Antibiotic resistance and genetic diversity of *Shigella sonnei* isolated from patients with diarrhoea between 1999 and 2003 in Bangladesh


*Shigella sonnei* is a significant cause of diarrhoeal infection in both developing and industrialized countries. From 1999 to 2003, 445 strains of *Shigella sonnei* were isolated from patients admitted to the diarrhoea treatment centre of the International Center for Diarrhoeal Disease Research, Bangladesh. More than 60% of the isolates were resistant to nalidixic acid, 89% to sulfamethoxazole-trimethoprim and 9-5% to ampicillin. In addition, 4% of strains were resistant to multiple antibiotics (Amp^R^ Tet^R^ Sxt^R^ Str^R^) and 4-2% of strains were sensitive to all antibiotics tested. None of the strains were positive for the set1 gene, whereas 46% were positive for the sen gene. Forty-six per cent of the strains (stored at −70 °C) harboured the 120 MDa invasive plasmid and representative strains produced keratoconjunctivitis in the guinea pig eye. In addition, three plasmids of approximately 5, 1 and 4 MDa were found to be present in more than 90% of the strains. A self-transmissible, middle-ranged plasmid (35–80 MDa) carrying the multiple antibiotic resistance gene was found in some strains. PFGE analysis of the strains identified five unique types with many subtypes, which were characterized into four unique types by ribotyping analysis. It can be concluded that endemic strains of *Shigella sonnei* isolated from patients in Bangladesh are diverse in their genetic pattern.

**METHODS**

**Strains.** One hundred and eighty-four clinical strains of *Shigella sonnei* were randomly selected from 445 strains isolated from patients attending the Dhaka treatment centre operated by the International Center for Diarrhoeal Disease Research, Bangladesh (ICDDR, B), in Bangladesh between January 1999 and December 2003. The strains were isolated and identified in the Clinical Microbiology Laboratory, according to standard microbiological and biochemical methods (World Health Organization, 1987). The resistance pattern has not been undertaken in the developing world and particularly in Bangladesh. In the past, several conventional typing methods were used for epidemiological subtyping of *Shigella sonnei* (Lin & Chang, 1992; Morris & Wells, 1974; Pruneda & Farmer, 1977) based on phenotypic properties, but the usefulness of these techniques is now limited, because of the availability of more discriminatory molecular typing methods, including plasmid profiling, ribotyping and PFGE. The aim of this study was to determine the aetiological significance of *Shigella sonnei* among patients with diarrhoea in Bangladesh and to determine its clonal distribution based on phenotypic and genotypic characteristics.
strains were grown in tryptcase soy broth containing 0–3 % yeast extract and stored at –70 °C after addition of 15 % glycerol. *Shigella flexneri* 2a YSH6000 (Sasakawa et al., 1986) and an *Escherichia coli* (ATCC 25922) strain lacking the 140 MDa invasive plasmid and sensitive to all antibiotics were used as positive and negative controls, respectively, in the Sereny test and for PCR. *E. coli* K-12 (Lac+, F–), resistant to nalidixic acid, was used as the recipient in the conjugation experiments (Haider et al., 1989).

**Serotyping.** Serotypes were determined by using a commercially available antisera kit (Denka Seiken). Strains were subcultured on MacConkey agar (Diffco) plates and serological reactions were performed after about 18 h of incubation by using the slide agglutination test, as described previously (Talukder et al., 2001).

**Biochemical characterization.** The biochemical reactions of the strains were determined by using standard methods (World Health Organization, 1987).

**Antimicrobial susceptibility.** Bacterial susceptibility to antimicrobial agents was determined by using the disc diffusion method, as recommended by the Clinical and Laboratory Standards Institute (CLSI, 2004) with commercial antimicrobial discs (Oxoid). The antibiotic discs used in this study were ampicillin (Amp; 10 µg), tetracycline (Tet; 30 µg), chloramphenicol (Cm; 30 µg), sulfamethoxazole-trimethoprim (Sxt; 25 µg), ciprofloxacin (5 µg), norfloxacin (10 µg), ofloxacin (5 µg), azithromycin (15 µg) and ceftiraxone (30 µg). *E. coli* ATCC 25922 and *Staphylococcus aureus* ATCC 25923 were used as control strains for the susceptibility tests.

