Journal of Hospital Infection 102 (2019) 45–53

Available online at www.sciencedirect.com

Journal of Hospital Infection

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

Acinetobacter – the trojan horse of infection control?

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ARTICLE INFO

Article history:
Received 22 November 2018
Accepted 19 December 2018
Available online 27 December 2018

Keywords:
Acinetobacter baumanii
Multi-resistant bacteria
International transfer
aromatherapy
Shower
Hosepipe
Burns
Misting
Fogging

SUMMARY

Background: Five cases of multi-resistant *Acinetobacter baumanii* (MRA) producing OXA-23 and OXA-51 occurred in a regional burn intensive care unit (BICU). Three were repatriated from other parts of the world (Dubai and Mumbai) and colonized on admission. Despite optimal precautions, two patients acquired MRA. Both had been nursed in the same room.

Methods: Multi-disciplinary outbreak investigation of MRA in a regional BICU.

Findings: The mechanism of transfer for the first case is thought to have been contaminated air from theatre activity releasing MRA bacteria into the communal corridor. No MRA patients went to theatre between the first and second acquired cases. The mechanism of transfer for the second case is thought to have been via a shower unit that was decontaminated inadequately between patients.

Conclusion: In an outbreak where contact precautions and environmental cleaning are optimal, it is important to give careful consideration to other mechanisms of spread. If there is a failure to do this, it is likely that the true causes of transmission will not be addressed and the problem will recur. It is recommended that burn theatres within burn facilities should be designed to operate at negative pressure; this is the opposite of normal operating theatre ventilation. Where showers are used, both the shower head and the hose should be changed after a patient with a resistant organism. The role of non-contact disinfection (e.g. hydrogen peroxide dispersal) should be reconsidered, and constant vigilance should be given to any 'trojan horse' item in the room.

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https://doi.org/10.1016/j.jhin.2018.12.013
0195-6701/

Key learning points

- Hand hygiene and adequate cleaning of the environment between patients are patient safety issues and fundamental standards of patient care. However, more is needed to prevent the spread of multi-resistant organisms.
- Burn theatres within a dedicated area should be under negative pressure.
- Identification of an isolation area for patients with multi-resistant bacteria is desirable.
- Anaesthetic room and recovery rooms should be under positive pressure to both the operating theatre and the corridor.
- Doors between the operating theatre, recovery room and preparation room should be closed at all times.
- There should be at least five air changes between patients undergoing surgery.
- Clutter should be minimized in the operating theatre, and attention should be given to bacteria which may settle on surfaces such as unopened packets of gloves and syringes.
- Shower trolleys drain into a receiving hopper that feeds into a drain via a waste trap.
- There should be no grid on the shower drain hopper because this will accumulate skin debris and is difficult to clean.
- The entire shower head and hose pipe should be changed after each patient with resistant organisms.
- Shower heads must be stored upright on a bespoke hook.
- Aromatherapy units should be for single patient use only.
- Proper decontamination must occur for anything going from one patient to another.
- False reliance should not be placed on the use of misting/fogging and/or ultraviolet light.
- Constant vigilance for 'trojan horse' items in the room.

Introduction

Burn wounds are highly vulnerable to long-term colonization by bacteria. Such colonization has the potential to result in invasive infection, an important cause of morbidity and mortality [1]. When international transfer is necessary to repatriate patients with burn injuries sustained overseas, the admission of those colonized and infected with multi-resistant organisms to burn intensive care units (BICUs) is an increasing challenge [2]. The issues involved include dealing with difficult-to-treat or pan-resistant micro-organisms and concern over transmission to other patients [3]. An additional concern is the possibility that multi-resistant organisms could become endemic in a burn facility and more widespread in the hospital [4,5].

Acinetobacter baumanii, with its propensity to survive and spread within a healthcare environment, represents one of the most serious challenges for the UK burn service, threatening to close units and reduce available beds [6,7].

This paper describes an outbreak involving four strains of multi-resistant *A. baumanii* (MRA) producing OXA-23 and OXA-51. Two strains were imported and two were acquired on the BICU.

Previous outbreak reports have concluded that the main route of transmission for *A. baumanii* is via hands and contaminated surfaces, and that the focus for infection prevention and control should be hand decontamination and appropriate environmental decontamination [7]. In the present outbreak, these were already thought to be optimal. Therefore, the authors sought to understand the more intricate mechanisms of transfer in both cases, and put systems in place to minimize the risk of recurrence.

Background/setting

The St Andrew's Burn Service in Chelmsford, UK is a regional burn centre that provides tertiary care within the London and South East Burn Network. It serves a population of approximately 10 million, treating approximately 1500 patients each year, with more than 700 patients requiring admission for definitive care. St Andrew's Burn Service is hosted within a large district general hospital, but is a self-contained department with its own infrastructure (Figure 1). The BICU has four Level 3 (ICU) beds in single rooms under negative pressure. Each room is accessed through an independent lobby area at neutral pressure. The burns high dependency unit (BHDU) has four Level 2 (HDU) beds in single rooms without specialist ventilation, accessed directly from the corridor. A dedicated operating theatre is located within the BICU/BHDU area and is used for all acute burn surgery in both adults and children. The BICU/BHDU and eight-bed adult burn ward have independent access and are separated from each other by closed double doors. The eight beds include one four-bedded bay and four single rooms. In addition, there is an eight-bed children's burn ward with outpatient area, and a dedicated adult burn outpatient and rehabilitation department.

