RESEARCH ARTICLE

The emergence of *Clostridium difficile* infection in Asia: A systematic review and meta-analysis of incidence and impact

Nienke Z. Borren¹,², Shadi Ghadermarzi³, Susan Hutfless³,⁴, Ashwin N. Ananthakrishnan¹,⁵*

¹ Division of Gastroenterology, Massachusetts General Hospital, Boston, Massachusetts, United States of America, ² University of Groningen, Groningen, The Netherlands, ³ Division of Gastroenterology & Hepatology, Johns Hopkins University, Baltimore, Maryland, United States of America, ⁴ Department of Epidemiology, Johns Hopkins Bloomberg School of Public Health, Baltimore, Maryland, United States of America, ⁵ Harvard Medical School, Boston, Massachusetts, United States of America

* aananthakrishnan@mgh.harvard.edu

Abstract

**Background**

*Clostridium difficile* infection (CDI) is the most common healthcare associated infection and is highly prevalent in Europe and North America. Limited data is available on the prevalence of CDI in Asia. However, secular increases in prevalence of risk factors for CDI suggest that it may be emerging as a major cause of morbidity, highlighting the urgent need for a systematic study of the prevalence of CDI in Asia.

**Methods**

We systematically searched PubMed/Medline and Embase for publications from Asia between 2000–16 examining prevalence of CDI. A random-effects meta-analysis was performed to calculate the pooled prevalence of CDI in Asia and to identify subgroups and regions at high risk.

**Results**

Our meta-analysis included 51 studies from throughout Asia including 37,663 patients at risk among whom confirmed CDI was found in 4,343 patients. The pooled proportion of confirmed CDI among all patients with diarrhea was 14.8% with a higher prevalence in East Asia (19.5%), compared with South Asia (10.5%) or the Middle East (11.1%). There were an estimated 5.3 episodes of CDI per 10,000 patient days, similar to rates reported from Europe and North America. Infections due to hypervirulent strains were rare. CDI-related mortality was 8.9%.

**Conclusions**

In a meta-analysis of 51 studies, we observed similar rates of CDI in Asia in comparison to Europe and North America. Increased awareness and improved surveillance of *Clostridium difficile* is essential to reduce incidence and morbidity.
**Introduction**

*Clostridium difficile* infection (CDI) is the most common healthcare associated infection (HAI). Since its identification as the cause of pseudomembranous colitis in 1978[1], it has emerged as an important cause of morbidity particularly among hospitalized patients and led to epidemics with high mortality. An estimated 453,000 infections occur annually in the United States, 172,000 in Europe, and 18,005 in England.[2–4] Recognition of the burden of CDI has led to a multi-pronged strategy of provider education, institution of systematic testing, antibiotic stewardship and infection control programs which has blunted the rise, and even reduced the incidence of this infection in North America and Europe.[5, 6]

In contrast, little is known about the prevalence and impact of CDI in Asia as few systematic studies exist and testing remains infrequent, hampered by both a low index of clinical suspicion and the lack of readily available laboratory testing.[7] Yet, several factors favor the possible emergence of *C. difficile* as an important pathogen in Asia.[8, 9] While traditionally considered home to a young population, with improved life expectancy and control of other infectious diseases, many countries in Asia are witnessing an aging of their demographics and in most studies, the elderly are particularly susceptible to CDI.[10, 11] Chronic diseases, also a risk factor for CDI, have increased in prevalence, and so has the need for frequent healthcare contact and hospitalizations. In addition, antibiotic use, the strongest risk factor for CDI, is often indiscriminate and unregulated in some Asian countries.[12, 13]

Thus, there is an important need for systematic study of the prevalence and impact of CDI in Asia to inform both clinical practice as well as healthcare policy. We performed this systematic review and meta-analysis to (1) quantify the burden of CDI among countries in Asia; (2) identify subgroups and regions at high risk within this population; and (3) define the proportion of hypervirulent epidemic strains of *C. difficile*; and (4) quantify CDI-related mortality in comparisons to studies from the west.

