Effects of Antibiotic Therapy in Primary Sclerosing Cholangitis with and without Inflammatory Bowel Disease: A Systematic Review and Meta-Analysis

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Abstract

The authors conducted a systematic review and meta-analysis to assess the effect of antibiotic therapy in primary sclerosing cholangitis (PSC). Effect of antibiotic therapy on Mayo PSC Risk Score (MRS), serum alkaline phosphatase (ALP), total serum bilirubin (TSB), and adverse events (AEs) rates were calculated and expressed as standardized difference of means or proportions. Five studies including 124 PSC patients who received antibiotics were included. Overall, antibiotic treatment was associated with a statistically significant reduction in ALP, MRS, and TSB by 33.2, 36.1, and 28.8%, respectively. ALP reduction was greatest for vancomycin (65.6%, p < 0.002) and smallest with metronidazole (22.7%, p = 0.18). Overall, 8.9% (95% confidence interval: 3.9–13.9) of patients had AEs severe enough to discontinue antibiotic therapy. In PSC patients, antibiotic treatment results in a significant improvement in markers of cholestasis and MRS. Antibiotics, particularly vancomycin, may have a positive effect on PSC either via direct effects on the microbiome or via host-mediated mechanisms.

Primary sclerosing cholangitis (PSC) is an immune-mediated chronic cholestatic liver disease of unknown etiology, characterized by ongoing inflammation, destruction, and subsequent fibrosis of intra- and extrahepatic bile ducts.1 PSC is progressive, leading to fibrosis, liver cirrhosis, portal hypertension, hepatic decompensation, and an increased risk of malignancy in the majority of patients.2–4

Keywords

► vancomycin
► antibiotics
► primary sclerosing cholangitis
► inflammatory bowel disease
► ulcerative colitis
► Crohn’s disease
► microbiome

* for the Australian Gastrointestinal Research Alliance (AGIRA).
Considered a rare disease, the incidence and prevalence ranges from approximately 0.5 to 1.3 cases per 100,000 person-years and 3.85 to 16.2 cases per 100,000 person-years, respectively.⁵⁻⁷ There is a strong association between PSC and inflammatory bowel disease (IBD), particularly ulcerative colitis (UC).⁸,⁹ and between 60 and 70% of patients with PSC have IBD.¹⁰

Due to the progressive chronic liver disease and subsequent liver failure, liver transplantation is often required in patients with PSC,¹¹⁻¹³ and median life expectancy after diagnosis of PSC ranges from 13 to 21 years¹⁴ without liver transplantation. After liver transplantation, PSC recurs in 8.6 to 27% of patients,¹⁵ emphasizing the need for more efficacious therapies in these patients. Thus far, there is lack of evidence that any drug treatment (immunosuppressive, anti-inflammatory, and antifibrotic agents) alters the natural course of the disease.¹,¹¹⁻¹³,¹⁶⁻¹⁸

The pathophysiology of PSC is incompletely understood, but the process is likely multifactorial. The epithelial cells lining the bile ducts (i.e., cholangiocytes) are now thought to be not only a target of injury in PSC but also actively involved drivers in the course of the disease.¹⁹⁻²⁰ PSC likely occurs in genetically susceptible individuals, perhaps after exposure to environmental triggers.¹¹,¹³ Altered bacterial (or placebo) treatment. Secondary outcomes included drug-related adverse events (AEs) leading to discontinuation of antibiotic treatment.

Selection of Studies
Two authors (G.H. and A.S.) independently conducted an initial screening of identified abstracts and titles. Abstracts were eliminated in this initial screening if they were case reports or case series, animal studies, or if they did not investigate the association between antibiotics and PSC with or without coexisting IBD. Full texts of the remaining articles were retrieved and reviewed. Articles were considered for inclusion only if they reported original data from single arm open-labeled studies or randomized controlled trials (RCTs), reporting use of antimicrobial agents for a minimum duration of 12 weeks in treatment of patients with an established diagnosis of PSC, and the manuscript or abstracts were published in peer-reviewed journals. The diagnosis of PSC was established by the following criteria: ALP greater than 1.5 times the upper limit of normal for at least 6 months with cholangiographic (e.g., magnetic resonance cholangiography, endoscopic retrograde cholangiography, percutaneous tranhepatic cholangiography) evidence of characteristic bile duct changes with multifocal strictures and segmental dilatations, and exclusion of secondary causes of sclerosing cholangitis. Detailed eligibility criteria for study inclusion are provided in Table 1. Disagreements between reviewers were resolved by mutual consensus after reference to the original published paper.

