Multidrug-resistant *Shigella* infection in pediatric patients with diarrhea from central Iran

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**Background:** *Shigella* spp. are primary pathogens of diarrhea in children worldwide. Emergence of resistance to fluoroquinolones and third-generation cephalosporins is crucial in the management of pediatric shigellosis. We determined the prevalence and the antibiotic resistance patterns of *Shigella* species isolated from pediatric patients in central Iran.

**Materials and methods:** Pediatric diarrhea samples (n=230) were cultured on MacConkey and XLD agar media and in GN broth. Genus-specific PCR for *ipaH* was also used for detection directly from fecal specimens. Antibiotic resistance and the frequency of ESBL and AmpC genes were determined.

**Results:** Out of the 230 samples, 19 (8.2%) cases of *Shigella* spp. were identified using culture. Twenty-six samples were positive by PCR (11.3%), *S. flexneri* (4/19; 21%) and *S. sonnei* (15/19; 78.9%) being the most detected. The highest antibiotic resistance rates were found for cotrimoxazole (19/19; 100%), ampicillin (16/19; 84.2%), cefotaxime (13/19; 68.4%) and ceftriaxone (12/19; 63.1%). Ten cases showed phenotypic ESBL presence and all these strains were positive for *bla*<sub>TEM</sub>, *bla*<sub>CTX-M-1</sub> and *bla*<sub>CTX-M-15</sub>. Three strains were AmpC positive, all of which harbored *bla*<sub>CVMY-2</sub> and two contained *bla*<sub>CIT</sub>. Of the 19 *Shigella* isolates 5 (26.3%), 2 (10.5%), and 1 (5.2%) were phenotypically resistant to nalidixic acid, ciprofloxacin, and norfloxacin, respectively. Class 1 integron was found in 18 (94.7%) isolates whereas class 2 integron was found in 19 (100%) strains.

**Conclusion:** We found a considerable presence of *Shigella* species with elevated antibiotic resistance levels. In particular, the resistance to third-generation cephalosporins (ESBL) and ciprofloxacin must be taken seriously.

**Keywords:** *Shigella*, dysentery, antibiotic resistance, MDR, integrons, Iran

**Introduction**

*Shigella* species belong to the Enterobacteriaceae and are Gram-negative rods, known as important causative agents of diarrhea and dysentery. *Shigella* spp. pose major public health problems in developing countries. In 2013, the annual and global number of deaths amongst children under 5 years due to shigellosis was estimated to be between 28,000 and 48,000.2 The most prevalent species causing those infections are *Shigella flexneri* and *Shigella sonnei*.3 Due to resistance to trimethoprim-sulfamethoxazole, ampicillin, sulphonamides, and tetracycline World Health Organization (WHO) recommends fluoroquinolone (ciprofloxacin) for first-line treatment of all patients with bloody diarrhea, regardless of age. Ceftriaxone is proposed as second-line therapy or alternative antimicrobial agent in adults and children.4 The increase of multidrug resistance (MDR) in *Shigella* spp., mostly due to third-generation cephalosporins (TGC), azithromycin and fluoroquinolones, is
a major issue in developing countries. The elevated resistance levels are often the consequence of the horizontal transfer of complex resistance determinants including plasmids, integrons, and transposons.

Although studies have found different frequencies and different Shigella species from north and south Iran, most reported phenotypic criteria such as frequency and antibiotic resistance profiles. In addition, Iran is a huge country with different climates in different geographical regions. In Central Iran, the prevalence of diarrhea and dysentery among children is especially high in the summer. Still, laboratory diagnosis of Shigella spp. is not common and most patients are treated empirically with TGCs.

Therefore, the main objective of the present study was to determine the frequency of Shigella spp. in children with diarrhea in Central Iran. In addition, we investigated their phenotypic antimicrobial resistance levels and resistance gene content.

Materials and methods

Ethics statement

This study was conducted in accordance with the Declaration of Helsinki and approved by the Ethics Committee of the Arak University of Medical Sciences under approval numbers ARAKMU.REC. 93–176-30. A questionnaire and a consent form were provided to the parents, guardians and/or patients. The two main inclusion criteria were as follows: 1) completion of the consent form; and 2) direct observation of over five white blood cells per high-power microscope field (HPF) in a diarrhea sample. None of the patients had taken antibiotics in the week before hospitalization.

