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Reduction in MRSA environmental contamination with a portable HEPA-filtration unit

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KEYWORDS

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Summary There is renewed interest in the hospital environment as a potentially important factor for cross-infection with methicillin-resistant *Staphylococcus aureus* (MRSA) and other nosocomial pathogens. The aim of this study was to evaluate the effectiveness of a portable high-efficiency particulate air (HEPA)-filtration unit (IQAir Cleanroom H13, Incen AG, Goldach, Switzerland) at reducing MRSA environmental surface contamination within a clinical setting. The MRSA contamination rate on horizontal surfaces was assessed with agar settle plates in ward side-rooms of three patients who were heavy MRSA dispersers. Contamination rates were measured at different air filtration rates (60–235 m³/h) and compared with no air filtration using Poisson regression. Without air filtration, between 80% and 100% of settle plates were positive for MRSA, with the mean number of MRSA colony-forming units (cfu)/10-h exposure/plate ranging from 4.1 to 27.7. Air filtration at a rate of 140 m³/h (one patient) and 235 m³/h (two patients), resulted in a highly significant decrease in contamination rates compared with no air filtration (adjusted rate ratios 0.037, 0.099 and 0.248, respectively; $P < 0.001$ for each). A strong association was demonstrated between the rate of air filtration and the mean number of MRSA cfu/10-h exposure/plate (P for trend < 0.001). In conclusion, this portable HEPA-filtration unit can significantly reduce MRSA environmental contamination within patient isolation rooms, and this may prove to be a useful addition to existing MRSA infection control measures.

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Introduction

Handwashing by healthcare workers is thought to be the most important method of control of methicillin-resistant *Staphylococcus aureus* (MRSA) and other nosocomial infections.¹ However, there is renewed interest in the hospital environment as a potentially important factor in cross-infection.²⁻⁴ The authors recently investigated an outbreak of Hickman-line-associated MRSA bacteraemia in a haematology day-case unit. As part of the investigations, significant MRSA contamination of the environment was found, and settle plates were positive for MRSA on a number of occasions, suggesting ongoing dispersal of MRSA into the air. At least two patients were identified as heavy shedders of MRSA, and the outbreak was controlled when a single room was designated for their further day-case treatment.

This outbreak prompted an investigation of technologies that may reduce future MRSA environmental contamination within such a setting. A number of air decontamination products have been reviewed recently by the Rapid Review Panel of the Health Protection Agency, including air filtration units and ultra-violet air disinfection units (www.hpa.org.uk/infections/topics_az/rapid_review). Two of these products have been recommended for in-use evaluations in a clinical setting (recommendation level 2), including the IQAir Cleanroom H13 portable air purification unit (Incen AG, Goldach, Switzerland). This article presents an evaluation of the effectiveness of the IQAir unit at preventing contamination of environmental surfaces with MRSA in three different clinical settings.

Methods

IQAir Cleanroom unit

Two IQAir Cleanroom H13 units were kindly provided by Air Science Ltd (Stroud, UK). The machines were free-standing floor units operating in recirculation mode. This portable air filtration purifier removes airborne micro-organisms by repeatedly drawing ambient room air through a pre-filter and then through a high-efficiency particulate air (HEPA) filter, with an efficiency of 99.97% for particles greater than or equal to 0.3 μm . The IQAir H13 unit's centrifugal fan can be set to run at five speeds, with air filtration rates ranging between 60 and 400 m^3/h .

Patients and clinical setting

The IQAir unit was evaluated in the environment of three patients who were known to have MRSA

colonization and who were likely to be heavy dispersers of MRSA.

Patient A was a 61-year-old male with acute myeloid leukaemia. He had previously received a bone marrow transplant complicated by graft-vs-host disease of his skin, and subsequent relapse of his leukaemia. MRSA colonization was first detected in April 2004, and MRSA was repeatedly detected from subsequent nose, perineal and skin swabs despite several courses of Aquasept washes and Bactroban nasal cream. This patient regularly attended the haematology day-case unit for blood product support, and had been previously linked with the MRSA outbreak on that unit. Since then, he had continued to receive day-case treatment (approximately once every two weeks) in a designated side-room on an elderly assessment ward, directly adjacent to the haematology day-case unit.

