Outbreak of carbapenem-resistant *Acinetobacter baumannii* carrying the carbapenemase OXA-23 in a German university medical centre

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A prolonged outbreak of carbapenem-resistant *Acinetobacter baumannii* in a German university medical centre in 2006 was investigated; the investigation included a descriptive epidemiological analysis, a case–control study, environmental sampling, molecular typing of *A. baumannii* isolates using PFGE and repetitive-sequence-based PCR (rep-PCR) typing, and detection of OXA-type carbapenemases by multiplex PCR. Thirty-two patients acquired the outbreak strain in five intensive care units (ICUs) and two regular wards at a tertiary care hospital within 10 months. The outbreak strain was resistant to penicillins, cephalosporins, ciprofloxacin, gentamicin, tobramycin, imipenem and meropenem, and carried the *bla*_{OXA-23}-like gene. Based on PFGE and rep-PCR typing, it was shown to be related to the pan-European *A. baumannii* clone II. The most likely mode of transmission was cross-transmission from colonized or infected patients via the hands of health-care workers, with the severity of disease and intensity of care (therapeutic intervention scoring system 28 score >median) being independently associated with acquisition of the outbreak strain (odds ratio 6.67, 95 % confidence interval 1.55–36.56). Control of the outbreak was achieved by enforcement of standard precautions, education of personnel, screening of ICU patients for carbapenem-resistant *A. baumannii* and cohorting of patients. This is believed to be the first report of an outbreak of *A. baumannii* carrying the carbapenemase OXA-23 in Germany.

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INTRODUCTION

Acinetobacter baumannii is an important nosocomial pathogen associated with a wide range of infections including nosocomial pneumonia and other respiratory tract infections, bloodstream infections, urinary tract infections and surgical site infections (Bergogne-Bérézin & Towner, 1996; Dijkshoorn *et al.*, 2007; Gaynes *et al.*, 2005). Multidrug-resistant *A. baumannii* has been recognized as an increasing threat in hospitals and as a global

challenge (Dijkshoorn *et al.*, 2007; Peleg *et al.*, 2008). In particular, carbapenem resistance is regarded as a sentinel event for the emergence of antimicrobial resistance in *A. baumannii* (Richet *et al.*, 2001). Because of the large variety of potential sources, its ability to rapidly acquire antimicrobial resistance and its propensity to persist in the environment, *A. baumannii* is difficult to control in the hospital setting. Numerous nosocomial outbreaks of *A. baumannii*, especially in intensive care units (ICUs), have been reported (Fournier & Richet, 2006; Villegas & Hartstein, 2003). Many of the outbreak strains have been found to belong to pan-European clones (lineages) I, II or III, as defined by amplified fragment-length polymorphism analysis (Dijkshoorn *et al.*, 2007).

Here, we have described the investigation and control of an outbreak of carbapenem-resistant *A. baumannii* affecting

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Abbreviations: CI, confidence interval; CLSI, Clinical and Laboratory Standards Institute; ICU, intensive care unit; MSICU, medical–surgical intensive care unit; OR, odds ratio; rep-PCR, repetitive-sequence-based PCR; SAPS, simplified acute physiology score; TISS, therapeutic intervention scoring system.

32 patients at a university medical centre in Germany within a time period of 10 months in 2006. The initial investigation of the outbreak, which included a review of cases, observation of procedures and patient care, and environmental sampling in affected wards, was followed by molecular characterization of *A. baumannii* isolates and a case-control study to identify risk factors for acquisition of the outbreak strain.

METHODS

Microbiology. Microbial species identification was performed by an automated identification system (Vitek 2 with GN identification cards; bioMérieux). The identification of *Acinetobacter* spp. to genomic species level was confirmed by *gyrB* multiplex PCR (Higgins *et al.*, 2007) and amplified rRNA gene restriction analysis (Vanechoutte *et al.*, 1995).

Antimicrobial susceptibility testing was initially performed using Vitek 2 AST-N061 cards (bioMérieux) following the manufacturer's instructions. Imipenem MICs were confirmed by agar dilution according to Clinical and Laboratory Standards Institute (CLSI) guidelines (CLSI, 2007). The results were interpreted according to the current CLSI guidelines; for tigecycline, the European Committee on Antimicrobial Susceptibility Testing clinical MIC breakpoints for *Enterobacteriaceae* were used. The presence of OXA-type carbapenemases and the metallo-carbapenemases VIM and IMP were investigated by PCR as described by Hujer *et al.* (2006) and Woodford *et al.* (2006).