Methods

Epidemiological investigation

Two UK nationals (Patients A and B) sustained significant burn injuries whilst in Dubai [mixed depth flame burns affecting 54% total body surface area (TBSA) and 44% TBSA, respectively]. They were admitted to a local hospital for emergency management and acute burn care. Once their clinical condition was stable, both were referred for repatriation to the St Andrew's Burn Service and arrived on Day 0 (see Figure 2).

Microbiological surveillance in Dubai before transfer had confirmed that Patient A was colonized with MRA that was sensitive to colistin alone. Patient B was assumed to have been exposed to MRA, and was therefore nursed with the same infection control procedures. Admission screening samples confirmed this. By the time of admission, Patient B had 36% TBSA residual burns as the superficial elements had healed successfully.

On admission, the patients were admitted to BICU Rooms 3 and 4. At the time of admission, there was only one other patient on the unit. Patient C had been admitted to BICU Room 2 42 days prior to the admission of Patients A and B. This patient had a large area of skin loss (25%) secondary to necrotizing fasciitis that had been skin grafted but still required additional reconstructive surgery.

The BICU remained open to admissions on the basis that Patients A and B were barrier nursed using the enhanced isolation procedures used for all patients with multi-drug-resistant organisms (see Appendix 1). These procedures necessitate the wearing of personal protective equipment for all personnel entering the rooms, including surgical hats and

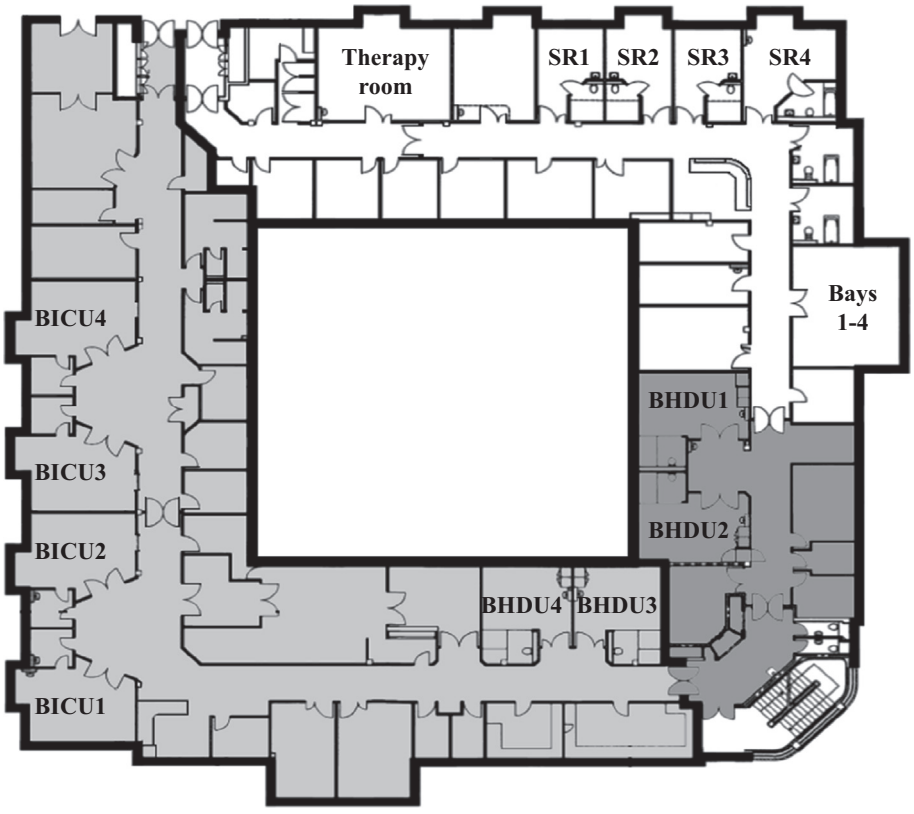

Figure 1. Burn intensive care unit/high dependency unit (BICU/BHDU) with isolation area. The BICU/BHDU (light grey zone) forms one-half of a quadrangle with the adult burn ward (white zone). BHDU Rooms 1 and 2 can be used for both BICU/BHDU and adult ward patients as needed, and form part of the resilience of the burn service in the event of a burn mass casualty event or surge within one of the national burn networks.