Sample collection

This descriptive cross-sectional study included samples from 230 pediatric patients with infectious diarrhea who were referred to the Educational-Therapeutic Centers affiliated with the Arak University of Medical Sciences (Valiasr, Amirkabir, Amiralmomenin) from May to September 2015.

Phenotypic investigation

First, 500 μL of the liquid stool samples were enriched in 5 mL of Gram-negative (GN) broth (Merck, Hamburg, Germany) and after 6 h at 37°C the enriched samples were streaked on xylose lysine deoxycholate (XLD) and MacConkey agar. In addition, stool samples were directly cultured on MacConkey agar, XLD (Merck) and incubated at 35–37°C for 18–24 h. Individual isolates were surveyed using previously defined standard biochemical and serological tests. All isolates were confirmed to be Shigella spp. applying API 20E test strips (bioMérieux, Craponne, France). Serogrouping of the Shigella spp. isolates was performed using slide agglutination with specific antisera (SSI, Copenhagen, Denmark). The confirmed Shigella spp. isolates were kept in brain heart infusion broth with 20% glycerol at −80°C. S. sonnei PTCC 1777 and S. flexneri PTCC 1234 were used as controls in each assay (obtained from the Iranian Research Organization for Science and Technology). S. boydii and S. dysenteriae control strains were obtained from the microbiology department of Arak University of Medical Sciences.

Investigating Shigella antibiotic resistance by disk diffusion

Antibiotic resistance of Shigella spp. isolates was determined using the disk diffusion method according to the Clinical and Laboratory Standards Institute (CLSI) 2016 guidelines. The antibiotic discs used contained cotrimoxazole (25 μg), cefoxitin (30 μg), ampicillin (10 μg), ceftizoxime (30 μg), ceftazidime (30 μg), ceftriaxone (30 μg), cefixime (5 μg), cefotaxime (30 μg), tetracycline (30 μg), gentamicin (10 μg), nalidixic acid (30 μg), chloramphenicol (30 μg), ciprofloxacin (5 μg), azithromycin (15 μg) and imipenem (10 μg) (Mast Diagnostics, Bootle, UK).

Detection of extended spectrum β-lactamase (ESBL) and AmpC by phenotypic methods

Shigella spp. isolates were subjected to double-disk synergy testing, combination disk diffusion methods, and AmpC disk testing and phenyl boronic acid assays for identification of ESBL and AmpC resistance according to the 2016 CLSI guidelines. The MICs of 19 of the isolates to ciprofloxacin were determined by the E-test (Liofilchem, Roseto degli Abruzzi, Italy).

Genotypic investigations

DNA extraction

DNA extraction was performed directly from the stool samples and the reference S. sonnei and S. flexneri isolates using the QIAamp DNA Stool Minikit (Qiagen GmbH, Hilden, Germany) according to the manufacturer’s protocol. The amount and purity of extracted DNA were measured using a NanoDrop device (Thermo Fisher Scientific, Waltham, MA, USA).
**Genotypic identification**

The *ipaH* gene was used as a genetic marker for confirming the *Shigella* genus by PCR.\(^1,10\) PCR assays were performed to detect the *stx* gene for Shiga toxin-producing isolates and the ESBL genes (*bla*<sub>TEM</sub>, *bla*<sub>SHV</sub>, and *bla*<sub>CTX-M-1</sub>, 2, 8, 14, 15) for the ESBL-producing *Shigella* spp. isolates. In addition, AmpC genes (*bla*<sub>CMY-2</sub>, *bla*<sub>ACC</sub>, *bla*<sub>FOX</sub>, *bla*<sub>MOX</sub>, and *bla*<sub>DHA</sub>) were also detected by PCR.\(^1,11-13\) PCR was carried out to amplify plasmid-mediated quinolone resistance (PMQR) targets for *qnr* determinants including *qnrA*, *qnrB*, and *qnrS*. Mutations in *gyrA* and *parC* among the fluoroquinolone-resistant *Shigella* spp. isolates were identified with the use of DNA sequencing as well.\(^11,13\)

