Molecular and genetic characterization of emerging carbapenemase-producing *Acinetobacter baumannii* strains from patients and hospital environments in Bangladesh

Refath Farzana a,c, Göte Swedberg b, Christian G. Giske d, Badrul Hasan a,b,d, *

a Section for Infectious Diseases, Department of Medical Sciences, Uppsala University, Uppsala, Sweden
b Department of Medical Biochemistry and Microbiology, Uppsala University, Uppsala, Sweden
c Department of Medical Microbiology, Institute of Infection and Immunity, Cardiff University, UK
d Department of Laboratory Medicine, Division of Clinical Microbiology, Karolinska Institutet, Stockholm, Sweden

**SUMMARY**

**Background:** Carbapenemase-producing multidrug-resistant (MDR) *Acinetobacter baumannii* is a global health care problem. MDR *A. baumannii* has emerged as an important nosocomial pathogen, costing many lives worldwide including Bangladesh.

**Aim:** To investigate the detailed molecular epidemiology of carbapenem-resistant *A. baumannii* (CRAB) both from patients and the hospital environment, to shed light on genetic characteristics and transmission dynamics.

**Methods:** A set of 49 clinical *A. baumannii* strains collected during early 2015 was received from the clinical microbiology laboratory of Dhaka Medical College Hospital (DMCH) in Bangladesh. Additionally, 100 environmental samples were also collected from the hospital surfaces of Dhaka Medical College Hospital and analyzed for carbapenemase-producing *A. baumannii*. CRAB were identified by culture on selective plates, biochemical testing and MALDI-TOF. All isolates were characterized by susceptibility testing, realtime-PCRs, conventional PCR, MLST and sequencing.

**Findings:** Clinical *A. baumannii* were resistant to ciprofloxacin (100%), imipenem (91.8%), meropenem (91.8%), gentamicin (91.8%), amikacin (87.7%), and trimethoprim-sulfamethoxazole (61.2%). The majority (59%) of the isolates were MDR. All environmental *A. baumannii* (n=10) were resistant to imipenem, meropenem, gentamicin, amikacin, and ciprofloxacin. Strains carried the following antibiotic resistant genes; *bla*OXA-23, *bla*OXA-58, *bla*PER-7, *qnr*B1, *qnr*C1, *aac*(6)*Ib-cr* and *arm*A. A total of 36 different clones were identified by rep-PCR and common clonal clusters were found both in patients and hospital environments. MLST analysis revealed different sequence types (ST2, ST10, ST149, ST575, ST1063 and ST1065). In clinical and environmental settings, *A. baumannii* ST2 dominated.

* Corresponding author: Department of Medical Biochemistry and Microbiology, Uppsala University, SE-75123, Uppsala, Sweden.
  Tel.: +46 (0)18 4714264; fax: +46 (0)184714673.
  E-mail address: badrul.hasan@imbim.uu.se (B. Hasan).

https://doi.org/10.1016/j.infpip.2022.100215
2590-0889/© 2022 The Authors. Published by Elsevier Ltd on behalf of The Healthcare Infection Society. This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/).
Introduction

*Acinetobacter baumannii* is an important opportunistic pathogen that has increasingly been reported worldwide. *A. baumannii* has emerged as an important nosocomial pathogen, costing many lives worldwide [1]. Over the last decades, multidrug-resistant (MDR) *A. baumannii* has become a serious public health issue as the treatment options are extremely limited. Different antibiotic resistance phenotypes and genotypes have been reported in *A. baumannii*. For example, *bla*PER-7 is an extended-spectrum β-lactamase with increased activity toward broad-spectrum cephalosporins in *A. baumannii* [2]. The most concerning resistance mechanism in this species is production of carbapenemases such as *bla*OXA-23-like, *bla*OXA-51-like, *bla*OXA-58-like, and *bla*OXA-143-like, as well as metallo-β-lactamases (MBL), most notably the New Delhi carbapenemase *bla*NDM [1,3,4]. Carbapenemase-producing *A. baumannii* has been reported globally, including in several developing countries [1,3,4]. Carbapenem resistance tends to occur in conjunction with other antibiotic resistances, such as fluoroquinolones and aminoglycosides. Several reports indicate that fluoroquinolone (e.g. *aac(6’)-Ib-cr*) and aminoglycoside (e.g. *armA*) resistance genes can be harboured on the same plasmids as those carrying genes encoding carbapenemase production [5]. In addition to antibiotic resistance, the ability to form biofilms is an important virulence factor in *A. baumannii*. Several genes are involved in biofilm formation of *A. baumannii* such as *csu* locus (encoding the chaperone–usher Csu fimbriae), *pga* locus (encoding the polysaccharide poly-N-acetyl-glucosamine), and *bap* (encoding the biofilm-associated protein) [6]. These genes are frequently reported in clinical isolates of *A. baumannii* [6].

