Effect of carbapenem consumption patterns on the molecular epidemiology and carbapenem resistance of *Acinetobacter baumannii*

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This study investigated the molecular epidemiology of *Acinetobacter baumannii* in the University of Debrecen in relation to antibiotic consumption. Overall and ward-specific antibiotic consumption was measured by the number of defined daily doses (DDD) per 100 bed-days between 2002 and 2012. Consumption was analysed against the number of *A. baumannii* positive patients per 100 bed-days, number of isolates per positive sample, and proportion of carbapenem resistant *A. baumannii*, using time-series analysis. Altogether 160 *A. baumannii* isolates from different wards were collected and analysed. Carbapenemase genes *bla*OXA-23-like, *bla*OXA-24-like, *bla*OXA-48-like, *bla*OXA-51-like, *bla*OXA-58-like and integrons were sought by PCR. Relatedness of isolates was assessed by PFGE. Prevalence and carbapenem resistance of *A. baumannii* were statistically associated with carbapenem consumption. Prevalence data followed carbapenem usage with three quarterly lags (*r*=0.51–0.53, *P*<0.001), and meropenem and ertapenem, but not imipenem usage, affected prevalence. Colistin usage, in turn, lagged behind prevalence with one lag (*r*=0.68–0.70, *P*<0.001). Six clusters were identified; the neurology ward with the lowest carbapenem consumption was associated with the carbapenem-susceptible cluster, as well as with the carbapenem-susceptible isolates in the cluster with variable susceptibility. Wards with high carbapenem usage almost exclusively harboured isolates from carbapenem-resistant clusters. All clusters were dominated by isolates of one or two wards, but most wards were represented in multiple clusters. Increases in prevalence and carbapenem resistance of *A. baumannii* were associated with usage of meropenem and ertapenem but not of imipenem, which led to the spread of multiple clones in the University.

**INTRODUCTION**

*Acinetobacter baumannii*, the clinically most important species in the *A. baumannii–Acinetobacter calcoaceticus* complex, represent a major nosocomial problem, especially due to the frequency of the multidrug resistant phenotype. Recently, extensively resistant clones susceptible only to polymyxins have emerged worldwide, for which even carbapenems, formerly the drug group of choice against *A. baumannii*, remain ineffective (Zarrilli et al., 2004). The emergence of carbapenem resistance is linked to plasmid-borne class D *Bla*OXA-23-like and *Bla*OXA-58-like carbapenemases. Though most clinically important *A. baumannii* subpopulations harbour a naturally occurring chromosomal *Bla*OXA-51-like carbapenemase, this alone is not sufficient for the carbapenem resistant phenotype (Poirel & Nordmann, 2006; Walther-Rasmussen & Høiby, 2006). These carbapenemases are associated with the insertion sequences ISAba-1, -2 and -3 (Karunasagar et al., 2011; Tsakris et al., 2008), and their production has been linked to certain pandemic clones (Ansaldi et al., 2011; Merkier et al., 2008; Tsakris et al., 2008; Villalón et al., 2013).

Emerging carbapenem resistance in *A. baumannii* has been shown by several authors to be a sequel to third-generation cephalosporin and carbapenem usage (Cisneros & Rodríguez-Baño, 2002; Goel et al., 2011; Iosifidis et al., 2008; Manikal et al., 2000; Ogutlu et al., 2014). This is attributed both to acquisition of mechanisms providing carbapenem resistance...
and to spread of carbapenem resistant clones (Goel et al., 2011; Manikal et al., 2000; Ogutlu et al., 2014; Poirel & Nordmann, 2006).

The aim of the present study was to investigate the molecular epidemiology of A. baumannii and its carbapenem resistance in a Hungarian tertiary care centre, in relation to changes in antibiotic consumption.

**METHODS**

**Antibiotic consumption and frequency of Acinetobacter spp.**

Quarterly antibiotic consumption [number of defined daily doses (DDD) per 100 bed-days] used by inpatient departments of the University was monitored between 2002 and 2012, based on the data of the University Pharmacy using the MS Excel application ABC Calc Version 3.0 (Monnet 2006). Department-specific data were collected between 2004 and 2012 (ICU-specific data were not available).

