Isolation of *Salmonella enterica* subspecies *enterica* serovar Paratyphi B dT⁺, or *Salmonella Java*, from Indonesia and alteration of the d-tartrate fermentation phenotype by disrupting the ORF STM 3356

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*Salmonella enterica* subspecies *enterica* serovar Paratyphi B [O1,4,(5),12:Hb : 1,2] can cause either an enteric fever (paratyphoid fever) or self-limiting gastroenteritis in humans. The d-tartrate non-fermenting variant *S. enterica* subsp. *enterica* serovar Paratyphi B dT⁻ (S. Paratyphi B) is the causative agent of paratyphoid fever, and the d-tartrate fermenting variant *S. enterica* subsp. *enterica* serovar Paratyphi B dT⁺ (Salmonella Java) causes gastroenteritis. *S. Java* is currently recognized as an emerging problem worldwide. Twelve dT⁺ *S. Java* isolates were collected in Indonesia between 2000 and 2002. One-third of them contained *Salmonella* genomic island 1 (SGI1), which gives the multidrug-resistant phenotype to the bacteria. In this study, a PCR-based method to detect a single nucleotide difference responsible for the inability to ferment d-tartrate, reported elsewhere, was validated. The d-tartrate fermenting phenotype of *S. Java* was converted to the non-fermenting phenotype by the disruption of the ORF STM 3356, and the d-tartrate non-fermenting phenotype of the ORF STM 3356-disrupted strain and the dT⁻ reference strain was changed to the dT⁺ phenotype by complementing ORF STM 3356 in trans. The results show that the dT⁺ phenotype requires a functional product encoded by STM 3356, and support the use of the PCR-based discrimination method for *S. Paratyphi B* and *S. Java* as the standard differentiation method.

**INTRODUCTION**

*Salmonella enterica* subspecies *enterica* serovar Paratyphi B, antigenic formula O1,4,(5),12:Hb 1,2, is one of the causative agents of enteric fever, along with *Salmonella Typhi*, and *Salmonella Paratyphi A* and *C*. It has been recognized, however, that this serovar, as well as causing systemic disease, can cause a less severe gastroenteritis in humans. The fermentation of dextrorotatory (L(+))-tartrate (d-tartrate) has been used to differentiate between the d-tartrate non-fermenting *S. enterica* subsp. *enterica* serovar Paratyphi B dT⁻ (S. Paratyphi B) and the d-tartrate fermenting *S. enterica* subsp. *enterica* serovar Paratyphi B dT⁺ (Salmonella Java). *S. Paratyphi B* causes systemic
disease (paratyphoid fever) in humans and S. Java triggers gastroenteritis in humans; however, the latter has also been isolated from animals (Barker, 1985; Chart, 2003). Multidrug-resistant (MDR) S. Java strains have been an emerging problem since the 1990s (Miko et al., 2002), and recent reports have shown that the incidence of S. Java is increasing significantly in a number of European countries, Canada and Malaysia (Goh et al., 2003; Miko et al., 2002; Mulvey et al., 2004; Threlfall et al., 2005; Weill et al., 2005). The MDR strains are generally resistant to ampicillin, chloramphenicol, streptomycin/spectinomycin, sulfonamides and tetracycline (ACSSuT), and the genes conferring antimicrobial resistance are located on a 14 kb region at the 3′ end of a chromosomal genomic island known as Salmonella genomic island 1 (SGI1). The 43 kb SGI1 was first identified in Salmonella Typhimurium DT104 (Boyd et al., 2001), and has also been found in other serovars, i.e., Salmonella Agona, S. Paratyphi B, Salmonella Albany and Salmonella Newport (Doubelt et al., 2003, 2004; Meunier et al., 2002). SGI1 harbours genes responsible for pentarresistance and is inserted into the chromosome between the thdF and int2 genes in S. Typhimurium and between the thdF and yidY genes in other serovars (Doubelt et al., 2004). Recently, SGI1 has been characterised as an integrative mobilizable element which can be conjointly transferred to S. enterica and Escherichia coli (Doubelt et al., 2005). Twelve S. Java isolates were collected in Indonesia between 2000 and 2002. Five isolates showed resistance to more than two antibiotics and three of those contained SGI1. One isolate contained a variant of SGI1, SGI1-C, responsible for resistance to streptomycin and sulfonamide. One of the isolates was resistant to streptomycin and chloramphenicol but did not contain the SGI1.

