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The Microbiological and Clinical Characteristics of Invasive *Salmonella* in Gallbladders from Cholecystectomy Patients in Kathmandu, Nepal

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Abstract

Gallbladder carriage of invasive *Salmonella* is considered fundamental in sustaining typhoid fever transmission. Bile and tissue was obtained from 1,377 individuals undergoing cholecystectomy in Kathmandu to investigate the prevalence, characteristics and relevance of invasive *Salmonella* in the gallbladder in an endemic area. Twenty percent of bile samples contained a Gram-negative organism, with *Salmonella Typhi* and *Salmonella Paratyphi A* isolated from 24 and 22 individuals, respectively. Gallbladders that contained *Salmonella* were more likely to show evidence of acute inflammation with extensive neutrophil infiltrate than those without *Salmonella*, corresponding with higher neutrophil and lower lymphocyte counts in the blood of *Salmonella* positive individuals. Antimicrobial resistance in the invasive *Salmonella* isolates was limited, indicating that gallbladder colonization is unlikely to be driven by antimicrobial resistance. The overall role of invasive *Salmonella* carriage in the gallbladder is not understood; here we show that 3.5% of individuals undergoing cholecystectomy in this setting have a high concentration of antimicrobial sensitive, invasive *Salmonella* in their bile. We predict that such individuals will become increasingly important if current transmission mechanisms are disturbed; prospectively identifying these individuals is, therefore, paramount for rapid local and regional elimination.


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Introduction

Enteric fever is a systemic infection caused by the invasive bacteria *Salmonella Typhi* (S. Typhi) and *Salmonella Paratyphi A* (S. Paratyphi A). The disease is contracted by the ingestion of fecal material containing the pathogens [1]. The disease remains common in regions with poor standards of hygiene and sanitation, with global estimates suggesting that 27 million people are affected annually, of which 200,000 people die [2]. With adequate treatment >95% of patients recover completely from typhoid [1]. However, an estimated 2–5% of individuals infected with S. Typhi develop a sustained infection of the gallbladder [3]. These individuals are referred to as ‘carriers’, and like the infamous ‘typhoid Mary’ [4], are outwardly asymptomatic, continue to intermittently shed organisms for a prolonged period and often have no recollection of an acute episodes of typhoid [1].

During acute typhoid, invasive *Salmonella* cross the intestinal epithelial barrier, invade and survive within macrophages, eventually reaching the bone marrow, liver, pancreas and spleen [5]. Invasion of the gallbladder occurs either directly from the blood or by retrograde spread from the bile [1]. In a subset of individuals infected with S. Typhi, the organisms chronically colonize the gallbladder and carriers shed these organisms intermittently into the intestinal lumen and thus in the feces. It is gallbladder colonization and fecal shedding that form a central dogma for the transmission and persistence of typhoid fever. As a consequence of the internal localization of organisms, this dogma is difficult to challenge in humans and the host-restricted nature of the relevant pathogens make carriage difficult to replicate precisely in non-mutant mouse models [6]. As a result, data regarding the prevalence, bacteriology and mechanisms of carriage are sparse. The only population-based study estimating chronic *Salmonella* carriage in an endemic setting is from Chile where investigators gathered data from autopsies, calculating a carriage rate of 694 per 100,000 [3].

Investigations of *Salmonella* carriage suggest that the propensity to become a chronic carrier follow the typical epidemiology of gallbladder disease. Thus, the likelihood of carriage increases with age and is more common in females [7]. Existing data also imply that individuals with gallstones or other gallbladder abnormalities are at increased risk of carriage [8]. These epidemiological theories...
are supported by laboratory-based investigations, which have shown that Salmonella can form biofilms and survive for prolonged period on gallstones [9,10].