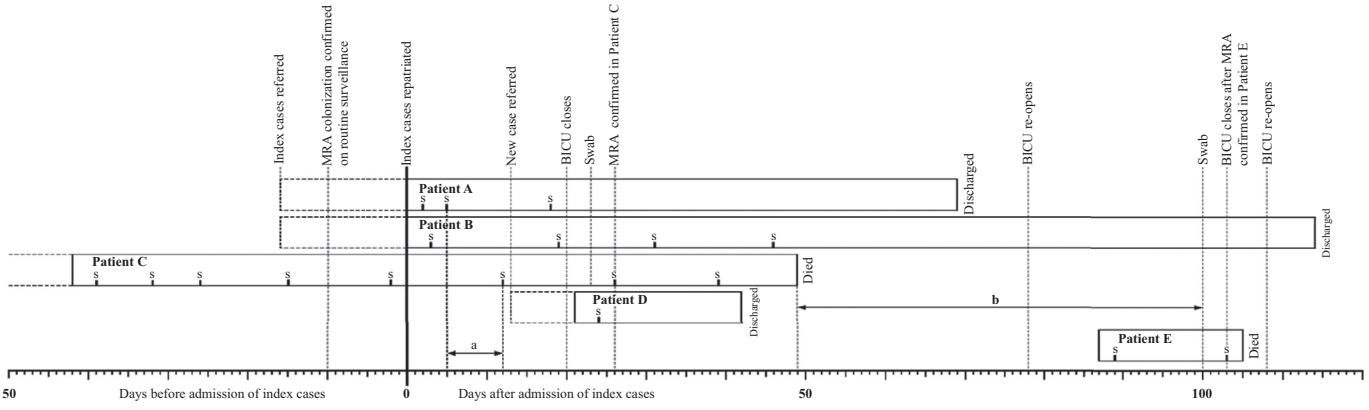

Figure 2. Annotated timeline. Patient C had been admitted to the burn intensive care unit (BICU) for more than 40 days before the arrival of the index cases, Patients A and B, one of whom had been confirmed to have multi-resistant *Acinetobacter baumanii* (MRA) on routine microbiological surveillance at the referring hospital. All three patients were taken to the burn operating theatre over the next three weeks (as indicated by 'S' annotations in each timeline). Patient C had one operation before MRA colonization was identified in the wounds. However, although all three patients used the operating theatre, Patient C was spatially separated by seven days (Interval a) from Patients A and B, during which time the infrastructure had been decontaminated after each patient as described in the main text. Patients A and B returned to the operating theatre six and seven days after Patient C, respectively. The BICU was closed in anticipation of the repatriation of Patient D. Routine swabs taken from Patient C shortly after the arrival of Patient D were reported three days later, and confirmed MRA colonization of the wounds as Patient C returned to the operating theatre. Patient C died 49 days after the repatriation of Patients A and B. The same MRA was identified in Patient E 51 days later (Interval b) despite extensive deep cleaning and decontamination of the BICU/burn high dependency unit (BHDU) complex. Patient B remained in the modified BHDU area during this time, but was isolated from the rest of the BICU/BHDU complex by strict infection control measures as described in the main text. This made it extremely unlikely that Patient E had acquired the wounds from staff contact, and suggested an unrecognized environmental source.

scrubs that are changed whenever leaving the room, plus mandatory showering and hair washing for all staff having direct patient contact (Appendix 1). Meticulous cleaning of the burn centre is performed to a high standard in line with previously published evidence [8].

Three weeks later (Day +21), Patient D was repatriated from Mumbai having sustained a 9% TBSA flame burn. The patient had been admitted to a local hospital for five days, and routine microbiological surveillance had confirmed MRA on Day 2. On arrival, Patient D was admitted to BICU Room 1, and received the same standard of isolation nursing as Patients A and B. Typing confirmed that the two strains originating from Dubai were identical, but distinct from that originating from Mumbai (Table I). Two days after the arrival of Patient D, Patient C was confirmed to have widespread MRA colonization of her wounds. This was subsequently typed as indistinguishable from the Dubai strain. Patient C had only been nursed in BICU Room 2 and had never had any direct contact with Patients A or B.

Patients B and D were successfully discharged 69 and 18 days after admission, respectively, with ongoing outreach wound care and rehabilitation support. Soon after, Patient A no longer required Level 3 (intensive care) support, but could not be moved to the adult burn ward due to the risk of cross-infection to other susceptible patients, as well as the potentially disastrous widespread contamination of a regional burn centre and wider hospital environment. It was decided to move Patient A to BHDU Room 2 by establishing a 'microbiological barrier' in order to facilitate ongoing wound care and rehabilitation in a self-contained clinical zone.

BHDU Rooms 1 and 2 are separated from the BICU/BHDU corridor by two sets of double doors. These were used to create a lobby area for the corridor outside BHDU Rooms 1 and 2. At the time, the BHDU rooms were unoccupied and, with minor adjustments to the ventilation system, could deliver negative pressure to all rooms with respect to the corridor. BHDU Room 1 was established as a nursing area, while BHDU Room 2 became a self-contained rehabilitation area. No patients were put in BHDU Rooms 3 or 4. Nursing staff provided care for the duration of their shift, with enhanced isolation and cleaning procedures in place at all times.

Patient C succumbed to progressive wound failure and died 91 days after admission, and 49 days after the arrival of Patients A and B. Although MRA was confirmed in her wounds at the time of her death, there had been a progressive decline and deteriorating physiological reserve for several weeks before the organism was identified. The consensus opinion was that the MRA was a colonizing organism rather than one that contributed directly to the patient's death.

Table I
Typing results from Patients A, B, C and E and all environmental samples

Acinetobacter baumannii
Resistance mechanism/type
bla(OXA-58-like): negative
bla(OXA-23-like): positive
bla(OXA-51-like): positive
bla(OXA-40-like): negative
Class 1 integrase gene: negative
PFGE result CHELPAC-6
VNTR profile: 7,9,12,7

PFGE, pulsed-field gel electrophoresis; VNTR, variable number tandem repeat.