In recent years, an increasing frequency of MDR *A. baumannii* infection has been causing severe problems among patients admitted to hospitals in Bangladesh. Infection control practice and medical waste management in Bangladeshi hospitals is very poor or hardly practiced [7]. Only a limited number of reports have so far described the burden of carbapenem-resistant *A. baumannii* carrying MBL genes in this geographical setting, and these reports are insufficient for understanding the detailed epidemiology or for assessing the human health risks associated with the hospital environments and medical devices in Bangladeshi hospitals [8]. The aim of this study was to investigate the detailed molecular epidemiology of carbapenem-resistant *A. baumannii* both from patients and the hospital environment, to shed light on genetic characteristics and transmission dynamics. In addition, some genes related to biofilm production were investigated for.

Methods

Ethical permission

Ethical approval was obtained from the Ethical Committee of Dhaka Medical College Hospital (DMC/Ethical/2013-159) to perform this study.

Sample collection and bacterial identification

In Sweden, we received a collection of 49 clinical *A. baumannii* isolates from the clinical microbiology laboratory of the Dhaka Medical College Hospital in Dhaka City, Bangladesh. All isolates were collected between January and March 2015 from 73 patients in various wards (Example: ICU, surgery, medicine, burn unit, obstetrics, and gynecology). Sources of the isolates included blood, urine, wound swab, cerebrospinal fluid, high vaginal swabs, catheter tips and tracheal aspirates. At the same time, 100 samples were collected from different environmental surfaces of the Dhaka Medical College Hospital using Amies transport medium (Sarstedt, Nürnberg, Germany); sites sampled were bed rails, bed sheets, switchboards, sinks, blood pressure cuffs, ventilators, catheters, O2 masks, suckers, toilets, and sewage-drains. *A. baumannii* clinical isolates were cultured on CHROMagar*™* Acinetobacter media. Environmental samples were enriched at 37°C overnight in Tryptic Soy broth supplemented with meropenem (0.125 mg/L), followed by inoculation onto CHROMagar*™* Acinetobacter media (CHROMagar, France). Species identification was performed using biochemical tests (e.g. oxidase and catalase) followed by MALDI-TOF/MS (Bruker Daltonics, Billerica, MA).

Phenotypic and genotypic characterization of antibiotic resistance and biofilm

All clinical and environmental strains were subjected to antibiotic susceptibility testing. EUCAST disc diffusion susceptibility testing was performed using 7 clinically important antibiotics; ciprofloxacin (5 μg), imipenem (10 μg), meropenem (10 μg), gentamicin (10 μg), amikacin (30 μg) and trimethoprim-sulfamethoxazole (25 μg). All discs were provided by Oxoid Ltd. (Basingstoke, Hampshire, England). *Escherichia coli* ATCC 25922 and *Pseudomonas aeruginosa* ATCC27853 were used as quality control strains. Isolates with resistance to three or more antibiotic classes were considered as MDR strains.

Genomic DNA was extracted from overnight culture by Maxwell® 16 Cell DNA Purification Kit (Promega, Madison, USA) using automated Maxwell® 16 SEV Instrument. Each extracted genomic DNA was centrifuged for 10 minutes at 13000 rpm and supernatant was stored at -20°C for further uses.