Patient B was a 66-year-old male who was an inpatient on a medical gastroenterology ward following complicated upper gastrointestinal surgery and a prolonged stay in the intensive care unit. MRSA colonization was first detected in March 2005, and MRSA was subsequently identified from nose, perineum, sputum (from tracheostomy), wound swabs and abdominal drain sites despite two courses of Aquasept/Bactroban. The patient was receiving total parenteral nutrition via a central line, required regular suctioning of his airway, and had developed a number of pressure sores. Although in a side-room on the ward, the door had often been left open and this patient had been linked with a cluster of MRSA infections on the ward.

Patient C was a previously fit and healthy 42-year-old male admitted with severe Stevens-Johnson syndrome following a course of penicillin. This had resulted in extensive skin blistering, akin to a severe burn injury. Six days after admission, MRSA was detected in sputum, blood cultures and, subsequently, numerous wound swabs. The patient was mechanically ventilated, hyperpyrexial (requiring haemofiltration for temperature control), and was having a complete dressing change every 48 h. MRSA sepsis was treated with intravenous vancomycin and gentamicin, but topical MRSA treatment was not contemplated.

Study design

Quantitative assessment of MRSA environmental surface contamination was measured with agar settle plates. Environmental surface contamination rates were measured both with and without air filtration on separate days (see Table I).

With Patient A, settle plates were used on six occasions over an eight-week period and the use of the IQAir unit at a filtration rate of 235 m³/h ($N=3$) was alternated with no air filtration ($N=3$). With Patient B, settle plates were used on eight occasions over a two-week period, first with no air filtration ($N=2$) and then with the IQAir unit running at air filtration rates of 140 m³/h ($N=2$), 95 m³/h ($N=2$) and 60 m³/h ($N=2$). With Patient C, settle plates were used on four occasions over a one-week period, first with no air filtration ($N=2$) and then with the IQAir unit running at a filtration rate of 235 m³/h ($N=2$). The air volume of the rooms and corresponding air filtration rates in terms of air changes/h for each study day are shown in Table I. The layout of each of the rooms and the position of the IQAir units within them are shown in Figure 1.

None of these patients received topical MRSA treatment during the study periods, and Patients A and B did not receive any systemic antibiotic treatment. Patient C was treated with intravenous vancomycin and gentamicin throughout the study period.

Settle plates

Standard-sized circular plates containing oxacillin resistance screening agar base (ORSAB) (Oxoid Ltd, Basingstoke, UK) were used as settle plates. Between four and 34 settle plates were placed in designated positions in the three rooms and exposed to the air for between 1.5 and 8 h (see Table I). Within each room, identical plate positions were used on each study day where possible. The settle plate positions used in each room are shown in Figure 1. Peripheral positions on the floor were most common, but settle plates were also placed under the bed, on window ledges, at the side of sinks, on overbed tables and on other horizontal surfaces where possible. Settle plate MRSA colony counts were expressed as colony-forming units (cfu)/10 h of exposure in order to calculate a standardized rate of MRSA environmental surface contamination over time.

Bacterial isolates and identification of MRSA

ORSAB plates were incubated for 48 h at 37°C, and the number of typical dark-blue colonies of MRSA was counted. Representative colonies from each plate were confirmed as *S. aureus* by agglutination for protein A and clumping factor (Slidex Staph Plus, bioMérieux, Basingstoke, UK), and for DNase production.

Methicillin resistance was determined after 24 h of incubation at 30°C on Columbia agar base supplemented with 2% oxacillin (PO0879A, Oxoid Ltd).

Statistical analysis

Statistical analysis was performed using EGRET software. Poisson regression was used to calculate adjusted rate ratios to compare the number of MRSA cfu/10-h exposure/plate, with and without the IQAir unit (controlled for the study day). Poisson regression was also used to look at the effect of different machine speeds on MRSA colony counts compared with no air filtration, and to calculate a P value for trend through the rate ratios.

