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1 VIM-2 β -LACTAMASE IN *PSEUDOMONAS AERUGINOSA* ISOLATES FROM ZAGREB,
2 CROATIA

3

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17

18 ABSTRACT

19 The aim of this investigation was to characterize MBLs in *P. aeruginosa* isolates from
20 Zagreb, Croatia.

21 100 *P. aeruginosa* isolates with reduced susceptibility to either imipenem or meropenem were
22 tested for the production of MBLs by E test MBL. The susceptibility to a wide range of
23 antibiotics was determined by broth microdilution method. The presence of *bla*_{MBL} genes was
24 detected by PCR. Hydrolysis of 0.1 mM imipenem by crude enzyme preparations of β -
25 lactamases was monitored by UV spectrophotometer.. Outer membrane proteins were
26 prepared and analysed by SDS-PAGE.

27 Six out of 100 isolates were positive for MBLs by E test. All strains were resistant to
28 gentamicin, ceftazidime and cefotaxime and all except of one to imipenem.

29 Six strains positive for MBLs in E test were identified as VIM MBLs producers by PCR.

30 Sequencing of *bla*_{VIM} genes revealed the production of VIM-2 β -lactamase in all six strains.

31 This investigation proved the occurrence of VIM-2 β -lactamase among *P. aeruginosa* strains
32 from Zagreb, Croatia. VIM-2 β -lactamase with similar properties was previously described in
33 another region of Croatia, Italy, France, Spain, Greece, Taiwan and South Korea suggesting
34 that this type of enzyme is widespread in Mediteranean region of Europe and in Far East.

35 **Key words:** meropenem, imipenem, metallo- β -lactamases, resistance, *Pseudomonas*
36 *aeruginosa*

37 INTRODUCTION

38 Carbapenemases may be defined as β -lactamases that significantly hydrolyse at least
39 imipenem or/and meropenem [1]. The most clinically significant carbapenemases belong to
40 class B [2]. They are metallo- enzymes which require zinc as a cofactor and comprise four
41 families: IMP, VIM, SPM, GIM and SIM [3-6]. The VIM-type enzymes appear to the most
42 prevalent in Europe and Korea, and at least 10 different variants have been described [4]. The

43 worldwide spread of acquired metallo- β -lactamases (MBLs) in gram-negative bacilli has
44 become a great concern. MBLs possess a broad hydrolysis profile that includes carbapenems
45 and almost all extended-spectrum β -lactams except of aztreonam. Carbapenem resistant
46 strains of *P.aeruginosa* have been detected with increasing frequency in hospitals in Zagreb
47 and pose serious therapeutic problem. The aim of this investigation was to characterize MBLs
48 in *P. aeruginosa* isolates from Zagreb, Croatia.

49

50 MATERIALS AND METHODS

51 *Bacteria*

52 100 *P. aeruginosa* isolates with reduced susceptibility to either imipenem or meropenem were
53 tested for the production of MBLs by E test MBL (Solna, Sweden). The strains were isolated
54 during 2002 to 2004 at the Clinical Hospital Center Zagreb and University Hospital Merkur
55 in Zagreb from various clinical specimens and wards (Table 1). Isolates were identified by
56 conventional biochemical methods.

57 *E test MBL test*

58 The strip (AB Biodisk, Solna, Sweden) contains a double-sided seven-dilution range of
59 imipenem (4 to 256 mg/L) and imipenem (1 to 64 mg/L) in combination with a fixed
60 concentration of EDTA. An overnight culture of the test strains in Mueller-Hinton (MH) broth
61 was diluted to match the turbidity of 0.5 McFarland, swabbed on the plates of MH agar and
62 the plates were incubated at 35°C. A decrease of imipenem MIC by ≥ 3 twofold dilutions in
63 the presence of EDTA was interpreted as being suggestive of MBL production [7].

64 *Susceptibility testing*

65 The susceptibility to a wide range of antibiotics was determined by twofold broth
66 microdilution method in cation supplemented MH broth in 96 well microtiter plates according
67 to CLSI [8]. The inoculum size was 5×10^5 CFU/ml. The plates were incubated for 18 h at 37

68 °C. The strains with MICs below the resistance breakpoint were tested with higher inoculum
69 of 10⁸ CFU/ml as well. The test was performed in triplicate. *P. aeruginosa* ATCC 27853 was
70 used for quality control. Antibiotic powders were obtained from the following manufacturers:
71 ceftazidime, gentamicin and clavulanic acid-Pliva, Zagreb; cefotaxime-Belupo, Koprivnica;
72 cefepime-Bristol Myers Squibb, Zagreb; imipenem-MSD, Zagreb; meropenem-AstraZeneca,
73 Zagreb.