Initially, 39 *A. baumannii* isolates from 39 different patients were typed by PFGE using the restriction enzyme *Apal* (Seifert *et al.*, 2005). Analysis of PFGE patterns was performed visually and band patterns were interpreted according to the criteria suggested by Tenover *et al.* (1995) with a difference of six or fewer bands defining epidemiological relatedness. A subset of isolates with representatives of each PFGE type were analysed further by the repetitive-sequence-based PCR (rep-PCR) DiversiLab microbial typing system (bioMérieux), a semi-automated PCR technique that amplifies the regions between the non-coding repetitive sequences in bacterial genomes (Healy *et al.*, 2005). Two control strains representing European *A. baumannii* clones I and II were included (RUH 2036 and RUH 3372, respectively).

Epidemiological investigation. A descriptive analysis including a review of electronic and paper medical records was conducted to determine basic demographic data, location, and duration of stay, primary diagnosis and hospital outcome of all patients infected or colonized with the *A. baumannii* outbreak strain. For the case-control study, cases were defined as patients hospitalized in the medical-surgical ICU (MSICU) during the time period from 18 June 2006 (admission of the index patient of the second phase of the outbreak to the MSICU) to 31 August 2006 who were colonized or infected with the *A. baumannii* outbreak strain, and controls as patients who stayed at least 5 days in the MSICU during the same time period and were found not to be colonized with *A. baumannii*. Patients who were under isolation precautions due to the presence of other multidrug-resistant bacteria were not included in the control group.

Data were collected from each patient on demographic characteristics, underlying diseases, presence of devices, invasive procedures, antibiotic therapy, duration of ICU and hospital stay prior to acquisition of *A. baumannii*, duration of exposure to the outbreak strain, presence of a patient with the outbreak strain in the same or an adjacent hospital room during overlapping time periods and prior presence of an occupant with the outbreak strain in the same hospital

room. The duration of exposure was defined as the duration of MSICU stay in the presence of an *A. baumannii* carrier. Data on all risk factors were collected prior to the first isolation of *A. baumannii*. The simplified acute physiology score (SAPS II), the sequential organ failure assessment (SOFA) score and the therapeutic intervention scoring system (TISS-28) score were documented daily for cases and controls, and the mean daily score for each patient was calculated.

Continuous variables were transformed into binary variables by using the median as a cut-off value. Odds ratios (ORs) and 95% confidence intervals (CIs) were calculated, and Fisher's exact test with a significance level of 0.05 was used for all risk factors. A multiple logistic regression analysis with stepwise variable selection was performed with acquisition of the outbreak strain as the outcome. The significance level for entering a variable into the model and for removing a variable was $P=0.05$. All analyses were performed using SAS statistical software (version 9.1; SAS Institute).

Environmental and personnel screening. Surfaces in patient rooms and common ward areas frequently touched by patients and personnel, and equipment and material in the wards affected by the outbreak, were sampled on six occasions when patients carrying *A. baumannii* were present on the ward, and immediately after discharge and surface decontamination. Samples were obtained from infusion pumps, monitors, oxygen masks, oxygen supply tubes, tubes and equipment of different ventilators, suctioning equipment, dressing carts and materials on these carts, the bronchoscopy cart and the bronchoscope of the MSICU, the ultrasound machine of the MSICU, a dialysis machine, stethoscopes, soaps, disinfectant dispensers and computer keyboards using moistened sterile cotton swabs. Sampling with Rodac plates was also performed on two occasions. One hundred and three environmental samples were taken in total throughout the outbreak period. In addition, the hands of 30 health-care workers from the MSICU were cultured on one occasion.

Infection control measures. Contact precautions including isolation in single rooms, wearing gloves and gowns, and hand disinfection before and after patient care were routinely implemented for all patients with multidrug-resistant *A. baumannii*. Surfaces in the rooms of these patients were disinfected daily with an aldehyde-containing disinfectant. In addition, education with special emphasis on hand disinfection was provided repeatedly by infection control personnel.