Results

Effect of air filtration on MRSA environmental contamination

Without air filtration, all three patients were confirmed to be heavy dispersers of MRSA (see Table I and Figure 1). Overall, between 80% and 100% of the settle plates were positive, with the mean number of MRSA cfu/10-h exposure/plate ranging from 4.1 to 27.7. The extent and distance of MRSA shedding without air filtration for each patient is shown graphically in Figure 1.

Air filtration at a rate of 235 m³/h (Patients A and C) and 140 m³/h (Patient B) resulted in a significant decrease in MRSA surface contamination in each case (Table I). With Patient A, the adjusted rate ratio comparing the mean number of MRSA cfu/10-h exposure/plate with and without air filtration was 0.099 [95% confidence intervals (CI) 0.077–0.128]; a reduction of approximately 90%. Similar adjusted rate ratios for Patients B and C were 0.037 (95% CI 0.017–0.081) and 0.248 (95% CI 0.215–0.285); reductions of 96% and 75%, respectively.

The effect of these air filtration rates on the pattern and distance of MRSA shedding for each patient is also shown in Figure 1.

Effect of different air filtration rates on MRSA environmental surface contamination

Air filtration at three different rates (60, 95 and 140 m³/h) was used with Patient B. There was a highly significant association between the reduction in MRSA surface contamination and the volume of air filtered (see Table I). Rate ratios

Table 1 Effect of portable high-efficiency particulate air filtration on methicillin-resistant *Staphylococcus aureus* (MRSA) environmental contamination

Patient and setting (room air volume)	Date	IQAir filtration rate (m ³ /h)	IQAir filtration rate (air changes/h)	No. of settle plates used	No. (%) of MRSA +ve plates	Exposure time (h)	Total no. of MRSA cfu	Mean MRSA cfu/10-h exposure/plate	Adjusted rate ratio (95% CI) P value
Patient A, day-case, single room (27.7 m ³)	01.12.04	0	0	4	4 (100)	1.5	10	16.7	—
	17.12.04	0	0	34	34 (100)	7.25	319	12.9	—
	02.02.05	0	0	30	26 (87)	5.6	81	4.9	—
Patient B, medical ward, single room (39.2 m ³)	01.12.04	235	8.5	4	2 (50)	2	4	4.0	0.099 (0.077, 0.128)
	28.01.05	235	8.5	34	7 (21)	6.5	10	0.5	P < 0.001
	17.02.05	235	8.5	34	17 (50)	7	25	1.1	—
Patient C, intensive care, single room (46.2 m ³)	21.04.05	0	0	20	16 (80)	7.75	74	5.6	—
	22.04.05	0	0	20	18 (90)	7	58	4.1	—
	03.05.05	60	1.5	20	16 (80)	6	61 ^a	5.1	0.639 (0.505, 0.808)
	04.05.05	60	1.5	20	8 (40)	6.5	8	0.6	—
	27.04.05	95	2.4	20	8 (40)	8	18	1.1	0.233 (0.166, 0.326)
	28.04.05	95	2.4	20	7 (35)	5.25	10	1.0	—
Patient C, intensive care, single room (46.2 m ³)	25.04.05	140	3.6	20	4 (20)	6	4	0.3	0.037 (0.017, 0.081)
	26.04.05	140	3.6	20	0 (0)	6.5	0	0.0	P (for trend) < 0.001
Patient C, intensive care, single room (46.2 m ³)	05.05.05	0	0	20	20 (100)	7	330	23.6	—
	06.05.05 ^b	0	0	12	12 (100)	7	233	27.7	—
Patient C, intensive care, single room (46.2 m ³)	11.05.05 ^b	235	5.1	20	14 (70)	7	74	5.3	0.248 (0.215, 0.285)
	13.05.05 ^b	235	5.1	20	13 (65)	7	105	7.5	P < 0.001

cfu, colony-forming units.

^a 37 cfu on one agar settle plate, 0–3 cfu on remainder.^b Patient had complete change of dressings whilst settle plates exposed.