74 *Enzyme characterization*

75 The bacterial cells were pelleted from exponential phase cultures in Lurian-Bentoni (LB)
76 broth by centrifugation at 6000 g. The pellet was washed and resuspended in cation
77 supplemented phosphate buffer (0.1 mM, pH 7). Enzymes were released by sonication in ice
78 bath. Cell debris was removed by centrifugation at 10 000 g and supernatant was stored at -
79 20°C as crude enzyme preparation. Hydrolysis of 0.1 mM imipenem by crude enzyme
80 preparations of β -lactamases was monitored by UV spectrophotometer at 298 nm. The change
81 of absorbance was recorded. Inhibition of enzyme activity was determined by 2 mM EDTA.
82 Enzyme activity was expressed as nmol of substrate hydrolyzed per minute expressed
83 relatively to the total protein content of the sample. Concentration of the protein in the
84 samples was determined with a commercial method (BioRad).

85 *Analytical isoelectric focusing (IEF)*

86 IEF was performed according to Matthew et al [9]. The organisms were grown overnight in
87 BHI broth, collected by centrifugation and β -lactamases were extracted from bacteria by
88 sonication. Cell debris was removed by centrifugation at 14 000 g. Supernatant was used as
89 crude enzyme. Isoelectric focusing was performed on polyacrylamide gels (acrylamide 7%,
90 bis-acrylamide 0.2%) containing ampholines with a pH range of 3.5 to 10. The β -lactamases
91 were detected by staining of the gel with nitrocefin, following IEF. β -lactamases of known

92 pI (isoelectric point) were used as standards: TEM-1, TEM-2, SHV-1, SHV-2, SHV-4 and
93 SHV-5.

94

95 *Polymerase chain reaction and sequencing of bla_{VIM} genes*

96 The presence of *bla_{VIM}* and *bla_{IMP}* genes was tested by PCR. Primers: VIM1F (5'-CAG-ATT-
97 GCC-GAT-GGT-GGT-TGG-3') and VIM1R (5'-AGG-TGG-GCC-ATT-CAG-CCA-GA-3')
98 were used to amplify *bla_{VIM}* genes. whereas primers IMP-A (5-GAA-GGY-GTT-TAT-GTT-
99 CAT-AC-3') and IMP-B (5'-GTA-MGT-TTC-AAG-AGT-GAT-GC-3') [1] were used for
100 detection of *bla_{IMP}* genes. The cycling conditions were as follows: 94°C-5min, and then 30
101 cycles-94°C-1 min, 55°C-1 min, 72°C-1-min and final extension at 72°C for 5 min. PCR
102 products were subjected to electrophoresis in agarose gel at 100 V. PCR products were
103 detected under UV light after staining with etidium bromide.

104 The amplicons were sequenced from both sides.

105 *Plasmid analysis*

106 Plasmids were extracted by alkaline lysis method as described previously [10]. Overnight
107 cultures of the test strains in LB broth (12 ml) were centrifuged at 14 000 rpm and the pellet
108 was resuspended in Solution I (25 mM Tris Hcl (pH 8), 50 mM Glucose, 10 mM EDTA (pH
109 8) containing 5 mg/ml lysozyme and 10 mg/ml RNA-se. The suspensions were mixed and
110 incubated on ice for 10 min before addition of the Solution II (0.2 N NaOH, 1% SDS). The
111 samples were then mixed gently by inversion of the tubes. After incubation on ice for 15 min,
112 Solution III was added (3 M K-Ac, pH 4.8). Solution III contained 120 ml 5 M K-Ac, 23 ml
113 glacial acetic acid and 57 ml H₂O. Samples were again mixed by inversion of the tubes,
114 incubated on ice for 15 min and centrifuged for 15 min at 14 000 rpm at room temperature.
115 The supernatant was transferred to the clean tube avoiding any floating precipitate. Equal
116 volume of phenol/chlorophorm was added, samples were mixed and centrifuged for 5 min.