The BICU/BHDU complex was deep cleaned using liquid chlorine dioxide at 250 ppm (Tristel Solutions Ltd, Newmarket, UK) and non-contact surface disinfection using diffusion of 12% hydrogen peroxide (Nocolyse One Shot, Oxy Pharm, Champigny sur Marne, France). An external contractor cleaned every part of the ventilation systems of BICU Rooms 1–4 and the operating theatre. BHDU Rooms 3 and 4, which share a common ventilation system with BHDU Rooms 1 and 2, were sealed and decommissioned to prevent inadvertent contamination from Patient A's isolation area. A further deep clean of all accessible parts of the BICU, including all store rooms and changing rooms, was performed before the BICU was re-opened. In total, the BICU was closed to admissions for 58 days.

The Dubai strain re-emerged three weeks later. Patient E had been admitted to BICU Room 2 with a life-changing 33% TBSA flame burn nine days after the BICU re-opened to admissions. At this time, wound swabs had been taken as part of routine sampling for progressive wound deterioration and systemic sepsis. Patient E's wounds consistently demonstrated heavy growth of coagulase-negative staphylococcus and *Candida albicans*, but with *Enterobacter cloacae*, *Escherichia coli* and *Klebsiella* spp. emerging to cause wound infection and graft failure. Patient E received appropriate antibiotics, and on Day 98 commenced daily showers under sedation in an effort to halt the deterioration of her wounds. Two days later, MRA was isolated from a single sample, reported formally three days afterwards. This was later confirmed as identical to the outbreak strain.

At this time, it was decided to take the patient to the operating theatre to determine whether further burn care was futile, based on the severity of the original injuries. There was a unanimous decision that Patient E had sustained non-salvageable burn injuries and a recognized end-of-life care pathway was commenced. The detection of MRA did not influence this multi-professional opinion. Patient E died two days later, 17 days after admission. Wound swabs taken in the operating theatre, and subsequently reported after the patient's death, confirmed the same microbial picture as before, but with MRA now present as a heavy growth in all wounds.

Microbiology and environmental investigation

The sampling methods used during the outbreak investigation included settle plates, environmental swabbing, and large item culture using enrichment broth.

On Day 31, 23 sites across the BICU were sampled using settle plates. Sets of settle plates were made up of blood agar (BA) and primary UTI chromogenic agar (UTI) (E&O Laboratories, Bonnybridge, UK). Pairs of plates were placed on flat surfaces around the unit with the lids removed and left for 4 h, after which time they were promptly transported to the laboratory and incubated at 36°C in CO_2 and air, respectively.

On Day 34, environmental sampling was performed by swabbing sites across the BICU using Aimes Transwabs (Remel, Thermo Fisher Scientific, Waltham, MA, USA). Sixty-three swabs were taken from communal areas and 17 were taken from the operating theatre. Both macroscopically clean and dirty sites were sampled. Swabs were lightly moistened before use, and surfaces were swabbed by rotation across a 2-inch minimum area, moving the swab horizontally, vertically and diagonally. Swabs were transported to the laboratory,

inoculated on to BA and UTI agar, and incubated at 36°C in CO_2 and air, respectively.

On Day 108, 14 swabs were collected from BICU Room 2. Five larger items were removed, including a radio, a computer keyboard, an aromatherapy unit, the shower head and the shower hose. These items were transported to the laboratory in plastic clinical waste bags. They were placed in individual large wide-mouth sterile containers, covered with brain heart infusion (BHI) broth (E&O Laboratories) and incubated for 48 h at 36°C. Containers were agitated regularly. At 24 and 48 h, 15 mL of BHI broth was removed and centrifuged at 1200 *g* for 5 min. The deposit was then subcultured on to BA and UTI.