**Integron detection**

To detect and distinguish class 1, 2 and 3 integrons, PCR analysis was performed as described before.\(^3,10,11\)

**Results**

Out of the 230 pediatric infectious diarrhea samples, 19 (8.2%) cases of shigellosis were identified using the culture method. All culture-positive samples were identified as positive using the PCR method and an additional seven samples which were culture-negative were identified as positive using the PCR method with specific primers 26 (11.3%). Of 230 patients included in the study, 10 (52.6%) male and 9 (47.3%) female patients were infected by *Shigella* spp., giving an infection ratio of males to females of 1.1:1. The average age of the patients was 6 years and 4 months. The youngest of these patients was a boy aged one year and 10 months, and the oldest was a 16-year-old boy. The majority of *Shigella* spp. infections (7 cases, 36.8%) were observed in pediatric patients between 5 and 10 years of age. Clinical symptoms of pediatric patients are given in Table 1.

**Phenotypic and genotypic investigation**

Of the 19 cultured *Shigella* spp. isolates, 15 (78.9%) were identified as *S. sonnei* and 4 (21%) as *S. flexneri*. No *Shigella* toxin-producing isolate was found.\(^14\)

**Phenotypic and genotypic antibiotic resistance determination**

Using the CLSI 2016 guidelines, the highest resistance rates in *Shigella* spp. were found against cotrimoxazole (19/19; 100%), ampicillin (16/19; 84.2%), cefixime (13/19; 68.4%), ceftriaxone (12/19; 63.1%), and cefotaxime (12/19; 63.1%). All *Shigella* isolates were susceptible to azithromycin and imipenem (Table 2). Ten *Shigella* spp. isolates were ESBL positive. All isolates contained *bla*<sub>TEM</sub>, *bla*<sub>CTX-M-1</sub>, and *bla*<sub>CTX-M-15</sub> resistance genes. In addition, all AmpC positive isolates (3/19; 15.8%) were *bla*<sub>CMY-2</sub> positive and were resistant to ciprofloxacin and nalidixic acid; only 2 (66.6%) were *bla*<sub>CTX-M-15</sub> type positive. (Table 2). Of the 19 *Shigella* isolates studied, 5 (26.3%), 2 (10.5%), and 1 (5.2%) showed resistance to nalidixic acid, ciprofloxacin, and norfloxacin, respectively. Among the PMQR determinants, *qnrS* was positive only in 60% (3/5) of the isolates. In addition, no isolates harbored *qnrA* or *qnrB* genes. The majority of the *Shigella* spp. isolates (89.4%) were multidrug resistant (Table 3). All the isolates harboring PMQR had the same mutations in *gyrA* at amino acid 83 (replacement of serine with leucine) and in *parC* at amino acid 80 (replacement of serine with isoleucine; GenBank accession no. HM068910). Out of 5 (26.3%) fluoroquinolone-resistant isolates, 4 (80%) were *S. sonnei* and 1 (20%) was identified as *S. flexneri*. Also, 3 of the fluoroquinolone-resistant isolates (two *S. sonnei* and one *S. flexneri*) were resistant to the TGC and fourth-GC and presented AmpC producer. Class 1 integrons were found in a total of 18 (94.7%) strains: *S. sonnei* (n=14) and *S. flexneri* (n=4), whereas class 2 integrons were found in all strains: *S. sonnei* (n=15) and *S. flexneri* (n=4); Class 3 integrons were not found (Table 4).

**Discussion**

In total, an 8.2% prevalence of Shigellosis was defined using cultures and 11.3% using PCR. The sensitivity of the PCR method is higher than those of the culture methods.\(^5,16\) However, our result was almost similar to studies conducted in Kerman, Iran and the North of Ethiopia, which had reported frequencies of 9% and 13.3%, respectively.\(^17,18\) Our result was different from studies conducted in India which had reported frequencies close to 2%.\(^19\) These differences in frequency of Shigellosis may be related to age, economic development level, geography, climate as well as many other environmental conditions. Facilities such as general water supply systems and sewage systems, closely related to the level of sanitation and individual hygiene, contamination of food, and improper medical health-care levels may be missing or of poor quality.

