First literature review of carbapenem-resistant *Providencia*

M. Abdallah¹ and A. Balshi²
¹) Pharmaceutical Care Services and ²) Intensive Care Unit, King Saud Medical City, Riyadh, Saudi Arabia

Abstract

*Providencia* species are Gram-negative bacteria that belong to the *Enterobacteriaceae* family. They have intrinsic resistance to colistin and tigecycline, which makes treatment of the multidrug-resistant strains of *Providencia* challenging. Carbapenem-resistant *Providencia* species are increasingly reported. In this review, patients’ characteristics, resistance mechanisms, treatment and infection control measures of carbapenem-resistant *Providencia* species in the literature are described.

Keywords: Carbapenem, carbapenem-resistant, *Providencia*, rettgeri, stuartii

Original Submission: 19 March 2018; Revised Submission: 22 May 2018; Accepted: 29 May 2018

Article published online: 4 June 2018

Introduction

Species of *Providencia* are Gram-negative bacteria that belong to the *Enterobacteriaceae* family. Unlike many other bacteria of this family, species of *Providencia* are an infrequent cause of nosocomial infections. Among species of *Providencia*, *stuartii* and *rettgeri* are the most common causes of infections in hospitalized patients, mainly urinary tract infections. In addition to urinary tract infections, *P. stuartii* and *P. rettgeri* can cause pneumonia, meningitis, endocarditis, wound and bloodstream infections [1–3]. Infections with species of *Providencia* have significant impact on patients’ morbidity, mortality and treatment [4,5].

In 1904, the first species of *Providencia* was isolated by Rettger [1]. At first the bacterium was noticed in chickens; it was believed to be an epidemic of fowl cholera. The bacterium was characterized in 1918, when it was named *Bacterium rettgerii* by Hadley et al. [6]. In 1951, Kauffmann and Edwards [7] first suggested the genus name *Providencia*, which included a cluster of microorganisms studied by Stuart and colleagues at Brown University in Providence, Rhode Island, USA. By 1983, *P. rettgeri*, *P. stuartii*, *P. ocalifaciens* and *P. rustigianii* were fully differentiated with urea hydrolyzation and DNA hybridization [8]. In 1986, *P. heimbachae* was the fifth species discovered in the genus *Providencia* [9].

Species of *Providencia* are non–lactose fermenting, methyl red and phenylpyruvic acid positive bacilli. Species of *Providencia* are positive for the phenylalanine deaminase test but negative for lysine decarboxylase, ornithine decarboxylase and arginine dihydrolase tests [1]. Generally, they can be recognized by their fruity smell. Species of *Providencia* are commonly susceptible to carbapenems, amikacin, aztreonam, and second and third-generation cephalosporins including cefaclor, cefuroxime, cefetamet, cefpodoxime, ceftazidime, ceftriaxone and cefotaxime [1]. Alternative choices for antimicrobial therapy include ciprofloxacin and cotrimoxazole [1]. Species of *Providencia* are generally resistant to gentamicin, tobramycin, aminopenicillins and first-generation cephalosporins [1]. *P. stuartii* and *P. rettgeri* can produce inducible AmpC β-lactamases [10]. Moreover, plasmid-mediated resistance mechanisms such as extended-spectrum β-lactamases and metallo-β-lactamases have also been recovered from species of *Providencia* causing nosocomial infections [11,12]. Unlike other Gram-negative bacteria (e.g. *Acinetobacter baumannii*, *Klebsiella pneumonia*), species of *Providencia* have intrinsic resistance to colistin and tigecycline, which makes treatment of the multidrug-resistant (MDR) strains of this pathogen challenging. Resistance can be transmissible from...
MDR Providencia species to other bacterial pathogens like susceptible strains of Escherichia coli and vice versa by transformation and conjugation [11,13]. Carbapenem-resistant Providencia species are increasingly reported.

In this review, patients’ characteristics, resistance mechanisms, treatment and infection control measures of carbapenem-resistant Providencia species in the literature are described.