**Methods**

**Literature search**

We conducted a systematic search of the MEDLINE/PubMed and EMBASE databases for studies providing prevalence or incidence rates of CDI in Asia. To quantify current burden, our search was limited to publications from January 2000 to June 2016. No language restrictions were applied in our search, but inclusion of the study in our full analysis required at least the abstract to be available in English. Our search strategy combined 3 different phrase groups by using the Boolean operator “AND” (S1 Table). The first search group consisted of terms relevant to identify CDI and included combination of "Clostridium difficile", "C difficile" and "C diff" and "Pseudomembranous colitis". The second group defining location included both broadly the phrase “Asia” as well as specific countries within Asia including China, Hong Kong, India, Iran, Israel, Japan, Korea, Malaysia, Singapore, Taiwan, Thailand and Turkey. The final search terms defined the outcome of interest and included “prevalence”, “incidence”, “epidemiology”, and “frequency”. The citation list from all eligible studies and reviews were also perused to identify other relevant studies.

**Inclusion and exclusion criteria**

Studies were eligible for inclusion if they provided information on the incidence of CDI in Asia reported either as proportion of tests positive for toxigenic *C. difficile* among symptomatic patients testing, per 1000 hospital discharges, or per 10,000 patient days. Studies examining C.
difficile carriage among asymptomatic individuals were excluded. Eligible studies could include either an inpatient or outpatient population.

Data collection
The decision for inclusion of each study was made by two authors (NZB and ANA) who independently screened the studies by title and abstract. The following data were extracted from each study: year of publication, location, setting (inpatient or outpatient), population (nosocomial diarrhea, antibiotic-associated diarrhea, other), number of patients tested, and number of patients with confirmed CDI. The microbiological method for diagnosis of CDI was noted and where available, the results of molecular characterization for specific ribotypes. From each study, mean age prevalence of risk factors for CDI including exposure to antibiotics, use of proton pump inhibitors (PPI), and recent hospitalization were noted. Studies were grouped into three geographic regions: South Asia (India, Malaysia, Pakistan, Singapore, and Thailand), East Asia (China, Hong Kong, Japan, Korea, Taiwan) and the Middle East (Iran, Jordan, Kuwait, Lebanon, Qatar, Turkey). When necessary, attempts were made to contact the corresponding authors for additional pertinent information.

Outcomes
The primary outcome of interest was expressed in one of three ways: (1) the proportion of tests positive for toxigenic C. difficile from among all patients with diarrhea; (2) rate of CDI per 1,000 admissions; and (3) the rate of CDI per 10,000 patient days. Our secondary outcome was CDI-associated mortality.

Assessment of study quality
We used the Newcastle-Ottawa Quality Assessment Scale (NOS) to assess study quality. This scale ranks studies in 3 groups based on the selection of the cohort; the comparability of the cohorts; and the completeness of ascertainment of the outcome. Each study could receive up to 4 stars. Studies were considered representative if they consisted of an unselected group of patients and did not focus on individuals with specific comorbidities alone. Ascertainment bias was considered to be absent if all patients with diarrhea underwent similar testing strategies; reliance on clinical suspicion to trigger testing for select patients was deemed susceptible to bias.

Statistical analysis
Heterogeneity between the studies was determined using the Cochran’s Q and I² statistics. An I² > 50% or p < 0.10 indicated significant heterogeneity. A DerSimonian and Laird random effects model was used for all analyses to determine the pooled prevalence rates (and 95% confidence intervals (CI)) for proportion of stool tests that were positive for C. difficile as well as rates per 1,000 admissions and 10,000 patient days. Pre-specified subgroup analysis was performed stratifying by setting, geographic region, and population under study (antibiotic-associated diarrhea, all nosocomial diarrhea). Publication bias was examined using the Egger test and visual examination of the funnel plot. Sources of heterogeneity between studies were identified by performing a meta-regression. All data were recorded in a Microsoft Excel spreadsheet (Microsoft Corp, Redmond, WA) and statistical analysis carried out using Stata 13.2 (StataCorp, College Station, TX).
Results