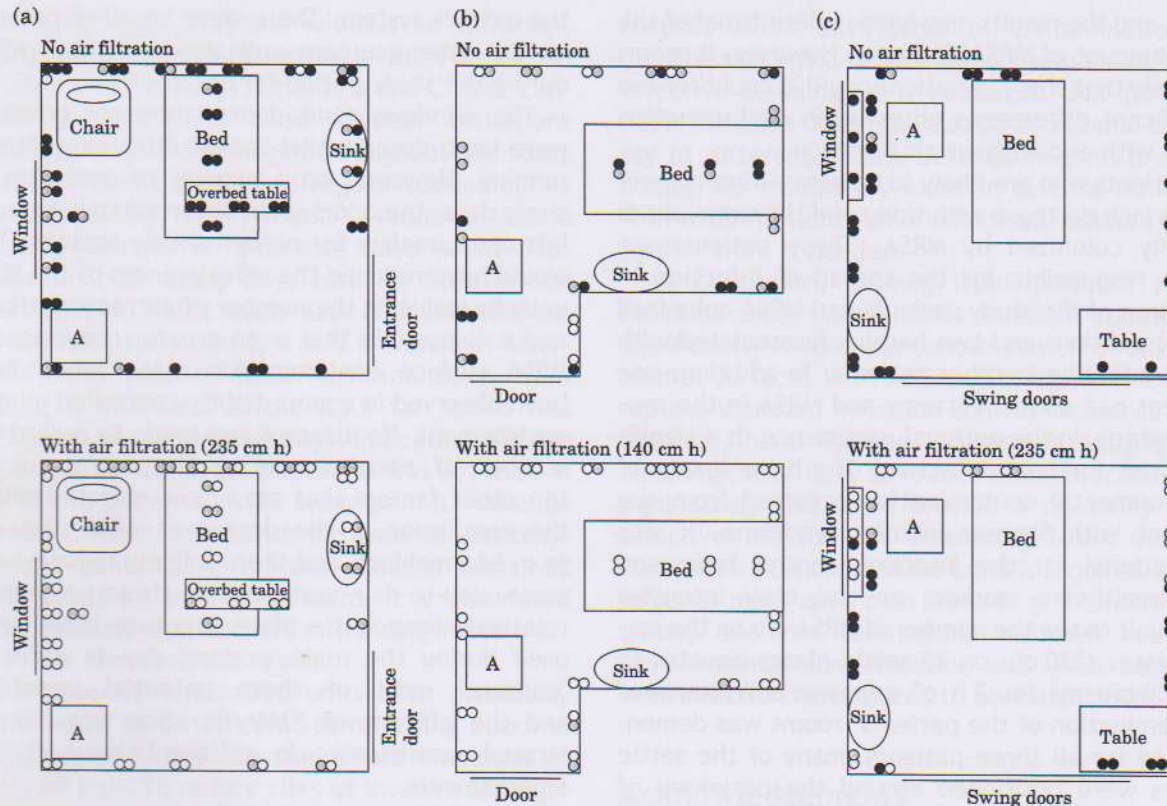


Figure 1 (a–c) Room schematics, position of settle plates and position of IQAir machine (A) are shown for Patients A–C, respectively. The results of the settle plates on the paired study days for each patient with and without IQAir filtration are combined. These are summarized as follows: open circle, settle plate with no methicillin-resistant *Staphylococcus aureus* (MRSA); grey circle, settle plate with 0.1–5.0 MRSA colony-forming units (cfu)/10-h exposure; black circle, settle plate with >5.0 MRSA cfu/10-h exposure. cm h, cubic metres per hour.

comparing the mean number of MRSA cfu/10-h exposure/plate with and without air filtration were 0.639 (95% CI 0.505–0.808) at a filtration rate of 60 m³/h, 0.233 (95% CI 0.166–0.326) at 95 m³/h, and 0.037 (95% CI 0.017–0.081) at 140 m³/h (*P* value for trend < 0.001).