Methods

We performed a nonsystematic narrative review about carbapenem-resistant Providencia species described in the literature. PubMed was searched using the following terms: (carbapenem) AND (resistant) AND (Providencia). The search returned 52 articles; all were screened for relevance to the subject of this review. Publications in languages other than English were excluded. Additional articles of interest were identified from the references listings of reviewed articles. Species of Providencia were included in this review if the isolate test revealed resistance to any of the carbapenem agents (doripenem, ertapenem, imipenem, or meropenem) or if testing demonstrated carbapenemase production through a phenotypic or molecular assay. Twenty-nine publications met our search criteria and are the subject of this review.

Patient characteristics

Eighty cases of carbapenem-resistant Providencia were described in 29 reports (Table 1). All studies were descriptive. There were no reports that included a case—control component. The first case of carbapenem-resistant Providencia was reported from Japan in 2003 [14]. Carbapenem-resistant Providencia was detected in other countries: Afghanistan, Algeria, Argentina, Brazil, Bulgaria, Canada, China, Ecuador, Greece, India, Israel, Italy, Mexico, Nepal, Pakistan, Portugal, South Africa, South Korea, United Kingdom and United States. Carbapenem resistance was discovered in only two Providencia species: P. stuartii (39 cases were described in 11 reports) and P. rettgeri (41 cases were described in 18 reports). Carbapenem-resistant Providencia species usually infect adult immunocompromised patients; they were not reported in paediatric patients. The mean age ± SD of the patients was 50.90 ± 18.63 years. Twenty-eight subjects were male, 20 female and gender not specified in 32. Carbapenem-resistant Providencia species were isolated from urine (n = 32 cases), bloodstream (n = 20), respiratory tract sites (n = 7), catheter tip (n = 3), soft tissue (n = 3), pus (n = 2), stool (n = 2) and bone (n = 1). Carbapenem-resistant Providencia was recovered from rectal swab in one case report [15]. The site of isolation of carbapenem-resistant Providencia was not mentioned in nine instances. Four outbreaks of carbapenem-resistant Providencia were reported in the literature [5,11,16,17]; three were caused by carbapenem-resistant P. stuartii (CRPS) and one was linked to carbapenem-resistant P. rettgeri (CRPR). All the outbreaks occurred in intensive care units (ICUs).

Nine of 29 reports mentioned whether or not the patients received prior antimicrobial therapy [5,11,13,15,18–21]; all patients in the nine reports received antibiotics before detection of carbapenem-resistant Providencia species except one. In one outbreak of CRPS [5], the elevated polymyxin B consumption in that ICU, because of high rates of Pseudomonas aeruginosa and A. baumannii, might be the cause of the emergence of CRPS. One patient with CRPS in this outbreak had received prior therapy with polymyxin before CRPS detection. Four patients with CRPS received colistin before the isolation of CRPS in two reports [20,21]. Six critically ill patients were infected with a CRPS isolate in one outbreak in Greece [11], and three received prior therapy with colistin. Three patients received prior tigecycline therapy before the isolation of CRPS [11,13,20].

Length of hospitalization before isolation of carbapenem-resistant Providencia was rarely reported. However, prolonged hospitalization before isolation of carbapenem-resistant Providencia was mentioned in four reports [11,17,22,23]. Prolonged hospitalization ranging from 24 to 106 days before isolation of CRPS was present in one outbreak [11]. In another report [17], the median length of ICU stay was 39 days while acquisition of CRPS occurred in a median of 16 days after ICU admission.

Regarding CRPR, the average time to positive urine cultures for CRPR was 29 days (range, 12–68 days) in one report [22]. In another report [23], the length of hospital stay was 68 days while acquisition of CRPR occurred 52 days after ICU admission. Common equipment such as dialysis machines might facilitate the spread of carbapenem-resistant Providencia. In one outbreak of CRPR in South Africa [16], all patients with CRPR were on dialysis; dialysis machines could be the source of CRPR in this outbreak. Three patients were HIV positive, which indicates that immunocompromised patients are more susceptible to CRPR infections. It is worth mentioning that many patients with carbapenem-resistant Providencia had urinary catheters [13,15–17,24].