The annual frequency of Acinetobacter isolations in the University was characterized by the number of patients positive for A. baumannii per 100 bed-days, the proportion of positive samples of inpatients yielding A. baumannii, the proportion of A. baumannii among the isolated Gram-negative aerobic/facultatively anaerobic bacteria, and the proportion of A. baumannii isolations out of positive blood culture samples. Antibiotic resistance data of non-duplicate (from one patient only the first isolate was considered) isolates were collected from the database of the Laboratory for Bacteriological Diagnostics serving the University.

The relationship between antibiotic consumption in the University and changes in isolation frequency, as well as antibiotic resistance of Acinetobacter spp., was analysed by linear regression. In the case of antibiotics where the consumption data showed significant correlation with prevalence or resistance data, after trend removal cross-correlation analysis was performed using quarterly time lags. The lag with the highest significant correlation coefficient was considered as the most probable delay with which antibiotic consumption precedes or follows the changes in resistance or prevalence. Out of the available drugs in the carbapenem group, the effect of imipenem, meropenem, piperacillin + tazobactam, colistin, ciprofloxacin, sulmethrim, doxycycline, tigecycline, amikacin, tobramycin and gentamicin was determined using the Clinical and Laboratory Standards Institute (CLSI, 2010) disc diffusion method. Isolates were stored frozen until analysis.

**Detection of carbapenemase, aminoglycoside and tetracycline resistance genes.** Isolates were grown overnight at 37 °C on blood agar. A loopful of bacteria was heated to 98 °C in TE buffer (100 mM Tris, 10 mM EDTA) for 15 min and centrifuged at 11 000 g for 3 min; the supernatant was used as a template for PCR analysis. Stock solutions were kept at −70 °C and were renewed after every five freeze–thaw cycles.

The carbapenemase genes blaKXA, 23-like, blaKXA, 24-like, blaKXA, 48-like and blaKXA, 51-like and blaKXA, 58-like were sought using the methods of Woodford et al. (2006). The association of blaKXA and the insertion sequences ISAba-1 was also assessed (Turton et al., 2006).

The genes coding for the aminoglycoside-modifying enzymes aac(3)-Ia, aac(6')-Ib, ant(2')-Ia, ant(3')-Ia, aphi(3')-Ia and aphi(3')-Vla were tested as described previously (Frana et al., 2001; Lévesque et al., 1995; Vila et al., 1999). Genes armA, rmtA, rmtB encoding 16S rRNA methylases were sought using the method reported by Bogaerts et al. (2007).

**Analysis of integrons and integron-associated gene cassettes.** The occurrence of resistance integrons was studied by integrase-specific PCRs (Mazel et al., 2000). Variable regions were amplified as described by White et al. (2001). At least two representative amplimers were purified using the Isolate PCR and gel kit (Bioline), and sequenced using the Sanger method with primer walking when necessary. CLC DNA Workbench 4.0 (CLC Bio) was used to assemble and analyse sequences, and genes were identified by GenBank (http://www.ncbi.nlm.nih.gov) search. The identity of integrons with variable regions of the same size was confirmed by restriction fragment length polymorphism analysis using XbaI, HindIII and DdeI (Fermentas), as determined by restriction site analysis of the fully sequenced representatives. Restriction analysis was performed as recommended by the manufacturer.

**Determination of the genotype.** Genetic relatedness among isolates was analysed by PFGE. Plugs were prepared as previously described (Mózes et al., 2014) and digested with Apul. A CHEF DRIII machine (Bio-Rad) was used to separate the fragments in 1 % SeaKem Gold agarose (Lonza) at 14 °C. Electrophoresis was performed at 6 V cm⁻¹, with a reorientation angle of 120°, and switch times were ramped between 2 s and 35 s for 20 h. DNA banding patterns were analysed with the Fingerprinting II software (Bio-Rad) using the Dice coefficient and the unweighted pair group method with averages (UPGMA). Setting of optimization and position tolerance was 1 %
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![Graphs showing antibiotic use and A. baumannii infections over time](image)

- **Graph (a)**: Proportion of A. baumannii/A. baumannii-infected patients per 100 bed-days.
- **Graph (b)**: No. of A. baumannii-positive samples.
- **Graph (c)**: A. baumannii/Gram-negative isolations.
- **Graph (d)**: No. of A. baumannii-infected patients per 100 bed-days.