There remains a significant burden of typhoid fever across Asia, yet the understanding of Salmonella carriage in these populations is limited. We have found previously that S. Paratyphi A can be isolated from the gallbladders of patients undergoing cholecystectomy and we suggested that carriage of invasive Salmonella play a pivotal role in the persistence of these pathogens in Kathmandu, Nepal [11]. We aimed to define the microbiology and epidemiology of invasive Salmonella carriage in Kathmandu. We demonstrate that S. Typhi and S. Paratyphi A are present in the gallbladder in a high concentration, are less common than other Gram-negative organisms, are not associated with lymphocytic infiltration in the gallbladder tissue, and do not exhibit resistance to multiple antimicrobials.

**Results**

**Microbiological Examination of Bile from Cholecystectomy Patients**

From June 2007 until October 2010, a total of 1,496 patients underwent cholecystectomy for acute or chronic cholecystitis at Patan hospital in Kathmandu. From the 1,496 patients, bile samples from 1,377 individuals were obtained and subjected to microbiological examination; 119 (8%) patients either denied consent or were unavailable for recruitment. A Gram-negative organism was isolated from 20% (274/1,377) of the bile samples. E. coli, Salmonella spp. and Klebsiella spp. were the most commonly isolated organisms, found in 78 (5.7%), 48 (3.5%) and 41 (3.0%) of the bile samples, respectively (Table 1). The remainder of the culture positive bile samples contained a range of organisms including Pseudomonas spp., Acinetobacter spp., Enterobacter spp., Citrobacter freundii, Vibrio spp. and Serratia marcescens (Table 1). Of the 48 Salmonellae isolated, 24 (1.7%) were S. Typhi, 22 (1.6%) were S. Paratyphi A and two (0.1%) were S. enterica group C.

Forty-six Salmonella isolates were available for antimicrobial susceptibility testing by disc diffusion. Fifty-nine percent (27/46) of the Salmonella isolates were resistant to nalidixic acid, and a single S. Paratyphi A isolate was resistant to both nalidixic acid and ciprofloxacin. All S. Typhi and S. Paratyphi A strains were susceptible to ceftriaxone, chloramphenicol, gentamicin and ofloxacin and we identified no multi-drug resistant (MDR) (resistant to chloramphenicol, ampicillin and co-trimoxazole) isolates. One S. enterica group C isolate demonstrated resistance to nalidixic acid, ceftriaxone, gentamicin and chloramphenicol (Table 1).

Baseline data, stratified by microbiological culture result are shown in Table 2. Notably, fitting with the typical epidemiological characteristics of cholelithiasis, 77% (1,066/1,377) of the patients were female and the median age was 39 years (range: 16 to 76 years). The median age of those with Salmonella in their bile was 35 years (range: 18 to 67 years) and 73% were female. It is noteworthy that none of the pre-surgical stool cultures from any patients were Salmonella positive and, when questioned, only 15% (7/46) of the Salmonella bile-positive patients had a memorable history of typhoid, none of which had been confirmed by microbiological culture. From available records, 16% (7/43) of Salmonella bile-positive patients reported >5 days of fever on entry, 7% (3/46) were admitted with jaundice, 5% (2/41) had a palpable gallbladder and 4% (2/45) were admitted with pancreatitis.