Mechanisms of carbapenem resistance

New Delhi metallo-β-lactamase 1 (NDM-1) is the most common resistance mechanism to carbapenems in Providencia
| Case no. | Reference | Location | Species | Year of isolation | Sex | Age (years) | Comorbidities | Site of isolation | Antimicrobial therapy | Prior antimicrobial therapy | Mechanism of carbapenem resistance | Outcome |
|----------|-----------|----------|---------|-------------------|-----|-------------|---------------|-----------------|----------------------|------------------------|----------------------------------|----------|
| 1        | 5         | Brazil   | P. stuartii | 2008 | M | 41 | NR | Urine | None | Ceftriaxone, ciprofloxacin, gentamicin | Derepression of chromosomally encoded AmpC and ESBL production | Died |
| 2        |           |          |         |                   | F | 54 | NR | Blood | Piperacillin/tazobactam plus meropenem Impenem plus amikacin | Cefepime, imipenem, polymyxin B Impenem | Discharged |
| 3        |           |          |         |                   | M | 14 | NR | Surgical wound | None for carbapenem-resistant Providencia stuartii | Cefepime, imipenem | Discharged |
| 4        |           |          |         |                   | F | 52 | NR | Central venous catheter | None | Did not receive antimicrobial therapy; it was considered colonization | NDM-1 | Discharged |
| 5        | 11        | Greece   | P. stuartii | December 2012 - March 2013 | F | 46 | NR | Tracheal aspirate | Levofloxacin | All the patients received several antimicrobial agents (β-lactams, quinolones and aminoglycosides) | VIM-1 | Discharged |
| 6        |           |          |         |                   | F | NR | NR | Urine | Cefepime | Died |
| 7        |           |          |         |                   | F | NR | NR | Catheter | Imipenem | Discharged |
| 8        |           |          |         |                   | M | 54 | NR | Tracheal aspirate | Meropenem | Died |
| 9        |           |          |         |                   | M | 27 | NR | Blood | Meropenem | Died |
| 10       |           |          |         |                   | F | 73 | NR | Blood | Meropenem | Died |
| 11       |           |          |         |                   | M | NR | NR | Blood | NR | Discharged |
| 12       | 13        | Canada   | P. stuartii | NR | M | 65 | Infected sacral ulcer | None | Cefazolin, metronidazole, tigecycline | NDM-1 | Discharged |
| 13       | 15        | Israel   | P. rettgeri | 2011 November 2014 - January 2015 | M | 74 | Diabetes, HTN, respiratory infection, HIV | Ractal swab | Imipenem | NDM-1 | NR | Transferred to high-care unit |
| 14       | 16        | South Africa | P. rettgeri | 2011 | F | 26 | Mediastral tumour, polytrauma, HIV | Urine | NR | NR | NR | Died |
| 15       |           |          |         |                   | F | 32 | RI on dialysis, HIV | Urine | NR | NR | NR | Discharged |
| 16       |           |          |         |                   | M | 40 | RI on dialysis | Urine | NR | NR | NR | Transferred to renal unit |
| 17       |           |          |         |                   | F | 33 | RI on dialysis | Tissue | NR | NR | NR | Died |
| 18       | 17        | Greece   | P. stuartii | 2011 | M | 74 | Medicalstial tumour | Blood | Piperacillin/tazobactam plus amikacin | VIM-1 | Died |
| 19       |           |          |         |                   | M | 66 | CABG, AVR, stroke | Urine | NR | NR | NR | Survived |
| 20       |           |          |         |                   | M | 75 | Pancreatitis | Blood | NR | NR | NR | Died |
| 21       |           |          |         |                   | F | 34 | Multiple trauma | Blood | NR | NR | NR | Died |
| 22       |           |          |         |                   | F | 67 | ALS, septic shock | Blood | NR | NR | NR | Died |
| 23       |           |          |         |                   | F | 63 | Malignancy, sepsis | Blood | NR | NR | NR | Died |
| 24       |           |          |         |                   | F | 47 | Cardiac arrest, pneumonia | Urine | NR | NR | NR | Survived |
| 25       |           |          |         |                   | M | 53 | Stroke | Blood | NR | NR | NR | Died |
| 26       |           |          |         |                   | F | 54 | Brain haemorrhage | Blood | NR | NR | NR | Survived |
| 27       |           |          |         |                   | M | 60 | Stroke | Blood | NR | NR | NR | Died |
| 28       |           |          |         |                   | M | 84 | AAA repair | Blood | NR | NR | NR | Survived |
