Molecular Monitoring of Fosfomycin Resistance in *Escherichia coli* Strains Isolated from Patients with Urinary Catheters in north-east of Iran

Sara Malekpour Kolbadinezhad1, Leila Fozouni*2

1Department of Biology, Gorgan Branch, Islamic Azad University, Gorgan, Iran

Received Apr. 20, 2019; Accepted Jun. 16, 2019

**INTRODUCTION**

Urinary tract infection (UTI) is a common infectious disease that could be either symptomatic or asymptomatic. Urinary catheters and pathogens emanating from the gastrointestinal tract are the leading causes of UTI [1]. Uropathogenic *Escherichia coli* (UPEC) is responsible for 70-90% of UTIs in humans. Therefore, early and accurate diagnosis of UTI is crucial for effective treatment and prevention of infection spread to the upper urinary tract [2]. Prevalence of multi-drug resistant *E. coli* strains that are resistant to beta-lactams, fluoroquinolones, and aminoglycosides have increased dramatically in recent years. As a bactericidal antibiotic, fosfomycin is used with different formulations for the treatment of complicated UTIs. Despite being an old-generation antibiotic, fosfomycin has recently played a significant role in controlling resistant bacteria, particularly *E. coli* [3, 4]. This antibiotic is a phosphoenolpyruvate analog that binds to UDP-N-acetylglucosamine enolpyruvyl transferase (MurA), (an essential enzyme for peptidoglycan biosynthesis) leading to bacterial cell lysis and death [5]. Fosfomycin can also inhibit this enzyme by covalently binding to a key cysteine residue (115 in *E. coli*) in the active site of MurA [6]. The *E. coli* MurA with the Cys115 to Asp mutation exhibits full enzymatic activity and makes the bacteria resistance to fosfomycin, while the gene with the Cys115 to Glu mutation shows no activity [7]. Glucose-6-phosphate (G6P) transporter, UhpT and glycerol-3-phosphate (G3P) transporter (GlpT) facilitate the incorporation of fosfomycin into the bacterial cells [8]. G3P induces expression of GlpT in *E. coli*. In these bacteria, two domains in the GlpT structure are attached to the central loop and act as a secondary active transporter to transfer substrates into the cytoplasm. However, mutations in the glpT, GlpT transporter, and murA may decrease fosfomycin susceptibility and uptake.

Expression of the GlpT and UhpT transporters is induced by their substrates, G3P and G6P, respectively, and requires the presence of cAMP. Mutations in the structural genes involved in these pathways lower the antibiotic uptake, thereby conferring different levels of fosfomycin resistance [9]. In this study, we aimed to investigate the genetic pattern of fosfomycin resistance in UPEC isolates from patients with UTI.

**MATERIAL AND METHODS**

**Patients and bacterial isolation.** Urine samples were collected from 106 patients with UTI in three hospitals of...
Evaluation of Fosfomycin resistance E. coli in ICU

RESULTS

Demographic specifications of bacterial isolates. Among the 106 patients with UTI (average age: 44 ± 18 years), the individuals ≥ 60 years of age showed the highest rate of infection (36.36%), while 15 and 25-year-old patients had the lowest rate of infection (9.09%). About 62.3% of the isolates were identified as E. coli, most of which were isolated from women (62.1%) and ICU patients (56.5%).

Susceptibility to antibiotics. In the Kirby-Bauer test, the highest rates of resistance and susceptibility were observed against imipenem (average=61.8%) and fosfomycin (average=85%), respectively (Table 2).

Table 1. The primers used for detection of murA and glpT genes

<table>
<thead>
<tr>
<th>Gene/Size</th>
<th>Primer</th>
<th>Primer Sequence</th>
</tr>
</thead>
<tbody>
<tr>
<td>murA/1542 bp</td>
<td>Forward</td>
<td>5'-AACAGCAGACGGTATATGG'</td>
</tr>
<tr>
<td></td>
<td>Reverse</td>
<td>5'-CCATGAATATCGACACGGTATATGG'</td>
</tr>
<tr>
<td>glpT/1785 bp</td>
<td>Forward</td>
<td>5'-GCGAGGTCCGAGTTTCCAGTGG'</td>
</tr>
<tr>
<td></td>
<td>Reverse</td>
<td>5'-GGCAAAATATCCACTGGGCACC'</td>
</tr>
</tbody>
</table>

Minimum Inhibitory Concentration. The effects of different concentrations of fosfomycin (0.5-1024 μg/mL) on the growth of E. coli strains showed that 80.3% of the isolates had a MIC of ≤64 μg/mL. The most significant growth changes were observed at concentrations 16 μg/mL and 32 μg/mL, and 44% of the isolates had a MIC of 16 μg/mL (Fig. 1).