<table>
<thead>
<tr>
<th>Organism</th>
<th>n (%)</th>
<th>Antimicrobial resistance n (%)</th>
<th>Amoxicillin</th>
<th>Cefotaxime</th>
<th>Ciprofloxacin</th>
<th>Ofloxacin</th>
<th>Chloramphenicol</th>
<th>Gentamicin</th>
<th>Amikacin</th>
<th>Nalidixic Acid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Typhi</td>
<td>26 (2.1)</td>
<td>0/26 (0)</td>
<td>23/26 (88.5)</td>
<td>26/26 (100)</td>
<td>26/26 (100)</td>
<td>26/26 (100)</td>
<td>26/26 (100)</td>
<td>26/26 (100)</td>
<td>26/26 (100)</td>
<td>26/26 (100)</td>
</tr>
<tr>
<td>Paratyphi A</td>
<td>20 (1.5)</td>
<td>0/20 (0)</td>
<td>19/20 (95)</td>
<td>20/20 (100)</td>
<td>20/20 (100)</td>
<td>20/20 (100)</td>
<td>20/20 (100)</td>
<td>20/20 (100)</td>
<td>20/20 (100)</td>
<td>20/20 (100)</td>
</tr>
<tr>
<td>Other</td>
<td>20 (1.5)</td>
<td>0/20 (0)</td>
<td>19/20 (95)</td>
<td>20/20 (100)</td>
<td>19/20 (95)</td>
<td>19/20 (95)</td>
<td>19/20 (95)</td>
<td>19/20 (95)</td>
<td>19/20 (95)</td>
<td>19/20 (95)</td>
</tr>
<tr>
<td>Total Salmonella</td>
<td>48 (3.5)</td>
<td>24/48 (50)</td>
<td>43/48 (89.6)</td>
<td>48/48 (100)</td>
<td>48/48 (100)</td>
<td>48/48 (100)</td>
<td>48/48 (100)</td>
<td>48/48 (100)</td>
<td>48/48 (100)</td>
<td>48/48 (100)</td>
</tr>
<tr>
<td>Enterobacter spp.</td>
<td>2 (0.1)</td>
<td>0/2 (0)</td>
<td>2/2 (100)</td>
<td>2/2 (100)</td>
<td>2/2 (100)</td>
<td>2/2 (100)</td>
<td>2/2 (100)</td>
<td>2/2 (100)</td>
<td>2/2 (100)</td>
<td>2/2 (100)</td>
</tr>
<tr>
<td>Total Non-Salmonella</td>
<td>226 (16.4)</td>
<td>135/226 (60.0)</td>
<td>205/226 (91.3)</td>
<td>226/226 (100)</td>
<td>226/226 (100)</td>
<td>226/226 (100)</td>
<td>226/226 (100)</td>
<td>226/226 (100)</td>
<td>226/226 (100)</td>
<td>226/226 (100)</td>
</tr>
</tbody>
</table>

Table 1. Antimicrobial resistance patterns of Gram-negative organisms from the bile of patients undergoing cholecystectomy.
Bacterial Load of Salmonella in Bile

To quantify the bacterial load in the bile, real-time PCR was performed on total nucleic extracted from the bile of six S. Paratyphi A positive individuals and 12 S. Typhi positive individuals. All qualitative serovar specific PCR data corresponded precisely with the culture data. The median target copy numbers/bacterial loads were $9.3 \times 10^4$ (IQR $5 \times 10^4-2.3 \times 10^5$) CFU/ml for S. Paratyphi A and $5.2 \times 10^4$ (IQR $2 \times 10^4-7.28 \times 10^5$) CFU/ml for S. Typhi. The difference in bacterial load between the two organisms was non-significant ($p=0.93$, Mann-Whitney U test), yet, were approximately two and three orders of magnitude greater than those previously reported in bone marrow and blood, respectively [12,13].

Hematological and Biochemical Characteristics

The 1,377 individuals undergoing cholecystectomy were divided into three groups on the basis of their bile culture results: Salmonella positive, culture negative, and culture positive for non-Salmonella. Individuals that were Salmonella positive were more likely to have experienced continuous right upper-quadrant pain (10%, 5/48) compared to those that were culture negative (3%, 37/1,151) ($p=0.008$, chi squared test) and those that were culture positive for non-Salmonella (2%, 5/214) ($p=0.008$, chi squared test).

Hematology and biochemistry data from the patients were compared using the Mann-Whitney U test (Table 3). There was no significant difference in liver enzyme or bilirubin levels between the Salmonella positive group and the other two groups. Yet, the Salmonella positive group had a higher median neutrophil count and a lower median lymphocyte count than the culture negative group and the culture positive non-Salmonella group (Table 3).