| 29       |           |          |         |                   | M | 25 | Multiple trauma | Blood | NR | NR | NR | Died |
| 30       |           |          |         |                   | F | 75 | Osteomyelitis, MOF | Blood | NR | NR | NR | Survived |
| 31       |           |          |         |                   | M | 56 | TTP | Blood | NR | NR | NR | Died |
| 32       |           |          |         |                   | M | 20 | Multiple trauma | Urine | NR | NR | NR | Survived |
| 33       | 25        | Afghanistan | P. stuartii | 2011 | NR | NR | Medicalstial tumour, polytrauma, HIV | Blood | Levofloxacin plus piperacillin/tazobactam | Patient received broad-spectrum antibiotics but were not reported | NDM-1 | Died |
| No. | Country | Species | Year | Gender | Age | Site | Isolation Method | Treatment | Outcome |
|-----|---------|---------|------|--------|-----|------|-----------------|-----------|---------|
| 34  | Portugal | P. stuartii | 2013 | M | 88 | Enterocutaneous fistula | Urine | NDM-1 | Discharged |
| 35  | Argentina | P. rettgeri | 2013 | M | 54 | Vascular disease | Catheter | NDM-1 | Discharged |
| 36  | Italy | P. stuartii | 2013 | M | 56 | Terminal prostate cancer | Urine | NDM-1 | Died |
| 37  | Brazil | P. rettgeri | 2013 | M | 55 | Diabetes, HTN, osteomyelitis | Bone | NDM-1 | Discharged |
| 38  | Mexico | P. rettgeri | 2013 | M | 22 | Urine | NR | NDM-1 | Discharged |
| 39  | India | P. rettgeri | 2014 | NR | NR | NR | Urine | NR | NDM-1 |
| 40  | China | P. rettgeri | 2012 | M | 16 | NR | Urine | NR | NDM-1 |
| 41  | Nepal | P. rettgeri | 2012 | F | 50 | NR | NR | NR | NDM-1 |
| 42  | Israel | P. rettgeri | 2011 | F | 53 | NR | Urine | NR | NDM-1 |
| 43  | Israel | P. rettgeri | 2011 | F | 51 | NR | Blood | NR | NDM-1 |
| 44  | USA | P. rettgeri | 2015 | NR | NR | NR | Bone | NR | NDM-1, IMP |
| 45  | Mexico | P. rettgeri | 2015 | M | 66 | NR | Blood | NR | NDM-1 |
| 46  | Mexico | P. rettgeri | 2015 | NR | NR | NR | Blood | NR | NDM-1 |
| 47  | Mexico | P. rettgeri | 2015 | NR | NR | NR | Blood | NR | NDM-1 |
| 48  | Mexico | P. rettgeri | 2015 | NR | NR | NR | Blood | NR | NDM-1 |
| 49  | Mexico | P. rettgeri | 2015 | NR | NR | NR | Bone | NR | NDM-1 |
| 50  | Brazil | P. rettgeri | 2013 | M | 22 | Diabetes, PVD | Tissue | Ciprofloxacin, amoxicillin/clavulanate | Discharged |
| 51  | India | P. rettgeri | 2014 | M | NR | NR | NR | Ciprofloxacin, colistin | VIMP-1 |
| 52  | China | P. rettgeri | 2012 | M | 16 | NR | NR | NR | NDM-1 |
| 53  | Nepal | P. rettgeri | 2012 | F | 50 | NR | NR | NR | NDM-1 |
| 54  | Nepal | P. rettgeri | 2012 | F | 53 | NR | NR | NR | NDM-1 |
| 55  | Nepal | P. rettgeri | 2012 | F | 51 | NR | NR | NR | NDM-1 |
| 56  | Nepal | P. rettgeri | 2012 | F | 52 | NR | NR | NR | NDM-1 |
| 57  | Nepal | P. rettgeri | 2012 | F | 53 | NR | NR | NR | NDM-1 |
| 58  | Canada | P. stuartii | 2010 | M | 45 | NSH | Bronchial secretions | Meropenem plus ciprofloxacin | VIMP-1 |
| 59  | Algeria | P. stuartii | 2010 | M | 72 | Severe diffuse cerebral ischaemia | Urine | Ciprofloxacin | NR |
| 60  | Algeria | P. stuartii | 2010 | M | 42 | Burn injuries | Bronchial secretions | Ciprofloxacin | NR |
| 61  | Algeria | P. stuartii | 2008 | F | NR | PE | Chronic RI, respiratory failure | Ceftazidime | NR |
| 62  | Brazil | P. stuartii | 2006 | M | 52 | NR | NR | NR | NDM-1 |
| 63  | Brazil | P. stuartii | 2009 and 2011 | NR | NR | NR | NR | NR | NDM-1 |
| 64  | Brazil | P. stuartii | 2009 and 2011 | NR | NR | NR | NR | NR | NDM-1 |
| 65  | Brazil | P. stuartii | 2009 and 2011 | NR | NR | NR | NR | NR | NDM-1 |
| 66  | Brazil | P. stuartii | 2009 and 2011 | NR | NR | NR | NR | NR | NDM-1 |
| 67  | Japan | P. rettgeri | 2002 | M | NR | NR | NR | NDM-1 | Discharged |
| 68  | Japan | P. stuartii | 2002 | M | NR | NR | NR | NDM-1 | Discharged |
| 69  | Japan | P. stuartii | 2002 | M | NR | NR | NR | NDM-1 | Discharged |
| 70  | Japan | P. stuartii | 2002 | M | NR | NR | NR | NDM-1 | Discharged |
| 71  | Japan | P. stuartii | 2002 | M | NR | NR | NR | NDM-1 | Discharged |
| 72  | Japan | P. stuartii | 2002 | M | NR | NR | NR | NDM-1 | Discharged |
| 73  | Japan | P. stuartii | 2002 | M | NR | NR | NR | NDM-1 | Discharged |
| 74  | Japan | P. stuartii | 2002 | M | NR | NR | NR | NDM-1 | Discharged |
| 75  | Japan | P. stuartii | 2002 | M | NR | NR | NR | NDM-1 | Discharged |
| 76  | Japan | P. stuartii | 2002 | M | NR | NR | NR | NDM-1 | Discharged |
| 77  | Pakistan | P. rettgeri | 2010 | M | NR | NR | NR | NDM-1 | Discharged |
| 78  | Pakistan | P. rettgeri | 2010 | M | NR | NR | NR | NDM-1 | Discharged |

