Molecular Epidemiology of Carbapenem-Nonsusceptible Acinetobacter baumannii in the United States

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Over the last decade, *Acinetobacter baumannii* has emerged as an important nosocomial pathogen worldwide. We report molecular epidemiology of 65 carbapenem-nonsusceptible *A. baumannii* isolates identified from hospitals in New York, Pennsylvania, Florida, Missouri, Nevada, and California between 2008 and 2009. All isolates were subjected to pulsed-field gel electrophoresis (PFGE). Select isolates then underwent multilocus sequence typing (MLST). While the PFGE patterns tended to cluster within each hospital, sequence types (STs) belonging to the clonal complex 92 (CC92) and the pan-European clonal lineage II (EUII; worldwide clonal lineage 2) were predominant in all hospitals. Of them, ST122 and ST208 were the most common and were found in four of the six hospitals. Isolates belonging to the pan-European clonal lineages I and III were identified in one hospital each. Carbapenemase-encoding genes *bla* _OXA-23_ and/or *IS _Aba1*_ were present among the majority of isolates. These findings suggest that carbapenem-nonsusceptible *A. baumannii* isolates found in U.S. hospitals constitute part of the global epidemic driven by CC92, but have unique STs other than ST92, which may be spreading by means of patient transfer between health care facilities within the United States.
this technique can substantially enhance our understanding of molecular epidemiology across different hospitals and geographic areas.

The primary aim of the present study was to investigate the molecular epidemiology of contemporary carbapenem-nonsusceptible A. baumannii isolates collected from hospitals across the continental United States using MLST.

MATERIALS AND METHODS

Bacterial isolates. A total of 65 carbapenem-nonsusceptible A. baumannii isolates were investigated. Only one isolate per patient was included. All isolates were identified from clinical specimens at hospitals across the United States between 2008 and 2009. The participating hospitals in New York, Pittsburgh, PA, and St. Louis, MO, have an ongoing collection of carbapenem-nonsusceptible A. baumannii isolates. From these hospitals, only one isolate was included for a given month. The hospitals in Jacksonville, FL, Las Vegas, NV, and Torrance, Los Angeles County, CA, collected serial carbapenem-nonsusceptible A. baumannii isolates for this study for 1 or 2 months in 2009. Only one isolate was included from each patient. The isolates were identified as A. baumannii using an automated instrument in each clinical microbiology laboratory (Microscan Walk-Away [Siemens Healthcare Diagnostics, Deerfield, IL], Vitek 2 [bioMérieux, Durham, NC], or Phoenix 100 [BD, Franklin Lakes, NJ]). The identification as A. baumannii was subsequently confirmed by detection of blaOXA-51-like by PCR in the research laboratory (34). In addition, nonsusceptibility to carbapenems was confirmed by resistance to imipenem and/or meropenem using the disk diffusion method in the research laboratory located at the University of Pittsburgh.

Susceptibility testing. Susceptibility testing was performed following the methodology and breakpoints defined by the Clinical and Laboratory Standards Institute (CLSI) (5). Disk diffusion testing was used for the following agents: ampicillin-sulbactam, piperacillin-tazobactam, ceftazidime, cefepime, meropenem, ciprofloxacin, gentamicin, and amikacin. For tigecycline, the Food and Drug Administration (FDA) breakpoints for Enterobacteriaceae were used. All isolates with MICs of 8 to 16 mg/ml were considered resistant; for amikacin, the susceptible range was 0 to 4 mg/ml.

PCR and sequencing of carbapenemase-encoding genes. Detection of the blaOXA-51-like and IS4ba1/blaOXA-51-like complex was performed by PCR using primer sets and conditions described previously (18, 33). The presence of the IS4ba1/blaOXA-51-like complex has been implicated in various degrees of carbapenem resistance in A. baumannii (33). PCR for the blaOXA-23, blaOXA-40, and blaOXA-58 genes, the three major groups of acquired carbapenemase-encoding genes that confer clinically relevant resistance to carbapenems, was conducted using a multiplex scheme (38). For sequencing, the full structural genes of blaOXA-23 and blaOXA-40 were amplified using primers described previously (18). Sequencing was performed on a 3730 DNA analyzer (Life Technologies, Carlsbad, CA).

RESULTS

Susceptibility of the carbapenem-nonsusceptible A. baumannii isolates. Of a total of 67 isolates in the initial collection, two were found to be susceptible to both imipenem and meropenem in the research laboratory and were excluded. All of the remaining 65 isolates were positive for blaOXA-51-like by PCR. The numbers of isolates from each participating hospital were as follows: New York, 12; Pittsburgh, 10; St. Louis, 13; Jacksonville, 6; Las Vegas, 14; and Los Angeles, 10. The isolates were identified from various sources, including blood, sputum, bronchoalveolar lavage, wound, and urine specimens.

