebral tumours, aneurysms, cavernomas, cranioplasty, shunt implantation, and deep brain stimulation. Six procedures were spinal, including spinal tumours and anterior cervical discectomies. None of the surgical procedures during sampling resulted in SSI within one year after the procedure.

When comparing samples in operating rooms using MLAF units with conventional ventilation, significant differences were found in the numbers of cfu close to the surgical site and the instrument table. The numbers of cfu in samples collected peripherally in the operating room did not differ between groups, neither did numbers of door openings nor persons present in the operating room (Table III).

Microbe detection

Bacterial species identification was performed on samples taken in the surgical site area during 21 operations, resulting in 31 samples. The most frequently occurring microbes were CoNS (Table IV).

In the logistic regression, 118 samples (collected in the surgical site area and above the instrument table) were analysed, and the full model significantly predicted cfu count ($\chi^2 = 60.28$; df = 3; $P < 0.001$). The model accounted for 40.0–55.6% of the variance, with 78.5% of ultraclean samples successfully predicted, and 92.3% of the non-ultraclean samples. Overall 83.1% of predictions were accurate. The use of MLAF was the only significant predictor affecting cfu count (odds ratio: 41.6; 95% confidence interval: 11.3–152.8; $P < 0.001$). Door openings and numbers of persons in the operating room were non-significant variables ($P = 0.848$ and 0.259, respectively).

Discussion

The results of our study show that MLAF significantly reduces airborne cfu in the surgical field during neurosurgical procedures. The MLAF only decreases the cfu count within reach of the laminar flow; outside the laminar flow, numbers of cfu remain high (Table III). Despite several door openings and persons present in the operating room, ultraclean air levels could be maintained within the surgical field by the MLAF units.

In neurosurgery, there is usually plenty of surgical equipment that needs to be placed close to the surgical site, such as operation microscope. The optimal position of the Operio MLAF was occasionally difficult to find, as well as a suitable cfu sampling position. Few samples collected within the MLAF airflow did not demonstrate an ultraclean air level; two samples were collected close to the surgical site, where the

Table III
Characteristics of all incubated agar samples ($N = 233$)

Sampling location	With MLAF ($N = 99$)	Without MLAF ($N = 134$)	*P*-value
≤0.5 m from surgical site	In the airflow of Operio	Conventional turbulent ventilation	
No. of samples	30	37[a]	
cfu (range)	0–13	2–127	
Median (IQR)	2.0 (0.0–4.0)	15.0 (7.5–43.5)	<0.001
Door openings (range)	0–8	0–9	
Median (IQR)	1.0 (0.0–3.3)	2.0 (0.0–4.0)	0.954
Maximum persons (range)	6–10	6–13	
Median (IQR)	8.0 (7.0–8.0)	8 (7.0–9.0)	0.495
≤0.5 m above instrument table	In the airflow of SteriStay	Conventional turbulent ventilation	
No. of samples	35	16	
cfu (range)	0–13	0–104	
Median (IQR)	0.0 (0.0–2.0)	11.5 (6.8–27.3)	<0.001
Door openings (range)	0–6	0–6	
Median (IQR)	2.0 (1.0–3.0)	3.5 (2.0–5.0)	0.050
Maximum persons (range)	6–11	7–11	
Median (IQR)	8.0 (7.0–9.0)	9.0 (8.0–10.0)	0.007
Peripheral in the OR	Operio and SteriStay in OR	Conventional turbulent ventilation	
No. of samples	34	81	
cfu (range)	2–157	1–157	
Median (IQR)	22.5 (9.0–60.5)	22.0 (13.0–37.0)	0.966
Door openings (range)	0–6	0–8	
Median (IQR)	2.0 (0.8–4.0)	2.0 (1.0–2.5)	0.846
Maximum persons (range)	6–12	5–11	
Median (IQR)	7.0 (7.0–8.0)	8.0 (6.0–8.0)	0.552

MLAF, mobile laminar airflow; IQR, interquartile range; OR, operating room.
[a] Including 12 samples collected in surgical site area in ORs using MLAF, but outside Operio airflow.

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Table IV
Bacterial species identification ($N = 31$) and characteristics during sampling