Surgical and Histopathological Characteristics

The major surgical and post-surgical characteristics of the gallbladders from the three groups were compared using Fisher’s exact test (Table 4). The majority of Salmonella positive individuals had gallstones (96%, 46/48); yet, there was no significant difference in the proportion of individuals with gallstones between the three groups. We did, however, identify several gallbladder characteristics that were associated the presence of Salmonella. Namely, gallbladder distension and inflammation was more frequently observed in the Salmonella positive group than the culture negative group and the non-Salmonella culture positive group (Table 3). Furthermore, the presence of an empyema (pus within the gallbladder cavity) was also more common in the Salmonella positive group than the other two groups. Inflammation was more likely to be due to polymorphonuclear infiltration than lymphocytic infiltration in the Salmonella infected gallbladder tissue, with 13% (6/48) of the Salmonella positive gallbladder specimens having massive neutrophil infiltrate near the lumen, compared to 4% (51/1,151) and 5% (10/214) of the culture negatives and the non-Salmonella culture positives, respectively. Furthermore, an additional 15% (7/48) of the Salmonella positive gallbladder specimens had acute-on-chronic cholecystitis (neutrophil infiltrate near the lumen with lymphocyte infiltrate and dysplasia in the mucosa) compared to 5% (10/214) and 7% (14/214) of the culture negatives and the non-Salmonella culture positives, respectively (Table 3). Correspondingly, chronic inflammation without large neutrophil infiltrate was not observed in gallbladder tissue from the Salmonella positive group.

Discussion

The mechanism of gallbladder infection/colonization remains contentious, and it is unknown if Salmonella promote gallbladder
damage during chronic infection or if the organisms exploit existing gallbladder damage to stimulate colonization [14]. Bile is typically sterile, and consists of organic and inorganic compounds, bile acids, cholesterol, phospholipids and the pigment biliverdin. Sterility is partially maintained by the secretion of IgA and mucus, preventing bacterial survival and adhesion to the surface of the lumen and the major bile duct, respectively [15]. Here, we found a wide array of organisms in the bile of individuals undergoing cholecystectomy, some of which have been previously isolated from the gallbladder [16–18]. Again, whether these organisms

<table>
<thead>
<tr>
<th>Hematology</th>
<th>Culture negative</th>
<th>Culture positive non-Salmonella</th>
<th>Salmonella positive</th>
<th>p1*</th>
<th>p2*</th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td>median IQR</td>
<td>n median IQR</td>
<td>n median IQR</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total cell (×10^3/µL)</td>
<td>953 7.9 6.6–9.5</td>
<td>188 7.85 6.45–10.15</td>
<td>42 9.45 6.4–14</td>
<td>0.025</td>
<td>0.058</td>
</tr>
<tr>
<td>Neutrophil (×10^3/µL)</td>
<td>917 66 58–74</td>
<td>177 65 58–75</td>
<td>41 72 60–82</td>
<td>0.012</td>
<td>0.042</td>
</tr>
<tr>
<td>Lymphocyte (×10^3/µL)</td>
<td>914 31 24–38</td>
<td>175 31 23–38</td>
<td>40 24.5 17–36</td>
<td>0.007</td>
<td>0.040</td>
</tr>
<tr>
<td>Monocyte (×10^3/µL)</td>
<td>270 1 1–2</td>
<td>70 1.5 1–2</td>
<td>9 1 1–2</td>
<td>0.676</td>
<td>0.848</td>
</tr>
<tr>
<td>Eosinophil (×10^3/µL)</td>
<td>641 2 1–4</td>
<td>131 2 1–4</td>
<td>22 2 2–4</td>
<td>0.999</td>
<td>0.515</td>
</tr>
<tr>
<td>Basophil (×10^3/µL)</td>
<td>54 0 0–1</td>
<td>14 0 0–0</td>
<td>1 6 –</td>
<td>0.058</td>
<td>0.020</td>
</tr>
<tr>
<td>Total bilirubin (mg/mL)</td>
<td>965 0.8 0.68–1</td>
<td>190 0.8 0.7–1</td>
<td>42 0.86 0.7–1.1</td>
<td>0.119</td>
<td>0.280</td>
</tr>
<tr>
<td>Conjugated bilirubin (mg/mL)</td>
<td>950 0.2 0.19–0.26</td>
<td>186 0.2 0.18–0.24</td>
<td>41 0.2 0.2–0.28</td>
<td>0.414</td>
<td>0.419</td>
</tr>
<tr>
<td>AST (u/L)</td>
<td>961 30 23–41</td>
<td>190 29.5 23–40</td>
<td>42 28 24–38.9</td>
<td>0.878</td>
<td>0.986</td>
</tr>
<tr>
<td>ALT (u/L)</td>
<td>960 30 21.9–43</td>
<td>188 29.5 21–43.5</td>
<td>42 30.5 24–41</td>
<td>0.898</td>
<td>0.953</td>
</tr>
<tr>
<td>ALP (u/L)</td>
<td>941 122 82–209</td>
<td>188 150.5 94.5–232.5</td>
<td>42 124.5 96–191</td>
<td>0.622</td>
<td>0.276</td>
</tr>
<tr>
<td>Amylase (u/L)</td>
<td>136 61.5 41.5–252.5</td>
<td>20 57.5 38–86.5</td>
<td>9 87 34–190</td>
<td>0.867</td>
<td>0.437</td>
</tr>
</tbody>
</table>