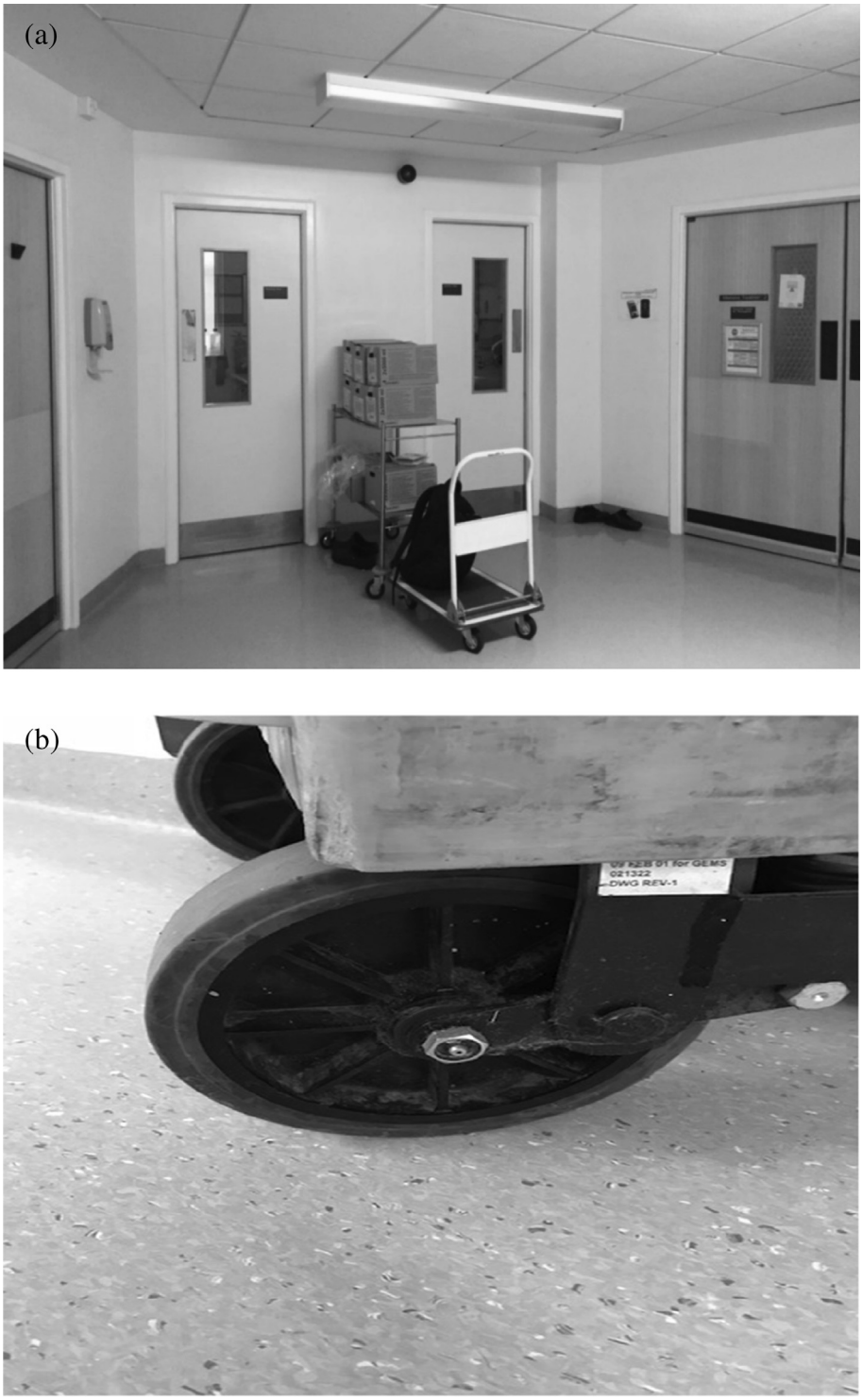

Figure 3. Positive environmental samples Round 1. (a) A settle plate placed on a trolley between Burn Intensive Care Unit Rooms 1 and 2. (b) A swab from the right rear wheel of a trolley housing the portable x-ray machine which was stored in the communal corridor outside the operating theatre.

