Investigation of NDM, VIM, KPC and OXA-48 genes, blue-carba and CIM in carbapenem resistant Enterobacterales isolates

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Abstract

Introduction: Carbapenem resistance is an emerging problem in Enterobacterales. We aimed to investigate the presence of carbapenemase genes blaNDM, blaKPC, blaVIM and blaOXA-48 and evaluate the phenotypic blue-carba method and carbapenem inactivation method (CIM) in Enterobacterales isolates.

Methodology: Total of 153 Enterobacterales isolates were tested in the study. Presence of blaNDM, blaKPC, blaVIM and blaOXA-48 genes was investigated by polymerase chain reaction (PCR) method. Carbapenemase production of the isolates was also tested by blue-carba method and CIM.

Results: The presence of blaOXA-48 gene was detected in 110 (71.4%) and blaNDM gene was detected in 2 (1.3%) of the Enterobacterales isolates by PCR method. None of the isolates were positive for blaKPC and blaVIM genes. The 121 (78.54%) of the isolates were found to be positive by blue-carba method and CIM. And 105 (68.18%) of the isolates were determined as positive by both PCR, blue-carba and CIM.

Conclusions: In our study, 112 (72.7%) of the Enterobacterales isolates were found to be positive for carbapenemase genes (blaOXA-48 and blaNDM), and 121 (78.57%) of different isolates were found to be positive for blue-carba and CIM. However, 105 (68.18%) of the carbapenem resistance isolates found to be positive for all three methods.

Key words: Carbapenem resistance; Enterobacterales; blue-carba; CIM.


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Introduction

Enterobacterales are inhabitants of the intestinal flora and are among the most common human pathogens, causing infections such as cystitis, pyelonephritis, septicemia, pneumonia, peritonitis, meningitis, and device-associated infections [1]. The emergence and transmission of carbapenem-resistant Enterobacterales (CRE) over the past two decades has attracted worldwide attention, for its indication that most currently available broad-spectrum antibiotics may no longer be a therapeutic option for some patients [2]. It is therefore mandatory to maintain the clinical efficacy of carbapenems (imipenem, ertapenem, meropenem, doripenem), which have become antimicrobial drugs of last resort [1].

Multidrug-resistant organisms are a major public health concern worldwide; of particular concern has been the emergence of resistance to carbapenem antimicrobial drugs among Enterobacterales [3]. Therefore, preventing transmission of carbapenemase-producing, carbapenem-resistant Enterobacterales is a public health priority [4].

Carbapenem resistance in Enterobacterales is often associated with presence of carbapenemases located on plasmids or other mobile genetic structures [5]. Carbapenem resistance due to the production of acquired carbapenemase genes is increasingly reported among members of Enterobacterales, these mechanisms are still less commonly observed in Enterobacter spp. than in Klebsiella spp. or Escherichia coli [6]. The other carbapenem resistance mechanisms for Enterobacterales species are combination of presence of extended-spectrum β-lactamases (ESBLs), increased efflux, porin alteration, and a strongly expressed (derepressed) endogenous AmpC enzyme [7].

Carbapenemases have been slow to emerge in the Enterobacterales, but now their prevalence is increasing. They are notable for their diversity, including enzymes belonging to molecular classes such as A [KPC (Klebsiella pneumoniae carbapenemase), SME and IMI types]), B [IMP (imipenemase), NDM (New Delhi metallo-β-lactamase) and VIM (Verona...
integron-encoded metallo-β-lactamase] and D [OXA-48 (oxacillinase)] [2].