* Mann-Whitney U test, boldface indicates p ≤0.05.
** p1: Comparing culture-negative to Salmonella-positive patients.
** p2: Comparing culture positive for non-Salmonella to Salmonella-positive patients.

IQR: Interquartile range.
doi:10.1371/journal.pone.0047342.t003

<table>
<thead>
<tr>
<th>Character</th>
<th>Culture negative</th>
<th>Culture positive non-Salmonella</th>
<th>Salmonella positive</th>
<th>p1*</th>
<th>p2*</th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td>median IQR</td>
<td>n median IQR</td>
<td>n median IQR</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gallbladder tissue thickness</td>
<td>1,103</td>
<td>214</td>
<td>48</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thick (&gt;4mm)</td>
<td>173 (15.7)</td>
<td>36 (16.8)</td>
<td>10 (20.8)</td>
<td>0.350</td>
<td>0.602</td>
</tr>
<tr>
<td>Normal (4mm)</td>
<td>493 (44.7)</td>
<td>86 (40.0)</td>
<td>21 (43.8)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thin (&lt;4mm)</td>
<td>74 (6.7)</td>
<td>12 (5.6)</td>
<td>1 (2.1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gallbladder size</td>
<td>1,103</td>
<td>214</td>
<td>48</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Contracted</td>
<td>108 (9.8)</td>
<td>25 (11.7)</td>
<td>1 (2.1)</td>
<td>0.026</td>
<td>0.035</td>
</tr>
<tr>
<td>Distended</td>
<td>221 (20.0)</td>
<td>52 (24.3)</td>
<td>15 (31.3)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gall stones</td>
<td>1,103</td>
<td>214</td>
<td>48</td>
<td></td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>19 (1.7)</td>
<td>6 (2.8)</td>
<td>3 (6.3)</td>
<td>0.101</td>
<td>0.481</td>
</tr>
<tr>
<td>Single</td>
<td>344 (31.2)</td>
<td>62 (29.0)</td>
<td>14 (29.2)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Multiple</td>
<td>684 (62.0)</td>
<td>133 (62.1)</td>
<td>28 (58.3)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pathology</td>
<td>1,103</td>
<td>214</td>
<td>48</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inflammation</td>
<td>93 (8.4)</td>
<td>17 (7.9)</td>
<td>8 (16.7)</td>
<td>0.046</td>
<td>0.060</td>
</tr>
<tr>
<td>Empyema</td>
<td>90 (8.2)</td>
<td>21 (9.8)</td>
<td>10 (20.8)</td>
<td>0.003</td>
<td>0.033</td>
</tr>
<tr>
<td>Sludge</td>
<td>57 (5.2)</td>
<td>8 (3.7)</td>
<td>1 (2.1)</td>
<td>0.338</td>
<td>0.581</td>
</tr>
<tr>
<td>Mucocele</td>
<td>50 (4.5)</td>
<td>7 (3.3)</td>
<td>1 (2.1)</td>
<td>0.427</td>
<td>0.664</td>
</tr>
</tbody>
</table>