117 This step was repeated twice. The supernatant was transferred to the clean tube without
118 touching the water /chlorophorm interface or the precipitate in this region and 0.6 volumes of
119 isopropanol were added. The samples were incubated 30 min at room temperature and
120 centrifuged at 14 000 rpm for 20 min. The supernatant was discarded and the pellet dried in
121 the vacuum centrifuge. The pellet was washed once with 70% ethanol and resuspended in TE
122 buffer. Samples were subjected to electrophoresis in 0.7 % agarose gel in TBE buffer. After
123 staining with ethidium bromide, the DNA was visualised by ultraviolet light.

124

125 *Genotyping of strains by pulsed-field gel electrophoresis*

126 Isolation of chromosomal DNA was performed as described by Kaufman et al [11]. For each
127 isolate 1,0 ml (optical suspension density 0,6-0,7 at 540 nm) of an overnight culture grown in
128 BHI broth was pelleted by centrifugation at 10 000 rpm for 2 min. After being washed in 1 ml
129 SE buffer (75mM NaCl;25mM EDTA, *Sigma*), bacteria were resuspended in 500µl SE buffer
130 with 10 µl lysosime (*Boehringer Mannheim GmbH*). Next, 500 µl of this bacterial suspension
131 was mixed with 500 µl 2,0% low- melting-temperature agarose (InCert agarose; FMC
132 Bioproducts) and left to solidify. Solid agarose plugs were then incubated for 24h at 56⁰ C in
133 2ml of ESP buffer (1% N-lauril sarcosine; 0,5 M EDTANa₂, pH 9,5; 500 µg/ml proteinase K,
134 *Sigma*). After 24h, the plugs were incubated at room temperature for 2 h in PMSF
135 (phenylmethanesulfonyl-fluoride, *Aldrich*) and then washed three times for 30 min at 4⁰ C
136 with TE buffer (10mM Tris-Hcl,pH 8, 0,1 mM EDTA, *Sigma*) before macrorestriction with
137 10U / 1 µl *Xba*I for 3 h at 37⁰ C. Restriction fragments of DNA were separated by PFGE with
138 a CHEF-DRIII apparatus (Bio-Rad Laboratories) through 1% pulsed-field certified agarose
139 (*Bio-Rad*) at a field strength of 6 V/cm for 20 h at 11⁰ C; with pulses from 5 to 50 -s in 0,5
140 TBE buffer with thiurea (50mM, *Sigma*). A lambda ladder (*Roche*) was used as the molecular
141 size marker. After electrophoresis, gels were stained with ethidium bromide, rinsed, and

142 photographed under UV light. The PFGE patterns were compared following the criteria of
143 Tenover and colleagues for bacterial strain typing [12] and analysed by computer software
144 (*GelComparII*). The patterns obtained were compared by clustering methods (unweighted
145 pairgroup method with arithmetic averages) using the *Dice* coefficient. An optimization of
146 0,50% and position tolerance of 3,00% were applied during the comparison of PFGE
147 fingerprinting patterns.

148

149 *Characterization of outer membrane proteins*

150 Outer membrane proteins of six MBL positive *P. aeruginosa* strains were prepared as
151 described previously [13]. Cells were harvested from overnight cultures in LB broth and
152 resuspended in phosphate buffer. Proteins were released from the cells by sonication in ice
153 bath and collected by centrifugation at 10 000 g. After solubilization in 10 mM Tris HCl , 5
154 mM MgCl₂ and to 2% sodium lauroyl sarconisate for for 1 h at 37°C the insoluble OMPs
155 were recovered at 14 000 g. A second solubilization step was performed and the OMPs were
156 again pelleted as above. Prior to SDS PAGE, the OMPs were denatured by the addition of
157 3% SDS-5% β-mercaptoethanol and boiled for 10 min. Laemmli's sample buffer (62.5 mM
158 Tris/Hcl, 2% SDS, 10% glycerol, 5% mercaptoethanol) and electrode buffer (25 mM Tris (pH
159 8.3), 190 mM glycine, 0.1% SDS) were used.

160 Electrophoretic analysis of *P. aeruginosa* OMPs was performed in polyacrylamide gel. The
161 gel contained 11% acrylamide, 0.54% bisacrylamide plus 0.2% SDS in 0.375 M Tris/HCl (pH
162 8.8). Gel was polymerised with 0.2% TEMED and 0.25% ammonium persulfate. Stacking gel
163 contained 4% acrylamide, 0.1% bisacrylamide, 0.1% SDS in 0.125 M Tris /HCl (pH 6.8), and
164 was polymerised as above. Staining was performed with 0.125% Coomassie brilliant blue
165 R250 in 45% methanol, 10% acetic acid for about 30 min. Destaining was performed in 45%
166 methanol, 10% acetic acid.