Surgery no.	OR	Type of surgery	Door openings	Persons present	Colony-forming units							
					CoNS	Micrococcus	Gram-positive rod	Gram-positive coccus	Moraxella	Corynebacterium	Streptomyces	Acinetobacter
Samples collected in surgical sire area in Operio airflow ($N = 9$)												
1	1	Aneurysm	1	8	3	7	0	0	0	0	1	0
2	3	Brain tumour	0	7	4	2	0	0	0	0	0	0
3	3	Brain tumour	5	7	3	0	0	0	0	0	0	0
4	1	Brain tumour	0	7	1	0	0	1	0	1	0	0
5	3	Brain tumour	1	8	1	1	0	0	0	0	0	0
6	1	Shunt	4	10	2	4	0	0	0	0	0	0
7	3	Brain metastasis	3	10	0	0	0	0	0	0	0	0
8	1	Brain tumour	3	8	0	0	0	0	0	0	0	0
9	3	Brain tumour	0	7	1	0	0	0	0	0	0	0
Samples collected in surgical site area in ORs using MLAF, but outside Operio airflow ($N = 12$)												
1	1	Aneurysm	1	8	45	14	0	0	0	0	3	0
2	3	Brain tumour	0	7	12	7	0	0	0	0	0	0
3	3	Brain tumour	9	8	10	5	0	0	0	0	0	0
4	1	Brain tumour	0	7	1	5	0	0	0	0	0	0
5	3	Brain tumour	0	8	40	50	0	0	0	0	0	0
6	1	Shunt	7	13	23	17	0	0	0	0	0	0
7	3	Brain metastasis	1	8	2	5	0	0	1	0	0	0
8	1	Brain tumour	1	7	2	0	0	0	0	0	0	0
9	3	Brain tumour	2	8	4	6	0	0	0	0	0	0
10	1	Brain tumour	0	6	9	21	3	0	0	0	0	1
10	1	Brain tumour	0	6	4	7	0	0	0	0	0	0
11	1	Vagus electrode	0	6	2	4	0	0	0	0	0	0
Samples collected in surgical site area in ORs with solely conventional turbulent ventilation ($N = 10$)												
12	1	Aneurysm	4	6	6	4	0	0	0	9	0	0
13	3	Brain tumour	0	7	5	2	1	0	0	0	0	0
14	1	Brain tumour	0	7	4	3	0	0	0	0	0	0
15	3	Brain tumour	4	7	3	0	1	1	0	0	0	0
16	1	Cavernoma	0	7	5	5	0	0	0	0	0	0
17	3	Brain tumour	0	8	0	5	0	0	0	0	0	0
18	1	Brain tumour	5	9	16	5	0	0	0	0	0	0
19	3	Brain tumour	2	11	20	2	0	0	0	0	0	0
20	1	Aneurysm	2	8	11	3	0	0	0	0	0	0
21	3	Cranioplasty	0	9	9	5	0	0	0	0	0	0

OR, operating room; CoNS, coagulase-negative staphylococci; MLAF, mobile laminar airflow.

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air sampler was within ≤0.5 m of the surgical site and possibly out of reach of the laminar airflow. The absence of a standardized cfu sampling position is a limitation, and the results concerning cfu counts in the surgical site area when using MLAF should be interpreted with precaution. When sampling for bacterial species identification and deliberately sampling out of reach of Operio airflow in the surgical site area, occasionally high cfu counts were detected (Table IV). We interpret this finding as contaminated air pushed from the centre of the surgical site, thus indicating proper functioning of the Operio MLAF.

The bacterial species identification showed that CoNS were the most frequently detected bacteria, found in all bacterial identification samples collected outside MLAF. Although a widely offending micro-organism after neurosurgery, *P. acnes* was not found in our samples. This is, however, expected since *P. acnes* is a normal inhabitant of the skin, situated particularly in the sebaceous glands, and of high concentration on the scalp and forehead [15]. It is not likely that *P. acnes* would be dispersed from the surgical team since all persons wore disposable hoods. The occurrence of *P. acnes* infections in previous studies may be endogenous from the patients' own bacterial flora, and explained by the lack of systemic prophylactic antibiotics reducing *P. acnes*, as well as the use of plastic adhesive drapes. Plastic adhesive drapes are widely used in neurosurgery, and may increase the risk of endogenously spread SSI by retaining moisture in the skin that facilitates bacterial growth [16]. The current systemic antibiotic prophylaxis regime at our department is cefuroxime, which reduces *P. acnes*.

According to Swedish guidelines [14] we collected at least three or four samples per procedure. More samples from the surgical site and instrument table were desired but were not possible due to time limitations, since sampling only was allowed between incision to closure. If more samples were required, only lengthy procedures could be included, which would not reflect the most usual neurosurgical procedures. The number of samples collected above the instrument table without MLAF ($N = 16$) may seem low compared to those collected in the SteriStay airflow ($N = 35$). Nevertheless, the power analysis showed that only six samples were needed to obtain a sufficient statistical power.

Our results show high variability in cfu counts in the non-MLAF group peripherally in the operating room. A possible explanation of this may be seasonal differences in temperature and humidity, which affects the airborne transmission of particles [1]. However, our operating rooms are old, humidity cannot be monitored, and the thermometers are imprecise. The fact that these variables were not measured is a limitation in our study.

Although we have shown that MLAF reduces the airborne cfu to ultraclean level during neurosurgical procedures, the clinical significance may be discussed; it still needs to be evaluated whether MLAF prevents the development of SSI. There are numerous intraoperative exogenous factors associated with increased risk for SSI after neurosurgery, such as longer duration of the surgical procedure, use of dural substitute, and wound closure with staples [2]. Our next step is to evaluate whether the use of MLAF units has affected the SSI incidence during the study period.

The current evidence shows no benefits for laminar airflow ceiling canopy systems compared with conventional turbulent ventilation [17]. However, since most bacteria found in wounds are airborne, action needs to be taken to reduce the bacteria inoculum, which may prevent the development of SSI [18]. Despite the obstacles in positioning the Operio MLAF correctly towards the surgical site during neurosurgical procedures, we found MLAF a valuable addition to achieve ultraclean air quality.

MLAF successfully reduced cfu during neurosurgery to ultraclean air levels in the surgical site area and above the instrument table. MLAF units are a valuable addition when the main operating room ventilation system is unable to produce ultraclean air in infection-prone clean neurosurgery. Further investigations are needed to evaluate whether this reduction in cfu has an impact on the frequency of SSI.

Conflicts of interest

None declared.

Funding sources

This study was funded by Vinnova (Innovation Against Infection project), grant number 2012-01252.

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