Continued
species; it has been increasingly detected among CRPS and CRPR in several countries [13,15,18,19,22–36]. Production of VIM-1 metallo-β-lactamase was responsible for carbapenem resistance in P. stuartii in two cases and one outbreak [11,17,20]. VIM-19 β-lactamase was detected in one case of CRPS associated urinary tract infection [37]. KPC-2 was recovered from CRPS isolates in Brazil [21,38]. OXA-72 carbapenemase was isolated from P. rettgeri in Nepal [33]. While metallo-β-lactamase IMP-1 was detected in CRPR isolates in Japan [14,39] and one isolate of CRPR was found to produce NDM-1 as well [30], to our knowledge, this is the only reported Providencia isolate to date that produced two carbapenemases. Two reports described carbapenemase production in Providencia, but they did not mention the species [12,40]; one report described VIM-2 production in three isolates of Providencia in South Korea [12], while the second report described NDM production in three isolates of Providencia in the United Kingdom [40].

In one outbreak of CRPS [5], the carbapenem-resistant phenotype was explained by AmpC hyperproduction and extended-spectrum β-lactamase production (CTX-M-2); hyperproduction of AmpC was due to derepressed chromosomally encoded AmpC. Carbapenem resistance in this outbreak probably occurred by of the following mechanisms: modification of the penicillin-binding proteins, conformational change in outer membrane protein or efflux-pump expression. These were not analyzed in this report. This is the first report of the emergence of carbapenem resistance in Providencia species due to noncarbapenemase mechanism.