glpT and murA PCR. Among the fosfomycin-resistant E. coli isolates, 22.2% yielded a 1785 bp band indicative of the glpT gene (1785 bp band), 77.8% showed a 1542 bp band representative of the murA gene. One isolate (11.1%) contained both genes (Figs. 2 and 3).
Table 2. Distribution of susceptibility to 8 antibiotics in *E. coli* Isolates

<table>
<thead>
<tr>
<th>Antibiotics</th>
<th>ICU (n=37) N (%)</th>
<th>CCU (n=29) N (%)</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fosfomycin</td>
<td>R 7 (18.9)</td>
<td>2 (6.9)</td>
<td>0.36</td>
</tr>
<tr>
<td></td>
<td>I 1 (2.7)</td>
<td>0 (0)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>S 29 (78.4)</td>
<td>27 (93.1)</td>
<td></td>
</tr>
<tr>
<td>Gentamicin</td>
<td>R 11 (29.7)</td>
<td>6 (20.7)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>I 9 (24.3)</td>
<td>2 (6.9)</td>
<td>0.00*</td>
</tr>
<tr>
<td></td>
<td>S 17 (46)</td>
<td>21 (72.4)</td>
<td></td>
</tr>
<tr>
<td>Cefepime</td>
<td>R 15 (40.5)</td>
<td>9 (31)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>I 7 (19)</td>
<td>0 (0)</td>
<td>0.00*</td>
</tr>
<tr>
<td></td>
<td>S 17 (46)</td>
<td>27 (93.1)</td>
<td></td>
</tr>
<tr>
<td>Ceftriaxone</td>
<td>R 15 (40.5)</td>
<td>9 (31)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>I 7 (19)</td>
<td>0 (0)</td>
<td>0.00*</td>
</tr>
<tr>
<td></td>
<td>S 18 (48.6)</td>
<td>27 (93.1)</td>
<td></td>
</tr>
<tr>
<td>Imipenem</td>
<td>R 24 (64.9)</td>
<td>17 (58.6)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>I 2 (5.4)</td>
<td>0 (0)</td>
<td>0.04</td>
</tr>
<tr>
<td></td>
<td>S 11 (29.7)</td>
<td>12 (41.4)</td>
<td></td>
</tr>
<tr>
<td>Ciprofloxacin</td>
<td>R 10 (27.1)</td>
<td>7 (24.1)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>I 12 (32.4)</td>
<td>0 (0)</td>
<td>0.36</td>
</tr>
<tr>
<td></td>
<td>S 15 (40.5)</td>
<td>22 (75.9)</td>
<td></td>
</tr>
<tr>
<td>Gemifloxacin</td>
<td>R 5 (13.5)</td>
<td>2 (6.9)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>I 6 (16.2)</td>
<td>1 (3.4)</td>
<td>0.07</td>
</tr>
<tr>
<td></td>
<td>S 26 (70.3)</td>
<td>26 (89.7)</td>
<td></td>
</tr>
<tr>
<td>Colistin</td>
<td>R 9 (24.3)</td>
<td>4 (13.8)</td>
<td>0.04</td>
</tr>
<tr>
<td></td>
<td>I 0 (0)</td>
<td>0 (0)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>S 28 (75.7)</td>
<td>25 (86.2)</td>
<td></td>
</tr>
</tbody>
</table>

*Significant difference between the study groups based on the one-way ANOVA. R: Resistant, I: Intermediate, S: Susceptible

![Fig. 1. Absolute Abundance of Fosfomycin MICs of *E. coli* clinical Isolates](image1)

![Fig. 2. PCR amplification of the *murA* gene in *E. coli* isolates. Lanes 17, 23, 33, 38, 41, 57, and 61, *murA*-positive *E. coli* isolates; C+, positive control; C-, negative control](image2)
DISCUSSION

UPEC is a significant cause of UTI in humans, and the pathogenicity of these strains relies on the presence of virulence factors [13]. Given the relatively high frequency of \( E. \) \( \text{coli} \) in urine specimens, it is necessary to investigate the virulence factors. With the emergence of multi-drug resistant strains, management of infections caused by \( E. \) \( \text{coli} \) strains has become challenging. Therefore, a better understanding of the virulence factors and identification of alternative antibiotics would allow physicians to predict the progression of infection and implement more effective treatment strategies [14].