### Key Points
- **Meropenem**: Significantly increased from 2002 to 2007, peaking around 2004.
- **Imipenem**: Showed a steady increase from 2002 to 2008.
- **Ertapenem**: Increased slightly from 2002 to 2005, with a slight decrease thereafter.
- **Doripenem**: Maintained a stable trend from 2002 to 2008 with minimal fluctuations.

### Summary
- The use of Meropenem and Imipenem saw a significant rise, indicating a possible increase in A. baumannii infections or a greater reliance on these antibiotics.
- The proportion of A. baumannii-positive samples increased steadily, suggesting a growing incidence of the organism.
- The number of A. baumannii-infected patients per 100 bed-days also trended upwards, aligning with the rise in antibiotic use and proportion of positive samples.

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**References**


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**Note:** The diagrams and data are indicative of trends in antibiotic use and the prevalence of A. baumannii infections over a span of years, highlighting the potential for antibiotic resistance and the need for continued monitoring and intervention strategies.
and 1.5% respectively; a similarity of at least 90% was considered as the threshold of probable genetic relatedness.

RESULTS

Association of prevalence and resistance data with antibiotic consumption

A. baumannii was isolated from approximately 1% of all positive samples submitted during the years 2000 to 2008, but in 2009 and 2010 a sudden increase in the isolation rates from all positive samples (to 2.3% and 2.5%, respectively) was detected. A similar increase was found in positive blood samples (from 1–2% to 4.4%). In parallel, the proportion of carbapenem-resistant isolates increased from 6.2% to 63.8% from 2000 to 2010, and increased further to 73.0% in 2011.

The antibiotic consumption of the University showed an increasing trend from 2006. This was mainly attributable to the increased consumption of broad-spectrum antibiotics, third-generation cephalosporins, fluoroquinolones and, from 2008, carbapenems. In a cross-correlation analysis, increases in carbapenem consumption followed the trend in third-generation cephalosporin (r=0.63, P<0.001 at the −9 quarterly lag corresponding to the period roughly two years earlier), but replaced piperacillin + tazobactam usage (r=−0.54, P<0.001 at +4 quarterly lag corresponding to the period a year later). Significant temporal correlation between carbapenem usage and consumption of other antibiotic classes was not found, except for polymyxins, which lagged behind carbapenem usage with five quarterly lags (slightly more than a year, r=0.80, P<0.001).

The prevalence as well as the carbapenem resistance of A. baumannii showed association with consumption of third-generation cephalosporins, carbapenems and colistin, but not with any other antibiotic classes. Consumption of third-generation cephalosporins preceded the increase in prevalence of A. baumannii among positive samples and among isolated Gram-negative bacteria with 13 (16 in case of blood samples) quarterly lags (three to four years; r=0.55–0.77, P≤0.001 in all cases), as well as the increase in prevalence of A. baumannii-positive patients (with 14 quarterly lags, three and a half years; r=0.58, P<0.001). However, this association was indirect, as carbapenem usage followed the consumption of third-generation cephalosporin with nine quarterly lags (see above).

Increasing carbapenem consumption led to an increase in prevalence of A. baumannii in all positive samples, as well as in positive blood samples, with a delay of three quarterly lags (nine months; r=0.53, P<0.001 and r=0.51, P<0.001, respectively). When analysing the increasing prevalence of A. baumannii among Gram-negative bacteria, the delay was slightly longer (five quarterly lags; r=0.54, P<0.001 and r=0.62, P<0.001, respectively). Increasing prevalence was not explained by the consumption of any other antibiotic group tested (fluoroquinolones, piperacillin + tazobactam or third-generation cephalosporins). The effect on the number of patients with A. baumannii positive culture was comparable (four quarterly lags; r=0.46, P=0.002).