**Test for invasiveness and detection of *Shigella* enterotoxin genes.** Nine representative strains were subjected to the keratoconjunctivitis assay in the guinea pig eye, according to the procedures described by Mackel et al. (1961) and Sereny (1957). The experimental procedures were approved by the animal experimentation ethics committee of ICDDR, B and were in accordance with ethical guidelines for the care of animals. The same bacterial colony was selected as described previously (Talukder et al., 2001) and by Brian et al. (1993), but with different pulse times, 1–10 s for 10 h, 3–28 s for 10 h, 3–35 s for 5 h and 5–70 s for 15 h. Genomic DNA was digested with *XbaI* (Gibco-BRL). The restriction fragments were separated by using a CHEF-DRII system apparatus in 1 % pulsed-field certified agarose in 0.5 × TBE buffer. The gel was stained, destained and photographed using a gel documentation system, according to procedures described previously (Talukder et al., 2002). The DNA size standards used were a bacteriophage lambda ladder ranging from 48.5 to 1000 kb (Bio-Rad) and *Salmonella* Branderup chromosomal DNA ranging from 15·8 to 917 kb. Band patterns were established by the criteria described by Tenover et al. (1995).

**RESULTS**

**Biochemical characterization.** All the 184 representative strains of *Shigella sonnei* were negative for indole production and positive for arabinose, mannitol, mannose, trehalose, maltose, rhamnose and ornithine fermentation. About 62 % (*n* = 114) of the strains showed raffinose fermentation, but none of the strains were positive for utilization of sodium acetate, sorbitol, dulcitol, xylose, arginine or lysine. Two different biotypes (BT1 and BT2) were found based on raffinose fermentation (Table 1).

**Antimicrobial susceptibility**

More than 60 % of the strains in the present study were resistant to nalidixic acid, 89 % to sulfamethoxazole-trimethoprim and 9·5 % to ampicillin. In addition, 4 % (*n* = 18) of strains were found to be resistant to multiple antibiotics (*AmpR* TetR SxtR StrR) and 4·2 % (*n* = 19) were sensitive to all antibiotics tested. None of the strains were resistant to ciprofloxacin, norfloxacin, ofloxacin, mecillinam, azithromycin or ceftiraxone.

**Test for invasiveness and detection of *Shigella* enterotoxin genes**

Five representative strains containing a 120 MDa invasive plasmid were positive for keratoconjunctivitis in the guinea pig eye. In contrast, the representative four strains that did not contain a 120 MDa plasmid were found to be negative in the Sereny test. The *Shigella* enterotoxin 1 (*set1*) gene was not present in the strains of *Shigella sonnei* tested, whereas
the Shigella enterotoxin 2 gene (sen) was present in all strains containing a 120 MDa plasmid.

**Plasmid profile analysis**

Heterogeneous plasmid profiles ranging in size from approximately 120 to 1.4 MDa were found among the strains. Three plasmids of approximately 5, 1.8 and 1.4 MDa in size were present in more than 90% of the strains and were considered to be the core plasmids of Shigella sonnei (Fig. 1). Interestingly, 54% of the strains (n = 100) isolated during the period 1999–2003 were found to lack the 120 MDa invasive plasmid. A middle-ranged plasmid of approximately 35–80 MDa in size was found in 12% (n = 22) of the strains.

**Determination of resistance factor**

Two strains designated K-656 and K-386 with the resistance pattern AmpR TetR SxtR StrR and containing an 80 MDa plasmid were selected for conjugation with E. coli K-12 (Lac+ and NalR). An 80 MDa plasmid was transferred with the multiple antibiotic resistance determinants (AmpR TetR SxtR) to the recipient cells via conjugation. The transfer frequency was very high for all the transmissible plasmids (Table 2). The transmissible resistance determinants were confirmed by curing the transconjugants (Table 2).