Literature search

Our search of MEDLINE/Pubmed yielded 448 citations. Of these, 393 citations were excluded on initial screening of the title and abstract and the full text of remaining 55 articles were reviewed (Fig 1). Two articles representing duplicate data[14, 15], 2 with insufficient information[16, 17], and 4 examining C. difficile carriage in healthy individuals were excluded[18–21], resulting in a final cohort of 48 unique studies.[9, 22–71] Of these, only the abstract was available for review in English in 7 studies but sufficient relevant information could be extracted to allow for inclusion.[60–66, 71] A search on Embase yielded 3 additional studies that were eligible for inclusion. One large study from Thailand was not included as it did not include microbiological confirmation of CDI.[72]

Study characteristics

The characteristics of the included studies are summarized in Table 1. Forty two included only hospitalized patients[9, 22–24, 28–40, 42, 43, 46, 48, 50–55, 57, 59–67, 69–71], 1 was exclusively among outpatients[47], and 8 included both groups.[25, 26, 41, 44, 45, 49, 56, 68] A total of 16 countries were represented, with China contributing the largest number of studies. Twenty-five studies were from East Asia[9, 22, 24, 26, 28, 34–37, 39–42, 44, 52–54, 56, 58–61, 67, 70, 71], 16 from South Asia[23, 25, 27, 29, 31, 33, 43, 46, 51, 55, 62–64, 66, 68, 69] and 10 from the Middle East.[30, 32, 38, 45, 47–50, 57, 65] The mean age of included patients was 60 years (data from 24 studies) and just fewer than half the cohort were women (43%, 34 studies). From 28 studies presenting data on antibiotic use; a mean of 84% of patients had been exposed recently (range 26–100%). Sixteen studies examining PPI use yielded a mean proportion of 49% (range 5–90%). From twenty-one studies where this data was available, the pooled proportion of recent hospitalization was 71% (range 19–100%).

The included studies varied in the testing modality to determine CDI. The most commonly performed tests were anaerobic or toxigenic culture (71%) and the enzyme immunoassay (EIA) (52%). Nearly half the studies also reported using polymerase chain reaction / nucleic acid amplification test (PCR-NAAT) (51%). Other diagnostic tests used were cell culture cytoxicity neutralization assay (CCNA) (8%), glutamate dehydrogenase assay (GDH) (6%), and lower gastrointestinal endoscopy (11%). Molecular characterization of C. difficile ribotype was

Fig 1. Flowchart of the literature search.

https://doi.org/10.1371/journal.pone.0176797.g001
Table 1. Characteristics of included studies.