Carbapenem resistance of A. baumannii showed a similar correlation with carbapenem usage, also with a delay of nine months (r=0.43, P=0.005 at the −3 quarterly lag), but not with usage of any other drug classes.

Out of the different carbapenem drugs, meropenem showed temporal association with prevalence (eight to four lags; r=0.45–0.49, P=0.002–0.006) and carbapenem resistance (eight lags; r=0.44, P=0.007) of A. baumannii or with the number of positive patients (two lags; r=0.39, P=0.01). Ertapenem showed a similar effect, but with shorter delays. Prevalence lagged behind ertapenem usage with one to five quarterly lags (r=0.54–0.58, P<0.001), and carbapenem resistance and the number of positive patients per 100 bed-days with six (r=0.42, P=0.009) and four (r=0.56, P<0.001) lags, respectively. These variables were not influenced by imipenem consumption (Fig. 1).

Increasing colistin consumption followed the increase in prevalence and carbapenem resistance of A. baumannii with a delay of one quarterly lag (r=0.68–0.70, P<0.001 for prevalence variables and r=0.58, P<0.001 for carbapenem resistance).

Ward-specific differences in antibiotic consumption, prevalence and carbapenem resistance

Examining carbapenem consumption among the wards with the highest isolation rates of A. baumannii revealed that usage in the department of surgery and pulmonology was above the University average, while the first department of internal medicine, paediatrics and neurology consumed fewer carbapenems (Fig. 2). The department of surgery consumed significantly more carbapenems than other wards (P=0.001–0.018), while the neurology department consumed significantly fewer carbapenems than any other wards analysed (P=0.010–0.026).

Meropenem was the most popular carbapenem accounting for 56.7% of yearly carbapenem cumulative doses (36.2–92.5%), followed by imipenem with 26.9% (6.8–42.8%) and ertapenem with 11.8% (0–27.8%). Doripenem usage was very low (4.6%; 0–12% of yearly carbapenem cumulative doses). The preferred carbapenems were different among wards; meropenem was less preferred in surgery and pulmonology departments (37.5% and 33.5% of all

Fig. 1. Distribution of use rates of all carbapenems (A), meropenem (B), imipenem (C) and ertapenem (D) between 2002 and 2012. Prevalence data are depicted with the delay revealed by the time-series analysis. DDD: Defined daily dose.
Carbapenem resistance in A. baumannii was highly prevalent in the surgery ICU, pulmonology ICU, first internal medicine ICU, perinatal ICU and neurosurgery ICU, as well as in other wards, but was significantly lower in the neurology ICU (P<0.001−P=0.002 in pairwise comparisons), and in the paediatric ICU during the study period (P=0.001−0.029 in pairwise comparisons). Cross-correlations between ward-specific consumption and prevalence/resistance data were not significant.

### Resistance genes and integrons

As expected, all isolates carried the chromosomal weak carbapenemase gene blaOXA-51 and the insertion sequence ISAba-1. blaOXA-23 and blaOXA-24 were present in 78.1 % (125/160) and 1.2 % (2/160), respectively, and blaOXA-48 and blaOXA-58 were not detected. Carbapenem susceptible isolates carried only the blaOXA-51 gene, and carbapenem resistance was linked to carriage of blaOXA-23 or blaOXA-24.

Genes coding for amikacin resistance, aph(3′)-VIIa and aac(6′)-Ib, were detected in 90.6 % (145/160) and 56.9 % (91/160) of the isolates, respectively. aph(3′)-Ia was found in 68.7 % (110/160), ant(3′)-Ia in 77.5 % (124/160) of isolates, and ant(2′)-Ia was not detected. Out of the tested aminoglycoside methylase genes only armA could be detected (11.9 %, 19/160), and rmtA and rmtB genes were not present. Two or more aminoglycoside resistance genes were harboured simultaneously in all isolates. Prevalence of tetracycline resistance genes tetA, tetB and tetD was 11.9 % (19/160), 6.9 % (11/160) and 39.4 % (63/160), respectively, and tetC was not encountered. Isolates carrying tetD were always positive for tetA as well.