*S. sonnei* is more generally found in industrialized countries, whereas *S. flexneri* seems overrepresented in the developing world.\(^1\) Our results show that *S. sonnei*...
<table>
<thead>
<tr>
<th>Age grouping</th>
<th>Gender</th>
<th>Shigella spp</th>
<th>Mucus in the stool</th>
<th>Blood in the stool</th>
<th>Abdominal pain/ Tenesmus</th>
<th>Fever</th>
<th>Vomiting</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>male/ female</td>
<td>S. flexneri</td>
<td>S. sonnei</td>
<td>S. flexneri</td>
<td>S. sonnei</td>
<td>S. flexneri</td>
<td>S. sonnei</td>
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<td>2</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Female</td>
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<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Total:</td>
<td></td>
<td>1/4, 25%</td>
<td>3/15, 20%</td>
<td>1/1, 100%</td>
<td>3/3, 100%</td>
<td>1/1, 100%</td>
<td>3/3, 100%</td>
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<tr>
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<td>1</td>
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<td>0</td>
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<tr>
<td>Total:</td>
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<td>0%</td>
<td>4/15, 26.6%</td>
<td>0%</td>
<td>4/4, 100%</td>
<td>0%</td>
<td>3/4, 75%</td>
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<tr>
<td>Total:</td>
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<td>2/4, 50%</td>
<td>5/15, 33.3%</td>
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<td>5/5, 100%</td>
<td>2/2, 100%</td>
<td>5/5, 100%</td>
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<tr>
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<td>Female</td>
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<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Total:</td>
<td></td>
<td>1/4, 25%</td>
<td>3/15, 20%</td>
<td>1/1, 100%</td>
<td>3/3, 100%</td>
<td>1/1, 100%</td>
<td>3/3, 100%</td>
</tr>
<tr>
<td>Final total</td>
<td></td>
<td>4/19, 21%</td>
<td>15/19, 78.9%</td>
<td>4/4, 100%</td>
<td>15/15, 100%</td>
<td>4/4, 100%</td>
<td>14/15, 93.3%</td>
</tr>
</tbody>
</table>
The antibiotic resistance properties of *Shigella* spp. are various, and regionally distinct. We provide the first report regarding the prevalence of shigellosis and associated resistance patterns to a panel of 16 antibiotics in the center of Iran. The appearance of multidrug-resistant (MDR) strains of *Shigella* spp. is a growing concern across the globe.

Cotrimoxazole is a drug often used for empirical therapy of diarrheal diseases; extensive use of this drug has led to the advent of resistant *Shigella* spp. strains. In this study, *Shigella* spp. showed a high rate of resistance to cotrimoxazole (100%). Previous reports in Iran have reported a 92.2% to 94% resistance level to cotrimoxazole (2000–2017). A high-level resistance to cotrimoxazole has also been reported from Turkey (95%).

Based on the reports from our region, resistance to ampicillin ranged from 12–20% to 87%. We here document 84.2%, and a previous study reported 57% from Iran. These results strongly suggest that cotrimoxazole and ampicillin can no longer be empirically used for the treatment of severe diarrhea and dysentery in central Iran.

A previous Iranian study from Tabriz found that 4.2% of *Shigella* spp. isolates were resistant to ciprofloxacin. Ciprofloxacin-resistant *S. flexneri* was also recognized from parts of India (56.2%). In the present study, 5 (26.3%) of *Shigella* isolates were resistant to nalidixic acid, a marked increase in resistance to nalidixic acid. In two reports from Tehran and Tabriz, Iran, 17.4% and 31% of *Shigella* spp. isolates were resistant to nalidixic acid, respectively. In China, Pu et al. found that 5 (33.3%) of 15 fluoroquinolone-resistant isolates contained the *qnrS* gene. The findings of the current study regarding other PMQR genes (*qnrA* and *qnrB*) are in accordance with the findings of Taneja et al., who explained that none of the *Shigella* spp. isolates they found were positive for *qnrA* and *qnrB* genes.