Conclusion: Widespread dissemination of MDR *A. baumannii* in the DMC hospital of Bangladesh is a serious problem.
The OXA-carbapenemase genes were screened; the presence of bla<sub>OXA-23</sub>-like, bla<sub>OXA-24</sub>-like, bla<sub>OXA-58</sub>-like, and bla<sub>OXA-143</sub>-like genes were investigated by PCR, as described previously [9,10]. The screening of MLSB genes was also performed by various real-time-PCRs for bla<sub>qim</sub>, bla<sub>qim</sub>, bla<sub>qim</sub>, bla<sub>Gim</sub>, bla<sub>qpa</sub> and bla<sub>SIM</sub> [11]. All isolates were screened for bla<sub>pem</sub> using a method described previously [12]. Detection of bla<sub>PER</sub> was performed using a method described before on selected strains [2]. The strains displaying resistance to aminoglycosides and fluoroquinolones were further tested for their respective resistance genes. To detect fluoroquinolone resistance genes (qnrA1, qnrB1, qnrS1, qepA, qnrC1 and aac(6)′-Ib-cr), a series of PCRs were performed [13,14]. Screening for the presence of 16S rDNA-methylase encoding genes (rmtA, rmtB, rmtC, rmtD, armA) was among aminoglycoside resistant isolates by simplex and multiplex PCRs [15]. A set of strains with known MLST-types were selected to investigate for biofilm-associated genes; the presence of the biofilm related genes bap, csuE, and pgaB were assessed using PCR as described previously [16–18]. PCR products were purified and sequenced by Eurofins MWG Operon (Ebersberg, Germany) for detail genotypic characterization.

Epidemiological typing by rep-PCR and MLST

The genetic fingerprint of A. baumannii isolates was determined by rep-PCR using ERIC1R (5′-ATGTAAGCTCTGGG-GATTACCA-3′) primer. Briefly, amplification was conducted in a total volume of 25 μl containing 2 mM dNTP, 10x PCR buffer, 25 mM MgCl2, 5 U/μl of HotStar taq polymerase (QIAGEN GmbH, Hilden, Germany), primer ERIC1R and 5 μl of the DNA template. Cycling parameters were as follows: 1 min at 94°C, 1 min. at 36°C, and 2 min. at 72°C for 45 cycles. A final extension at 72°C for 5 min. was performed afterward. The amplified products were visualized on a 1.5 % agarose gel and band patterns were further analyzed visually. In order to explore detailed epidemiological features and sequence types (ST), 15 clinical isolates were selected randomly for MLST analysis according to Pasteur’s MLST scheme (http://pubmlst.org/abaumannii/) focusing on 7 standard housekeeping genes (cpx60, fusA, gltA, pyrG, recA, rplB and rpoB). Additionally, all environmental (n=10) isolates were also included in the MLST analysis. PCR amplification was carried out in T100™ Thermal Cycler (Bio-rad, USA). PCR products were purified according to the manufacturer’s instructions using a QIAquick PCR purification kit (Qiagen, Germany) and then sequenced at Eurofins MWG Operon, Germany. Determination of the sequence type was carried out using the Pasteur MLST Database.

Results

Strain distribution and antibiotic resistance profile

In total, 49 clinical isolates and 10 environmental isolates were confirmed as A. baumannii. Clinical A. baumannii were resistant to ciprofloxacin (100%), imipenem (91%), meropenem (91%), gentamicin (91%), amikacin (87%), and trimethoprim-sulfamethoxazole (61%). The majority (~59%) of the isolates were MDR (resistant to 3–4 different antibiotic classes). All environmental A. baumannii were completely resistant to imipenem, meropenem, gentamicin, amikacin, and ciprofloxacin. All environmental isolates were MDR (resistant to 3–4 different antibiotic classes). The phenotypic diversity of antibiotic resistance among all the clinical and environmental A. baumannii is presented in Table 1.

Detection of antibiotic resistance and biofilm genes

Genotypic screening of clinical samples revealed the presence of bla<sub>OXA-23</sub> in 41 strains and bla<sub>OXA-58</sub> in one strain. The genes bla<sub>OXA-23</sub> and bla<sub>OXA-58</sub> are considered as carbapenem resistance markers. The gene bla<sub>PER</sub> was present in 6 clinical strains. Other genes detected among the clinical A. baumannii isolates were aac(6)′-Ib-cr (1/49) and qnrB1 (7/49) encoding fluoroquinolone resistance, and armA (33/49) encoding aminoglycoside resistance. All environmental A. baumannii were positive for bla<sub>OXA-23</sub> but no bla<sub>OXA-58</sub> genes were found in the environmental collection. The bla<sub>PER</sub> was present in 4 environmental strains. Regarding fluoroquinolone resistance markers, only qnrC1 was found in one environmental strain. The aminoglycoside resistance gene armA was present in 8 environmental strains. All tested A. baumannii strains were positive for biofilm-related genes; bap, csuE, and pgaB were found in both clinical and environmental samples.