Many phenotypic methods for detection of carbapenemase-producers have been described for the Enterobacterales [8]. Phenotypic methods defined by the Clinical and Laboratory Standards Institute (CLSI) that clinical microbiology laboratories can apply to detect carbapenemase producers include the Modified Hodge Test (to be removed from the M100 in 2018; CLSI, January 2017 meeting minutes), the Carba NP and most recently the modified Carbenapenem Inactivation Method (mCIM) [9]. The blue-carba, has the same principle as the CarbaNP but uses bromothymol blue as a pH indicator and does not need the enzymatic extraction step [10]. The CIM utilizes readily available reagents not requiring reagent preparation and results are more objective in nature as a zone diameter reading is used for interpretation of results [9]. The CIM concept has the potential to also be applied to assess enzymatic hydrolysis of other antibiotics, e.g. allowing detection of ESBL activity. Preliminary experiments in laboratory have shown this maybe feasible [11].

In our study, we aimed to investigate the presence of blaNDM, blaVIM, blaKPC and blaOXA-48 genes, which are responsible for the development of resistance to carbapenem antibiotics in Enterobacterales isolates, and to evaluate the phenotypic carbapenemase detection methods blue-carba and CIM.

Methodology

Carbenapenem resistant 153 Enterobacterales isolates that were isolated from various clinical samples sent to the Medical Microbiology Laboratory of Ondokuz Mayis University Faculty of Medicine were included in the study (Table 1). Identification of the isolates was done using conventional methods and Vitek-MS (Biomeirux, France) automated system. The antibiotic susceptibility was tested with the Vitek2 Compact (Biomeirux, France) automated system. Susceptibility of the isolates were evaluated according to the EUCAST criteria. For quality control, reference strains E. coli ATCC 25922 and K. pneumoniae ATCC 700603 were used. Isolates that were resistant to one of the carbapenems (imipenem, meropenem or ertapenem) were considered as carbapenem resistance and enrolled in the study. Enterobacterales isolates were stored at -20°C until the molecular study. The existence of blaNDM, blaVIM, blaKPC and blaOXA-48 genes were studied by polymerase chain reaction (PCR) using specific primers (Table 2) [12,13]. DNA extraction were made by the method of boiling. Positive strains for blaNDM, blaVIM, blaKPC and blaOXA-48 were as positive control and E. coli ATCC 25922 was used as negative control in the PCR assays. Positive strains for blaNDM, blaVIM, blaKPC and blaOXA-48 were obtained as a part of national quality control program. blaNDM and selected blaOXA-48 positive isolates were sequenced in Sentegen (Turkey), they confirmed positive for blaNDM and blaOXA-48.

Bromothymol blue was selected as the indicator in the blue-carba test. A commercially available imipenem (Tienam500; Merck Sharp & Dohme, France) was used as the substrate for carbapenemases. The test solution consisted of an aqueous solution of bromothymol blue at 0.04% (Merck Millipore, Germany) adjusted to pH 6.0, 0.1 mmol/liter ZnSO4, and 3 mg/mL of imipenem, with a final pH of 7.0. A negative-control solution (0.04% bromothymol blue solution, pH 7.0) was prepared. A loop (approximately 5 μl) of bacteria was directly suspended in 100 μL of both test and negative-control solutions in a plate and incubated at 37°C for 2 hours. Carbapenemase activity was revealed when the test and negative-control solutions, respectively, were (i) yellow versus blue, (ii) yellow versus green, or (iii)

Table 1. Distribution of Enterobacterales spp in our study.

<table>
<thead>
<tr>
<th>Microorganisms</th>
<th>No (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Klebsiella pneumoniae</td>
<td>120</td>
</tr>
<tr>
<td>Escherichia coli</td>
<td>14</td>
</tr>
<tr>
<td>Klebsiella oxytoca</td>
<td>10</td>
</tr>
<tr>
<td>Enterobacter cloacae</td>
<td>4</td>
</tr>
<tr>
<td>Enterobacter aerogenes</td>
<td>2</td>
</tr>
<tr>
<td>Proteus mirabilis</td>
<td>2</td>
</tr>
<tr>
<td>Proteus vulgaris</td>
<td>1</td>
</tr>
<tr>
<td>Providencia rettgeri</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 2. Sequences of the primers.