**Treatment**

Like other bacterial infections, treatment of carbapenem-resistant Providencia should depend on the susceptibility of isolates to antibiotics. In addition, the duration of treatment will be dependent on the daily clinical assessment of the treating physician and the microbiologic response to antimicrobial agents. Treatment of carbapenem-resistant Providencia was described in nine reports [5,11,17,18,20,23,25,27,37]. Because extended infusion of high-dose meropenem (2 g every 8 hours provided via intravenous infusion over 3 hours) is an effective strategy for treating carbapenemase-producing Enterobacteriaceae [41], it was part of the antibiotic regimen of many cases of infection with carbapenem-resistant Providencia described in the literature. Zavascki et al. [5] described the treatment of three of five patients who were infected with CRPS in one outbreak; one patient with bloodstream infection was treated with a combination regimen of high-dose piperacillin/tazobactam (4.5 g every 6 hours) and high-dose extended-infusion
meropenem (2 g every 8 hours in a 3-hour infusion); a second patient was treated with amikacin 1 g every 24 hours in combination with imipenem 500 mg every 6 hours for a relatively mild surgical wound infection; and a third patient received levofloxacin (the dose was not reported). The three patients had good outcomes and were discharged from the hospital.

Tshisevhe et al. [16] described the treatment of four patients who had urinary tract infections resulting from CRPR. The four patients received carbapenem therapy (drug and dose were not mentioned). Three patients survived and were transferred to home, a high-care unit or a renal unit. Only one patient died; the cause of death was not described in this outbreak. Oikonomou et al. [11] reported the treatment of a CRPS isolate that caused infection in six critically ill patients; the P. stuartii isolates retained some susceptibility to doripenem and meropenem. Three of six patients (the three had bloodstream infection) were treated with meropenem by prolonged infusion in this outbreak; these three patients died.

Antibiotic synergy tests were proven to be effective in achieving microbiologic eradication in patients infected with CRPS [17]. Douka et al. [17] reported one outbreak of CRPS; all isolates had identical susceptibility, patterns with MICs ≥ 16 g/mL to meropenem and imipenem. An antibiotic synergy test was carried out by Etest according to the Clinical and Laboratory Standards Institute guidelines. The most effective combination in vitro was piperacillin/tazobactam with amikacin for all the P. stuartii isolates. All patients were treated with piperacillin/tazobactam (4.5 g every 8 hours) plus amikacin (1 g every 24 hours) according to the in vitro synergy, resulting in microbiologic eradication in all patients involved. However, seven patients died during their hospitalization. Third-generation cephalosporins were used to treat two cases of CRPS [20,37]. One case of CRPS, in a patient with severe burns and inhalational injury, was treated with levofloxacin and piperacillin/tazobactam; the patient died from complications of severe injuries and central nervous system infection 12 days after injury [25].

### Infection control measures

Stringent infection control practices are important in preventing the spread of carbapenem-resistant Providencia species [5,16,17,20,29]. Any new cases of carbapenem-resistant Providencia species in a healthcare facility should promptly draw the attention of the infection control teams. Isolation of patients infected or colonized with carbapenem-resistant Providencia species is indispensable. All patients should be under contact precautions. Exclusive medical and nursing equipment for each patient is recommended as well. Thorough sterilization and cleaning of medical equipment like dialysis machines is of paramount importance in the prevention of bacterial contamination and infection [16]. Education of healthcare personnel plays a pivotal role in controlling carbapenem-resistant Providencia species—related outbreaks. Hand hygiene practice must be repeated to healthcare personnel, as proper hygienic practice is important in the prevention of bacterial infections in any healthcare facility [16,17]. One report described four CRPR clinical isolates [22]; a possible epidemiologic link between the patients was a surgical resident involved in the care of the four patients.

Zavascki et al. [5] described the infection control measures that were applied to an outbreak of CRPS; private rooms were used to isolate all patients with CRPS. All patients were under contact precautions, including the use of gloves and gowns by any healthcare professional involved in patient treatment. Medical and nursing equipment were restricted for each patient. A strict environmental cleaning policy for rooms and objects that might have contacted colonized patients was applied. The outbreak was terminated after a 40-month period; no additional CRPS cases were detected. If isolating the patients with MDR microorganisms is not feasible, placing the patients in one area of any unit can prevent the further spread of highly MDR Gram-negative bacteria [42]. Identifying and eradicating the outbreak source is essential. In the CRPR outbreak that was described earlier [16], dialysis machines might have been the source. Healthcare providers should thus pay attention when using common equipment. A point prevalence surveillance of colonization must be performed on a regular basis for early identification of equipment and environmental contamination.