Susceptibility testing results of the study isolates are shown in Table 1. All isolates were nonsusceptible to meropenem, whereas 16 isolates (25%) were susceptible to imipenem by the disk diffusion method. All 5 isolates that were intermediate to meropenem were susceptible to imipenem. Most isolates were nonsusceptible to β-lactams other than carbapenems, including piperacillin-tazobactam, ceftazidime, and cefepime. Of the β-lactams, susceptibility to ampicillin-sulbactam was relatively conserved, with 51% of the isolates being susceptible and another 26% intermediate. All isolates were susceptible to tigecycline when using the breakpoint for Enterobacteriaceae defined by the FDA. The MIC50 and MIC90 of imipenem were 16 and 64 μg/ml, respectively, whereas MIC50 and MIC90 of meropenem were 32 and 128 μg/ml, respectively (Table 2).

Molecular typing. The results of PFGE and MLST are summarized in Fig. 1, along with the information on the specimen sources and the hospital locations.

PFGE. PFGE was performed on all 65 isolates. Using a cutoff of 80% similarity, the isolates were grouped into 24 clusters (Fig. 1). The largest cluster contained 13 isolates from St. Louis and Pittsburgh. The second and third largest clusters had 7 and 6 isolates from New York and Los Angeles, respectively. Only one other cluster contained isolates from more than one hospital (one isolate each from Pittsburgh and Las Vegas).

MLST. (i) Bartual scheme. At least one isolate from each cluster was selected for MLST. Overall, 36 of the 65 isolates were typed by MLST under the Bartual scheme. The STs...
FIG. 1. PFGE and MLST results from the carbapenem-nonsusceptible study isolates. STs are based on the Bartual scheme.
We only determined ST for approximately half of the study isolates. If we assume that isolates from the same PFGE cluster belong to the same clonal complex, then 55 of the 65 isolates would be assigned to CC92.

(ii) Pasteur Institute scheme. To examine how the two MLST schemes compare, we then conducted MLST based on the Pasteur Institute scheme for isolates representing each ST based on the Bartual scheme. The five STs representing CC92 under the latter scheme were all assigned to ST2 under the Pasteur Institute scheme (Table 3).

Carbapenemase-encoding genes. Twenty-seven of the 65 isolates (42%) were positive for bla<sub>OXA-23</sub> by PCR. Thirteen of them were subjected to sequencing of the entire gene, and they were all consistent with OXA-23, underscoring the homogeneity of this enzyme. bla<sub>OXA-23</sub>-positive isolates were found from all six hospitals and in multiple STs (ST122 and ST204 to -208). Nine isolates (14%) were positive for bla<sub>OXA-40</sub>. Seven of them were from ST123 isolates from New York and were found to encode OXA-40 upon sequencing, which is a single-amino-acid variant of OXA-40 (32). The other two isolates were from Pittsburgh (ST122) and Jacksonville (ST124) and encoded OXA-40. None of the isolates was positive for bla<sub>OXA-58</sub>. Forty-two isolates (65%) were positive for the IS<sub>Abba</sub>/bla<sub>OXA-51-like</sub> complex, which may contribute to carbapenem resistance (33). Two isolates were negative for any of the carbapenemase genes mentioned above.

**DISCUSSION**

It is increasingly recognized that *A. baumannii* is clonal in nature and that a large part of the global epidemic of multidrug-resistant *A. baumannii* is driven by strains that belong to EU11, in particular those defined as CC92 by MLST (11, 15, 17, 21, 23, 28). In the United States, an outbreak of multidrug-resistant *A. baumannii* from a hospital in Houston that took place between 2005 and 2006 was caused by CC92 strains (30). A survey of bacteremic isolates collected from 52 U.S. hospitals between 1998 and 2004 also showed the preponderance of CC92 isolates in U.S. hospitals (11, 13, 15, 17, 21, 23, 28, 32, 37). The next most common ST was ST204 (4 isolates), which along with ST206 (1 isolate) comprised isolates from three hospitals and also belonged to CC92. Three isolates belonged to CC113, which is commonly reported from Argentina and Brazil (http://pubmlst.org/abaumannii/) (12a). They included ST124 (1 isolate) and ST203 to -208 and ST345. ST203 was identified in nine of the six hospitals and in multiple STs (ST122 and ST204 to -208). Nine isolates (14%) were positive for bla<sub>OXA-40</sub>. Seven of them were from ST123 isolates from New York and were found to encode OXA-40 upon sequencing, which is a single-amino-acid variant of OXA-40 (32). The other two isolates were from Pittsburgh (ST122) and Jacksonville (ST124) and encoded OXA-40. None of the isolates was positive for bla<sub>OXA-58</sub>. Forty-two isolates (65%) were positive for the IS<sub>Abba</sub>/bla<sub>OXA-51-like</sub> complex, which may contribute to carbapenem resistance (33). Two isolates were negative for any of the carbapenemase genes mentioned above.
ular epidemiology of carbapenem-nonsusceptible *A. baumannii* in U.S. hospitals, with the aim of identifying predominant clonal lineages currently circulating in this country.