<table>
<thead>
<tr>
<th>Publication year</th>
<th>Author</th>
<th>Region</th>
<th>Setting</th>
<th>Study population</th>
<th>Study design</th>
<th>Diagnostic test(s) used</th>
<th>Number at risk</th>
<th>Number confirmed CDI</th>
<th>Proportion CDI +</th>
</tr>
</thead>
<tbody>
<tr>
<td>2007</td>
<td>Kikkawa H</td>
<td>East</td>
<td>Hospitalized</td>
<td>Patients with diarrhea</td>
<td>Prospective</td>
<td>Toxigenic culture and PCR</td>
<td>332</td>
<td>159</td>
<td>47.89</td>
</tr>
<tr>
<td>2008</td>
<td>Huang H</td>
<td>East</td>
<td>Hospitalized</td>
<td>Patients with diarrhea</td>
<td>Prospective</td>
<td>Toxigenic culture, CCNA and PCR</td>
<td>587</td>
<td>56</td>
<td>9.54</td>
</tr>
<tr>
<td>2008</td>
<td>Shin BM</td>
<td>East</td>
<td>Hospitalized</td>
<td>Patients with diarrhea</td>
<td>Retrospective</td>
<td>Toxigenic culture, EIA and PCR</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2009</td>
<td>Cheng VC</td>
<td>East</td>
<td>Hospitalized</td>
<td>Patients with diarrhea</td>
<td>Prospective</td>
<td>Toxigenic culture and PCR</td>
<td>496</td>
<td>37</td>
<td>7.46</td>
</tr>
<tr>
<td>2010</td>
<td>Chung CH</td>
<td>East</td>
<td>Hospitalized</td>
<td>Patients with diarrhea</td>
<td>Retrospective</td>
<td>EIA</td>
<td>316</td>
<td>86</td>
<td>27.22</td>
</tr>
<tr>
<td>2010</td>
<td>Lee JH</td>
<td>East</td>
<td>Hospitalized</td>
<td>Patients with diarrhea</td>
<td>Retrospective</td>
<td>Anaerobic culture and EIA</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2010</td>
<td>Lee YJ</td>
<td>East</td>
<td>Hospitalized</td>
<td>Patients with diarrhea</td>
<td>Retrospective</td>
<td>Toxigenic culture and endoscopy</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2011</td>
<td>Cheng VC</td>
<td>East</td>
<td>Hospitalized</td>
<td>Patients with diarrhea</td>
<td>Retrospective</td>
<td>Toxigenic culture, CCNA and PCR</td>
<td>2440</td>
<td>307</td>
<td>12.58</td>
</tr>
<tr>
<td>2012</td>
<td>Lee YC</td>
<td>East</td>
<td>Hospitalized</td>
<td>Patients with diarrhea</td>
<td>Prospective</td>
<td>Toxigenic culture, GDH and EIA</td>
<td>80</td>
<td>8</td>
<td>10.00</td>
</tr>
<tr>
<td>2012</td>
<td>Hung YP</td>
<td>East</td>
<td>Hospitalized</td>
<td>Patients with diarrhea</td>
<td>Prospective</td>
<td>Toxigenic culture and PCR</td>
<td>168</td>
<td>7</td>
<td>4.17</td>
</tr>
<tr>
<td>2013</td>
<td>Kim J</td>
<td>East</td>
<td>Hospitalized</td>
<td>Patients with AAD</td>
<td>Prospective</td>
<td>Toxigenic culture and PCR</td>
<td>769</td>
<td>166</td>
<td>21.59</td>
</tr>
<tr>
<td>2013</td>
<td>Hawkey PM</td>
<td>East</td>
<td>Hospitalized</td>
<td>Patients with AAD</td>
<td>Retrospective</td>
<td>Toxigenic culture and PCR</td>
<td>70</td>
<td>21</td>
<td>30.00</td>
</tr>
<tr>
<td>2013</td>
<td>Kim YS</td>
<td>East</td>
<td>Hospitalized</td>
<td>Patients with diarrhea</td>
<td>Retrospective</td>
<td>Toxigenic culture, EIA and endoscopy</td>
<td>1367</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2013</td>
<td>Han XH</td>
<td>East</td>
<td>Hospitalized</td>
<td>Patients with diarrhea</td>
<td>Prospective</td>
<td>EIA</td>
<td>277</td>
<td>41</td>
<td>14.80</td>
</tr>
<tr>
<td>2014</td>
<td>Wang X</td>
<td>East</td>
<td>Hospitalized</td>
<td>All patients</td>
<td>Prospective</td>
<td>Toxigenic culture and PCR</td>
<td>124</td>
<td>31</td>
<td>25.00</td>
</tr>
<tr>
<td>2014</td>
<td>Huang H</td>
<td>East</td>
<td>Hospitalized</td>
<td>Patients with diarrhea</td>
<td>Prospective</td>
<td>Anaerobic culture, ccna, pcr</td>
<td>240</td>
<td>90</td>
<td>37.50</td>
</tr>
<tr>
<td>2014</td>
<td>Honda</td>
<td>East</td>
<td>In- and outpatients</td>
<td>Patients with diarrhea</td>
<td>Retrospective</td>
<td>EIA</td>
<td>851</td>
<td>126</td>
<td>14.81</td>
</tr>
<tr>
<td>2014</td>
<td>Zhou FF</td>
<td>East</td>
<td>Hospitalized</td>
<td>Patients with AAD</td>
<td>Prospective</td>
<td>Toxigenic culture, CCNA, PCR and endoscopy</td>
<td>206</td>
<td>63</td>
<td>30.58</td>
</tr>
<tr>
<td>2014</td>
<td>Fang WJ</td>
<td>East</td>
<td>Hospitalized</td>
<td>Patients with diarrhea</td>
<td>Prospective</td>
<td>Toxigenic culture, EIA and PCR</td>
<td>400</td>
<td>82</td>
<td>20.50</td>
</tr>
<tr>
<td>2014</td>
<td>Ji D</td>
<td>East</td>
<td>Hospitalized</td>
<td>All patients</td>
<td>Prospective</td>
<td>PCR</td>
<td>513</td>
<td>12</td>
<td>2.34</td>
</tr>
<tr>
<td>2014</td>
<td>Yang BK</td>
<td>East</td>
<td>Hospitalized</td>
<td>Patients with diarrhea</td>
<td>Prospective</td>
<td>Toxigenic culture, PCR and endoscopy</td>
<td>1420</td>
<td>330</td>
<td>23.24</td>
</tr>
</tbody>
</table>