**Ribotyping**

Hybridization of HindIII-digested chromosomal DNA with the 16S rDNA probe revealed a total of seven to nine fragments ranging in size from 5 to 15 kb in all the representative strains of Shigella sonnei (Fig. 2). Four unique rRNA gene restriction patterns, ribotypes R1, R2, R3 and R4, were obtained among the representative strains.

### Table 1. Characteristics of Shigella sonnei strains isolated in Bangladesh

<table>
<thead>
<tr>
<th>No. of strains tested</th>
<th>PFGE pattern</th>
<th>Ribotype</th>
<th>Biotype*</th>
<th>Antibiogram (no. of strains)</th>
</tr>
</thead>
<tbody>
<tr>
<td>27</td>
<td>A1</td>
<td>R1</td>
<td>BT1</td>
<td>SxtR NalR (17), SxtR (10)</td>
</tr>
<tr>
<td>28</td>
<td>A2</td>
<td>R1</td>
<td>BT1</td>
<td>SxtR NalR (26), SxtR (2)</td>
</tr>
<tr>
<td>20</td>
<td>A3</td>
<td>R1</td>
<td>BT1</td>
<td>SxtR (9), SxtR NalR (11)</td>
</tr>
<tr>
<td>2</td>
<td>A4</td>
<td>R1</td>
<td>BT1</td>
<td>SxtR NalR (2)</td>
</tr>
<tr>
<td>2</td>
<td>A5</td>
<td>R1</td>
<td>BT1</td>
<td>AmpR SxtR (2)</td>
</tr>
<tr>
<td>4</td>
<td>A6</td>
<td>R1</td>
<td>BT1</td>
<td>AmpR SxtR (2), SxtR NalR (2)</td>
</tr>
<tr>
<td>4</td>
<td>A7</td>
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<td>BT1</td>
<td>SxtR NalR (4)</td>
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<tr>
<td>1</td>
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<td>R1</td>
<td>BT1</td>
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<tr>
<td>2</td>
<td>B1</td>
<td>R2</td>
<td>BT2</td>
<td>All sensitive (2)</td>
</tr>
<tr>
<td>2</td>
<td>B2</td>
<td>R2</td>
<td>BT2</td>
<td>All sensitive (2)</td>
</tr>
<tr>
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<td>C</td>
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<td>BT2</td>
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<tr>
<td>2</td>
<td>D</td>
<td>R4</td>
<td>BT2</td>
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</tr>
<tr>
<td>2</td>
<td>E1</td>
<td>R1</td>
<td>BT2</td>
<td>All sensitive (2)</td>
</tr>
<tr>
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<td>E2</td>
<td>R1</td>
<td>BT2</td>
<td>All sensitive (1)</td>
</tr>
<tr>
<td>1</td>
<td>E3</td>
<td>R1</td>
<td>BT2</td>
<td>All sensitive (1)</td>
</tr>
</tbody>
</table>

*BT1: fermentation of ornithine, lactose, arabinose, mannose, mannotol, trehalose, raffinose and maltose; BT2: fermentation of ornithine, lactose, arabinose, mannose, mannotol, trehalose and maltose.

### Fig. 1. (a) Agarose gel electrophoresis of plasmid DNA showing the representative patterns among isolates of Shigella sonnei. Lanes: 1, E. coli PDK-9 (marker); 2, S. sonnei K-476; 3, S. sonnei K-544; 4, S. sonnei K-548; 5, S. sonnei K-564; 6, S. sonnei K-567; 7, S. sonnei K-586; 8, S. sonnei K-1038; 9, S. sonnei K-1051; 10, S. sonnei K-1036; 11, S. sonnei K-1075; 12, S. sonnei KD-446; 13, S. sonnei KD-462; 14, S. sonnei KD-226; 15, E. coli V517+R1. (b) Agarose gel electrophoresis of plasmid DNA of Shigella sonnei strains run for 16 h. Lanes: 1, E. coli PDK-9 (marker); 2, S. sonnei KD-412; 3, S. sonnei K-544; 4, S. sonnei K-567; 5, S. flexneri YSH6000.
PFGE