The emergence of the S. Java strains as a public health problem calls for efficient identification and detection of this serovar. The discrimination method using lead acetate for d-tartrate fermentation takes up to 6 days and can give unreliable results (Barker, 1985; Malorny et al., 2003). A PCR-based discrimination method has been developed by Malorny et al. (2003) and tested empirically against a well-defined collection of dT+ and dT− Salmonella strains. Among the ORFs possibly involved in d-tartrate fermentation, a single nucleotide difference in the ORF STM 3356 (a putative cation transporter) between d-tartrate fermenting and non-fermenting strains has been recognized. In dT+ strains, an ATG translation start codon is present for STM 3356, whereas this is altered to ATA in dT− strains. A discriminatory PCR primer using this one-nucleotide difference gave 100% discrimination of dT+ and dT− Salmonella strains. Although the PCR-based discrimination method gives reliable results, it has not been elucidated that the encoded product of STM 3356 is compulsory for the d-tartrate fermenting phenotype. To determine whether the product encoded by STM 3356 is essential for the d-tartrate fermenting phenotype, we disrupted the STM 3356 ORF by inserting a suicide vector in the middle of the STM 3356 ORF in a d-tartrate fermenting S. Java isolate. The STM 3356 mutant showed a d-tartrate non-fermenting phenotype, while the dT− phenotype of the STM 3356 mutant and the dT− reference strain NCTC 3176 was changed to a dT+ phenotype by complementing with the STM 3356 of a dT+ strain in trans, which implies that the functional product encoded by STM 3356 is required for the d-tartrate fermenting phenotype. These results support the use of the PCR-based discrimination method of Malorny et al. (2003) as the standard method for identification of d-tartrate fermenting and non-fermenting S. Paratyphi B strains. This is particularly important in view of the increased incidence of S. Java infections around the world.

**METHODS**

**Bacterial strains and serotyping.** During a population-based typhoid fever surveillance study at Jakarta, Indonesia, between 2000 and 2002, twelve Salmonella group B isolates were collected and transported to the International Vaccine Institute (IVI), Seoul, Korea, for phenotypic and genotypic analyses. All isolates were serotyped by the Kauffmann–White scheme (Kauffmann, 1955), resulting in the antigenic formula O1,4,5,12:Hb1:2 specific to S. Paratyphi B, or S. Java. The d-tartrate fermentation test reference strains NCTC 3176 and NCTC 5706 were purchased from the UK National Collection of Type Cultures (NCTC).

**Antimicrobial susceptibility tests.** All isolates were screened for resistance to 20 antimicrobial agents by either the disc diffusion method (BBL, Sensi-Disc, Becton Dickinson) or the Vitek automated system and susceptibility testing card GNS-433 (bioMérieux). The following antibiotic agents were tested: ampicillin, nalidixic acid, trimethoprim/sulfamethoxazole (SXT), streptomycin, ciprofloxacin, chloramphenicol, tetracycline, amikacin, ampicillin/sulbac tam, aztreonam, cefepime, cefoxitin, ceftriaxone, cefuroxime, cephalin, cefotaxime, cefoxitin, ceftizoxime, ciprofloxacin, gentamicin, imipenem, piperacillin/tazobactam, sulfonamides and tobramycin. MICs of the antibiotics to which the isolates were resistant were determined by the agar dilution method. *E. coli* ATCC 25922 was used as a quality reference for all the tests.