After failure of these measures to prevent further spread of *A. baumannii* in the MSICU, patients harbouring the outbreak strain were cohorted in one part of the unit with a separate entrance, and separate teams of personnel were assigned to care for patients who were positive or negative for *A. baumannii*. In addition, active surveillance was performed by screening every patient in the MSICU for carbapenem-resistant *A. baumannii* on admission, once weekly thereafter and on discharge. The screening protocol included nasal/pharyngeal swabs, rectal swabs, urine, endotracheal aspirate in ventilated patients and wound swabs in surgical patients.

RESULTS AND DISCUSSION

Microbiology

A total of 39 *Acinetobacter* isolates from 39 patients was collected during the outbreak and the isolates were confirmed as *A. baumannii*. Using PFGE, 32 isolates were found to have an identical PFGE pattern denoted pattern A. Two isolates had PFGE patterns related to pattern A, denoted A1 and A2 (six band differences compared with

pattern A). One isolate had a distantly related pattern, denoted A3 (seven band differences) (Table 1; Fig. 1). All type A isolates were resistant to penicillins, cephalosporins, ciprofloxacin, gentamicin, tobramycin, tigecycline (4 mg l^{-1}), meropenem and imipenem ($\text{MIC} \geq 32 \text{ mg l}^{-1}$), and were susceptible to colistin ($\leq 0.5 \text{ mg l}^{-1}$) and amikacin ($4\text{--}8 \text{ mg l}^{-1}$). All of these isolates possessed, in addition to the intrinsic OXA-51 enzyme, an OXA-23-like enzyme. The two isolates with patterns A1 and A2 were susceptible to imipenem and possessed only the intrinsic OXA-51 enzyme. The isolate showing pattern A3 was resistant to imipenem and harboured, in addition to OXA-51, an OXA-58-like enzyme. Rep-PCR analysis clustered all isolates with $>95\%$ similarity to the European clone II strain RUH 3372 (Fig. 2). The remaining four isolates had aberrant PFGE typing results (Figs 1 and 2), as well as aberrant OXA-type carbapenemases (OXA-51 and OXA-58-like), indicating that they were not part of the outbreak.

Epidemiological investigation

Based on molecular typing results, a total of 32 patients acquired the *A. baumannii* outbreak strain. Patients 2 and 8 had isolates that were considered related to the outbreak strain based on PFGE (PFGE types A1 and A2); however, they were susceptible to imipenem and did not possess an OXA-23-like enzyme. The isolate from patient 30 was also resistant to imipenem and was considered to be distantly related to the outbreak strain (PFGE type A3); however, it had an OXA-58-like enzyme instead of the OXA-23-like enzyme. Patients 2, 8 and 30 had stayed in other countries (Greece and Senegal) immediately prior to admission, and had cultures positive for *A. baumannii* on the day of admission (patients 2 and 8) or within 4 days of admission (patient 30). All three patients had no epidemiological link to other patients colonized with the outbreak strain and were therefore considered not to be part of the outbreak. The demographic and clinical characteristics of the 32 patients with the outbreak strain and the 3 patients with related isolates, together with date of primary isolation and culture sites of *A. baumannii* and microbiological results are depicted in Table 1.

The index patient was admitted on 21 December 2005. He had been transferred by ambulance flight from Thailand where he had received hospital treatment after a motor vehicle accident in November 2005. From an intraoperative wound swab of this patient taken on 27 February 2006, a carbapenem-resistant *A. baumannii* was isolated for the first time. Nine additional patients acquired this outbreak strain in this first phase of the outbreak until control was achieved by enforcement of infection control measures by the end of April, and no further cases occurred for a period of 7 weeks (Fig. 3).

The second phase of the outbreak started in mid-June, when the outbreak strain was introduced into the MSICU by transmission from a long-term carrier. Three weeks after his admission, severe water damage occurred following

heavy rains, requiring immediate transfer of all patients residing in the MSICU to other ICUs. Two days later, after reopening of the unit and readmission of patients, five patients, who had all been staying in the MSICU at the time of the water damage, had cultures positive for the outbreak strain. Despite enhanced infection control measures, including closing off part of the unit for cohorting of patients with *A. baumannii*, ten additional patients in the MSICU acquired the outbreak strain during the following weeks. The outbreak strain was also transmitted via patient transfer from the MSICU to another six patients residing in different units (Fig. 4). The outbreak ended in November 2006.

Although patients carrying the *A. baumannii* outbreak strain were transferred to 9 different ICUs and 15 different regular wards, only 2 of the 29 transmissions occurred in regular wards, whilst the other 27 transmissions occurred in 5 different ICUs.

