MCR-1 and OXA-48 In Vivo Acquisition in KPC-Producing Escherichia coli after Colistin Treatment

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ABSTRACT The spread of mcr-1-encoding plasmids into carbapenem-resistant Enterobacteriaceae raises concerns about the emergence of untreatable bacteria. We report the acquisition of mcr-1 in a carbapenem-resistant Escherichia coli strain after a 3-week course of colistin in a patient repatriated to France from Portugal. Whole-genome sequencing revealed that the Klebsiella pneumoniae carbapenemase-producing E. coli strain acquired two plasmids, an IncL OXA-48-encoding plasmid and an IncX4 mcr-1-encoding plasmid. This is the first report of mcr-1 in carbapenemase-encoding bacteria in France.

KEYWORDS colistin, Escherichia coli, KPC-28, KPC-3, OXA-48, antibiotic resistance, β-lactamases, carbapenemase, mcr-1

Colistin is a last-resort antibiotic reserved for treating multidrug-resistant Gram-negative bacilli. However, the increased use of colistin in clinical treatment and agricultural and animal production has led to the emergence of bacterial resistance to the drug. In November 2015, the first transferable plasmid-mediated colistin resistance gene, mcr-1, was detected in China in retail meat and human samples (1). The gene was observed worldwide a few months later. The spread of mcr-1-encoding plasmids into carbapenem-resistant Enterobacteriaceae (2–5) is causing concern about the rise of untreatable bacteria (6).

In this work, we report an in vivo acquisition of mcr-1 in carbapenemase-producing Escherichia coli after a 3-week course of colistin in a patient repatriated to France from Portugal in 2016. The 44-year-old man was hospitalized in Portugal for 2 months after a traffic accident. He had multiple traumas, including a thoracic injury associated with a respiratory Enterobacter cloacae infection that was treated with a combination of piperacillin and tazobactam. Carbapenemase-producing Enterobacteriaceae (CPE) belonging to the species Klebsiella pneumoniae and E. coli were isolated from a stool sample after treatment. A second episode of lower respiratory tract infection involving Acinetobacter baumannii, Pseudomonas aeruginosa, and the carbapenemase-producing K. pneumoniae was successfully treated by a 20-day course of colistin. The patient was then repatriated to an intensive care unit in France, where two E. coli isolates designated WI1 and WI2 were recovered from a feces CPE screening sample taken on the patient’s admission with CarbaSmart medium (bioMérieux, La Balme, France).

The E. coli WI1 and WI2 isolates were resistant to penicillins, oxy-imino-
The isolates were typed from WGSs by assigning sequence types according to the MLST Warwick University website. WI1 and WI2 belonged to sequence type ST1288 and phylogroup C (12). Single nucleotide polymorphism calling was performed from alignments generated by parsnp in deeply sequenced regions (>60×) (13), which were filtered for repeat elements, phages, and putative recombination events. Among 4,219,421 bp, WI1 and WI2 diverged by only four single nucleotide variants (SNVs) and four single nucleotide polymorphisms (SNPs), with a value of 4 μg/mL, as usually observed for mcr-1-harboring E. coli. The whole-genome sequence (WGS) of strain WI2 was determined by hybrid de novo assembly of 2× 150-bp paired-end reads generated with Illumina sequencing technology (San Diego, CA, USA) and long reads generated with Pacific Biosciences RS II SMRT technology (Menlo Park, CA, USA). WGS of strain WI1 was determined by de novo assembly of 2× 150-bp paired-end reads (Illumina) and mapping to the genome of strain WI2. De novo assemblies were performed with SPAdes (7), the mappings with Burrows-Wheeler aligner (8), and the final polishing of the assembly with Pilon (9). The average depth sequencing (ADS) was 125× and 145× for WI1 and WI2 chromosomes (4.8 Mb), respectively. Three plasmids were detected in strain WI1 (ADS, 282× to 320×; sizes, 54,502 to 83,831 bp) and five in strain WI2 (ADS, 81× to 213×; sizes, 33,304 to 83,832 bp). The plasmid content of the strains and the size of the plasmids were confirmed with plasmid DNA extracted by alkaline lysis, as previously described (10).

The antibiotic resistance genes were detected with the Comprehensive Antibiotic Resistance Database (CARD) (11). E. coli WI1 did not harbor mcr-1 but did harbor the carbapenemase-encoding gene bla\textsubscript{KPC-3}. In contrast, E. coli WI2 harbored the mcr-1 gene and two carbapenemase-encoding genes, bla\textsubscript{OXA-48} and a bla\textsubscript{KPC-3} variant gene designated bla\textsubscript{KPC-28} (accession number KY282958). The sequence of bla\textsubscript{KPC-28} was confirmed by PCR and Sanger sequencing. The deduced amino acid sequence of KPC-28 was derived from KPC-3 by two amino acid deletions in the catalytic pocket at positions 241 and 242. The KPC-28- and KPC-3-encoding open reading frames were cloned in E. coli DH5\textit{a} with pBK-CMV vector (Stratagene, San Diego, CA, USA). MIC values suggested that the deletions at positions 241 and 242 decrease the activity against amoxicillin and carbapenems but improve the activity against ceftazidime (Table 1).