<table>
<thead>
<tr>
<th>Gene</th>
<th>Primer</th>
<th>Sequence</th>
<th>Expected amplicon size (bp)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>NDM</td>
<td>NDM-F</td>
<td>GCA GCT TGT CGG CCA TGC GGG C</td>
<td>782</td>
<td>[13]</td>
</tr>
<tr>
<td></td>
<td>NDM-R</td>
<td>GGT CGC GAA GCT GAG CAC CGC AT</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VIM</td>
<td>VIM-F</td>
<td>GTT TGG TCG CAT ATC GCA AC</td>
<td>389</td>
<td>[13]</td>
</tr>
<tr>
<td></td>
<td>VIM-R</td>
<td>AAT GCG CAG CAC CAG GAT AG</td>
<td></td>
<td></td>
</tr>
<tr>
<td>KPC</td>
<td>KPC-F</td>
<td>TGT GTAGTATGCGGCTC</td>
<td>900</td>
<td>[13]</td>
</tr>
<tr>
<td></td>
<td>KPC-R</td>
<td>CTCAGTGCTCTACAGAAAACC</td>
<td></td>
<td></td>
</tr>
<tr>
<td>OXA-48</td>
<td>OXA-48-F</td>
<td>TTT TTG GCA TCG ATT ATC GG</td>
<td>438</td>
<td>[14]</td>
</tr>
<tr>
<td></td>
<td>OXA-48-R</td>
<td>GAG CAC TTC TTT TGT GAT GGC</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
green versus blue. Non-carbapenemase producers remained blue or green on both solutions. The test was performed in duplicate for all isolates [10].

In carbapenem inactivation method (CIM), a suspension was made by suspending a full 10 μL inoculation loop of culture, taken from blood agar plate in 400 μL water. Subsequently, a susceptibility-testing disk containing 10 μg meropenem was immersed in the suspension and incubated for a minimum of two hours at 35°C. After incubation, the disk was removed from the suspension, placed on a Mueller-Hinton agar plate inoculated with a susceptible E. coli ATCC 29522 and subsequently incubated at 35°C. The inhibition zone around the disc was evaluated after 6 or 24 hours. If the tested bacterial isolate produced carbapenemase, the meropenem in the susceptibility disk was inactivated allowing uninhibited growth of the susceptible E. coli ATCC 29522. Disks incubated in suspensions that do not contain carbapenemases yielded a clear inhibition zone. [11].

Results
Total of 153 carbepenem resistant isolates were tested in the study. These isolates were isolated from various clinical specimens. Majority of the clinical specimens were urine specimens (n = 75, 49%), and followed by blood specimen (n = 35, 22.9%), tracheal aspirate (n = 16, 10.4%), wound specimen (n = 16, 10.4%), sterile body fluid (n = 6, 3.9%), sputum (n = 5, 3.4%). Ertapenem resistance were determined at 150 of the isolates. And 103 of the isolates and 87 of the isolates were found to be resistant and/or intermediate to imipenem and meropenem, respectively. MIC distribution of the imipenem resistant isolates were 0.25 ≥ 32 µg/mL and 1 ≥ 32µg/mL.

In this study, 110 (71.9%) isolates were determined positive for blaOXA-48 and 2 (1.3%) isolates were positive for blaNDM. BlaVIM and KPC genes were not detected (Figure 1). Most of the isolates were sent from internal medicine clinics (77.92%). And majority of the blaOXA-48 positive isolates were isolated from the specimens that sent form internal medicine clinics (61.68%) blaNDM positive isolates were isolated the clinical specimens that sent from intensive care unit and internal medicine clinic (Table 3). The sequenced blaNDM and selected blaOXA-48 positive isolates were confirmed positive for blaNDM and blaOXA-48.