The most common sites of isolation of *A. baumannii* were wounds or wound drainage fluids, and the lower respiratory tract. Of the 28 patients with the outbreak strain with complete medical records, 15 patients were colonized only, whilst 13 patients had *A. baumannii* infections, i.e. ventilator-associated pneumonia ($n=8$), surgical site infection ($n=5$) and bloodstream infection ($n=3$; Table 1). For the remaining four patients with the outbreak strain, it was not possible to determine whether they were colonized or infected due to incomplete medical records.

A total of 4 (12.5%) of the 32 patients colonized or infected with the *A. baumannii* outbreak strain died during their hospital course. However, only one death was considered to be possibly related to *A. baumannii* infection.

Case-control study

During the study period, 166 patients were admitted to the MSICU. Of these, 13 patients acquired the *A. baumannii* outbreak strain (cases), accounting for an attack rate of 7.8%. Twenty-four patients who stayed at least 5 days in the MSICU during the study period without acquiring *A. baumannii* served as controls.

The results of the univariate analysis of risk factors are depicted in Table 2. Only the variables haemodialysis ($P=0.043$), SAPS II score $>$ median ($P=0.017$) and TISS-28 score $>$ median ($P=0.017$) were associated ($P<0.05$) with acquisition of *A. baumannii* in the univariate analysis. As both scores measure similar factors, only the variable TISS-28 score was included with all other risk factors in the multiple logistic regression analysis and was the only factor that independently predicted acquisition of *A. baumannii* (OR 6.67, 95% CI 1.55–36.56).

Environmental and personnel screening

Two environmental samples taken from the surface of an infusion pump in the room of a patient harbouring the

Table 1. Demographic and clinical characteristics of patients with *A. baumannii* infection or colonization

Patient no.	Age (years)	Admission diagnosis	First isolation of <i>A. baumannii</i>	Culture sites of <i>A. baumannii</i>	Colonization/infection	PFGE pattern	IPM MIC	OXA type
1	61	Multiple trauma	27.02.2006	Abdominal drainage fluid, abdominal wound	Colonization	A	32	51, 23
2	77	Cardiac arrest	09.03.2006	Respiratory tract	VAP	A1	1	51
3	38	Venous port infection	13.03.2006	CVC, respiratory tract, wound	VAP, SSI	A	32	51, 23
4	54	Necrotizing fasciitis	19.03.2006	Soft tissue, wound	Colonization	A	32	51, 23
5	74	Common bile duct injury	21.03.2006	Urine	Colonization	A	32	51, 23
6	42	Abdominal liposarcoma	22.03.2006	Wound	Colonization	A	64	51, 23
7	62	Acute liver failure	05.04.2006	Pharyngeal swab, rectal swab	Colonization	A	64	51, 23
8	43	Common bile duct fistula	10.04.2006	Abdominal drainage fluid, blood	BSI	A2	1	51
9	29	Multiple trauma	25.04.2006	Rectal swab, respiratory tract, wound, urine	Unknown*	A	32	51, 23
10	60	Vascular prosthesis infection	29.04.2006	Wound	Unknown*	A	32	51, 23
11	54	Colon carcinoma	22.06.2006	Respiratory tract, wound, drainage fluid, blood, soft tissue	VAP, BSI	A	32	51, 23
12	70	Multiple trauma	27.06.2006	Respiratory tract	Colonization	A	32	51, 23
13	44	Multiple trauma	30.06.2006	Soft tissue, wound	Colonization	A	32	51, 23
14	46	ARDS	10.07.2006	Urine	Unknown*	A	32	51, 23
15	53	Multiple trauma	13.07.2006	Urine, respiratory tract, blood, wound	VAP, BSI	A	32	51, 23
16	74	Duodenal carcinoma	14.07.2006	Respiratory tract, CVC, blood	BSI	A	32	51, 23
17	53	ARDS	16.07.2006	Respiratory tract, urine, conjunctiva	VAP	A	32	51, 23
18	77	Serial rib fracture	16.07.2006	CVC, respiratory tract	Colonization	A	32	51, 23
19	66	Colon carcinoma	29.07.2006	Respiratory tract, urine	Colonization	A	32	51, 23
20	18	Multiple trauma	04.08.2006	Wound	SSI	A	64	51, 23
21	49	Cervical spine fracture	18.08.2006	Drainage fluid	SSI	A	32	51, 23
22	38	Abdominal wall abscess	22.08.2006	Wound, blood, urine	Unknown*	A	32	51, 23
23	62	Oesophageal carcinoma	23.08.2006	CVC, pharyngeal swab	Colonization	A	64	51, 23
24	21	Ovarian carcinoma	24.08.2006	Nasal/pharyngeal swab	Colonization	A	64	51, 23
25	83	Vertebral osteomyelitis	27.08.2006	Wound, respiratory tract	SSI	A	32	51, 23
26	93	Osteoblastic sarcoma	28.08.2006	Urine	Colonization	A	32	51, 23
27	72	Right-sided heart failure	29.08.2006	Pharyngeal swab, rectal swab	Colonization	A	32	51, 23
28	67	Rectal carcinoma	30.08.2006	Wound, respiratory tract, urine, pharyngeal swab	VAP	A	64	51, 23
29	86	Proximal femoral fracture	30.08.2006	Urine	Colonization	A	32	51, 23
30	68	Sepsis	27.09.2006	Respiratory tract	Colonization	A3	32	51, 58
31	63	Aortic aneurysm	29.09.2006	Wound	SSI	A	64	51, 23
32	58	Multiple trauma	02.10.2006	Nasal swab, respiratory tract, wound	VAP	A	32	51, 23
33	58	Cardiac arrhythmia	04.11.2006	Respiratory tract	Colonization	A	32	51, 23
34	22	Cerebral vascular disease	16.11.2006	CVC, pharyngeal swab, rectal swab, respiratory tract, urine	VAP	A	64	51, 23
35	69	Cardiac arrhythmia	30.11.2006	Respiratory tract	VAP	A	64	51, 23