Discussion

It is well established that MRSA contamination of the environment occurs in the vicinity of MRSA patients, and this is the principal reason for isolating patients in single rooms.⁵ However, relatively few reported studies have used agar settle (sedimentation) plates to assess the rate of MRSA contamination of environmental surfaces.⁶ This simple methodology was used in the present study to identify heavy shedders of MRSA and to measure the effect of using a portable HEPA-filtration unit on the contamination rates of environmental surfaces. The main reason for selecting this methodology instead of volumetric air sampling was that the authors were less concerned with determining

the rate of MRSA shedding into the air, and more interested in whether recirculating HEPA filtration could reduce the rate of MRSA settling on horizontal surfaces within the rooms of known MRSA dispersers. Whilst settle plates may be regarded as a relatively crude measure of airborne contamination, they do provide a simple and cost-effective way of enumerating the contamination rate of horizontal surfaces at multiple points within an occupied side-room. Contact plates or other environmental sampling methods were not used because the horizontal environmental surfaces within the occupied rooms could have been contaminated with MRSA at the start of each study day, dependent on the time and effectiveness of the previous room cleaning.

Despite attempts to keep the settle plate exposure times constant, there was inevitably some variation in the duration of exposure of the settle plates on different study days (for practical, logistical and sometimes clinical reasons), and relatively long exposure times were used (up to 8 h). The rate of recovery of MRSA may have been affected by some degree of dehydration of the

agar, and the results may have underestimated the true amount of MRSA dispersal. However, it seems unlikely that these variations could account for the significant differences observed in contamination rates with and without air filtration.

Patients who are likely to be heavy dispersers of MRSA include those with skin conditions or wounds heavily colonized by MRSA. These patients are often responsible for the spread of infection.^{5,7} All three of the study patients had MRSA-colonized skin conditions and two had been associated with cross-infection to other patients. In addition, one patient had a tracheostomy and MRSA in the sputum which, in the authors' experience, is a significant risk for cross-infection. The highest rate of environmental contamination occurred from the patient with Stevens-Johnson syndrome. It was educational for the infection control team and the healthcare workers on the busy intensive care unit to see the number of MRSA cfu on the settle plates (330 cfu on 20 settle plates equates to ~2750 cfu/m² for 7 h of exposure). Widespread contamination of the patients' rooms was demonstrated for all three patients. Many of the settle plates were positioned around the periphery of the rooms (e.g. window and other ledges, floor and sink), and the majority of these plates were positive, as were settle plates closer to the patient (e.g. under the bed and on the overbed table).

The rate of MRSA environmental contamination from each patient was significantly reduced by 75–93% using a portable HEPA-filtration unit. This reduction was directly related to the rate of air filtration. The IQAir unit can filter air at a maximum rate of 400 m³/h; however, at this fan speed, the unit is unacceptably noisy for both patients and staff. The IQAir unit was operated at 235 m³/h for two patients and at 140 m³/h for one patient. With the volume of the rooms, this equates to between 3.6 (Patient B) and 8.5 (Patient A) air changes/h. None of the rooms had ceiling-mounted supply or extract ventilation, or an en-suite facility with extract ventilation, but the single room in the intensive care unit (Patient C) had a wall-mounted extract system that was on continuously throughout the study period. The authors were unable to determine the rate of extraction through this extract system, and thus the additional number of air changes/h within the room. However, this extract system alone appeared to have little effect on preventing MRSA surface contamination rates. The mean number of MRSA cfu/10-h exposure/plate was 23.6 and 27.7 on the two days without IQAir filtration, and a highly significant effect was still demonstrable when the IQAir filtration was used in addition to

the extract system. There were no other patients on the intensive care unit shown to have MRSA during the study period for Patient C.

The windows (and doors whenever possible) were kept closed whilst the air-filtration unit was running. However, on a number of occasions on study days, the doors were observed to have been left open, mainly for patient safety reasons. This would have reduced the effectiveness of the IQAir units by reducing the number of air recirculations, and it is possible that even greater reductions in MRSA surface contamination rates would have been observed in a more tightly controlled clinical environment. No attempt was made to record the number of people entering the rooms, or all the other factors that may have affected either the ventilation or the degree of MRSA dispersal (e.g. bed making), and there is likely to have been some day-to-day variation in these. However, relatively long settle plate exposure times were used during the main working day in order to 'capture' most of these potential variables, and the efficacy of IQAir filtration was demonstrated consistently in different busy clinical environments.