Epidemiologic features of A. baumannii

Epidemiological typing by rep-PCR identified 36 different genotypes from the clinical and environmental sets. Isolates differing by one strong band or more were assigned to different genotypes, whereas isolates differing with one weak band from their genotype were assigned to different subtypes. The predominant genotypes were AC and FC. There were some genotypes (AC, BC, DC, FC, HC and PC) that were predominantly circulating only in patients. Some of the A. baumannii genotypes were found both in humans and the hospital environment, such as CC, RC, P3, and P6. Notably, environmentally disseminated genotypes RC and P6 were found in ICU environments. MLST analysis of all clinical and environmental A. baumannii isolates (n=25) revealed 6 different sequence types; ST2 (n=16), ST10 (n=2), ST149 (n=2), ST575 (n=3), ST1063 (n=1) and ST1065 (n=1). ST1063 and ST1065 were novel sequence types assigned by MLST curator. ST1063 and ST1065 were described previously [16–18].

Table 1

| Antibiotic Resistance Phenotypes | No of Isolates | Source |
|---------------------------------|---------------|--------|
| IPM-MEM-AK-CN-CIP-SXT           | 28 (26+2)     | Human & Environment |
| IPM-MEM-AK-CIP-SXT              | 3             | Human |
| IPM-MEM-AK-CN-CIP               | 22 (14+8)     | Human & Environment |
| IPM-MEM-CN-CIP                  | 2             | Human |
| CN-CIP-SXT                      | 1             | Human |
| CN-CIP                          | 2             | Human |
| CIP                             | 1             | Human |
| IMP: Imipenem(10μg), MER: Meropenem(10μg), CN: Gentamicin(10μg), AK: Amikacin(30μg), CIP: Ciprofloxacin(5μg) and SXT: Trimethoprim-sulfamethoxazole(25μg). | | |
ST1065 have their evolutionary origins from ST149 and ST25 respectively. A detailed epidemiologic and molecular profile is shown in Table 2.

**Discussion**

In this study, a majority of the clinical and environmental strains were MDR; displaying resistance to 3–4 different groups of broad spectrum antibiotics. Ciprofloxacin, gentamicin, amikacin and trimethoprim-sulfamethoxazole are extensively used in human medicine [19]. Genotypic analysis revealed the presence of blaOXA-23 and blaOXA-58 genes as carbapenemase-encoding genes. The blaOXA-23 gene is global disseminated in patients and hospital environments, including Asian countries [3,20]. Thus, blaOXA-23 is widely disseminated in patients and hospital environments of the examined hospitals of Bangladesh. On the other hand, the blaOXA-58 gene has not been able to spread as widely in Bangladesh as it has in other Asian countries [20]. The blaper-7 gene is plasmid-associated and has been reported in clinical isolates in the United Arab Emirates [2]. The blaper-7-carrying A. baumannii isolates are reported in Bangladesh for the first time and found in both clinical and environmental isolates, indicating that the gene could be widespread in Bangladesh. All clinical and environmental isolates were phenotypically resistant to ciprofloxacin and few of their corresponding genotypes were found through molecular approach; qnrB1, acc(6)-Ib-cr and qnrC1. Since all A. baumannii isolates were phenotypically resistant to fluoroquinolones, and genotyping screening revealed few plasmid-mediated fluoroquinolone resistance determinants, it is likely that the remaining isolates had chromosomal resistance mechanisms [21]. In this study, armA was the only aminoglycoside resistance gene found in the majority of the aminoglycoside resistant isolates. Hospital dissemination of armA in relation to high levels of aminoglycoside resistance in A. baumannii was reported from Asia [22]. MDR A. baumannii isolates are widespread in both the clinical and environmental settings of Bangladeshi hospitals, therefore, leaving limited options for the treatment of A. baumannii infections in Bangladesh.

Studies suggested that antibiotic resistant bacteria are highly associated with biofilm formation capacities, and biofilm related genes of A. baumannii including bap, csuE, and pgaB were responsible for biofilm development [6]. In this study, both clinical and environmental isolates with known sequence types were carrying all biofilm-associated genes investigated: bap, csuE, and pgaB. This is the first study reporting the presence of biofilm associated genes in the A. baumannii isolates from patients and hospital environments in Bangladesh.