ARDS, Adult respiratory distress syndrome; BSI, bloodstream infection; CVC, central venous catheter; SSI, surgical site infection; VAP, ventilator-associated pneumonia.

*Incomplete medical records did not allow determination of colonization or infection.

Fig. 1. PFGE patterns of *A. baumannii* isolates. Lanes: 1, reference strain *A. baumannii* COL 20820; 2, *A. baumannii* RUH 2036, representing EU clone I; 3, *A. baumannii* RUH 3372, representing EU clone II; 4–8, *A. baumannii* isolates from patients 21, 23, 31 and 33, as well as from the infusion pump, respectively, representing PFGE pattern A; 9, *A. baumannii* isolate from patient 8 representing PFGE pattern A2; 10, *A. baumannii* isolate from patient 2 representing PFGE pattern A1; lane 11, *A. baumannii* isolate from patient 30 representing PFGE pattern A3; 12 and 13, *A. baumannii* isolates from patients not part of the outbreak representing PFGE patterns B and C, respectively. M, Molecular size marker.

outbreak strain and from an oxygen mask located on a bronchoscopy cart, and one sample from the hands of a health-care worker yielded *A. baumannii*. All three isolates

Fig. 2. Dendrogram and virtual gel images using the DiversiLab system representing rep-PCR fingerprint patterns from *A. baumannii* isolates: 95, 97, 110 and 115 (recovered from patients 21, 23, 31 and 33, respectively); 108 (patient 30); 61 (patient 8); 54 (patient 2); 39 and 42 (from patients not part of the outbreak); and RUH 2036 and RUH 3372 representing *A. baumannii* EU clones I and II.

represented the outbreak strain as determined by PFGE (Fig. 1).

This prolonged outbreak of carbapenem-resistant *A. baumannii* affected 32 patients in two wards and five ICUs over a period of 10 months after introduction of the outbreak strain by a repatriated trauma patient. Nosocomial outbreaks of multidrug-resistant *A. baumannii* strains introduced by trauma patients have been reported, especially in injured American soldiers repatriated from field hospitals in Iraq (Scott *et al.*, 2007), but patients repatriated from other tropical or Mediterranean countries after hospital treatment for accidents or other severe illness have also caused subsequent outbreaks with multidrug-resistant *A. baumannii*, for example in Belgium (Wybo *et al.*, 2007), in the Netherlands (Wagenvoort *et al.*, 2002) and in Germany (Borgmann *et al.*, 2004). *A. baumannii* isolates carrying OXA-23 have been reported from countries in the Asia-Pacific region, including Thailand (Mendes *et al.*, 2009). However, as the index patient of this outbreak had been admitted 2 months before *A. baumannii* was isolated for the first time, it is not possible to determine whether he was colonized on admission or whether he had acquired the outbreak strain from an unknown carrier sometime between admission and first isolation. Of note, the outbreak strain was found to be related to the pan-European *A. baumannii* clone II.