(Continued)
<table>
<thead>
<tr>
<th>Publication year</th>
<th>Author</th>
<th>Region</th>
<th>Setting</th>
<th>Study population</th>
<th>Study design</th>
<th>Diagnostic test(s) used</th>
<th>Number at risk</th>
<th>Number confirmed CDI</th>
<th>Proportion CDI +</th>
</tr>
</thead>
<tbody>
<tr>
<td>2014</td>
<td>Zhu Y</td>
<td>East Asia</td>
<td>Hospitalized patients</td>
<td>Patients with diarrhea</td>
<td>Prospective</td>
<td>Anaerobic culture and Toxigenic culture</td>
<td>277</td>
<td>41</td>
<td>14.80</td>
</tr>
<tr>
<td>2015</td>
<td>Choi HY</td>
<td>East Asia</td>
<td>In- and outpatients</td>
<td>Unclear</td>
<td>Retrospective</td>
<td>Unclear</td>
<td>111</td>
<td>31</td>
<td>27.93</td>
</tr>
<tr>
<td>2015</td>
<td>Galaydick J</td>
<td>East Asia</td>
<td>Hospitalized patients</td>
<td>Patients with diarrhea</td>
<td>Prospective</td>
<td>PCR</td>
<td>470</td>
<td>93</td>
<td>19.79</td>
</tr>
<tr>
<td>2016</td>
<td>Li Y</td>
<td>East Asia</td>
<td>Hospitalized patients</td>
<td>Patients with AAD</td>
<td>Prospective</td>
<td>EIA</td>
<td>300</td>
<td>29</td>
<td>9.70</td>
</tr>
<tr>
<td>2001</td>
<td>Shehabi AA</td>
<td>Middle East</td>
<td>Hospitalized patients</td>
<td>Patients with diarrhea</td>
<td>Prospective</td>
<td>EIA</td>
<td>40</td>
<td>17</td>
<td>43.00</td>
</tr>
<tr>
<td>2009</td>
<td>Ergen EK</td>
<td>Middle East</td>
<td>Hospitalized patients</td>
<td>Patients with diarrhea</td>
<td>Prospective</td>
<td>Toxigenic culture, PCR and Endoscopy</td>
<td>697</td>
<td>56</td>
<td>8.03</td>
</tr>
<tr>
<td>2010</td>
<td>Jamal W</td>
<td>Middle East</td>
<td>In- and outpatients</td>
<td>Patients with diarrhea</td>
<td>Prospective</td>
<td>Toxigenic culture, EIA and PCR</td>
<td>942</td>
<td>57</td>
<td>6.05</td>
</tr>
<tr>
<td>2011</td>
<td>Nazemalhosseini-Mojjarad E</td>
<td>Middle East</td>
<td>Hospitalized patients</td>
<td>Patients with diarrhea</td>
<td>Prospective</td>
<td>EIA</td>
<td>356</td>
<td>19</td>
<td>5.34</td>
</tr>
<tr>
<td>2012</td>
<td>Khan FY</td>
<td>Middle East</td>
<td>In- and outpatients</td>
<td>Patients with diarrhea</td>
<td>Retrospective</td>
<td>EIA and Endoscopy</td>
<td>86</td>
<td>17</td>
<td>19.77</td>
</tr>
<tr>
<td>2012</td>
<td>Jalali M</td>
<td>Middle East</td>
<td>In- and outpatients</td>
<td>Patients with diarrhea</td>
<td>Prospective</td>