* Fisher’s exact test, boldface indicates p ≤0.05.
** p1: Comparing culture-negative to Salmonella-positive patients.
** p2: Comparing culture-positive, Salmonella-negative to Salmonella-positive patients.
doi:10.1371/journal.pone.0047342.t004
functionally stimulate cholecystitis or cholelithiasis, or merely have the ability to colonize damaged gallbladders, remains unclear. Our data confirm that non-Salmonellae organisms, with a spectrum of pathogenic potential, are as equally adept at colonizing the gallbladder and surviving within the bile as typhoidal Salmonella. Yet, non-Salmonellae appear not to stimulate the same pathology as Salmonella. Salmonella infected tissue was more commonly associated with systemic and local acute inflammatory responses. Mouse experiments, utilizing Salmonella Typhimurium, have shown that Salmonella can replicate within the epithelial cells of the gallbladder [19], and that colonized gallbladders displayed evidence of the epithelial destruction and local neutrophil infiltrate. Here, we also find extensive neutrophil infiltrate, yet are unable to confirm if the bacteria are damaging the tissue or colonizing previously damaged tissue. However, as shown by an increased prevalence of gallbladder distention, right upper quadrant pain, empyema and a raised systemic neutrophil count, there is an evident association of invasive Salmonella in the gallbladder with an acute inflammatory response.

We have previously noted the presence of individuals in Kathmandu with Salmonella in their gallbladder, highlighting the presence of S. Paratyphi A [11]. The role of chronic carriage of S. Paratyphi A has received much less attention than that of S. Typhi, and it is unknown as to what extent chronic gallbladder carriage is contributing to the increasing burden of S. Paratyphi A across many parts of Asia [20]. Enteric fever caused by S. Paratyphi A increased from 17.5% (155/883) in 1993 to 34% (926/2,718) in 2003 in the location of this study [21].

Furthermore, we found an almost equal ratio of S. Typhi and S. Paratyphi A (1:0.9) isolated from bile, yet the isolates from blood from acutely infected patients over the same period is lower (1:0.4) [22]. This disparity may result from a multitude of factors, but may predict that S. Paratyphi A is a more adept at inducing carriage in this population, or, once in the gallbladder, may be more likely to induce an acute inflammatory response, requiring a surgical intervention, than S. Typhi.

We found that 3.5% of the individuals undergoing gallbladder surgery had invasive Salmonella in their bile in this area with a high incidence of enteric fever [23]. A report from a similar patient demographic in India suggest an equivalent rate of <5%, and in Chile, 7.3% of bile cultures were found to be positive for Salmonella [7]. The long-term carriage of invasive Salmonella in the gallbladder is thought to be central to the maintenance and transmission of these human-restricted pathogens [14]. However, data from our previous work in Kathmandu suggests that direct transmission plays a negligible role in acute infections, and we have hypothesized that carriers merely act as a reservoir for maintaining local strain diversity in areas of high endemicity [22]. Here, we found antimicrobial resistance to only nalidixic acid in the Salmonella from the gallbladder. Although nalidixic acid resistance often precedes resistance to other fluoroquinolones, these isolates were susceptible to gatifloxacin and ciprofloxacin. Firstly, these data show that infection with an antimicrobial resistant organism is not likely to be associated with Salmonella carriage. Secondly, if one considers nalidixic acid resistance as a proxy marker of contemporary strains, the organisms in the gallbladder have probably been there for some time (i.e. from a period when nalidixic acid resistance was less prevalent) [21,24]. Nalidixic acid resistance is a growing problem in Kathmandu. From an ongoing clinical trial enrolling enteric fever patients over the last two years at Patan Hospital, 80% (171/214) of invasive Salmonella isolates demonstrated resistance to nalidixic acid, which is greater than the proportion (59%) found from bile isolates in the current study (unpublished data). This evidence supports our current hypothesis of gallbladder carriage playing a limited role in the acute transmission of typhoid in Kathmandu.