The epidemiological typing identified some dominant clinical genotypes found in the ICU of the hospital. There were some other minor genotypes found both in ICU and non-ICU hospital environments including medical devices, which indicates cross contamination of the ICU from environmental sources or vice versa. The dissemination and dominance of A. baumannii clonal type ST 2 was reported in several hospitals globally [1]. MLST indicated that A. baumannii ST2 (international clone 2) was disseminated in hospital settings of Bangladesh. A majority of the Bangladeshi A. baumannii ST2 were associated with blaoxa-23 and armA genes, and this strain type

**Table 2**

| MLST type | rep-PCR profile | Antibiotic resistance genes | Biofilm genes | Source |
|-----------|-----------------|----------------------------|---------------|--------|
| ST149     | CC              | armA+blaOXA-23+blaper-7    | bap, csuE, pgaB | Human |
|           | CC              | armA+blaOXA-23+blaper-7    | bap, csuE, pgaB | Environment (Ventilator) |
| ST2       | P3              | armA+blaOXA-23             | bap, csuE, pgaB | Human |
|           | AC              | qnrB1+armA+blaOXA-23       | bap, csuE, pgaB | Human |
|           | AC              | armA+blaOXA-58             | bap, csuE, pgaB | Human |
|           | BC              | qnrB1+armA+blaOXA-23       | bap, csuE, pgaB | Human |
|           | BC              | qnrB1+armA+blaOXA-23       | bap, csuE, pgaB | Human |
|           | PC              | armA+blaOXA-23             | bap, csuE, pgaB | Human |
|           | FC              | qnrB1+armA+blaOXA-23       | bap, csuE, pgaB | Human |
|           | WC              | acc(6)-Ib-cr+armA+blaOXA-23+blaper-7 | bap, csuE, pgaB | Human |
|           | Z4              | armA+blaOXA-23             | bap, csuE, pgaB | Environment (Catheter) |
|           | Z4              | armA+blaOXA-21             | bap, csuE, pgaB | Environment (Ventilator) |
|           | Z3              | armA+blaOXA-23             | bap, csuE, pgaB | Environment (Bed side table) |
|           | P1              | armA+blaOXA-21             | bap, csuE, pgaB | Human |
|           | P6              | armA+blaOXA-21             | bap, csuE, pgaB | Environment (Ventilator) |
|           | RC              | armA+blaOXA-23             | bap, csuE, pgaB | Environment (Oxygen mask) |
|           | P3              | armA+blaOXA-23             | bap, csuE, pgaB | Environment (Bed sheet) |
| ST10      | P6              | armA+blaOXA-23+blaper-7    | bap, csuE, pgaB | Human |
|           | QC              | armA+blaOXA-23+blaper-7    | bap, csuE, pgaB | Human |
| ST575ss   | RC              | blaoxa-23+blaper-7         | bap, csuE, pgaB | Human |
|           | Z2              | qnrC1+blaoxa-23+blaper-7   | bap, csuE, pgaB | Environment (Sucker) |
| ST1063    | EC              | armA+blaoxa-23+blaper-7    | bap, csuE, pgaB | Human |
| ST1065    | Z1              | armA+blaoxa-23+blaper-7    | bap, csuE, pgaB | Environment (Toilet Sink) |
has a global spread that includes other Asian countries like Vietnam [23]. In the present study, ST10 and ST575 were found to be common after ST2 in this Bangladeshi hospital. In this study, *A. baumannii* ST575 was the second most dominant sequence type, found in both clinical and environmental settings of Bangladesh, which was reported previously as an emerging strain in Vietnam [23]. The sharing of common ST clusters between clinical and environmental strains indicated cross contamination and suggests problems with infection control practices. The presence of these *A. baumannii* STs in surfaces of the hospital could potentially be a source of hospital-acquired infections.

Hygiene practices are very poorly managed or not managed at all in a majority of Bangladeshi hospitals due to limited economic and technical resources (personal communication). A study from Bangladesh reported an abundance of ESBL-producing bacteria in patients and hospitals environments resulting from mismanagement of hospital wastes and poor hygiene practices [7]. Improper hospital hygiene, overcrowding, misuse of antibiotics, and poor infection control strategies seem to be contributing factors to this situation in Bangladeshi hospitals. Thus, the spread of carbapenem-resistant clones is an indication of the concerning situation in major Bangladeshi hospitals.

**Conclusion**

Carbapenemase-producing MDR *A. baumannii* capable to develop biofilm were found in patients and in environmental cultures from Bangladeshi hospitals. This study explored the dissemination of carbapenem-resistant *A. baumannii* clones in hospital settings in Bangladesh and indicate the possible clonal spread. This warrants further detailed investigation by high-resolution typing method like whole genome sequencing. There is an urgent need to establish nationwide antimicrobial resistance surveillance and infection control strategies in Bangladeshi hospitals.