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The assembled genomes were analyzed by PlasmidFinder (http://www.genomicepidemiology.org/) using the Enterobacteriaceae database with the detection thresholds set at 95% sequence identity. Three replicons (IncN, IncFII, and IncI1) were shared by both isolates. However, WI2 contained two additional replicons (IncX4 and IncI). The 33,304-bp-long IncX4 plasmid, designated pWI2-mcr, harbored mcr-1 and encoded no other antimicrobial resistance gene. The most closely related plasmid is the unpublished mcr-1-harboring plasmid pICBEC72Hmcr characterized in Brazil

### Table 1: Susceptibilities of the studied strains to β-lactams, by microdilution method

<table>
<thead>
<tr>
<th>Strain</th>
<th>Carbapenemase-encoding genes</th>
<th>MIC (μg/ml)</th>
<th>AMX</th>
<th>FOX</th>
<th>CAZ</th>
<th>CTX</th>
<th>FEP</th>
<th>IPM</th>
<th>ETP</th>
<th>MEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>WI1</td>
<td>bla\textsubscript{KPC-3}</td>
<td>&gt;256</td>
<td>16</td>
<td>&gt;256</td>
<td>&gt;32</td>
<td>12</td>
<td>4</td>
<td>6</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>WI2</td>
<td>bla\textsubscript{KPC-28}, bla\textsubscript{OXA-48}</td>
<td>&gt;256</td>
<td>8</td>
<td>&gt;256</td>
<td>8</td>
<td>6</td>
<td>1</td>
<td>3</td>
<td>0.38</td>
<td></td>
</tr>
<tr>
<td>E. coli DH5\textsubscript{a}-KPC-3</td>
<td>bla\textsubscript{KPC-28}</td>
<td>&gt;256</td>
<td>4</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0.125</td>
<td>0.25</td>
<td></td>
<td></td>
</tr>
<tr>
<td>E. coli DH5\textsubscript{a} KPC-28</td>
<td>bla\textsubscript{KPC-28}</td>
<td>64</td>
<td>8</td>
<td>64</td>
<td>0.5</td>
<td>1</td>
<td>0.125</td>
<td>0.032</td>
<td>0.032</td>
<td></td>
</tr>
<tr>
<td>E. coli DH5\textsubscript{a}</td>
<td></td>
<td>1</td>
<td>4</td>
<td>0.06</td>
<td>0.06</td>
<td>0.032</td>
<td>0.05</td>
<td>0.006</td>
<td>0.006</td>
<td></td>
</tr>
</tbody>
</table>

*AMX, amoxicillin; FOX, cefoxitin; CAZ, ceftazidime; CTX, cefotaxime; FEP, cephalothin; IPM, imipenem; ETP, ertapenem; MEM, meropenem.*

carboxyporphins, and carbapenems. The colistin MIC (broth microdilution method) was in the sensitive range (0.25 μg/mL) for the WI1 isolate. In contrast, the MIC was in the resistance range for the E. coli WI2 isolate, with a value of 4 μg/mL, as usually observed for mcr-1-harboring E. coli. The whole-genome sequence (WGS) of strain WI2 was determined by hybrid de novo assembly of 2× 150-bp paired-end reads generated with Illumina sequencing technology (San Diego, CA, USA) and long reads generated with Pacific Biosciences RS II SMRT technology (Menlo Park, CA, USA). WGS of strain WI1 was determined by de novo assembly of 2× 150-bp paired-end reads (Illumina) and mapping to the genome of strain WI2. De novo assemblies were performed with SPAdes (7), the mappings with Burrows-Wheeler aligner (8), and the final polishing of the assembly with Pilon (9). The average depth sequencing (ADS) was 125× and 145× for WI1 and WI2 chromosomes (4.8 Mb), respectively. Three plasmids were detected in strain WI1 (ADS, 282× to 320×; sizes, 54,502 to 83,831 bp) and five in strain WI2 (ADS, 81× to 213×; sizes, 33,304 to 83,832 bp). The plasmid content of the strains and the size of the plasmids were confirmed with plasmid DNA extracted by alkaline lysis, as previously described (10).

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OXA48 differed from the pOXA-48a reference plasmid by a 2,762-bp deletion (14). The deletion occurred within orf25 at base 22,738, leading to the suppression of cccA1 and orf26 genes. The deleted region was replaced by insertion sequence IS1R, which is probably involved in this novel arrangement within the backbone of a pOXA-48-like plasmid (15).

In the WI1 and WI2 isolates, bla{sub}KPC-3 and bla{sub}KPC-28 were carried by ST15-IncN 54,518-bp and 54,533-bp plasmids, designated pWI1-KPC3 and pWI2-KPC28, respectively. The plasmid pWI2-KPC28 differed from pWI1-KPC3 by the deletion of 6 bp, which probably involved in this novel arrangement within the backbone of a pOXA-48-like plasmid (15).

In conclusion, our data support the in vivo acquisition of mcr-1- and bla{sub}OXA-48- bearing plasmids by a KPC-producing E. coli probably following treatment with colistin. The emergence of multidrug-resistant isolates, such as E. coli WI2, that need to be carefully monitored is becoming a major burden on health care systems worldwide.

**Accession number(s).** The complete genome sequences of WI1 and WI2 strains were deposited in EMBL/GenBank under assembly accessions LT838196, LT838197, LT838198, and LT838199 (WI1) and LT838200, LT838201, LT838202, LT838203, and LT838204 (WI2).

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**REFERENCES**