Materials and Methods

Search Strategy
Electronic databases, including PUBMED, MEDLINE (OvidSP), and EMBASE, were searched from initiation up to June 2018 for all studies assessing the use of antibiotics in PSC patients with or without IBD. This was supplemented by “snowball” methods such as manual searches of the bibliographies of relevant papers, specialist journals, to identify all relevant studies. The search strategy included [PSC OR ‘primary sclerosing cholangitis’ OR ‘cholangitis’] AND [(‘IBD’ OR ‘inflammatory bowel disease’ OR ‘UC’ OR ‘ulcerative colitis’ OR CD OR ‘Crohn’s disease’)]. These were combined using the set operator AND with studies identified with the terms: “antibiotics or antimicrobial agents” and the following free-text terms: vancomycin, metronidazole, tetracycline, doxycycline, gentamycin, tetracycline, minocycline, azithromycin, rifaximin, sulfasalazine, cephalosporins, and penicillin. The search was not limited by language to ensure that all appropriate papers were captured. All manuscripts were required to have an English abstract. The detailed search strategy was developed in consultation with a research librarian and the results of the literature search are outlined in – Fig. 1.

Outcome Assessment
The primary outcomes assessed were the change from baseline in ALP, total serum bilirubin levels, and MRS postantibiotic (or placebo) treatment. Secondary outcomes included drug-related adverse events (AEs) leading to discontinuation of antibiotic treatment.

Data Extraction and Quality Assessment
All data were extracted independently by two reviewers onto a Microsoft Excel spreadsheet (Office 2016 professional edition; Microsoft Corp.), with disagreements resolved by consensus. For each trial, pre- and post-treatment values for ALP, serum total bilirubin, C-reactive protein, and MRS were extracted. In addition, the following information was
extracted from each trial: author, year of publication, study design, country of origin, proportion of male patients, proportion of patients with coexisting IBD, mean age, dose, type and duration of antibiotic therapy, concurrent use of other medications, total number of reported AEs, total number of AEs leading to discontinuation of antibiotic therapy, clinical criteria for diagnosis of PSC, and definition of primary and secondary outcomes.

The current systematic review and meta-analysis was consistent with the proposals for the reporting of meta-analysis of observational studies in epidemiology (Meta-analysis Of Observational Studies in Epidemiology) and met the preferred reporting items for systematic reviews and meta-analysis statement requirements (see► Supplementary Material, online only).

Data Analysis

In an initial step, changes from the baseline values in ALP, MRS, total bilirubin postantibiotic treatment, or placebo were as calculated. In a second step, the pooled difference in means and 95% confidence intervals (CIs) for the primary outcome measures (ALP, MRS, and total bilirubin) in PSC patients receiving antibiotic therapy (or placebo) were separately determined as described below. Subgroup analyses according to type of antibiotic therapy (vancomycin, metronidazole, minocycline, rifaximin) on each primary outcome measures were also performed. Pooled discontinuation rates due to AEs were calculated. Proportions and 95% CI were calculated when appropriate.

Analyses were performed utilizing the Comprehensive Meta-analysis (CMA), Version 3.3.070 (Biostat, Inc.). Pooled estimates of effect of antibiotic therapy on primary outcome measures were calculated using a random effects model as all tests of between-study homogeneity indicated that variation between individual study estimates was consistent with random sampling variation. Between-study variation was evaluated using Cochrane’s test and was quantified through the I² index in which values close to 100 indicate substantial variation between studies while values close to zero indicate minimal between-study variation. The statistical package CMA

<table>
<thead>
<tr>
<th>Table 1 Eligibility criteria for the studies included in systematic review and meta-analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eligibility criteria</td>
</tr>
<tr>
<td>Adults (participants aged &gt; 16 y)</td>
</tr>
<tr>
<td>Randomized controlled trials or open-labeled trials</td>
</tr>
<tr>
<td>Patients with established diagnosis of PSC (utilizing clinically validated methods), treated with antibiotics</td>
</tr>
<tr>
<td>Minimum duration of therapy 12 wk</td>
</tr>
</tbody>
</table>

Abbreviation: ALP, alkaline phosphatase; PSC, primary sclerosing cholangitis.

*ALP greater than 1.5 times the upper limit of normal for at least 6 months with cholangiographic (e.g., magnetic resonance cholangiography, endoscopic retrograde cholangiography, percutaneous transhepatic cholangiography) evidence of characteristic bile duct changes with multifocal strictures and segmental dilatations, and exclusion of secondary causes of sclerosing cholangitis.
uses logit transformation of proportions and the variance of the logit to estimate pooled event rates within groups and to compare event rates between groups. If one or more cells had a value of 0, then the CMA software automatically adds a fixed value of 0.5 to all the cells of the study results tables where the problems occur for computation of log odds ratio and variance. Further, either chi-square test, p-value of < 0.10, or I^2 > 50% indicated substantial heterogeneity.