In our study, out of 106 urine samples, 66 showed infection with \( E. \) \( \text{coli} \). Frequency of isolates was higher in samples collected from women (62.1%). Although, according to the type of patients, it was expected to find more infected men than women. Consistent with this finding, the frequency of \( E. \) \( \text{coli} \) isolates in some studies was highest among women [15-17]. In a study, most \( E. \) \( \text{coli} \) strains were isolated from subjects aged 12-50 years [14], while in another study, the prevalence of infection was highest among subjects aged 27-39 years and 1-5 years [16]. In line with our findings, researchers observed the highest infection rates in individuals aged 60-80 years [18]. This inconsistency could be related to the difference in characteristics of the study population, including age, ethnicity, and geographical factors. Due to conditions such as weakened immune system, urinary tract obstruction, diabetes mellitus, enlarged prostate, and incomplete bladder emptying, the elderly are more susceptible to develop infections, particularly nosocomial infections caused by opportunistic microorganisms [19].

In the present study, the isolation rate of \( E. \) \( \text{coli} \) was the highest in ICU patients (56.5%), which is somewhat consistent with previous findings in Iran [20].

The introduction of new therapies has saved human lives but has also contributed to the emergence of antibiotic resistance and the development of life-threatening nosocomial infections [21]. Such infections not only lower the efficiency of current therapeutic protocols but also increase the duration of hospitalization, amount and frequency of antibiotic administration, and treatment costs [22-24].

In our study, the highest and lowest resistance rates were observed against imipenem (56.1%) and fosfomycin (15%), respectively. Previously, a survey reported a 3% rate of resistance to imipenem in Iran [25], which is much lower than the rate observed in our study. However, the survey included isolates from both blood and urine samples. Another study reported the rate of imipenem resistance around 25% [26], which is also lower than the rate observed in our study. Ciprofloxacin is prescribed as an effective drug for the treatment of various infections caused by gram-negative bacteria. In western Iran, \( E. \) \( \text{coli} \) isolates showed a resistance rate of 68% to ciprofloxacin, which is lower than the rate in our study [27]. The resistance to this antibiotic in Canada and Syria were reported 79% and 68%, respectively [28, 29]. The difference in the resistance rates might be due to variations in the patient samples. Nevertheless, the increased rate of resistance to imipenem and ciprofloxacin in our study could be attributed to the origin of isolates, i.e., from ICU and CCU wards.

In the present study, the rate of resistance to cefepime and gentamicin was 42.4% and 34.8%, respectively, which were higher than the rates reported in similar studies in Iran (36% and 19.1%) [26] and (32% and 14%) [30]. The differences might be due to this proven fact that the isolates from ICU and CCU are more resistant than others. However, a study in Pakistan reported an 87% rate of resistance to cefepime [31], which is significantly higher than the rate obtained in our study. The previous study in Iran has also indicated higher rates of antibiotic resistance among \( E. \) \( \text{coli} \) isolates from ICU compared to general wards [32], but a study in the USA demonstrated that among Enterobacteriaceae, the highest susceptibility rates were related to ICU isolates compared to the non-ICU organism [33].

We observed the lowest rate of antibiotic resistance against fosfomycin. This antibiotic is less frequently administered in healthcare centers in Iran and is not
available over the counter. In line with our findings, high rates of fosfomycin susceptibility were reported from Taiwan (94%) [34], Iran (97.3%) [35], and Korea (92.9%) [36]. Despite the favorable therapeutic efficacy of fosfomycin against gram-negative bacterial infections, there have been reports of bacterial resistance to this antibiotic. The bactericidal effects of fosfomycin on various gram-negative and gram-positve bacteria are mainly mediated through inhibition of the MurA enzyme. Resistance to fosfomycin among extended spectrum beta-lactamase-producing E. coli isolates is plasmid-mediated [4].

Our results showed that the glpT and murA genes were present in 22.2% and 77.8% of the E. coli isolates, respectively. Moreover, 11.1% of the isolates (one isolate) contained both genes. Similar studies in other countries have shown that most E. coli isolates carry at least one virulence gene [37, 38]. Unlike our findings, one study demonstrated that murA was not present in fosfomycin-resistant isolates [39]. This disparity between the findings could be due to genetic changes in the sources of antibiotic resistance and geographical factors.

Our results demonstrated a high prevalence rate of antibiotic-resistant among E. coli isolates originated from the care units of hospitals of Gorgan, Iran. Such significant resistance rates may contribute to the spread of the antibiotic resistance genes to other E. coli communities or similar bacteria. We found that fosfomycin has a favorable effect on clinical isolates of E. coli, which necessitate the monitoring of its use to lower the risk of developing resistance to this antibiotic.

ACKNOWLEDGMENT

The authors are grateful to all those who helped in this study as well as the staff of the Microbiology Laboratory at the Islamic Azad University, Gorgan branch, Iran.

CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest associated with this manuscript.

REFERENCES