Different modes of transmission of *A. baumannii* have been described including transmission via contaminated medical equipment, patient care items or the environment, cross-transmission via the hands of hospital personnel from colonized or infected patients, and transmission related to specific procedures such as pulsatile lavage wound treatment (Bergogne-Bérézin & Towner, 1996; Bernards *et al.*, 2004; D'Agata *et al.*, 2000; Dijkshoorn *et al.*, 2007; Maragakis *et al.*, 2004; Villegas & Hartstein, 2003). Even airborne transmission has been suggested (Bernards *et al.*, 1998). The most likely mode of spreading in this outbreak was cross-transmission via the hands of health-care workers, with colonized or infected patients serving as a reservoir. As transmissions occurred in seven wards in patients who shared neither equipment nor materials and had no treatment procedures in common, a common source was highly unlikely, although a temporary common source in the MSICU could not be excluded.

Risk factors for *A. baumannii* infection and/or colonization in epidemic settings have included host factors, specific procedures, previous antimicrobial therapy, length of stay, high work load and admission to wards with a high density of infected and/or colonized patients (Fournier & Richet, 2006). Case-control studies have been performed to determine risk factors specific for the acquisition of carbapenem-resistant *A. baumannii*. Identified risk factors included aminoglycoside use and prolonged stay in the unit (Katragkou *et al.*, 2006), previous ICU stay, prior exposure to imipenem or third-generation cephalosporins in endemic settings (Lee *et al.*, 2004), and the presence of

Fig. 3. Epidemic curve of the *A. baumannii* outbreak and timing of infection control measures. Hatched bars, intermediate care unit; grey bars, other ICUs and regular wards; black bars, MSICU.

an arterial catheter and imipenem monotherapy in an outbreak setting (del Mar Tomas *et al.*, 2005). In the present case-control study, we did not find any evidence that acquisition of the outbreak strain was linked to a specific device or procedure, or to the duration of exposure. In contrast, the risk for acquisition was related to the severity of disease and the intensity of care providing multiple opportunities for exposure to the outbreak strain,

because there was a significant correlation between a high TISS-28 score and acquisition of the outbreak strain. The TISS score measures the intensity of nursing care and of ventilatory, cardiovascular, renal, neurological and metabolic support (Lefering *et al.*, 2000; Miranda *et al.*, 1996). A high mean daily TISS score was also identified as an independent risk factor for acquisition of imipenem-resistant *A. baumannii* in an outbreak in a surgical ICU

Fig. 4. Spread of the *A. baumannii* outbreak strain to 29 patients with known direct epidemiological links during the outbreak period from 27 February 2006 to 30 November 2006.

Table 2. Univariate analysis of risk factors for acquisition of the *A. baumannii* outbreak strain in patients in the MSICU between 18 June 2006 and 31 August 2006