The effectiveness of air filtration may be dependent on the positioning of the portable unit.^{8,9} However, the IQAir units were placed in relatively different positions for each patient (so as not to be in the way of clinical staff) (see Figure 1), and this did not appear to alter the overall efficiency of air filtration. Similarly, Rutala *et al.* found no difference in the clearance rate of airborne particles with portable units positioned in different locations within a room.¹⁰ Figure 1 clearly shows the effect of IQAir filtration on MRSA contamination rates throughout the rooms of Patients A and B. Figure 1(c) could be interpreted as showing a greater effect nearer the machine, but this is not apparent if the actual numbers of MRSA cfu/10-h exposure/plate (data not shown) are compared, and the reduction in the number of MRSA cfu was relatively evenly distributed across the room.

One possible confounding explanation for these results is that the patients shed less MRSA on days when air filtration was used. The rate of dispersal of MRSA may be related to factors such as patient movement, clothing, medical procedures (e.g. dressing changes, suctioning), bed making, and topical or systemic MRSA antiseptics or antibiotics.¹¹ Patient A was ambulatory, but his pattern of movement within the room was relatively consistent on each study day, and he wore similar clothes. His rate of MRSA shedding decreased over time, but this was controlled for by

alternating days with and without air filtration, and using adjusted rate ratios in the Poisson regression analysis. Both Patients B and C were confined to bed, and their clinical conditions remained largely unchanged throughout the study periods. Patient B required regular suctioning via a tracheostomy, and Patient C required wound dressing changes on alternate days which happened on both study days with air filtration on (see Table I). Whilst study days with and without air filtration for Patients B and C were not alternated, the rate of MRSA contamination from Patient B increased as the IQAir fan speed was decreased on consecutive days, indicating ongoing dispersal. Topical MRSA treatment was not used in any of the patients in the study period. Although Patient C was treated with intravenous vancomycin and gentamicin, his skin wounds remained MRSA positive. For these reasons, it is considered to be unlikely that these confounding factors account for the observed results.

Portable HEPA-filtration units have previously been shown to be efficient at removing airborne particles, and they are sometimes employed in high-risk units to reduce risks of invasive aspergillosis during nearby building demolition or construction.¹² Published evaluations have generally used artificially generated aerosols in a test setting to demonstrate that particles of the size of bacteria, droplet nuclei or fungal spores are removed efficiently and quickly.⁸⁻¹⁰ The present study has demonstrated that portable HEPA-filtration units can significantly reduce the amount of potential MRSA contamination of horizontal surfaces and equipment within the rooms of patients who are heavy MRSA dispersers.

Although there is no direct proof, there is increasing evidence that the environment can act as a reservoir for *S. aureus*, including MRSA, and that this can pose a risk of cross-infection to patients.^{2,3,7,13-16} A heavily contaminated environment poses a risk that healthcare workers may contaminate their hands, gloves and clothing. Boyce *et al.* found that 65% of nurses had contaminated their uniform or gowns with MRSA whilst looking after MRSA patients, and 42% of personnel who had no direct contact with these patients, but had touched contaminated surfaces within their rooms, had contaminated their gloves with MRSA.⁷ The present study has shown that the rate of environmental MRSA contamination can be reduced significantly by portable air filtration, and this should reduce these cross-infection risks. Studies have also shown that routine and terminal cleaning are not 100% effective in clearing MRSA from the environment,^{3,4} so a measure that

reduces MRSA environmental contamination in the first place will reduce the consequences of ineffective cleaning. It is envisaged that portable HEPA-filtration units may also be of value in a variety of different clinical settings (e.g. in dressing clinics, for respiratory function tests or on wards with MRSA patients who cannot be isolated), but further work is needed.

In conclusion, placing IQAir portable HEPA-filtration units within MRSA isolation rooms can significantly reduce the contamination of environmental surfaces with MRSA. Although this cannot replace standard infection control measures (e.g. isolation, hand hygiene, protective clothing and cleaning), it is likely to reduce cross-infection risks significantly and could provide a relatively cost-effective method for enhancing MRSA control. Further evaluation of these units is required within larger or more open-plan areas (e.g. intensive care units), and the relationship between reducing environmental contamination and MRSA colonization/infection rates needs to be established.

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