Results

The initial literature search revealed 163 publications. Of these, 20 published articles appeared to be relevant for the study question and were retrieved for further evaluation. Fifteen articles were excluded for not fulfilling the inclusion criteria leaving five eligible studies (►Fig. 1). Three of the five studies were RCTs^35–37 and two were open-labeled studies^34,38 Two RCTs compared the efficacy of antibiotics (vancomycin^37 and metronidazole^35) against placebo in PSC patients, while one nonplacebo-controlled RCT^36 compared the efficacy of low and high doses of vancomycin and metronidazole in PSC patients. One open-labeled trial used rifaximin^38 and one used minocycline. Three of the five studies were conducted in the U.S. and the remaining two were from Iran^37 and Finland. The primary and secondary outcomes and patient characteristics of the studies included in the systematic review and meta-analysis are outlined in ►Tables 2 and 3, respectively.

Effects of Placebo on Outcome Parameters

Two studies utilizing metronidazole for 36 months^35 and vancomycin for 12 weeks^37 included placebo arms. During placebo treatment, no significant improvements of ALP, total serum bilirubin, and MRS were observed (►Table 2).

Effect of Antibiotic Treatment on Primary Outcome Measure in PSC Patients

A total of 124 PSC patients (98 [79%], with concurrent IBD) received antibiotic therapy (57 treated with metronidazole, 35 with vancomycin, 16 each with rifaximin and minocycline). Treatment with antibiotics in PSC patients was associated with a statistically significant reduction in ALP, MRS, and total serum bilirubin level by 33.2, 36.1, and 28.8%, respectively (►Figs. 2–4). Moderate heterogeneity was detected between those studies reporting ALP (I^2 = 44.93, p = 0.08) and MRS (I^2 = 47.60, p = 0.06). In contrast, only minimal heterogeneity was detected between those studies reporting change in total serum bilirubin level (I^2 = 20.02, p = 0.23).

Effects of Different Antibiotics

Alkaline phosphatase reduction was greatest with vancomycin (65.6%, p < 0.002) and smallest for metronidazole (22.7%, p = 0.18). Both antibiotics had similar effects on MRS (46.8 and 46.6% by vancomycin and metronidazole, respectively, all p < 0.05), while vancomycin (38.6%, p = 0.12) was not significantly better than metronidazole (34.2%, p = 0.07) in decreasing total bilirubin level. A single open-labeled study utilizing minocycline in 16 PSC patients had significant effects on ALP, MRS, and total serum bilirubin levels (reduction by 56.2%, p = 0.03; 53.3%, p = 0.05; and 42.5%, p = 0.10, respectively). Treatment with rifaximin did not result in an improvement of ALP, total serum bilirubin, or MRS.

Adverse Events with Antibiotic (Placebo) Treatment

All five trials reported on AEs in PSC patients that lead to discontinuation of treatment. Overall, 8.9% (95% CI: 3.9–13.9) of patients had AEs severe enough to discontinue antibiotic therapy. Placebo did not result in discontinuation of therapy due to AEs (►Table 2). Among antibiotics, the incidence of AEs was smallest for vancomycin (5.7%) and greatest for rifaximin (19%, n.s.).

Effect of Antibiotic Therapy on IBD Associated with PSC

Only one study^37 specifically assessed the effect of antibiotic therapy on IBD-related symptoms. Twelve weeks after initiation of treatment with vancomycin as compared with placebo, they found significant differences in the improvement in IBD-related symptoms (diarrhea, blood in stools, and abdominal pain, nausea, and vomiting). The remaining studies did not report any further IBD activity parameters. Thus, no further analysis of the effect of antibiotics on the IBD activity could be conducted.

Discussion

Primary sclerosing cholangitis is a rare disease, and within 8 to 12 years of diagnosis patients die or require liver transplantation. The low incidence and prevalence is a barrier for large RCTs. However, case series and, more recently, small RCTs have evaluated the efficacy of antibiotics as a therapeutically option in PSC. This is the first systematic review and meta-analysis on the effects of antibiotics in adult patients with PSC. While limited to cohort studies and small RCTs, the data strongly suggest that at least some antibiotics improve markers of cholestasis and MRS and thus have the potential to modify the course of disease in patients with PSC.