Whilst we argue that in locations such as Kathmandu, the role of carriers in typhoid fever transmission may be negligible, it is reasonable to suggest that those shedding invasive Salmonella play a vital important role in low transmission setting. In the USA, up to 50% of typhoid fever infections are anticipated to result from contact with a chronic carrier [25]. Therefore, these individuals will become increasingly important as indirect transmission this area begins to subside after the introduction of an effective intervention strategy. However, currently there is no appropriate diagnostic test for the detection of long-term carriers [26]. Bile cultures from string devices are considered effective [27], but are impractical for screening large cohorts [28]. The presence of gallbladder disease is, perhaps, currently the best clinical predictor of carriage of invasive Salmonella [7]. However, it remains unclear as to why some patients progress to become chronic shedders and others do not. The development of a rapid diagnostic for the detection of invasive Salmonella carriage should accelerate regional elimination of typhoid and add insight into the epidemiological role of these individuals.

One of the major caveats of our study that limits the generalizability of our findings is the fact that our passively acquired patient population may not accurately reflect the general population of Kathmandu. Additionally, all patients in the study had some form of gallbladder abnormality, although it is unclear whether such abnormalities had been induced by the infecting organisms. Nevertheless, in the absence of an alternative methodology, our study represents a reasonable estimation of the burden and mechanism of invasive Salmonella carriage.

In conclusion, we have calculated a prevalence of 3.5% of invasive Salmonella in bile from patients undergoing cholecystectomy in Kathmandu, Nepal. We demonstrate that S. Paratyphi A is almost as prevalent as S. Typhi in the gallbladder in this population and that carriage is not driven by antimicrobial resistance. The overall role of invasive Salmonella carriage in settings such as Kathmandu is not understood, and we suggest that organisms in the gallbladder may not play a dominant role in acute typhoid fever in this location. We predict, however, that carriers will become more important if current transmission mechanisms are disturbed; prospectively identifying these individuals is paramount for rapid local and regional elimination.

Methods

Ethics Statement

This study was conducted according to the principles expressed in the Declaration of Helsinki and was approved by the institutional ethical review boards of Patan Hospital, The Nepal Health Research Council and The Oxford University Tropical Research Ethics Committee (OX1REC; Reference number: 2108). All enrollees were required to provide written informed consent for the collection and storage of all samples and subsequent data analysis. In the case of those under 18 years of age, a parent or guardian was asked to provide written informed consent.

Setting and Study Population

The study was conducted at Patan Hospital, a 318-bed government hospital located in the Lalitpur Sub-Metropolitan City in the Kathmandu valley, Nepal. Patan Hospital provides both emergency and elective inpatient services. Typhoid fever is a common complaint at Patan Hospital and S. Typhi and S. Paratyphi A are the most common bacteria cultured from blood.
of febrile patients in this location. Antimicrobials are available without prescription in the community in a variety of public and private outlets and there are numerous private physician clinics where patients may seek advice and clinical diagnosis for febrile disease. There has been no widespread implementation of a typhoid vaccine in this area, yet a generic typhoid Vi vaccine is available for purchase in some health care settings. However, at the time of this investigation there was limited community uptake of the vaccine.