167

168 RESULTS

169 *E test*

170 Six out of 100 isolates were positive for MBLs by E test.

171 *Prevalence*

172 The prevalence of MBLs among carbapenem resistant isolates of *P. aeruginosa* was 6%.

173 *Susceptibility testing*

174 All strains were resistant to gentamicin, ceftazidime and cefotaxime. All except of strain
175 (132) were resistant to imipenem. Strains 6, 12, 132 and 135 were resistant to ciprofloxacin,
176 strains 12, 22, 35 and 135 to aztreonam, strains 6, 12, 22 and 135 to cefoperazon and strains
177 22, 35 and 135 to cefepime. Resistance to piperacillin alone and combined with tazobactam
178 was observed in only one strain (135).

179 *Enzyme characterization*

180 The enzyme activity ranged from 6 to 420 nmol/imipenem/min/mg of protein. Carbapenemase
181 activity was almost completely inhibited by 2 mM EDTA. (Table 2) .

182 IEF revealed a band with the pI of 5.3 in all strains.

183 *Polymerase chain reaction and sequencing of bla_{VIM} genes*

184 Six strains yielded an amplicon of 523 bp with primers specific for VIM β -lactamases.

185 Sequencing of *bla_{VIM}* genes revealed the production of VIM-2 β -lactamase in all six strains
186 (Fig. 1). No IMP MBLs producers were detected by PCR.

187 *Plasmid analysis*

188 No plasmid DNA was found.

189 *Pulsed field gel electrophoresis*

190 The strains showed distinct PFGE patterns and were not clonally related (Fig. 2).

191 *Characterization of outer membrane proteins*

192 Four of the tested strains lacked altered OmpD2 protein (Table 1).

193

194 DISCUSSION

195 This investigation proved the occurrence of VIM-2 β -lactamase among *P. aeruginosa* strains
196 from Zagreb, Croatia. VIM-2 β -lactamase was previously reported from another region in
197 Croatia [14] suggesting that there is a regional spread of this resistance determinant. VIM-2 β
198 -lactamase with similar properties was previously described in Italy [15], France [16], Spain
199 [17], Greece [18], Taiwan [19] and South Korea [20] suggesting that this type of enzyme is
200 widespread in Mediterranean region of Europe and Far East. VIM-2 is the most prevalent
201 MBL in Taiwan [21].

202 The fact that all strains displayed similar enzyme activities, but one strain (132) showed
203 markedly lower carbapenem MIC than the others suggests that there are other resistance
204 mechanisms involved in the strains with high carbapenem MIC such as loss of outer
205 membrane proteins detected in four strains (6, 12, 22, 135) or efflux. The strain with low
206 carbapenem MIC probably had higher permeability coefficient or less efficient efflux pump.
207 However, the carbapenem MICs rose above the resistance breakpoint for the strain 132 when
208 a higher inoculum which is more likely to occur in *in vivo* situation, was applied. It is possible
209 that *in vivo* in the presence of a high inoculum, high level resistance arises. Little clinical
210 information is available on the outcome of patients infected with carbapenem-susceptible
211 MBL producing *P. aeruginosa*. There is no consensus on the interpretation and reporting of
212 the antibiograms for the MBL producers. Four strains were resistant to aztreonam contrary to
213 the results obtained from other authors [16-17,22]. Aztreonam is not hydrolyzed by MBLs [1]
214 but resistance could be due to other mechanisms like overproduction of AmpC β -lactamase,
215 coexistence of other β -lactamase or efflux as reported previously [23]. The macrorestriction of
216 the Xba digested chromosomal DNA showed distinct patterns indicating that strains
217 harbouring bla_{VIM} genes are not clonally related. Thus it is more likely that the spread of MBL
218 genes is due to the genetic exchange between different clones. The occurrence of MBLs was

219 sporadic. The strains were obtained from various wards in two hospitals during a wide time
220 period.

221 Since all three attempts to transfer ceftazidime resistance to recipient strain and to isolate
222 plasmid DNA were unsuccessful we can conclude that gene cassettes harbouring *bla*_{VIM} genes
223 were located in the integrons [20] which are inserted in the chromosome and that their
224 dissemination in Croatia is due to the mobilization of the resistance genes.