<td>Anaerobic culture, Toxigenic culture and PCR</td>
<td>1532</td>
<td>122</td>
<td>7.96</td>
</tr>
<tr>
<td>2014</td>
<td>Al-Thani AA</td>
<td>Middle East</td>
<td>In- and outpatients</td>
<td>Patients with diarrhea</td>
<td>Prospective</td>
<td>GDH, EIA and PCR</td>
<td>50</td>
<td>5</td>
<td>10.00</td>
</tr>
<tr>
<td>2015</td>
<td>Moukhaiber R</td>
<td>Middle East</td>
<td>Hospitalized patients</td>
<td>Patients with AAD</td>
<td>Retrospective</td>
<td>Toxigenic culture, EIA and PCR</td>
<td>37</td>
<td>8</td>
<td>21.62</td>
</tr>
<tr>
<td>2015</td>
<td>Alinejad F</td>
<td>Middle East</td>
<td>Hospitalized patients</td>
<td>All patients</td>
<td>Prospective</td>
<td>EIA</td>
<td>928</td>
<td>58</td>
<td>6.25</td>
</tr>
<tr>
<td>2007</td>
<td>Koh TH</td>
<td>South Asia</td>
<td>Hospitalized patients</td>
<td>Patients with diarrhea</td>
<td>Prospective</td>
<td>Toxigenic culture, EIA and PCR</td>
<td>191</td>
<td>57</td>
<td>29.84</td>
</tr>
<tr>
<td>2008</td>
<td>Lim PL</td>
<td>South Asia</td>
<td>Hospitalized patients</td>
<td>Patients with diarrhea</td>
<td>Prospective</td>
<td>EIA</td>
<td>524</td>
<td>37</td>
<td>7.06</td>
</tr>
<tr>
<td>2011</td>
<td>Hsu LY</td>
<td>South Asia</td>
<td>Unclear</td>
<td>Unclear</td>
<td>Prospective</td>
<td>EIA</td>
<td>7379</td>
<td>324</td>
<td>4.39</td>
</tr>
<tr>
<td>2011</td>
<td>Thipmontree W</td>
<td>South Asia</td>
<td>Hospitalized patients</td>
<td>Patients with diarrhea</td>
<td>Retrospective</td>
<td>Unclear</td>
<td>255</td>
<td>31</td>
<td>12.30</td>
</tr>
<tr>
<td>2011</td>
<td>Ingle M</td>
<td>South Asia</td>
<td>In- and outpatients</td>
<td>Patients with diarrhea</td>
<td>Retrospective</td>
<td>EIA</td>
<td>99</td>
<td>17</td>
<td>17.17</td>
</tr>
<tr>
<td>2012</td>
<td>Haider Naqvi SA</td>
<td>South Asia</td>
<td>Hospitalized patients</td>
<td>Patients with AAD</td>
<td>Retrospective</td>
<td>Toxigenic culture</td>
<td>191</td>
<td>57</td>
<td>29.84</td>
</tr>
<tr>
<td>2012</td>
<td>Kaneria MV</td>
<td>South Asia</td>
<td>Hospitalized patients</td>
<td>Patients with AAD</td>
<td>Retrospective</td>
<td>EIA</td>
<td>50</td>
<td>5</td>
<td>10.00</td>
</tr>
</tbody>
</table>
performed in one-third of the included studies (n = 15). The mean proportion of infections due to ribotype 027 was 0.3% (range 0–2.1%) and from 12 studies, the proportion of ribotype 017 was 14% (range 0–48%).