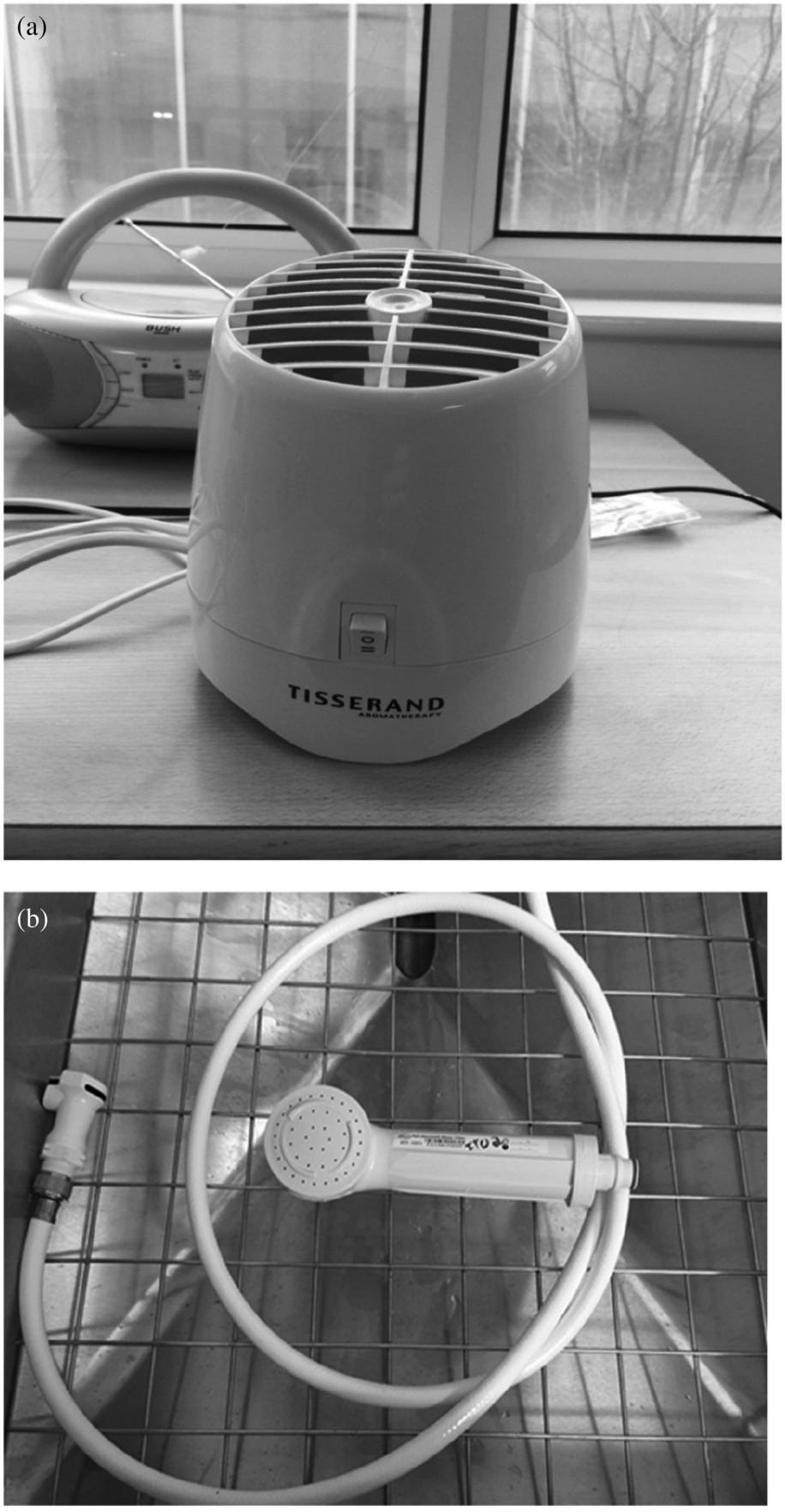

Figure 4. Positive environmental samples Round 2. (a) An aromatherapy unit in Burn Intensive Care Unit (BICU) Room 2. (b) The shower head and hosing from BICU Room 2.

Results

In the first round of environmental sampling (Days 31 and 34), there were two isolates of the outbreak strain (Figure 3): a settle plate placed on a trolley between BITU Rooms 1 and 2 (and opposite the operating theatre); and a swab from the right rear wheel of a trolley housing the portable x-ray machine which was stored in the communal corridor outside the operating theatre.

In the second round of environmental sampling (Day 108), there were three isolates of the outbreak strain, all via enrichment culture (Figure 4): an aromatherapy unit housed in BITU Room 2 since Patient C's admission; the shower head from BICU Room 2 which had been changed since Patient C's admission; and the shower hosing from BICU Room 2 which had not been changed since Patient C's admission.

Typing results of MRA strains isolated are summarized in Tables I and II.

Discussion

A systematic review [7] on outbreaks of *Acinetobacter* spp. concluded that 'with respect to the main route of transmission, which was via hands and contaminated surfaces, particular emphasis should be placed on the use of alcohol-based disinfection and appropriate environmental cleaning'.

Aware of this recommendation, we had ensured that all infection prevention measures were managed and observed in detail throughout admission of repatriated patients. Details of the contact procedures used are shown in Appendix 1. A requirement was set that any member of staff who had contact with an MRA patient or the patient's environment would shower, including hair washing, and change their scrubs before returning to the BICU/BHDU corridor. Footwear was removed in the BICU lobby room and cleaned with chlorine dioxide. Sufficient footwear was purchased for each room to allow up to six members of staff access during resource intensive interventions, such as dressing changes and rehabilitation sessions. Footwear was not transferred between rooms and was destroyed when the patient left the room. Staff were instructed on the required hygienic precautions in very specific detail, and supervision of practice was intensive. As this was multifaceted, meaningful audit was not possible. The requirement to change, shower and hair wash provided clarity that, once undertaken, staff were 'safe' to work elsewhere in the hospital. In discussions with staff, this also provided confidence that they would not contaminate their home environment. One member of staff said that 'the requirement to shower, hair wash and change scrubs was a red line for me — I realized I had to take this seriously'.

Whilst the practicalities of such a requirement were difficult, they were not impossible. In such a serious situation, it was evident that 'human factors' were largely eliminated because the process was strictly monitored and adhered to.

Similarly, cleaning was carried out to a high standard throughout the BICU/BHDU complex. External contractors were brought in for wall washing and terminal cleaning prior to re-opening the BICU. The cleaners also complied with infection control requirements. The BICU has its own domestic team and team leader, and senior members of the Hotel Services Department attended outbreak meetings to ensure that requirements were being met.

In view of optimal contact precautions and cleaning, it was considered illogical to attribute acquisition of MRA to either of these factors, so there was a need to identify other possible explanations for the spread of MRA.

In relation to the first MRA acquisition, there were two positive environmental results, both from items stored in the corridor opposite the operating theatre. The anaesthetic room leading to the operating theatre opens into this corridor opposite BICU Rooms 1 and 2.

Patient C had been to the operating theatre five times before the repatriation of Patients A and B. Patients A and B had a total of three operations before Patient C returned to the operating theatre. This was seven days after the last MRA patient had been operated on, and the entire operating theatre was fully cleaned and decontaminated after each procedure. Patients A and B returned to the operating theatre six and seven days later. Wound swabs taken from Patient C four days later isolated the Dubai strain of MRA. Patient D had been admitted two days beforehand, and when the swab results were reported, it was widely assumed that this was the most likely source given the shared corridor environment between BICU Rooms 1 and 2.