The surgical department performs approximately 400 cholecystectomies annually. For the purposes of this study, consecutive patients admitted to the surgical ward from June 2007 to October 2010 for either open cholecystectomy or laparotomy surgery for symptomatic cholelithiasis between 0 am and 4 pm were approached for participation. All patients who gave written informed consent were eligible for the study; there were no exclusion criteria. All enrollees were also required to provide written informed consent for the collection, use and storage of the tissue samples removed during surgery. A questionnaire related to the patient’s health and demographics was administered prior to surgery along with a stool sample for microbiological culture. Surgeons collected bile samples and gallbladder tissue during the procedure.

**Gallbladder Morphology and Histopathology**

Patients were routinely examined by ultrasonography before surgery to assess the presence of gallstones and to detect inflammation. The surgeon performing the procedure curated a report, assessing the thickness of the gallbladder wall (stratified into three categories, thick: >4 mm, normal: 4 mm and thin: <4 mm), the presence and the number of gallstones, the presence and characteristics of fluid (pus: empyema, mucoid/clear/watery: mucocoele and sludge) and overall morphology (contracted or distended). Hematocrit, total leukocytes with differential count, total bilirubin, conjugated bilirubin, alanine aminotransferase (ALT), aspartate aminotransferase (AST), and amylase were measured prior to surgical intervention. All extracted tissue was subjected to a histopathological examination to assess/confirm the extent of the inflammation; all histopathology was performed by experienced pathologists. Biopsies were examined by light microscopy after staining with haematoxylin and eosin. Inflammation was identified by tissue morphology and the presence of neutrophils (acute) and lymphocytes (chronic).

**Microbiological Culture, Antimicrobial Susceptibility Testing and Real-time PCR**

Bile and stool were collected for culture from all patients undergoing cholecystectomy. Bile was inoculated into equal volumes of Selenite F broth and Peptone broth and incubated at 37°C overnight. Broths were sub-cultured onto MacConkey agar and Xylen Lysine Deoxycholate (XLD) agar. After overnight incubation at 37°C the plates were examined for the growth of Gram-negative bacteria and colonies were identified by standard microbiological methods and identified by API20E manufactured by bioMerieux, Inc. S. Typhi and S. Paratyphi A isolates were confirmed by slide agglutination by specific antiserum (Murex Biotech, Biotech, England). The antimicrobial sensitivity profile was performed by Kirby Bauer disc diffusion method using standard BSAC and CLSI guidelines [29]. The antimicrobials tested were amoxicillin, chloramphenicol, co-trimoxazole, nalidixic acid, ciprofloxacin, ofloxacin, ceftriaxone and gatifloxacin. The minimum inhibitory concentrations (MICs) were performed for nalidixic acid, ciprofloxacin, ofloxacin and azithromycin by Etest (AB Biodisk, Sweden). Susceptibility to ciprofloxacin and ofloxacin were evaluated using newly suggested susceptibility breakpoints for these antimicrobials; ≥0.125 μg/ml and ≥0.25 μg/ml for ciprofloxacin and ofloxacin respectively [30]. Real-time PCR was performed using a standard curve for quantitation as previously described [12], using DNA extracted from 200μl bile samples as template.

**Data Analysis**

Data were entered into a database using Excel 2007 (Microsoft) and analyzed using Stata/Ic version 9.2 (StataCorp, TX, USA). Chi-square and Fisher’s exact tests were used to compare proportions between groups and Mann-Whitney U tests were used for continuous non-parametric data. P-values ≤0.05 were considered to be statistically significant.

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**Author Contributions**

Conceived and designed the experiments: SD SB. Performed the experiments: SC TVTN PTD PM SP VKJ SV. Analyzed the data: SD. Contributed reagents/materials/analysis tools: AK AA SK NSK GD. Contributed to the writing of the manuscript: SD SB. All authors contributed to and approved the final manuscript.

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