In this study, high resistance (21–68.4%) to TGC was observed in the *Shigella* spp. isolates. Previous studies from Iran have also indicated the resistance of *Shigella* spp. to cephalosporins at the range of 7.3–57.7% between 2008 and 2018. This indicated that the rate of resistance to cephalosporins is growing among *Shigella* spp. in Iran, similar to what is happening in other countries. This finding is alarming and contrary to previous studies from China, the Middle East, and Southeast Asia which have reported lower level resistance to cephalosporins (2.0–15.1%).

In the present investigation, *blaTEM*, *blaCTX-M-1*, and *blaCTX-M-15* were the most common ESBL genes, and *blaCMY-2* and *blaCTT* were the most common AmpC genes.
The current report shows that resistance to β-lactams mediated by blaCMY enzymes in Iran has a similar pattern as in other parts of the world. In recent years, various ESBL-producing Shigella were also reported from Argentina (blaCTX-M-2), Korea and China (blaCTX-M-14), and Vietnam (blaCTX-M-15 and blaCTX-M-24).40–42 blaCMY-2 type AmpC β-lactamase producers were predominant. However, in several other studies, the blaCMY-2 type AmpC β-lactamases were the most prevalent cephalosporinases in Iran (Tehran) and Taiwan.43,44

In this study, class 1 integrons were found in 18 (94.7%) strains, whereas class 2 integrons were found in 19 (100%) of the strains. In Brazil, it was found that class 1 integrons were achieved in only two strains, whereas class 2 integrons were achieved in 56 (90.3%) of the strains.45 Of the three classes of integrons linked to antimicrobial resistance, the class I integron is the most frequently found in Gram-negative bacteria.46 The class II integron is the most predominant integron in S. sonnei.47 The prevalence of integrons in the Enterobacteriaceae family has varied and played an important role in the development of drug-resistant bacteria. Therefore, a high prevalence of antibiotic resistance is probably related to a high prevalence of class I and II integrons. In epidemiologic studies, particularly of infectious diseases caused by bacteria, typing of the isolates is a useful method for source tracing and understanding the pathogenesis and eventual disease prevention. One limitation of the present study was that typing of Shigella isolates was not performed.

**Conclusion**

The recent emergence of S. sonnei in developing countries reinforces the need for effective epidemiological surveillance systems.48 The wide distribution of MDR Shigella spp.
Table 4 Phenotypic and genotypic antibiotic resistance rates in *Shigella* spp