Class I integrons were found in the majority of isolates (93.7 %, 150/160), and class II and III integrons were not present.

### Identification and characterization of A. baumannii clusters

PFGE distinguished six clusters (A1, A2, B, C1, C2, D), a pair of isolates with identical patterns and two isolates with unique profiles. Clusters A1 and A2, as well as clusters C1 and C2, showed somewhat similar profiles (with similarities of 84.6 % and 86.3 %, respectively).

Cluster A1 contained 26 isolates from 19 patients. The majority of the isolates originated from the neurology ICU/stroke ward (15/26) and from the paediatric ICU (7/26). The isolates of this cluster were carbapenem susceptible, but uniformly resistant to ciprofloxacin, amikacin and tobramycin. All isolates harboured the blaOXA-51 gene, the ISAba-1 sequence and a class I integron with the gene cassette array acac(6′)-Ib, hypothetical protein; blaOXA-20 (In426). The genes aph(3′)-Ia, aph(3′)-VIIa, tetA and tetD were detected in 76.9 % (20/26), 50.0 % (13/26), 73.0 % (19/26) and 42.3 % (11/26) of the isolates, respectively.
Cluster A2 contained seven isolates from four patients. Six of the seven isolates in this cluster originated from the surgery ICU, and only one isolate originated from the neurosurgery ICU. They were found to be susceptible only to doxycycline, tigecycline and polymyxins showing resistance to all other antibiotic groups, excepting the neurosurgery isolate. Besides bla\textit{OXA}-51-like of all them carried a bla\textit{OXA}-23-like gene. They were positive for the \textit{aph(3')-Ia} and \textit{aph(3')-Vla} genes, but not for any other aminoglycoside or tetracycline resistance genes tested. None of the isolates harboured integrons.

Cluster B included 19 isolates from 11 patients. The majority of the isolates (14/19) in the cluster were originated from the perinatal ICU, and all tested isolates from the perinatal ICU belonged to this cluster. Antibiotic susceptibility was characterized by carbapenem and aminoglycoside resistance. Both bla\textit{OXA}-51-like and bla\textit{OXA}-23-like carbapenemase genes, \textit{aph(3')-Ia}, \textit{aph(3')-Vla} and \textit{ant(3')-la} were detected in all members. They uniformly carried a class I integron with a gene cassette array of \textit{aac(3')-Ia}; hypothetical protein; hypothetical protein; \textit{ant(3')-la} (In561).

Cluster C1 contained 12 isolates of 10 patients, all except one from the first internal medicine ICU. Ten isolates were susceptible to doxycycline, tigecycline and polymyxin-B, one isolate was susceptible to tigecycline and polymyxin-B, and one was susceptible only to polymyxins. Genes bla\textit{OXA}-51-like with ISAba-1, bla\textit{OXA}-23-like \textit{ant(3')-la} and \textit{aph(3')-Vla} were identified in all isolates. Other tested resistance genes \textit{armA}, \textit{rmtA}, \textit{rmtB}, \textit{tetA}, \textit{tetB}, \textit{tetC}, \textit{tetD}, \textit{tetE}) were not found. All isolates were class I integron positive, and the gene cassette array in 11 isolates was \textit{aac(3')-Ia}; hypothetical protein; hypothetical protein; \textit{ant(3')-la} (In561). Curiously, the remaining isolate carried an integron with a sole \textit{ant(3')-Ib} gene (In127).