### Conclusion

Infections with carbapenem-resistant Providencia species greatly affect patient morbidity, mortality and treatment. To our knowledge, this is the first review of the literature about carbapenem-resistant Providencia species. Usually carbapenem-resistant Providencia species are recovered from adult, critically ill and/or immunocompromised patients. Carbapenemase production is the main mechanism of carbapenem resistance in Providencia species; the most common isolated carbapenemase is NDM-1. Treatment of carbapenem-resistant Providencia should depend on the susceptibility of isolates to antibiotics. Extended infusion of high-dose meropenem is usually part of the antibiotic regimen. Finally, stringent infection control practices are important in preventing the spread of carbapenem-resistant Providencia species.
Conflict of interest

None declared.

References

[1] O’Hara CM, Brenner FW, Miller JM. Classification, identification, and clinical significance of Proteus, Providencia, and Morganella. Clin Microbiol Rev 2000;13:534–46.
[2] Krake PR, Tandon N. Infective endocarditis due to Providencia stuartii. South Med J 2004;97:1022–3.
[3] Sapih OR, Bardak-Ozcem S, Ozgiray E, Aydemir S, Yurttseven T, Yanazhan T, et al. Meningitis due to Providencia stuartii. J Clin Microbiol 2010;48:4667–8.
[4] Wenzel RP, Hunting KJ, Osterman CA, Sande MA. Selection of KPC–2–producing Providencia stuartii during treatment for septicaemia. Diagn Microbiol Infect Dis 2016;84:95–6.
[5] Sipahi OR, Bardak-Ozcem S, Ozgiray E, Aydemir S, Yurtseven T, Rojas-Moreno T, Garza-Gonzalez E, et al. Isolation of carbapenem-resistant NDM–1–positive Providencia rettgeri in Mexico. J Antimicrob Chemother 2013;68:1934–6.
[6] Zurita J, Parra H, Gestal MC, McDermott J, Barba P. First case of NDM–1–producing Providencia rettgeri in Ecuador. J Glob Antimicrob Resist 2015;3:302–3.
[7] Pohl S, Miller S, Hindler J, Uslan D, Carvalho M, Humphries RM. Phenotypic and molecular characteristics of carbapenem-resistant Enterobacteriaceae in a health care system in Los Angeles, California, from 2011 to 2013. J Clin Microbiol 2014;52:4003–9.
[8] Pfeifer Y, Trifonova A, Pietsch M, Brunner M, Todorova I, Gergova I, et al. Clonal transmission of Gram-negative bacteria with carbapenemase KPC–2 production in an intensive care unit. Int J Antimicrob Agents 2015;45:533–6.
[9] Barrios H, Garza-Ramos U, Reyna-Flores F, Sanchez-Perez A, Rojas-Moreno T, Garza-Gonzalez E, et al. Complete sequence of a novel 178-kilobase plasmid carrying blaNDM–1 in a Providencia stuartii strain isolated in Afghanistan. Antimicrob Agents Chemother 2012;56:1673–9.
[10] Manageiro V, Sampaio DA, Pereira P, Rodrigues P, Vieira L, Palos C, et al. Draft genome sequence of the first NDM–1–producing Providencia stuartii strain isolated in Portugal. Genome Announc 2015;3(5).
[11] Pfeifer Y, Trifonova A, Pietsch M, Brunner M, Todorova I, Gergova I, et al. Characterization of carbapenem-resistant Gram-negative bacteria from Tamil Nadu. J Chemother 2016;28:371–4.
[12] Zhou G, Guo S, Luo Y, Li, Song Y, Sun G, et al. NDM–1-producing strains, family Enterobacteriaceae, in hospital, Beijing, China. Emerg Infect Dis 2014;20:340–2.
[13] Tada T, Miyoshi-Akiyama T, Dahal RK, Sah MK, Ohara H, Shimada K, et al. NDM–1–producing Stenotrophomonas maltophilia clinical isolate in Japan. J Antimicrob Chemother 2013;68:1934–6.
[14] Matsaeje LF, Boyd DA, Lefebvre B, Bryce E, Embree J, Gravel D, et al. Complete sequences of a novel plasmid carrying blaNDM–1–producing Providencia rettgeri in an Italian setting: report from the trench. Infect Genet Evol 2015;30:8–14.
[15] Guten-Halevi S, Hindiyyeh MY, Ben-David D, Smollan G, Gal-Mor O, Azar R, et al. Isolation of genetically unrelated blaNDM–1–positive Providencia rettgeri strains in Israel. J Clin Microbiol 2013;51:1642–3.
[16] Bocanegra-Ibarias P, Garza-Gonzalez E, Morfin-Otero R, Barrigos H, Villarres-Treviño L, Rodriguez-Noriega E, et al. Molecular and microbiological report of a hospital outbreak of NDM–1–carrying Providencia rettgeri in Mexico. PLoS One 2017;12(6).
[17] Bocanegra-Ibarias P, Garza-Gonzalez E, Morfin-Otero R, Barrigos H, Villarres-Treviño L, Rodriguez-Noriega E, et al. Molecular and microbiological report of a hospital outbreak of NDM–1–carrying Providencia rettgeri in Mexico. PLoS One 2017;12(6).
[18] Barros H, Garza-Ramos U, Reyna-Flores F, Sanchez-Perez A, Rojas-Moreno T, Garza-Gonzalez E, et al. Emergence of a pandrug-resistant VIM–1–producing Providencia stuartii clonal strain causing an outbreak in a Greek intensive care unit. J Antimicrob Agents 2015;45:533–6.
[19] Carvalho-Assef AP, Pereira PS, Albano RM, Bertóio GC, Chagas TP, Timm LN, et al. Isolation of NDM–producing Providencia rettgeri in Brazil. J Antimicrob Chemother 2013;68:2956–7.
[20] Galani L, Galani I, Souli M, Karaiskos I, Katsoouda E, Patrrozou E, et al. Nosocomial dissemination of Providencia stuartii isolates producing extended-spectrum β-lactamases VEB–1 and SHV–5, metallo-β-lactamase VIM–1, and RNA methylase RmtB. J Glob Antimicrob Resist 2013;1:115–6.
carbapenemases NDM-1, VIM-1, and OXA-23/72 in a Bulgarian hospital. Microb Drug Resist 2017;23:301–7.