For blue-carba test and CIM, 120 isolates were determined positive (78.43%). In our study 99 (64.7%) of the tested isolates were found positive by three methods (PCR, blue-carba and CIM). And 19 (12.4%) isolates were found to be negative by three methods. For the blaOXA-48 and blaNDM positive isolates 101 (90.2%) of them were found to be positive by blue-carba and 111(99.1%) of them were found to be positive by CIM.

But 12 of the PCR positive isolates were determined negative by blue-carba test, and two of the PCR positive isolates were found negative by CIM. Nineteen and nine of the PCR negative isolates were detected positive by blue-carba and CIM, respectively (Table 4). The sensitivity and specitivty of the blue-carba was determined as 89.4% and 52.5%, respectively. The sensitivity and specitivty of CIM was determined as 98.2% and 77.5%.

Discussion
The Enterobacterales account for up to 25% of healthcare associated infections (HAIs) reported to the U.S. National Healthcare Safety Network [14]. Carbapenemases increasingly have been reported in Enterobacterales in the past 10 years [1]. The emergence and spread of carbapenemase-producing Enterobacterales (CPE) is a serious global threat that
considerably limits therapeutic options available for life threatening Gram-negative infections [15]. Detection of infected patients and carriers with carbapenemase producers is necessary for prevention of their spread, also may help prevent development of nosocomial outbreaks caused by carbapenemase producers, particularly *K. pneumoniae* [1].

Carbapenem-resistant *Enterobacterales* have been reported worldwide as a result of various kind of carbapenemase genes [16]. The first carbapenemase producer in *Enterobacterales* (NmcA) was identified in 1993 [17]. *Bla*KPC have been reported from worldwide with higher endemicity in USA and Greece. *bla*OXA-48 type have been reported mostly from European and Mediterranean countries and India [1].

NDM-1 firstly isolated in 2008 and now it is the focus of worldwide attention [18,19]. Deshpande et al. (2010) reported that of the 24 carbapenem resistant *Enterobacterales*, 22 were *bla*NDM producers while 2 were *bla*NDM non-producers. Amongst the 22 *bla*NDM producing organisms 10 were *Klebsiella* spp, 9 were *Escherichia coli*, 2 were *Enterobacter* spp and 1 was *Morganella morganii* [20]. Since mid-August 2010, *bla*NDM producers have been identified on all continents except in Central and South America with, in most of the cases, a direct link with the Indian subcontinent, also recent findings suggest that the Balkan states and the Middle East may act as secondary reservoirs of *bla*NDM producers [19]. Yanik et al. (2013) investigated the presence of *bla*NDM by PCR method in 210 carbapenem-resistant Gram-negative isolates (132 *Acinetobacter baumannii*, 54 *Pseudomonas aeruginosa*, 5 *Pseudomonas putida*, 8 *Enterobacter cloacae*, 3 *Enterobacter aerogenes*, 3 *Klebsiella pneumoniae*, 2 *Providencia rettgeri*, 2 *Escherichia coli* and 1 *Citrobacter freundii*) recovered from clinical specimens in Samsun, Turkey. But *bla*NDM gene was not detected in any of the clinical isolates [21]. Poirel et al. (2012) report a 16-year-old male patient who was admitted to the hematology unit of a hospital situated near Istanbul, Turkey, in October 2011. That leukemic patient had been transferred from a hospital in Baghdad, Iraq, and received allogeneic hematopoietic stem cell transplantation the day after his admission. Blood cultures grew two types of multidrug-resistant *Enterobacterales* isolates, *K. pneumoniae* and *E. coli*. PCR, sequencing revealed that *K. pneumoniae bla*NDM carbapenemase. This study has also constituted to the very first report of an *bla*NDM positive isolate in Turkey [22].

The first acquired MBL, *bla*IMP, was reported in *Serratia marcescens* in Japan in 1991 [23]. IMP types and, more recently, of the New Delhi metallo-β-lactamase-1 (*bla*NDM) type. Endemicity of VIM- and IMP-type enzymes has been reported in Greece, Taiwan, and Japan [24,25]. Death rates, associated with MBL producers, range from 18% to 67% [26].