BICU rooms are under negative pressure and are separated from the corridor by a lobby, such that airborne contamination cannot flow from the rooms into the corridor. Therefore, in order to explain the positive result found on the settle plate in the ICU corridor, an alternative source of airborne contamination must have been in effect.

The operating theatre is ventilated under positive pressure as this is the standard for UK operating theatres [9]. High volumes of filtered air are supplied to both the operating theatre and the preparation room where instruments are stored and prepared for use. Smoke testing confirmed that air flowed either directly from the operating theatre into the corridor, or into the anaesthetic room and then into the corridor. The outbreak team concluded that the most likely source of contamination was air flowing out of the positive pressure operating theatre via the anaesthetic room. The two positive environmental sample results probably illustrate an important general route of contamination, namely the transfer of airborne pathogens from a patient in the operating theatre contaminating communal areas of the BICU/BHDU corridor. The

Table II
Typing results from Patient D

Acinetobacter baumannii
bla(OXA-58-like): negative
bla(OXA-23-like): positive
bla (OXA-51-like): positive
bla (OXA-40-like): negative
Class 1 integrase gene: positive
PGFE result: unique

PFGE, pulsed-field gel electrophoresis.
Identification was by detection of the bla (OXA-51-like) carbapenemese gene intrinsic in *A. baumannii*, expression of which is dependent on provision of a promoter by an insertion sequence element. Isolates were also polymerase chain reaction positive for bla (OXA-23-like)-acquired carbapenemese gene, consistently associated with resistance.
Comparison by PFGE showed that the isolate from Patient D was unique.

contaminated equipment is then moved into the BICU rooms as part of routine clinical care, and cross-contamination of the patient occurs directly or indirectly as a result. All portable equipment is thoroughly cleaned and disinfected before it leaves the BICU rooms but, until now, was not routinely cleaned before entering the room via the lobby areas. Both Patients C and D were in negative pressure rooms off the same section of corridor. Patient D was theoretically exposed to the same corridor air as Patient C, but did not become secondarily contaminated with the Dubai strain of MRA whilst admitted. Staff and equipment still moved from the corridor into the BICU room via the lobby but, in general, Patient D required far less support than Patient C because complete wound cover was achieved quickly with a single operation to excise and resurface the burns with skin grafts. Patient D did not have open wounds for prolonged periods and, once healed, required minimal nursing and rehabilitation support bringing staff and equipment into the room. Therefore, although Patient D was nursed in a room that shared the same corridor space, their more robust clinical condition and significantly less footfall into the room is likely to have markedly reduced the exposure risk.

Patient C died 29 days after closure of the BICU. The room remained unoccupied for more than one month, during which time it was deep cleaned twice before the BICU was re-opened and Patient E was admitted. Indeed, within the BICU/BHDU complex, all disposable items were discarded, and all equipment and soft furnishings were risk assessed as to whether they could be cleaned to a sufficiently high standard to be left in place. If any doubt remained, the item was discarded. The whole BICU/BHDU complex was deep cleaned room by room using liquid chlorine dioxide and a non-contact surface disinfection hydrogen peroxide dispersal system. In addition, by the time Patient E was admitted, Patients A and D had been discharged, and Patient B was being nursed in the modified isolation area, further reducing the sources of possible exposure. No MRA-colonized patients had any procedure in the operating theatre during Patient E's admission. Contamination from the operating theatre could not explain MRA acquisition of the second case.

Therefore, attention was focused on BICU Room 2, and the authors spent some time examining this area in order to collect targeted samples. The most likely source was now considered to be a failure in adequately decontaminating this room after Patient C had died, despite using apparently optimal terminal decontamination on two separate occasions.

The terminal cleaning strategy on discharge of an MRA patient is summarized in Appendix 2. This had taken place and, in addition, the ventilation ductwork had been cleaned by an external contractor. An additional terminal clean had also taken place. It became clear that this was insufficient. Environmental decontamination in respect of *Acinetobacter* spp. is particularly difficult due to their prolonged survival ability [10]. Burn units are particularly vulnerable due to bacteria being able to survive in dried organic matter such as burn exudate, thought to buffer microbes against the effects of dehydration and enhance whatever innate survival a strain may have [11].

During this period, BICU Room 2 was revisited and three sites amongst numerous environmental samples were positive. Room 2 contained a small aromatherapy unit (Figure 4). This is a fan-driven device with air entering via a coarse mesh filter in the base. This unit had been in BICU Room 2 at the time Patient C had been admitted. Its external surface had been cleaned with chlorine dioxide and it had remained in the room during non-contact disinfection (hydrogen peroxide dispersal). This was almost certainly the 'trojan horse'. Also in the room was a shower head and hose (Figure 4). Both grew the outbreak strain of MRA. Three days prior to Patient E's acquisition of MRA, she had been showered. Whilst the shower head is changed between patients, this connects to a hose via a metal connector. The hose and connector were not changed between patients.