225 Our strains harbouring VIM-2 β -lactamase were resistant to all β -lactam antibiotics,
226 aminoglycosides and fluoroquinolones and pose a serious therapeutic problem in our
227 hospitals. The fact that all strains were resistant to gentamicin suggests that *bla*_{VIM} genes are
228 located on integrons containing gene cassettes with resistance determinants for
229 aminoglycosides. Since most of the strains were resistant to aminoglycosides and
230 fluoroquinolones as well only toxic compounds such as colistine are left to be administered as
231 a therapeutic agent. The prevalence of MBL positive *P. aeruginosa* among our carbapenem
232 resistant strains of this species is still low (6%) but there is a possibility of horizontal spread
233 of *bla*_{VIM} genes to *Enterobacteriaceae* which are more frequent pathogens. MBLs have
234 already been found in the members of the family *Enterobacteriaceae* [18-19]. The difficulties
235 in detecting MBLs producers in the routine laboratories together with the mobile nature of the
236 gene cassettes carrying *bla*_{VIM} genes facilitates their dissemination. Meropenem has been
237 extensively used in our hospitals and the presence of MBLs among carbapenem resistant
238 *P. aeruginosa* of different genotypes, isolated from different hospitals, although in low
239 frequency, underscores the need for restricted use of carbapenems and their systematic
240 surveillance. Constant and consistent surveillance of the MBL producing strains will be the
241 prime measure to prevent their further dissemination.

242

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Table1. Epidemiologic characteristics, minimum inhibitory concentrations (MIC) of various antibiotics against MBL positive *P. aeruginosa* strains and alteration of outer membrane proteins.

| Strain No | Epidemiologic characteristics of <i>P. aeruginosa</i> strains | | | | | | MIC (mg/L) ¹ | | | | | | | | | | | Porins |
|-----------|---|-----------------------|----------------|-----------|---------------------------|------|-------------------------|------|--------|------|------|------|------|------|------|------|------|-------------------|
| | Specimen | Hospital ² | Unit | PFGE type | Date of isolation (D/M/Y) | IMI | MEM | CAZ | CAZ/CL | CTX | CFP | FEP | AMT | PIP | TZP | GM | CIP | OMPD ₂ |
| 6 | urine | A | nephrology | 1 | 15/01/2004 | >128 | 64 | 16 | >128 | >128 | >128 | 16 | 8 | 64 | 32 | >128 | 16 | - |
| 12 | stool | A | haematology | 2 | 14/01/2003 | 64 | 32 | >128 | >128 | 32 | >128 | 16 | >128 | 64 | 32 | >128 | 64 | - |
| 22 | Tracheal aspirate | A | Paediatric ICU | 3 | 15/02/2003 | >128 | 32 | 32 | 64 | >128 | 16 | 64 | >128 | 32 | 16 | 64 | 0.5 | - |
| 35 | Wound swab | A | oncology | 4 | 25/02/2003 | >128 | 32 | 16 | 32 | 32 | 4 | 32 | >128 | 64 | 32 | >128 | 4 | + |
| 132 | Tracheal aspirate | B | Surgery ICU | 4 | 09/08/2003 | 16 | 8 | >128 | >128 | 64 | 4 | 16 | 0.12 | 32 | 8 | 16 | 32 | + |
| 135 | Bronchal aspirate | B | Internal ICU | 5 | 07/01/2002 | >128 | 64 | >128 | >128 | >128 | >128 | >128 | >128 | >128 | >128 | >128 | >128 | - |

¹ Abbreviations-IMI-imipenem, MEM-meropenem, CAZ-ceftazidime, CAZ/CL-ceftazidime+clavulanic acid, CTX-cefotaxime, CFP-cefoperazone, FEP-cefepime, AMT-aztreonam, PIP-piperacillin, TZP-Tazobactam/piperacillin, GM-gentamicin, CIP-ciprofloxacin

² A- University Hospital Center-Zagreb, B-University Hospital Merkur

Table 2. Hydrolysis rates against imipenem of metallo- β -lactamases produced by *P. aeruginosa* strains.

| Strain No | Hydrolysis rate (nmol/min/mg protein) | Hydrolysis rate in the presence of 2 mM EDTA (nmol/min/mg protein) |
|-----------|--|--|
| 6 | 6×10^{-9} | 1×10^{-13} |
| 12 | 9×10^{-9} | 1.8×10^{-11} |
| 22 | 4.2×10^{-8} | 9.4×10^{-12} |
| 35 | 4×10^{-8} | 3.8×10^{-12} |
| 132 | 3.5×10^{-8} | 2.7×10^{-10} |
| 135 | 4×10^{-8} | 1.2×10^{-9} |