The first *bla*KPC producer (KPC-2 in *K. pneumoniae*) was identified in 1996 in the eastern United States [27]. KPC-mediated carbapenem resistance in members of the *Enterobacterales* has emerged recently in Israel, as observed in clinical strains of *Escherichia coli* [28], *Enterobacter cloacae* [29], and *Klebsiella pneumoniae* [30]. *Bla*KPC producers have been reported, mostly from nosocomial *K. pneumoniae* isolates and to a much lesser extent from *E. coli* (especially in Israel) and from other *Enterobacterales* species [2]. Institutional outbreaks of KPC-producing *Enterobacterales* due to the spread of a single strain have also been reported for other species, including *Enterobacter* spp. and *Serratia marcescens* [29,31].

The first identified *bla*OXA-48 producer was from a *K. pneumoniae* strain isolated in Turkey in 2001 [32]. More than 250 class D β-lactamases (OXAs) have been described in recent years, with variations in hydrolytic activity for β-lactams [33]. Although *bla*OXA-48 β-lactamase and its variants typically have low-level hydrolytic activity against many carbapenems, they can contribute to high-level carbapenem resistance in combination with other mechanisms [34]. Since then, *bla*OXA-48 producers have been extensively reported from Turkey as a source of nosocomial outbreaks [35,36]. Their worldwide distribution now includes countries in Europe, in the southern and eastern part of the Mediterranean Sea, and Africa [32,36]. Several *bla*OXA-48 producing clones have been identified, and dissemination of this resistance trait is associated with a 62.5-kb plasmid (previously identified as a plasmid of ≈ 70 kb) [35]. Although reported in various enterobacterial species, *bla*OXA-48 producers are mostly identified in *K. pneumoniae* and *E. coli*, and the level of

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**Table 4.** PCR, blue-carba and CIM test results in *Enterobacterales* isolates.

<table>
<thead>
<tr>
<th></th>
<th>Blue-carba positive (n = 120)</th>
<th>Blue-carba negative (n = 33)</th>
<th>CIM positive (n = 120)</th>
<th>CIM negative (n = 33)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PCR positive (n = 112)</td>
<td>101</td>
<td>12</td>
<td>111</td>
<td>2</td>
</tr>
<tr>
<td>PCR negative (n = 41)</td>
<td>19</td>
<td>21</td>
<td>9</td>
<td>31</td>
</tr>
</tbody>
</table>
resistance to carbapenems is usually higher when ESBL and permeability defects are associated [35,37]. Out of 296 carbapenem-non-susceptible isolates, blaOXA-48 gene was detected in 12 K. pneumoniae isolates in Croatia [38].

Perçin et al. (2012) investigated the presence of blaIMP, blaOXA OXA, blaNDM, blaKPC genes in carbapenem-resistant K. pneumoniae from rectal swabs. Carbapenem susceptibility was evaluated by using E-test method, the presence of beta-lactamases was determined by using modified Hodge test (MHT). Of the 801 isolates 33 were determined as carbapenem resistant. No resistance gene were identified by PCR in 13 of 33 isolates, whereas blaOXA-48 was detected in 19 and blaIMP in 1 of 20 positive isolates [39].

Eser et al. (2014) investigated the presence of carbapenem resistance in 210 Enterobacteriales isolates (E. coli (n = 153), K. pneumoniae (n = 47) and Klebsiella oxytoca (n = 10)) recovered from invasive infections, in Hacettepe University Hospital, Ankara, Turkey, between 2005-2009, by PCR (AmpC, CTX-M, KPC, NDM, OXA, IMP and VIM). One K. pneumoniae isolate was found to inhabit blaOXA-48 gene. Five isolates were positive for OXA-1 and one for OXA-10. Two isolates were positive for blaCTX-M, however blaIMP, blavIM, blakPC and blanDM-1 genes were not detected among the isolates [40].