**Multilocus sequence typing (MLST) and genetic analyses.** All isolates were grown overnight on tryptic soy agar (Difco) plates at 37°C. The genomic DNA was prepared from a bacterial culture plate using a Prepman Ultra kit (Applied Biosystems). The seven genes for the MLST analysis, *aroC* (chorismate synthase), *dhaV* (DNA polymerase III beta subunit), *hemD* (urorphyrinogen III cosynthase), *hisD* (histidinol dehydrogenase), *purE* (phosphoribosylaminomimidazole carboxylase), *sucC* (α-ketoglutarate dehydrogenase) and *thrA* (aspartokinase--s-homoserine dehydrogenase), were amplified using the primers and PCR conditions described elsewhere (http://www.mpiib-berlin.mpg.de/mlst/dbs/Senterica/documents/primersEntérica.html). The purified PCR products were sequenced in both directions by using a BigDye cycle sequencing kit (ABI). Sequencing was performed on an ABI 3770 automatic sequencer. Alleles were assigned by comparing the sequences to those in the *Salmonella* MLST database. No new allele type was identified, and those already present were assigned the relevant allele number. The presence of SGI1 was confirmed by PCR amplification of left and right junctions, as described elsewhere (Weill et al., 2005). In addition to that of either junction, the presence of SGI1 was further confirmed by PCR mapping of two different regions on SGI1. A primer pair P1f (5′-ATA ACG CCA GGT TCC GGT TC-3′)/P1r (5′-CGG ATG AAG CGC ACA AAT TTT G-3′) was used to amplify the p1-probe region (from nucleotide 20173 to 21109), and the presence of the QS probe region was verified by PCR amplification using the primer pair QSI (5′-ATG AAA GCC TGG CTT TTT G-3′)
RESULTS AND DISCUSSION

Identification of S. Paratyphi B dT⁻, or S. Java

Twelve S. Java isolates collected from patients’ stool samples in Indonesia were found to have the antigenic formula O1,A(5),12:Hb : 1,2, specific for S. Paratyphi B, or S. Java, by standard tests (isolate numbers IB70 to IB81). Lead acetate results showed that all isolates were dT⁻, and PCR using primers 166/167 and sequence analysis of the STM 3356 amplified fragment supported the d-tartrate positive phenotype, as described elsewhere (Malorny et al., 2003). All isolates were subjected to MLST analysis using seven genetic loci, and their allele types were all identical as aroC: 2, dnaN: 14, hemD: 24, hisD: 14, purE: 2, susA: 19 and thrA: 8, which correspond to sequence type (ST) 43. ST 43 has previously been reported as S. Paratyphi B var. Java from Denmark (http://web.mpiib-berlin.mpg.de/mlst/dbs/Senterica). The virulence genes sopE1 and avrA, which are usually found in systemic and enteric pathovars, respectively (Prager et al., 2003), were not present among the isolates (data not shown). From these results, 12 isolates were identified as S. Paratyphi B dT⁻, or S. Java.
Antimicrobial resistance and the presence of SGI1

OF 12 isolates examined for antibiotic susceptibility, five (IB70, IB72, IB75, IB76 and IB80) were resistant to at least two antibiotic agents, and seven were sensitive to all the antibiotic agents tested (Table 1). All of the isolates were sensitive or intermediate in resistance to nalidixic acid. Three isolates, IB70, IB76 and IB80, showed a pentaresistant phenotype – resistant to ampicillin, chloramphenicol, streptomycin and sulfonamide and tetracycline (ACSSuT). IB70, IB76 and IB80 exhibited a dT−tartrate non-fermenting phenotype (Fig. 2). The STM 3356 mutant of IB75, in which the STM 3356 was inactivated by disruption of ORF STM 3356-tartrate fermentation, we constructed a derivative of STM 3356 (IB75ins). The STM 3356 mutant exhibited a dT-tartrate non-fermenting phenotype (Fig. 2). This isolate has acquired the resistance mechanism independently from SGI1. S. Java isolates carrying SGI1 were detected at 33% (four of 12) in this study, including one isolate carrying SGI1-C, a variant of SGI1. Ribotyping results obtained after EcoRI digestion using the Riboprinter automated system (DuPont) revealed that all the isolates belonged to the same ribotype (data not shown). From the results that show that all the isolates have the same MLST sequence type and ribotype, the S. Java isolates examined in this study appear to be closely related. However, for further detailed studies, including the distribution, occurrence and phylogenetic relationship among the isolates in Indonesia and adjacent areas, a larger collection of isolates, and subtyping methods such as PFGE and IS200 analysis, should be performed. Miko et al. (2002) have described that from the mid-1990s, new clones of S. Java emerged, and one clonal lineage displaced the older ones in Germany and neighbouring countries. Goh et al. (2003) have reported that one major cluster of S. Java was observed among Malaysian isolates. The relationship of S. Java strains among the European and non-European lineages remains to be studied.