Proportion of C. difficile positivity

This pooled analysis included 37,663 patients tested among whom CDI was confirmed in 4,343 patients. The overall pooled C. difficile positive rate was 14.8% (95% CI 12.9–16.7%) (Fig 2). However, there was significant heterogeneity between the studies (I² = 96.3%, p < 0.001), with rates from individual studies ranging from 2.0% to 61.4%. The pooled proportion of CDI was greater in the 37 studies restricted to hospitalized patients (16.4%, 95% CI 14.1–18.7%) than those with a mixed inpatient-outpatient population (11.1%, 95% CI 7.9–14.4%). The single study examining outpatients alone reported a significantly lower prevalence of 5.3% (p < 0.001) [47]. The prevalence of CDI was greater among studies restricting testing to antibiotic-associated diarrhea (25 studies, 20.9%) compared to all hospitalized patients with diarrhea (33 studies, 13.5%; p < 0.001).

There was significant regional variation in occurrence of CDI. The proportion of C. difficile positivity was significantly higher among studies from East Asia (19.5%, 95% CI 15.5–23.5%, 21 studies) compared to those from the Middle East (11.1%, 95% CI 7.8–14.4%, 9 studies) or South Asia (10.5%, 95% CI 7.9–13.1%, 16 studies) (p < 0.001) (Fig 3, S1 Fig).

Rates of C. difficile infection among hospitalized patients

Eighteen studies provided extractable data on incidence per 1,000 admissions, yielding a pooled rate of 3.2 cases of CDI per 1,000 admissions (95% CI 2.4–3.9). However there was significant heterogeneity between the studies (I² = 99.3%). Eleven studies provided sufficient information to estimate the incidence rate of CDI per 10,000 patient days. This yielded a
pooled incidence of CDI of 5.3 per 10,000 patient-days (95% CI 4.0–6.7) (Fig 4). Excluding one study conducted exclusively in a high risk ICU population did not significantly alter the pooled incidence (4.9 per 10,000 patient days).[36]

Outcomes of CDI

Thirteen studies provided information on CDI-related mortality (range 30–180 days). The random effects pooled rate of CDI-related death was 8.9% (95% CI 5.4%–12.3%).

Meta-regression

As most studies reported proportion of *C. difficile* positive tests as their outcome, meta-regression to identify influential covariates were performed for this outcome. Only geographic region of origin achieved statistical significance while there was a trend towards significance for the proportion of patients recently (S2 Table). Study setting, number of included patients, year of study, and proportion of patients exposed to antibiotics or PPI were not associated with rate of CDI. Specifically, we also did not identify a temporal trend over time in the proportion of stool tests that were positive for *C. difficile* (S2 Fig).

Study quality and publication bias

S3 Table presents the quality scores for the included studies. While not all fields of the NOS were applicable for our meta-analysis, all studies were deemed of adequate quality to be included in the analysis. Begg and Egger tests both showed significant likelihood of publication bias (p = 0.046 and p<0.001, respectively) (S3 Fig).
Discussion

The contribution of CDI to morbidity and mortality among hospitalized patients is well recognized in North America and Europe. However, little is known about whether *C. difficile* is...
equally prevalent and consequential in Asia. A systematic study of this is important to not only accurately quantify the burden of CDI in a population witnessing an increase in many of its risk factors, but also essential to inform disease surveillance and interventions to prevent the dramatic rise in incidence noted elsewhere.

Our systematic review demonstrated a pooled prevalence of CDI of 14.8% among all patients tested and 16.4% among hospitalized patients with diarrhea. These findings are similar to the estimates from other regions. In a multi-country European surveillance study, the proportion of stool samples positive for *C. difficile* ranged from 4 to 39%.[73] A multicenter study by the Centers for Disease Control (CDC) in the United States performing surveillance for *C. difficile* revealed a similar rate of positive tests, ranging from 7% to 20%.[74] In a nationwide study from Spain analyzing 807 stool specimens, 7.8% were found to be positive for *C. difficile.[75]