**Credit author statement**

Refath Farzana; Methodology, Investigation, Formal analysis, Writing- Original draft. Göte Swedberg; Formal analysis, Writing - Review & Editing. Christian G. Giske; Formal analysis, Writing - Review & Editing. Badrul Hasan; Conceptualization, Funding acquisition, Supervision, Investigation, Methodology, Formal analysis, Writing - Review & Editing.

**Conflict of interest**

No competing financial interests exist.

**Funding**

This work was financially supported by Emil & Ragna Börjeson Foundation (Uppsala University), ISID-ESCMID fellowship scheme (International Society for Infectious Diseases), Tore Nilson’s Fund for Medical Research (2014-00083) and Åke Wibergs Foundation (M14-0291).

**Acknowledgements**

The authors would also like to thank the Dept. of Microbiology at Dhaka Medical College for providing facilities for sample processing. We thank the team of curators of the Institut Pasteur Acinetobacter MLST system for curating the data and making them publicly available at http://pubmlst.org/abaumannii/.

**References**

[1] Zarrilli R, Giannouli M, Tomasone F, Triassi M, Tsakris A. Carbapenem resistance in Acinetobacter baumannii: the molecular epidemic features of an emerging problem in health care facilities. J Infect Dev Ctries 2009;3(5):335–41.

[2] Opazo A, Sonnevend A, Lopes B, Hamouda A, Ghazawi A, Pal T, et al. Plasmid-encoded PER-7 β-lactamase responsible for ceftazidime resistance in Acinetobacter baumannii isolated in the United Arab Emirates. J Antimicrob Chemotherapy 2012;67(7):1619–22. https://doi.org/10.1093/jac/dks087.

[3] Hasan B, Perveen K, Olsen B, Zahra R. Emergence of carbapenem-resistant Acinetobacter baumannii in hospitals in Pakistan. J Med Microbiol 2014;63(Pt 1):50–5. https://doi.org/10.1099/jmm.0.063925-0.

[4] Peleg AY, Seifert H, Paterson DL. Acinetobacter baumannii: emergence of a successful pathogen. Clin Microbiol Rev 2008;21(3):538–82. https://doi.org/10.1128/cmr.00058-07.

[5] Yang H, Hu L, Liu Y, Ye Y, Li J. Detection of the plasmid-mediated quinolone resistance determinants in clinical isolates of Acinetobacter baumannii in China. J Chemother 2015:1973947815y000000017. https://doi.org/10.1179/1973947815y.0000000017.

[6] Thummeepak R, Kongthai P, Leungtongkam U, Sittisak S. Distribution of virulence genes involved in biofilm formation in multidrug resistant Acinetobacter baumannii clinical isolates. Int Microbiol 2016;19(2):121–9. https://doi.org/10.2436/20.1501.01.270.

[7] Hasan Badrul OB, Alam Ahasanul, Laboni Akter. Melhus Åsa. Dissemination of multidrug resistant ESBL-producing E.coli O25b-ST131 Clone and role of House Crow (Corvus splendens) foraging on hospital waste in Bangladesh. Clin Microbiol Infect 2015. http://www.clinicalmicrobiologyandinfection.com/article/S1198-743X(15)00661-8/abstract.

[8] Farzana R, Shamsuzzaman S, Mamun KZ. Isolation and molecular characterization of New Delhi metallo-beta-lactamase-1 producing superbug in Bangladesh. J Infect Dev Ctries 2013;7(3):161–8. https://doi.org/10.3855/jidc.2493.

[9] Woodford N, Ellington MJ, Coelho JM, Turton JF, Ward ME, Brown S, et al. Multiplex PCR for genes encoding prevalent OXA carbapenemases in Acinetobacter baumannii strains. J Antimicrob Agents 2006;27(4):351–3. https://doi.org/10.1016/j.ijantimicag.2006.01.004.

[10] Higgins PG, Lehmann M, Seifert H. Inclusion of OXA-143 primers in a multiplex polymerase chain reaction (PCR) for genes encoding prevalent OXA carbapenemases in Acinetobacter baumannii. J Antimicrob Agents 2010;35(3):305. https://doi.org/10.1016/j.ijantimicag.2009.10.014.