Cluster C2 contained 29 isolates from 24 patients. The origin of the isolates was varied, with 11, six, six and two isolates from the surgery ICU, neurosurgery ICU, neurology ICU/stroke and first internal medicine ICU departments, respectively, and the remaining four isolates from four other wards. Antibiotic susceptibility was highly diverse within the cluster; while all isolates from neurology were susceptible to carbapenems, isolates from other departments showed susceptibility only to doxycycline, tigecycline and polymyxins or only to polymyxins. The resistance gene pattern was similar to that of isolates from cluster C1 except the bla\textit{OXA}-23-like gene, which was absent in the six carbapenem susceptible isolates from neurology. The class I integron carried by all isolates was also identical to that found in Cluster 1.

Cluster D included 63 isolates, 50 of which originated from the pulmonology ICU, and the 13 other isolates were from different wards of the second internal medicine department (eight isolates), first internal medicine ICU (three isolates), surgery ICU (two isolates) and various other wards (three isolates). The majority of the isolates were resistant to all drugs except polymyxins and tigecycline. Isolates within this cluster had the highest number of resistance genes; all isolates carried bla\textit{OXA}-23-like bla\textit{OXA}-51-like and ISAba-1, \textit{aac(6')-Ia}, \textit{aph(3')-Ia}, \textit{ant(3')-Ia}, \textit{aph(3')-Vla}, \textit{aac(3')-Ia} and \textit{tetB} genes. Moreover, 30.2\% (19/63) of the isolates in the cluster carried a 165 rRNA methylase gene \textit{armA}. All isolates carried a class I integron with a variable region containing \textit{aac(6')-Ib}; \textit{catB}; \textit{ant(3')-la} gene cassette array (In439). Curiously, the integrase gene of this integron was not amplifiable with the primers widely used to detect class I integrase.

Four isolates did not belong to any cluster. One from the surgery ICU was similar to cluster A2 (showing a similarity of 86.6\%), but carried an additional \textit{aac(6')-Ib} gene. An identical pair of isolates from different departments (pulmonology ICU and first internal medicine ICU) showed extensive drug resistance (susceptible only to tigecycline and colistin). These two isolates carried \textit{bla\textit{OXA}-24-like} carbapenemase gene besides \textit{bla\textit{OXA}-51-like} and ISAba-1, but none of the aminoglycoside or tetracycline resistance genes tested. They were also integron negative. The fourth isolate was also extensively resistant, and was similar to cluster D regarding resistance genes, except it was lacking the \textit{aph(3')-Ia}, the \textit{armA} and the \textit{tetB} genes. It also carried the integron found in cluster D.

\textbf{Distribution of the clusters among different wards}

Isolates originating from the neurology department (except for a single isolate) and from the paediatric ICU were susceptible to carbapenems; all other wards were dominated by carbapenem-resistant \textit{A. baumannii} (\(P<0.001\)). Neurology ICU and paediatric ICU had a significantly lower number of patients with carbapenem-resistant than with carbapenem-susceptible \textit{A. baumannii} (\(P<0.001–0.002\) and \(P=0.001–0.03\), respectively) as compared with other wards in pairwise comparisons.

All clusters were dominated by isolates from one or two wards. Cluster A1 was dominated by isolates from neurology and from the paediatric ICU; all except one isolate from cluster A2 originated from the surgery ICU; the majority of isolates in cluster B were found in the perinatal ICU; isolates from the first internal ICU dominated cluster C1; surgery ICU and neurology were the most frequent source for isolates in cluster C2 and the pulmonology ICU was the main site for isolates in cluster D. Cluster distribution among different wards was significantly different (\(P<0.0001\)). Eight of the 17 patients with \textit{armA} positive isolates originated from the pulmonology ICU (\(P<0.001–P=0.036\) in pairwise comparisons with other wards).

\textbf{DISCUSSION}

Prolonged outbreaks or endemic occurrence by multi-resistant pathogens is often provoked and maintained by
selection pressure exerted by antibiotic consumption. This has been demonstrated in the case of Gram-negative as well as Gram-positive pathogens (Bergman et al., 2009; Bronzwaer et al., 2002; Harthug et al., 2000; Rogues et al., 2007), including several cases of multidrug resistant Pseudomonas aeruginosa (Rogues et al., 2014; Suarez et al., 2011), vancomycin-resistant enterococci (Harthug et al., 2000) and A. baumannii (Paul et al., 2005). Some of these are associated with clonal spread and maintenance of a single multiresistant clone (Giannouli et al., 2010), while in other cases resistance is acquired by the pathogens during the outbreaks (Corbella et al., 2000; Harthug et al., 2000). Stopping the outbreaks very frequently necessitated restriction of the usage of the provoker antibiotic (Suarez et al., 2011), further confirming the importance of antibiotic usage as a driving force.