Our analysis revealed CC92 to be the most prevalent clonal complex, identified in isolates from all 6 participating hospitals. Interestingly, however, ST92, the predicted founder of CC92 and reported from a number of European and East Asian countries as well as Australia, was not found in this study. Instead, ST122, ST123, ST204, ST206, and ST208 were identified as CC92 STs, with predominance of ST122 and ST208, both of which were found in 4 of the 6 participating hospitals. While ST123 was only found in the hospital in New York in this study, we previously reported this ST from an isolate in Pittsburgh (32). To our knowledge, these STs have not been identified outside the United States. Furthermore, they share a novel *gdhB* allele encoding quinoprotein glucose dehydrogenase B (allele 61), with the exception of ST206. Taken together, these findings may suggest that the current epidemic of carbapenem-nonsusceptible CC92 strains in the United States represents clonal expansion of progenitor strains, which was likely facilitated by patient transfer, rather than repeated importation of CC92 strains from overseas. The other clonal complex identified in this study was CC113 (ST124 and ST205). Only two singletons were identified from the other pan-European lineages: ST203 from New York (EUIII) and ST207 from Los Angeles (EUII), further underscoring the clonal nature of carbapenem-nonsusceptible *A. baumannii* isolates currently circulating in the United States.

While MLST is a powerful molecular typing methodology, its cost could be forbidding for routine use. We opted to first group isolates by PFGE, which is more discriminatory than MLST, and then subject representative isolates from each pulse type to MLST. As can be seen in Fig. 1, the isolates from the same hospital tended to cluster together. There were also some instances where isolates from different hospitals could be categorized as the same pulse type (e.g., ST122 isolates from Pittsburgh and St. Louis), but the PFGE patterns were generally diverse for isolates from different hospitals, even when the STs were identical. This finding is in line with the operating characteristics of these two typing methods, where PFGE is well suited for studying isolates from a defined temporal and spatial epidemiologic setting, whereas MLST has an advantage in defining clonal lineages of isolates from larger geographic areas over time.

It has been suggested that two MLST loci used in the Bartual scheme (*gyrB* and *gpi*) are prone to recombination (13). In our comparison of the two MLST schemes, ST2 under the Pasteur Institute scheme was represented by 5 STs under the Bartual scheme. This variation resulted from the presence of 4, 3, and 2 alleles at the *gpi*, *gyrB*, and *gdhB* loci in the Bartual scheme, respectively. We did not have enough STs in EUI and EUIII to make a useful comparison.

As expected, *bla*<sub>OXA-23</sub> was the most common carbapenemase-encoding gene, which was found across different clonal complexes of carbapenem-nonsusceptible isolates from all hospitals. Globally, *bla*<sub>OXA-23</sub> is the most prevalent acquired carbapenemase-encoding gene that is associated with carbapenem resistance (21). *bla*<sub>OXA-40</sub> and its variant *bla*<sub>OXA-72</sub> were found in isolates from three hospitals. The finding of isolates with *bla*<sub>OXA-23</sub> and *bla*<sub>OXA-72</sub> from the hospital in New York was noteworthy, since a previous comprehensive study describing resistance mechanisms of 40 multidrug-resistant *A. baumannii* isolates collected from hospitals in the area between 2001 and 2006 did not reveal the presence of acquired OXA-type carbapenemase-encoding genes (4). It is thus possible that an ST204 strain with *bla*<sub>OXA-23</sub> and an ST123 strain with *bla*<sub>OXA-72</sub> were introduced in the area between the two study periods.

While the primary scope of this study was molecular epidemiology, we also found that susceptibility to ampicillin-sulbactam was maintained in 33 of 65 isolates, all of which were nonsusceptible to at least one carbapenem tested. They included 12 *bla*<sub>OXA-23</sub>-positive isolates, 2 *bla*<sub>OXA-40</sub>-positive isolates, and 7 *bla*<sub>OXA-72</sub>-positive isolates. Sulbactam, the beta-lactamase inhibitor component of this formulation, is known to have intrinsic activity against *A. baumannii*, which is believed to be due to its high affinity to certain penicillin-binding proteins (35). Several clinical studies have suggested that ampicillin-sulbactam may be clinically efficacious in the management of infections due to carbapenem-resistant *A. baumannii* (3, 22). While susceptibility to tigecycline was maintained well, we included only the initial isolate from each patient for this study. Since resistance to tigecycline may develop in subsequent isolates after exposure to this agent (24, 27), our results may underestimate the prevalence of nonsusceptibility on a per case basis.

The limitation of our study was that the isolates were collected in a relatively brief time period at some of the participating hospitals, which may not represent the overall epidemiology of carbapenem-nonsusceptible *A. baumannii* at those hospitals. Based on our findings, we plan to conduct a longitudinal surveillance study to further elucidate the epidemiology of this organism in the United States.

In conclusion, STs representing CC92 appear to be predominant among carbapenem-nonsusceptible *A. baumannii* isolates in U.S. hospitals, suggesting that they constitute part of the global epidemic driven by this clonal complex belonging to EUII. However, the finding that STs in CC92 were not ST92 but predominantly ST122 and ST208, which are thus far unique to the United States, suggests that these organisms may be spreading through transfer of colonized patients between health care facilities within the country.

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