The pooled incidence rate of CDI from Asia in our meta-analysis was 5.3 per 10,000 patient days. This is similar to reports from western countries. In a multicenter study from Europe, the incidence of CDI was reported as 4.1 per 10,000 patient days.[73] In the EUCLID study, the mean incidence rate was similarly 7 per 10,000 patient days with estimates from individual countries varying from 0.7 to 28.7.[76] A nationwide systematic study from Spain placed the rate at 3.8 per 10,000 patient-days.[75] The incidence is similar in the United States with a median hospital-onset CDI rate of 5.4 per 10,000 patient days.[77] As well, the pooled CDI-related mortality rate of 8.9% is also comparable to western estimates; for example, Lessa et al. reported a mortality rate of 6.4% in a systematic study from the United States.[78] Thus, despite the perception of CDI being uncommon in Asia, our findings suggest that the incidence and impact is similar to that noted in the West.

Among studies where molecular characterization of CDI was performed, the prevalence of hypervirulent ribotype 027 was only 0.3%. In comparison, this ribotype accounted for 21% of all *C. difficile* isolates[79] in the CDRN and 19% in the European EUCLID study.[76] While literature is not uniformly consistent on the impact of this strain, it has been associated with higher levels of toxin production and hypervirulence, [80, 81] leading to outbreaks initially in Canada and subsequently.[81] While the low prevalence among isolates in Asia is reassuring, the high rates of fluoroquinolone use in this population and the resistance of the ribotype 027 strain to this antibiotic class makes it essential to conduct regular surveillance for this strain.[13, 82]

There are several implications to our findings. Despite the recognition of CDI as an important HAI, there remains the perception of it being infrequent or inconsequential in Asia. In contrast to this, our results demonstrate both an incidence and mortality comparable to the west. Two narrative reviews, by Collins et al.[8] and Burke et al.[83] similarly emphasized the lack of awareness of CDI among physicians, that, along with our findings here, highlight the urgent need for education of healthcare professionals in Asia about its burden and impact. There is the need for appropriate infection control methods within hospitals including hand washing, contact isolation, minimization of unnecessary and over the counter dispensation of antibiotics, and development of antibiotic stewardship programs to reduce risk of CDI and prevent emergence of epidemic strains. The need for such measures attains additional urgency as several epidemiologic trends including aging of the population and growing burden of chronic disease favor escalation of CDI in Asia.

We readily acknowledge several limitations to evidence base contributing to our study. First, there was significant heterogeneity between the studies. However, a similar wide variation in incidence has also been observed across hospitals and between countries in the West. The heterogeneity was not completely explained by region, period of study, sample size, or testing strategy suggesting that either true variability in prevalence of CDI or the effect of other
The burden of CDI in Asia is similar to that identified in North America and Europe. This highlights the need not only for further examination of the impact of C. difficile in this understudied geographic region but also the urgent need to educate providers about its consequence. There is also an important need for institution of appropriate measures to reduce the risk for development and transmission of this infection to reduce its adverse impact on patient outcomes.

Supporting information

S1 Table. Electronic search strategy for Pubmed.
(DOC)

S2 Table. Meta-regression analysis to identify covariates influencing proportion of C. difficile positivity. AAD—antibiotic associated diarrhea; EIA—Enzyme immuno assay; PCR—polymerase chain reaction.
(DOC)

S3 Table. Quality of included studies using the Newcastle-Ottawa Quality Assessment Scale.
(DOC)

S1 Checklist. PRISMA checklist for meta-analyses.
(DOC)

S1 Dataset. Minimally identified dataset used for analysis.
(XLS)

S1 Fig. Geographic distribution of proportion of tests positive for Clostridium difficile within Asia.
(JPG)

S2 Fig. Secular trend in the proportion of stool tests that were positive for C. difficile.
(JPG)

S3 Fig. Funnel plot for assessment of publication bias.
(JPG)

Author Contributions

Conceptualization: NZB SG SH AA.

Data curation: NZB SG AA.

Formal analysis: NZB AA.
Supervision: AA.
Writing – original draft: NZB AA.
Writing – review & editing: SG SH AA.

References