The choice of antibiotic is often motivated by the concern about drug resistance, leading to increased usage of broad-spectrum antibiotics, which in turn provokes another outbreak, creating the resistance spiral. The present study reports such a situation, when concern about extended-spectrum beta-lactamase (ESBL) producers provoked by the consumption of third cephalosporins (unpublished data) led to increase in carbapenem usage with an approximately two-year lag, which brought about increased prevalence and carbapenem resistance in A. baumannii. A similar relationship has also been reported previously (Goel et al., 2011; Xu et al., 2013). Increasing colistin use, in turn, was linked to increasing A. baumannii prevalence, thus representing a further turn in the resistance spiral, and a threat to emergence of non-treatable pandrug-resistant A. baumannii.

Increased prevalence and carbapenem resistance were directly linked to carbapenem consumption at the ward level. In the neurology department, where carbapenem consumption was significantly lower than in any other department analysed, the majority of A. baumannii isolates were carbapenem-susceptible, while carbapenem resistance is a concern in almost all other departments.

The usage of different carbapenems showed different effects; while imipenem consumption seemed to be less important as a cause for carbapenem resistance, meropenem and especially ertapenem consumption was associated with increased prevalence of A. baumannii. This corresponds well to the observation that imipenem is slightly more effective against A. baumannii than meropenem (MacGowan et al., 1995; Villar et al., 1997). Ertapenem was also shown as a provoker of carbapenem resistance in P. aeruginosa, at least in vitro (Vainio et al., 2013). Although data were inconclusive on the differential role of the different carbapenems at the ward level, the surgery and pulmonology departments, where ertapenem is a preferred carbapenem, are heavily burdened. These data raise the possibility that not only increased carbapenem consumption is important in the causality of the spread of carbapenem resistance, but also the pattern of the particular drugs used may also play an important role. This issue needs to be addressed by upcoming studies, as this information may be crucial in optimizing the choice of carbapenems.

Analysis of the molecular epidemiology revealed that carbapenem resistance could not be linked to a single clone; it was rather due to acquisition of BlaOXA-23-like carbapenemases, similarly to previous findings (Corbella et al., 2000; Giannouli et al., 2010; Zarrilli et al., 2004). All resistant clones harboured this gene; moreover, the resistant isolates in cluster C2 differed from susceptible isolates in the cluster by the carriage of the blaOXA-23-like carbapenemase gene. Interestingly, these susceptible isolates originated from, and were exclusively found in, samples from the neurology department, the ward with the lowest carbapenem consumption, suggesting that antibiotic use may have directly facilitated horizontal acquisition of resistance genes (Couce & Blázquez, 2009; Hawkey & Jones, 2009; Valenzuela et al., 2007). The majority of patients harbouring isolates that carried the aminoglycoside resistance methylase gene armA were patients of the pulmonology department, the one with the highest aminoglycoside consumption, similarly suggesting the role of antibiotic consumption in horizontal gene transfer. This assumption is supported by the known genome plasticity of A. baumannii (Imperi et al., 2011).

Interestingly, most clusters were dominated by isolates from one or two wards, but many clusters were represented in multiple wards by a few isolates, suggesting that the ward-specific strains are continuously transferred to other wards, creating a polyclonal endemicity pattern.

In conclusion, low carbapenem use was associated with carbapenem susceptibility even within a single A. baumannii clone, while the spread of carbapenem resistance of A. baumannii was clearly linked to meropenem and ertapenem but not to imipenem consumption. This points to non-equivalence of even very similar drugs not only in terms of efficacy but also as provokers of drug resistance.

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