<table>
<thead>
<tr>
<th>Antibiotic</th>
<th><em>Shigella</em> spp, n=19</th>
<th><em>Shigella</em> sonnei, n=15</th>
<th><em>Shigella</em> flexneri, n=4</th>
<th>Resistance</th>
<th>Target gene</th>
<th>Frequency of resistance genes</th>
<th>Resistance</th>
<th>Target gene</th>
<th>Frequency of resistance genes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cotrimoxazole</td>
<td>19 (100%)</td>
<td>15 (100%)</td>
<td>4 (100%)</td>
<td>Sulfonamide</td>
<td>SulI</td>
<td>0 (0%)</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>SulI2</td>
<td>19 (100%)</td>
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<tr>
<td>Ampicillin</td>
<td>16 (84.2%)</td>
<td>12 (80%)</td>
<td>4 (100%)</td>
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</tr>
<tr>
<td>Cefixime</td>
<td>13 (68.4%)</td>
<td>11 (73.3%)</td>
<td>2 (50%)</td>
<td>ESBL+</td>
<td>bla&lt;sub&gt;TEM&lt;/sub&gt;</td>
<td>10 (100%)</td>
<td>Ap&lt;sub&gt;AP&lt;/sub&gt;C+</td>
<td>3 (100%)</td>
<td></td>
</tr>
<tr>
<td>Cefotaxime</td>
<td>12 (63.1%)</td>
<td>11 (73.3%)</td>
<td>1 (25%)</td>
<td>bla&lt;sub&gt;CTX-M1&lt;/sub&gt;</td>
<td>10 (100%)</td>
<td>bl&lt;sub&gt;CT&lt;/sub&gt;A&lt;sub&gt;M&lt;/sub&gt;1</td>
<td>2 (66.6%)</td>
<td></td>
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<tr>
<td>Ceftriaxone</td>
<td>12 (63.1%)</td>
<td>11 (73.3%)</td>
<td>1 (25%)</td>
<td>bla&lt;sub&gt;CTX-M15&lt;/sub&gt;</td>
<td>10 (100%)</td>
<td>bl&lt;sub&gt;AA&lt;/sub&gt;C</td>
<td>1 (33.3%)</td>
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<tr>
<td>Cefazidime</td>
<td>6 (31.5%)</td>
<td>6 (40%)</td>
<td>0%</td>
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<tr>
<td>Cefotaxime</td>
<td>4 (21%)</td>
<td>4 (26.6%)</td>
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<td></td>
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<tr>
<td>Cefoxitin</td>
<td>3 (15.7%)</td>
<td>2 (13.3%)</td>
<td>1 (25%)</td>
<td>bl&lt;sub&gt;CT&lt;/sub&gt;A&lt;sub&gt;CTX-M2&lt;/sub&gt;</td>
<td>1 (10%)</td>
<td>bl&lt;sub&gt;CH&lt;/sub&gt;A</td>
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<td></td>
<td>bl&lt;sub&gt;CT&lt;/sub&gt;A&lt;sub&gt;CTX-M4&lt;/sub&gt;</td>
<td>9 (90%)</td>
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<tr>
<td>Tetracycline</td>
<td>7 (36.8%)</td>
<td>4 (26.6%)</td>
<td>3 (75%)</td>
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<tr>
<td>Gentamicin</td>
<td>7 (36.8%)</td>
<td>6 (40%)</td>
<td>1 (25%)</td>
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<tr>
<td>Chloramphenicol</td>
<td>2 (10.5%)</td>
<td>0 (0%)</td>
<td>2 (50%)</td>
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<tr>
<td>Nalidixic acid</td>
<td>5 (26.3%)</td>
<td>4 (26.6%)</td>
<td>1 (25%)</td>
<td>Fluoroquinolone</td>
<td></td>
<td>gyrA</td>
<td>5 (100%)</td>
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<tr>
<td>Ciprofloxacin</td>
<td>2 (10.5%)</td>
<td>2 (13.3%)</td>
<td>0%</td>
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<tr>
<td>Norfloxacin</td>
<td>1 (5.2%)</td>
<td>1 (6.6%)</td>
<td>0%</td>
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<tr>
<td>Azithromycin</td>
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<td>0%</td>
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<tr>
<td>Imipenem</td>
<td>0%</td>
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(Continued)
isolates and the continuing emergence of ESBL-producing and ciprofloxacin-resistant isolates were shown in the study. The high prevalence of ESBL-producing genes in *Shigella* spp. isolates in pediatric patients in our study can be a major challenge for dysentery treatment. We found that the frequency of ESBL producing *Shigella* spp. isolates was higher than those in many other countries. Our results enhance concerns about the dissemination of ESBL among the strains of endemic *S. sonni* throughout the country, because it is now the most frequently isolated *Shigella* species in Iran. Thus, to prevent outbreaks due to these resistant isolates, the surveillance of the antimicrobial resistance of *Shigella* spp. isolates should be continuously considered, and empiric antibiotic therapy should be adapted appropriately.

### Abbreviation list

ESBL, third generation cephalosporins; MDR, multidrug resistance; TGC, third generation cephalosporins; GN, Gram-negative; XLD, xylose lysine deoxycholate; CLSI, Clinical and Laboratory Standards Institute; PMQR, plasmid mediated quinolones resistance.

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### Disclosure

AvB is an employee of bioMerieux, a company designing, developing and selling infectious disease tests. The company had no influence on the design and execution, either of the study or in the writing of the manuscript. The authors report no other conflicts of interest in this work.

### References