[37] Robin F, Aggoune-Khinache N, Delmas J, Naim M, Bonnet R. Novel VIM metallobeta-lactamase variant from clinical isolates of Enterobacteriaceae from Algeria. Antimicrob Agents Chemother 2010;54:466–70.

[38] Tavares CP, Pereira PS, Marques Ede A, Faria Jr C, de Souza Mda P, de Almeida R, et al. Molecular epidemiology of KPC-2–producing Enterobacteriaceae (non–Klebsiella pneumoniae) isolated from Brazil. Diagn Microbiol Infect Dis 2015;82:326–30.

[39] Shiroto K, Ishii Y, Kimura S, Alba J, Watanabe K, Matsushima Y, et al. Metallo-beta-lactamase IMP-1 in Providencia rettgeri from two different hospitals in Japan. J Med Microbiol 2005;54:1065–70.

[40] Jain A, Hopkins KL, Turton J, Doumith M, Hill R, Loy R, et al. NDM carbapenemases in the United Kingdom: an analysis of the first 250 cases. J Antimicrob Chemother 2014;69:1777–84.

[41] Levy Hara G, Gould I, Endimiani A, Pardo PR, Daikos G, Hsueh PR, et al. Detection, treatment, and prevention of carbapenemase-producing Enterobacteriaceae: recommendations from an International Working Group. J Chemother 2013;25:129–40.

[42] Rosenberger LH, Hranjec T, Politano AD, Swenson BR, Metzger R, Bonatti H, et al. Effective cohorting and ‘superisolation’ in a single intensive care unit in response to an outbreak of diverse multi-drug-resistant organisms. Surg Infect (Larchmt) 2011;12:345–50.