Helvacı (2014) investigated the blaIMP, blavIM, blakPC, blaxOXA and blanDM-1 genes in carbapenem resistant Enterobacteriales isolates from blood cultures by PCR. PCR was performed on 11 E. coli strains and 36 Klebsiella spp. strains. They reported that 7 of E. coli strains (63.6%) and 28 of Klebsiella spp. strains (77%) were carbapenemase positive. Klebsiella spp. subgroup analysis showed that 22 strains were OXA, 3 were VIM, 2 were IMP and one strain was OXA+VIM positive. For E.coli strains; 5 were OXA, 2 were OXA+IMP positive. NDM and KPC subtypes weren’t detected [41].

A total of 312 isolates were included in Chea et al. (2015) study; a carbapenemase gene was identified in 94 (30%). Seventy-two (65%) Klebsiella spp. isolates had a carbapenemase gene, of which 67 (93%) were blakPC and 5 (7%) were blanDM. Of all Enterobacter spp. and E. coli isolates, 14 (14%) and 8 (8%), respectively, had a carbapenemase gene, and all were blakPC. The percentage of carbapenemase-producing CRE at the various sites was 73% in Maryland (40 [93%] blakPC), 3 [7%] blanDM); 30% in Minnesota (31 [94%] blakPC, 2 [6%] blanDM); 20% in Tennessee (13 [100%] blakPC); 6% in New York (3 [100%] blakPC); 7% in New Mexico (1 [100%] blakPC); and 0 in Colorado [4].

Studies have shown that locally class D OXA-48-like enzymes and NDM are the most common carbapenemases in Enterobacteriales with sporadic occurrence of KPC and VIM type enzymes [42,43]. Turkey is known to be an area of endemicity for OXA-48-producing Enterobacteriales [22], and in this study most of the carbapenem resistant isolates were positive OXA-48 and NDM were determined in two isolates.

In García-Fernández et al. (2015) study, the 159 CRE comprised the following variants: blaxOXA-48 (n = 53), blakPC-2 (n = 45), blakPC-3 (n = 36), blavIM-1 (n = 24), and blanDM-1 (n = 1). In 8 and 6 isolates of the 159 CRE, ambiguous or false negative results were obtained with blue-Carba test and Carba NP test, respectively. With the blue-carba test, 156 out of 159 isolates were correctly detected, thus sensitivity and negative predictive result were slightly lower, 98% and 96%, respectively. Blue-carba detected 100% of KPC, VIM and NDM and 94% of OXA-48 enzymes. To note that the three OXA-48-producing isolates (2 K. pneumoniae, 1 E. aerogenes) with negative result with the Blue-Carba test had a hypermucoid phenotype [12].

In Erdem et al. (2017) study, carbapenem-resistant Enterobacteriales (CRE) isolates were used to evaluate modified Blue-Carba test for the rapid detection of OXA-48 carbapenemase in comparison with polymerase chain reaction (PCR) amplification. These CREs of various enterobacterial species were isolated from various clinical samples including OXA-48 (47), NDM-1 (6), KPC-1 (1), IMP-1 (1), VIM-2-4 (2), IMP-2 (1), OXA-51 (1), and OXA-23 (1) producers. The Blue-Carba test detected carbapenemase producers with 93% sensitivity and 100% specificity [13].

In Tamma et al. (2017) study, two collections of carbapenem-resistant Enterobacteriales (CRE) isolates were evaluated including 191 retrospective isolates (122 CP-CRE and 69 non-CP isolates) as well as 45 prospective clinical isolates (15 CP-CRE and 30 non-CP-CRE) obtained over a 3-month period. Among the retrospective cohort, sensitivities ranged from 72% for the boronic acid synergy test for the detection of KPC-producers to ≥ 98% for the Modified Carba NP, the RAPIDEC® CARBA NP, the manual Blue-Carba, and the modified carbapenem inactivation method for the detection of any CRE. All assays had excellent specificity exceeding 95% with the exception of the boronic acid synergy test (88%) and modified Hodge test (91%). Prospectively, 45 CRE isolates were encountered over a three-month period including 15 CPE (33%) and 30 non-CP-CRE (67%) [44].