Following this outbreak, the authors are investigating the feasibility of changing the ventilation strategy for the operating theatre to negative pressure. At present, the operating theatre functions at positive pressure with respect to the exterior corridor, so that external contamination is not drawn into the surgical field while extensive burn wounds are uncovered. However, when the surgical patient is colonized or infected with multi-drug-resistant organisms, this presents a risk to the rest of the BICU/BHDU complex. Changing to a negative pressure strategy would ensure that air flows in from the external corridors, and thus contains dispersed microbes within the operating theatre. Another important consideration, especially on commissioning a burn unit, is to identify an isolation area for patients with multi-resistant bacteria. The increasing problem of antibiotic resistance requires infection prevention and control to be designed into high-risk patient management from before admission. This is necessary to avoid such resistance becoming endemic in UK burn facilities and beyond.

In addition, any preparation room used for instrument layup or sterile pack storage should be under positive pressure to ensure that airborne contamination released from patients in the operating theatre does not settle on to exposed instruments or packs to be used on other patients. This requires that the door between the operating theatre and the preparation room remain closed at all times, except when instruments are actually being brought into the operating theatre. The anaesthetic room and recovery rooms can be at negative pressure to the burn unit but at positive pressure to the operating theatre (i.e. air flows from the burn unit through these rooms into the operating theatre). The dirty utility (disposal room or 'sluice') should be at negative pressure to all surrounding areas.

In a conventional theatre, air change rates (rate of ventilation expressed in terms of room volume) are targeted at reducing contamination generated contained on skin scales shed from the surgical team. In a burn theatre, however, the main aim of ventilation is to protect one patient from contamination shed by another. The air change rate (defined as the volume of air supplied to or extracted from a room, whichever is the greater, expressed in terms of the volume of that room) will determine the rate of dilution of airborne contamination. One air change will remove 63% of airborne contamination [i.e. one air change will leave 37% of the original contamination, the next air change will leave 37% of that (13.5%) and so on]. Thus, when an end to dispersion can be defined (by a patient leaving the theatre), five air changes will result in less than 1% of the original contamination remaining; this is in addition to those lost by settling out on to surfaces. Following this outbreak, it is now recommended that at least five air changes should occur after one patient leaves the operating theatre before setting up for the next patient; for a theatre with 20 air changes per hour, this equates to approximately 15 min.

At the study hospital, the shower trolleys drain into a receiving hopper that feeds into a drain via a waste trap. The

grids on the hopper have been removed. This has been subject to accumulation of skin debris on the grid which is difficult to clean. It is now recommended that the entire shower head and hose pipe should be changed after each patient with resistant organisms. Shower heads are now stored upright on a bespoke hook. Aromatherapy units are for single patient use only.

In conclusion, in an outbreak where contact precautions and environmental cleaning appear to be optimal, it is important to give careful consideration to other mechanisms of spread. If there is a failure to do this, it is likely that the true causes of transmission will not be addressed and the problem will recur. It is recommended that burn theatres within burn facilities should be designed to operate at negative pressure; this is the opposite of normal operating theatre ventilation. Where showers are used, both the shower head and the hose should be changed after a patient with a resistant organism. The role of non-contact disinfection (e.g. hydrogen peroxide dispersal) should be reconsidered, and constant vigilance should be given to any 'trojan horse' item in the room.

Acknowledgements

The authors would like to thank the staff in the Antimicrobial Resistance and Healthcare Associated Infection Reference Unit, National Infection Service, Public Health England, London for typing and antimicrobial susceptibility investigations. The authors are also grateful to the staff of St Andrew's Burn Service for their commitment to the highest standards of patient care during this outbreak episode.

Conflict of interest statement
None declared.

Funding sources
None.

Appendix 1. Staff process for the care of patients with confirmed multi-drug-resistant organisms in the burn intensive care unit (BICU).

- All staff wear scrubs in the unit.
- All staff wear long-sleeved fluid-repellent gowns and gloves for patient contact.
- Staff are cohorted to nurse patients where practicable.
- The gowning area has deliniated clean and dirty zones.
- All staff wear isolation clogs (for disposal at the end of care) whilst in the patient's room.
- When a care delivery episode is complete, the exiting nurse will doff personal protective equipment (PPE) in the patient's room, and dispose of PPE as clinical waste, and wash hands.
- The staff member will enter the gowning area and doff the 'dirty' clogs in the 'dirty zone', leave the gowning area and don their usual clogs.
- The staff member then enters the shower facility within the BICU, showers (including hair wash) and changes into new scrubs, and continues working on the BICU.
- The process above is also adopted for the burn operating theatre, which is contained within the unit. Surgical teams will remain in the operating theatre until a shower becomes available.

Appendix 2. Terminal cleaning strategy on discharge of a patient colonized/infected with multi-resistant *Acinetobacter baumanii*.

- Disposal of all consumables exposed to air that cannot be decontaminated adequately.
- Normal room and ward clean using chlorine dioxide.
- Nursing staff.
- Domestic staff.
- Normal hydrogen peroxide vapour fogging with cupboard doors open.
- Repair and refurbishment of ward.
- Repeat ward clean by nurses and domestic staff as appropriate.
- Repeat ward hydrogen peroxide vapour fogging.
- Pillows and mattresses used by patients, and the mattress on the shower trolley were destroyed.

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