Of 184 strains, 100 were randomly selected for PFGE analysis. XbaI-digested chromosomal DNA of these strains yielded 15–24 reproducible DNA fragments, ranging in size from approximately 20 to 485 kb (Fig. 3). These strains yielded five unique PFGE types designated A, B, C, D and E with numerous subtypes (Fig. 3), of which 88 % of the strains belonged to type A, 4 % belonged to types B and E each and 2 % belonged to types C and D each (Fig. 3). Type A was further subdivided into five subtypes (A1–A5), and types B and E into two (B1 and B2) and three (E1–E3) subtypes, respectively.

DISCUSSION

We examined 184 clinical strains of *Shigella sonnei* that were isolated between January 1999 and December 2003, using biochemical characterization, antimicrobial susceptibility testing, plasmid profile analysis, PFGE and ribotyping, in order to define the aetiological significance of endemic shigellosis due to infection by *Shigella sonnei* in Bangladesh. According to our previous study, during the period 1999–2002, each year about 8 % of the total number of cases of shigellosis were caused by infection due to *Shigella sonnei* (Talukder et al., 2003b). A similar trend was observed in 2003. The first step in the characterization scheme for all strains in the present study was biochemical reaction pattern, in which we did not observe any significant change from the typical reactions of *Shigella sonnei* described by Ewing (1986). Based on the biochemical reaction profiles, strains could not be divided into different clonal groups.

Resistance of *Shigella* species to commonly used antimicrobial agents has been increasing in Bangladesh (Hossain et al., 1998). Ampicillin or trimethoprim combined with sulfamethoxazole has been used to treat shigellosis during the past two decades. However, a high proportion of *Shigella sonnei* strains were resistant to these antibiotics (Kim et al.,

<table>
<thead>
<tr>
<th>Strain no.</th>
<th>Parent strain</th>
<th>Transconjugant</th>
<th>Transfer frequency of R-plasmid</th>
<th>Cured strain</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Resistance pattern</td>
<td>Resistance pattern</td>
<td>Plasmid profile (MDa)</td>
<td>Plasmid profile (MDa)</td>
</tr>
<tr>
<td></td>
<td>Amp Sxt Str Tet</td>
<td>Amp Sxt Tet Nal</td>
<td>140, 80, 5-0, 1-8, 1-4</td>
<td>80</td>
</tr>
<tr>
<td>K-656</td>
<td>Amp Sxt Str Tet</td>
<td>Amp Sxt Tet Nal</td>
<td>140, 80, 5-0, 1-8, 1-4</td>
<td>80</td>
</tr>
<tr>
<td>K-386</td>
<td>Amp Sxt Str Tet</td>
<td>Amp Sxt Tet Nal</td>
<td>140, 80, 5-0, 1-8, 1-4</td>
<td>80</td>
</tr>
</tbody>
</table>

**Table 2. Results of conjugation between two strains of* Shigella sonnei* and *E. coli* K-12**

Amp, Ampicillin; Nal, nalidixic acid; Str, streptomycin; Sxt, trimethoprim-sulfamethoxazole; Tet, tetracycline.
In this study, none of the strains were found to be resistant to ciprofloxacin, norfloxacin, ofloxacin, mecillinam, azithromycin or ceftriaxone.