Risk factor	No. (%) of cases (n=13)	No. (%) of controls (n=24)	OR (95 % CI)	P value*
Female gender	6 (46.2)	10 (41.7)	1.20 (0.31–4.67)	1.000
Age >median	6 (46.2)	12 (50)	0.86 (0.22–3.32)	1.000
Diabetes mellitus	11 (84.6)	19 (79.2)	1.45 (0.24–8.76)	1.000
Malignant disease	5 (38.5)	7 (29.2)	1.52 (0.37–6.29)	0.716
Trauma	5 (38.5)	10 (41.7)	0.87 (0.22–3.48)	1.000
Ventilation use	13 (100)	19 (79.2)	–	0.140
Ventilator days >median	9 (69.2)	9 (37.5)	3.75 (0.89–15.8)	0.091
Central venous catheter use	12 (92.3)	21 (87.5)	1.71 (0.16–18.40)	1.000
Urinary catheter use	13 (100)	23 (95.8)	–	1.000
Haemodialysis	6 (46.2)	3 (12.5)	6.00 (1.18–30.6)	0.043
Bronchoscopy	5 (38.5)	8 (33.3)	1.25 (0.31–5.08)	1.000
Abdominal surgery	3 (23.1)	6 (25.0)	0.90 (0.18–4.40)	1.000
Trauma surgery	4 (30.8)	8 (33.3)	0.89 (0.21–3.80)	1.000
Change of wound dressings	8 (61.5)	16 (66.7)	0.80 (0.20–3.25)	1.000
Prior antibiotic therapy	13 (100)	23 (95.8)	–	1.000
Duration of antibiotic therapy >median	7 (53.8)	11 (45.8)	1.38 (0.36–5.34)	0.737
Broad-spectrum penicillin therapy	5 (38.5)	12 (50.0)	0.63 (0.16–2.47)	0.731
Cephalosporin therapy	5 (38.5)	11 (45.8)	0.74 (0.19–2.92)	0.739
Carbapenem therapy	3 (23.1)	3 (12.5)	2.10 (0.36–12.3)	0.644
Quinolone therapy	4 (30.8)	5 (20.8)	1.69 (0.36–7.84)	0.691
Aminoglycoside therapy	1 (7.7)	4 (16.7)	0.42 (0.04–4.18)	0.638
No. of antibiotics of different classes >median	4 (30.8)	6 (25.0)	1.33 (0.30–5.96)	0.716
Duration of hospital stay >median	8 (61.5)	10 (41.7)	2.24 (0.56–8.91)	0.313
Duration of ICU stay >median	7 (53.8)	11 (45.8)	1.38 (0.36–5.34)	0.737
Duration of exposure >median	6 (46.2)	9 (37.5)	1.43 (0.36–5.61)	0.730
Presence of a patient with the outbreak strain in the same room	4 (30.8)	5 (20.8)	1.69 (0.36–7.84)	0.691
Presence of a patient with the outbreak strain in the adjacent room	9 (69.2)	16 (66.7)	1.13 (0.26–4.80)	1.000
Prior room occupant with the outbreak strain	6 (46.2)	13 (54.2)	0.74 (0.19–2.81)	0.725
SAPS II score >median	10 (76.9)	8 (33.3)	6.67 (1.42–31.2)	0.017
SOFA score >median	9 (69.2)	9 (37.5)	3.75 (0.89–15.8)	0.091
TISS-28 score >median	10 (76.9)	8 (33.3)	6.67 (1.42–31.2)	0.017

SOFA, sequential organ failure assessment.

*Entries in bold indicate a significant *P* value (*P* < 0.05).

(Fierobe *et al.*, 2001). This correlation between severity of disease and intensity of care and acquisition of the outbreak strain may explain why nearly all *A. baumannii* transmissions were observed in ICUs. However, the low number of regular ward patients who were found to be positive for the outbreak strain might at least in part be a consequence of sampling bias, as microbiological sampling is performed more often in ICU patients.

The correlation between the severity of disease and intensity of care and acquisition of *A. baumannii* alone, however, does not explain why as many as 17 transmissions occurred only in the MSICU and why the other four ICUs were much less affected. It is tempting to speculate that the high number of transmissions in the MSICU may have resulted from breaks in infection control during the evacuation of patients in response to the water damage

and the resulting increase in carriers in the MSICU. The importance of the proportion of carriers as a determinant of cross-transmission and acquisition of multidrug-resistant bacteria such as methicillin-resistant *Staphylococcus aureus*, vancomycin-resistant enterococci and also *A. baumannii* has been described by Bonten *et al.* (1998), Merrer *et al.* (2000) and Playford *et al.* (2007). Exposure to a high number of patients with *A. baumannii* infections was also shown to be an independent risk factor for *A. baumannii* infection in an outbreak in a surgical ICU (D'Agata *et al.*, 2000).

Control of this outbreak relied mainly on standard measures such as hand disinfection, contact isolation precautions, and daily cleaning and disinfection of the environment. Long-term carriage of *A. baumannii* has been described by Marchaim *et al.* (2007) and long-term carriers

also posed a challenge in this outbreak because of the necessity to maintain strict adherence to infection control measures over prolonged time periods.

As transmissions seemed to occur before the carrier status of patients was known and proper isolation precautions were instituted, screening of patients for carbapenem-resistant *A. baumannii* in the mainly affected ICU was performed during the second phase of the outbreak, and all patients carrying *A. baumannii* were cohorted in a separate part of the unit to reduce opportunities for cross-transmission. Control of this prolonged outbreak was achieved by screening and cohorting of patients in addition to contact precautions, and no further cases were detected with laboratory-based surveillance and surveillance in the affected ICUs since November 2006.

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