[11] Swayne R, Ellington MJ, Curran MD, Woodford N, Aliyu SH. Utility of a novel multiplex TaqMan PCR assay for metallo-β-lactamase genes plus other TaqMan assays in detecting genes encoding serine carbapenemases and clinically significant extended-spectrum β-lactamases. Int J Antimicrob Agents 2013;42(4):352–6. https://doi.org/10.1016/j.ijantimicag.2013.06.018.

[12] Poirel L, Walsh TR, Cuvillier V, Nordmann P. Multiplex PCR for detection of acquired carbapenemases genes. Diagn Microbiol Infect Dis 2011;70(1):119–23. https://doi.org/10.1016/j.diagmicrobio.2010.12.002.
[13] Park CH, Robicsek A, Jacoby GA, Sahm D, Hooper DC. Prevalence in the United States of aac(6')-Ib-cr encoding a ciprofloxacin-modifying enzyme. Antimicrob Agents Chemother 2006;50(11):3953–5. https://doi.org/10.1128/aac.00915-06.

[14] Wang M, Guo Q, Xu X, Wang X, Ye X, Wu S, et al. New plasmid-mediated quinolone resistance gene, qnrC, found in a clinical isolate of Proteus mirabilis. Antimicrob Agents Chemother 2009;53(5):1892–7. https://doi.org/10.1128/aac.01400-08.

[15] Doi Y, Arakawa Y. 16S ribosomal RNA methylation: emerging resistance mechanism against aminoglycosides. Clin Infect Dis 2007;45(1):88–94. https://doi.org/10.1086/518605.

[16] Lee HW, Koh YM, Kim J, Lee JC, Lee YC, Seol SY, et al. Capacity of multidrug-resistant clinical isolates of Acinetobacter baumannii to form biofilm and adhere to epithelial cell surfaces. Clin Microbiol Infect 2008;14(1):49–54. https://doi.org/10.1111/j.1469-0691.2007.01842.x.

[17] Braun G, Vidotto MC. Evaluation of adherence, hemagglutination, and presence of genes conferring for virulence factors of Acinetobacter baumannii causing urinary tract infection. Mem Inst Oswaldo Cruz 2004;99(8):839–44. https://doi.org/10.1590/s0074-02762004000800010.

[18] Liou ML, Soo PC, Ling SR, Kuo HY, Tang CY, Chang KC. The sensor kinase BfmS mediates virulence in Acinetobacter baumannii. J Microbiol Immunol Infect 2014;47(4):275–81. https://doi.org/10.1016/j.jmii.2012.12.004.

[19] Biswas M, Roy DN, Tajmim A, Rajib SS, Hossain M, Farzana F, et al. Prescription antibiotics for outpatients in Bangladesh: a cross-sectional health survey conducted in three cities. Ann Clin Microbiol Antimicrob 2014;13:15. https://doi.org/10.1186/1476-0711-13-15.

[20] Mendes RE, Bell JM, Turnidge JD, Castanheira M, Jones RN. Emergence and widespread dissemination of OXA-23, -24/40 and -58 carbapenemases among Acinetobacter spp. in Asia-Pacific nations: report from the SENTRY Surveillance Program. J Antimicrob Chemother 2009;63(1):55–9. https://doi.org/10.1093/jac/dkn434.

[21] Biglari S, Hanafiah A, Mohd Puzi S, Ramli R, Rahman M, Lopes BS. Antimicrobial Resistance Mechanisms and Genetic Diversity of Multidrug-Resistant Acinetobacter baumannii Isolated from a Teaching Hospital in Malaysia. Microb Drug Resist 2017;23(5):545–55. https://doi.org/10.1089/mdr.2016.0130.

[22] Shen M, Luan G, Wang Y, Chang Y, Zhang C, Yang J, et al. Coexistence of blaOXA-23 with armA in quinolone-resistant Acinetobacter baumannii from a Chinese university hospital. Diagn Microbiol Infect Dis 2016;84(3):230–1. https://doi.org/10.1016/j.diagmicrobio.2015.10.009.

[23] Tada T, Miyoshi-Akiyama T, Shimada K, Nga TT, Thu le TA, Son NT, et al. Dissemination of clonal complex 2 Acinetobacter baumannii strains co-producing carbapenemases and 16S rRNA methylase ArmA in Vietnam. BMC Infect Dis 2015;15:433. https://doi.org/10.1186/s12879-015-1171-x.