A new phenotypic test called the carbapenem inactivation method (CIM) was developed to detect
Carbapenemase activity in Gram-negative bacilli within six hours. This method has been found to be highly compatible with the results obtained with PCR to detect genes encoding blaKPC, blaNDM, blaOXA-48, blaVIM, blaIMP and blaOXA-23 carbapenemases. Comparing the results of PCR and CIM determined by genes producing several carbapenemase in Enterobacteriales, *P. aeruginosa* and *A. baumannii* isolates; CIM (92.1%) has been shown to be a phenotypic screening method that can reliably detect carbapenemase activity. It was observed that, 67 isolates (16.3%) whose carbapenemase gene determined by PCR method of 411 isolates tested in the study were positive and according to CIM result, 65 (97.0%) of 67 isolates were positive. It was seen that blaKPC gene was not detected in the *Pseudomonas* isolates used in the study [11].

In Laolerd et al. (2018) study, A total of 287 Enterobacteriales isolates, which were at least resistant to one of the carbapenems, were identified for carbapenemase genes by multiplex PCR (blaKPC, blaNDM, blaOXA-48, blaVIM, blaIMP), mCIM and Carba NP. Species of carbapenem-resistant isolates mainly *Klebsiella pneumoniae*, *Escherichia coli*, and *Enterobacter cloacae* were detected. Of these isolates, three families of carbapenemase genes [223 (77.70%)], including blaOXA-DM [160 (46.64%)], blaOXA-48 [56 (25.11%)] and blaIMP-14 [7 (3.14%)] were found. In addition, 25.11% (56/223) of the carbapenemase-producing isolates harbored a combination of NDM and OXA-48-like. Phenotypic detection methods, mCIM and Carba NP, showed 100% sensitivity and specificity to NDM, IMP-14, and OXA-48, while the mCIM was positive in all OXA-181 and OXA-232 isolates, only 12.5% (1/8) and 28.95% (11/38), respectively, were detected by the Carba NP test. This result reflected the greater efficacies of mCIM over the Carba NP test on detection of OXA-181 and OXA-232. This study revealed of carbapenemase genes in Bangkok, Thailand, where NDM-1 and OXA-232 were predominant [45].

A total of 125 isolates were included in Bayraktar et al. (2018) study. The strain collection of CPEs included 89 OXA-48 (80 *K. pneumoniae*, six *E. coli*, and three *K. oxytoca*), two KPC (two *K. pneumoniae*), five NDM (four *K. pneumoniae* and one *E. cloacae*), two VIM (one *K. pneumoniae* and one *E. coli*), one IMP (*K. pneumoniae*), 10 OXA-48+NDM (eight *K. pneumoniae*, one *E. coli*, and one *E. cloacae*), and one OXA-48+VIM (*K. pneumoniae*) producer. Of the 110 CPE isolates (including the positive control isolate), 100 were found to be positive by all three tests and 10 isolates showed discordant results. Carba NP-direct, CIM, and b-CARBA tests detected 109 (99.0%), 102 (92.7%) and 108 (93.6%) isolates as positive, respectively [46]. Tijet et al. (2015) reported that the sensitivity (98.8%) of the CIM test were higher than those of the Carba NP test (90.1% and 88.2%, respectively) [47]. In our study sensitivity of the CIM test was higher than blue-carba test. The sensitivity of the CIM and blue-carba tests found to be similar to the other studies. However specificity of the blue-carba test was found to be 52.5%.

**Conclusions**

Carbapenem resistance is an emerging problem in worldwide. Determination of carbapenem resistance determinants is important for prevention of health-care associated infection.

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