Plasmid profile analysis has been applied extensively in epidemiological investigations of various enteric pathogens, particularly if there is a wide range of stable plasmids present in the bacterial population (Shahid et al., 1985; Surdeanu et al., 2000; Prado et al., 1987). Shigella sonnei usually harbours a heterogeneous population of plasmids, which may range in number from two to as many as 10 (Haider et al., 1989) and from 1·4 to 120 MDa in molecular mass. Of 184 strains, 54% did not harbour the 120 MDa plasmid, which carries the major determinants for invasiveness. One of the possible explanations for this result might be the loss of the 120 MDa plasmid because of: (i) prolonged storage of the strains at −70°C; and (ii) repeated subculturing of the strains, which has also been described previously by Vargas et al. (1999). In addition to the large plasmid, about 90% of the strains contained three plasmids of approximately 5, 1·8 and 1·4 MDa in size. In order to validate this cluster of plasmids as core plasmids of Shigella sonnei, it was compared with the plasmid profiles of all the serotypes and subserotypes of Shigella species (data not shown). The cluster of these three plasmids was found to be unique to Shigella sonnei and did not match the plasmid profiles of any of the existing Shigella serotypes.

Conjugative plasmids encoding resistance to antibiotics have been detected in numerous studies on Shigella sonnei (DeLappe et al., 2003). The experiment in the present study demonstrated that middle-range plasmids were self-transmissible, conferring resistance to ampicillin, tetracycline and trimethoprim-sulfamethoxazole. The co-transfer of streptomycin resistance was not observed, suggesting that the resistance determinants of this antibiotic in Shigella sonnei are not associated with the conjugative plasmids.

Invasiveness is an important property of pathogenic Shigella species. Shigella flexneri produces an enteroxin (Kinsey et al., 1976; Rout et al., 1975), mainly of two types, Shigella enterotoxin 1 (ShET-1) and Shigella enterotoxin 2 (ShET-2). In our study, ShET-1 was not found in Shigella sonnei, confirming previous results (Nataro et al., 1995). In contrast to the study of Vargas et al. (1999), which showed that 100% of Shigella sonnei strains isolated between 1996 and 1998 were positive for ShET-2 (sen), we found that only 46% of Shigella sonnei strains in this study were positive for this gene. In addition, a correlation between the presence of the 120 MDa plasmid and the sen gene was observed.

PFGE and ribotyping have been used more widely to determine the genetic diversity of various enteropathogens including Shigella sonnei (Hinojosa-Ahumada et al., 1991; Korpela et al., 1995; Pace et al., 1986). Applying these two techniques, we identified four ribotypes, R1, R2, R3 and R4, whereas five PFGE types (A, B, C, D and E) were found in the same set of strains of Shigella sonnei. Among these four ribotypes, one (R1) was shared by two different PFGE types (A and E). The present study showed the poor discriminatory power of ribotyping for Shigella sonnei isolates, compared with PFGE. This finding is similar to previous reports on strains from Taiwan (Henry, 1991; Liu et al., 1995). However, ribotyping has been used successfully for epidemiological investigation of Shigella sonnei in Spain (Pace et al., 1986) and other countries (Hinojosa-Ahumada et al., 1991; Korpela et al., 1995). It is interesting to note here that PFGE type A belonged to biotype BT1 and all the other types (PFGE types B, C, D and E) belonged to biotype BT2 only. PFGE type A was found to be predominant, encompassing approximately 88% of the strains in the present study. A good correlation was observed between PFGE type, ribotype, antimicrobial resistance pattern and biotyping (Table 1). Strains that were resistant to single or multiple drugs belonged to PFGE type A, whereas strains that were sensitive to all antibiotics tested were more heterogeneous in PFGE type. Although Shigella sonnei is a more common problem in the developed and industrialized countries, this study underlines a significant burden of this pathogen in overall Shigella infections in Bangladesh, with strains of heterogeneous traits.

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REFERENCES


Shigella flexneri isolated in Bangladesh. Epidemiol Infect 102, 421–428.


dfr genes of Shigella sonnei isolates in Korea during the last two decades. J Microbiol Biotechnol 12, 106–113.


Shigella sonnei by use of plasmid DNA analysis and pulse-field gel electrophoresis to detect patterns of transmission. J Infect Dis 175, 864–870.