Table 1. Antibiotic resistance and the presence of SGI1 in S. Paratyphi B dT+ isolates in this study

<table>
<thead>
<tr>
<th>Isolate</th>
<th>Antimicrobial susceptibility test*</th>
<th>SGII junction PCR</th>
<th>SG1 variant</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Amp</td>
<td>Tet</td>
<td>Nal</td>
</tr>
<tr>
<td>IB70</td>
<td>256</td>
<td>128</td>
<td>4</td>
</tr>
<tr>
<td>IB71</td>
<td>1</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>IB72</td>
<td>1</td>
<td>8</td>
<td>4</td>
</tr>
<tr>
<td>IB73</td>
<td>2</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>IB74</td>
<td>1</td>
<td>8</td>
<td>4</td>
</tr>
<tr>
<td>IB75</td>
<td>2</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>IB76</td>
<td>≥256</td>
<td>128</td>
<td>8</td>
</tr>
<tr>
<td>IB77</td>
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<td>8</td>
<td>8</td>
</tr>
<tr>
<td>IB78</td>
<td>2</td>
<td>8</td>
<td>4</td>
</tr>
<tr>
<td>IB79</td>
<td>2</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>IB80</td>
<td>≥256</td>
<td>128</td>
<td>8</td>
</tr>
<tr>
<td>IB81</td>
<td>2</td>
<td>8</td>
<td>8</td>
</tr>
</tbody>
</table>

* Amp, ampicillin; Tet, tetracycline; Nal, nalidixic acid; Str, streptomycin; Chl, chloramphenicol.
†A, ampicillin; C, chloramphenicol; S, streptomycin; Su, sulfonamide; T, tetracycline. Sulfonamide resistance was tested on LB plates containing 100 µg sulfonamide ml−1.
‡MIC by agar dilution test.
results within the range $5 \times 10^6$ to $5 \times 10^7$ bacteria. These results indicate that the product of ORF STM 3356 is necessary for d-tartrate fermentation. To determine whether expression of wild-type STM 3356 would be sufficient to revert the negative phenotype of the IB75ins mutant and d-tartrate non-fermenting reference strain NCTC 3176, we constructed the plasmid pAC3356, a derivative of pACYC184 carrying a DNA fragment encompassing the upstream region of STM 3356 (up to the termination codon of upstream ORF STM 3357) and the whole STM 3356 ORF from the dT$^+$ reference strain NCTC 5706. For the detection of the expression of STM 3356 from pAC3356, we included six His residues at the end of ORF 3356 on pAC3356. The derivative of NCTC 3176 harbouring pAC3356 exhibited a d-tartrate fermentation-positive phenotype (Fig. 2), although the expression of STM 3356 was not detected by Western blot using Penta-His Antibody (Qiagen; data not shown). This result indicates that the negative phenotype of NCTC 3176 is solely due to the lack of production of STM 3356. The dT$^+$ phenotype of IB75ins was also converted into the dT$^+$ phenotype by the same trans-complementing plasmid (Fig. 2), and the complementing plasmid was maintained for several overnight culture passages without a selection marker in both trans-complemented bacteria.

In conclusion, we have found that S. Java strains harbouring the SGI1 element are common in Indonesia (four of 12 isolates), although we need to analyse a larger number of strains for more precise results. Since the SGI1 element can be transferred to other Salmonella serovars (Doublet et al., 2005), it is important to monitor the dissemination of the SGI1 element, especially to S. Typhi and S. Paratyphi A, which are common in this area (Tjaniadi et al., 2003). We have shown the involvement of the functional product of STM 3356 in d-tartrate fermentation, and our results strongly support the effectiveness of the method using specific PCR for d-tartrate fermentation phenotype differentiation suggested by Malorny et al. (2003), although the exact role of the protein remains to be revealed.

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