This systematic review and meta-analyses applied strict criteria and includes only five studies conducted in three countries with a sample size of 124 PSC patients, where 79% had coexisting IBD. Overall, antibiotic therapy significantly improved ALP and MRS. Vancomycin appeared to be the most effective antibiotic with the best safety profile. Vancomycin treatment specifically targets Gram-positive bacteria, which includes various Clostridium spp. known to be primarily involved with the dehydroxylation of primary bile acids, into the secondary bile acids present in the distal small intestine and colon. Secondary bile acids are highly hydrophobic and toxic, and increased concentrations in the liver have been linked to inflammation, cholestasis, gallstone formation, and carcinogenesis. Thus, it could be speculated that antibiotic therapy influences bile acid metabolism. This is a potential explanation for the superior effect of this antibiotic effect in PSC. While the other antibiotics used in the studies included here are widely considered to be “broad-spectrum,” the relatively narrow specificity of vancomycin might be a potential
Table 2: Summary of the results of antibiotic treatment in patients with primary sclerosing cholangitis

<table>
<thead>
<tr>
<th>No.</th>
<th>Study name</th>
<th>Study type</th>
<th>Antibiotic type</th>
<th>Antibiotic dose, mg</th>
<th>N</th>
<th>Treatment duration</th>
<th>pValue</th>
<th>Post-therapy change from baseline in ALP (U/L)&lt;sup&gt;b&lt;/sup&gt;</th>
<th>pValue</th>
<th>Post-therapy change from baseline in MRS</th>
<th>pValue</th>
<th>Post-therapy change from baseline in total bilirubin (mg/dL)&lt;sup&gt;b&lt;/sup&gt;</th>
<th>pValue</th>
<th>AEs leading to discontinuation of antibiotics</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Tabibian et al&lt;sup&gt;36&lt;/sup&gt;</td>
<td>RCT</td>
<td>Vancomycin</td>
<td>125 QIDS</td>
<td>8</td>
<td>12 wk</td>
<td>0.03</td>
<td>–188</td>
<td>0.03</td>
<td>–0.55</td>
<td>0.06</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Vancomycin</td>
<td>250 QIDS</td>
<td>9</td>
<td>12 wk</td>
<td>0.02</td>
<td>–136</td>
<td>0.98</td>
<td>0</td>
<td>0.48</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Metronidazole</td>
<td>250 QIDS</td>
<td>9</td>
<td>12 wk</td>
<td>0.47</td>
<td>–46</td>
<td>0.03</td>
<td>–0.2</td>
<td>0.03</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Metronidazole</td>
<td>500 QIDS</td>
<td>9</td>
<td>12 wk</td>
<td>0.22</td>
<td>–138</td>
<td>0.16</td>
<td>0.1</td>
<td>0.78</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Rahimpour et al&lt;sup&gt;37&lt;/sup&gt;</td>
<td>RCT</td>
<td>Vancomycin</td>
<td>125 QIDS</td>
<td>18</td>
<td>12 wk</td>
<td>0.11</td>
<td>–519.68</td>
<td>0.03</td>
<td>–1.35</td>
<td>0.41</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Placebo</td>
<td></td>
<td>11</td>
<td></td>
<td>0.49</td>
<td>–0.05</td>
<td>0.34</td>
<td>–0.91</td>
<td>0.28</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Färkkilä et al&lt;sup&gt;35&lt;/sup&gt;</td>
<td>RCT</td>
<td>Metronidazole</td>
<td>800 OD</td>
<td>39</td>
<td>36 mo</td>
<td>0.05</td>
<td>–337</td>
<td>0.05</td>
<td>–1</td>
<td>NS</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Placebo</td>
<td></td>
<td>41</td>
<td></td>
<td>NS</td>
<td>–214</td>
<td>NS</td>
<td>–0.8</td>
<td>NS</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Tabibian et al&lt;sup&gt;38&lt;/sup&gt;</td>
<td>Open label study</td>
<td>Rifaximin</td>
<td>550 BD</td>
<td>16</td>
<td>12 wk</td>
<td>0.47</td>
<td>–3</td>
<td>0.21</td>
<td>0.4</td>
<td>0.57</td>
<td>3&lt;sup&gt;a&lt;/sup&gt;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Silveria et al&lt;sup&gt;34&lt;/sup&gt;</td>
<td>Open label study</td>
<td>Minocycline</td>
<td>100 BD</td>
<td>16</td>
<td>1 y</td>
<td>0.04</td>
<td>–65</td>
<td>0.05</td>
<td>–0.3</td>
<td>0.11</td>
<td>3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Abbreviations: AEs, adverse events; ALP, alkaline phosphatase; BD, twice daily; MRS, Mayo PSC Risks Score; NS, not significant; OD, once daily; QIDS, four times a day; RCT, randomized controlled trial.

<sup>a</sup>Two out of 3 patients experiencing AEs discontinued minocycline and in 1 patient the medication dose was reduced.

<sup>b</sup>The baseline weighted average for total bilirubin was 8.1 mg/dL and ALP was 586 U/L.

Table 3: Characteristics of the studies included in the systematic review and meta-analysis

<table>
<thead>
<tr>
<th>No.</th>
<th>Author</th>
<th>Study type</th>
<th>Year</th>
<th>Country</th>
<th>Median age (y)</th>
<th>Sex, male, n</th>
<th>Coexisting BD(n)%</th>
<th>Primary endpoint (improvement/normalization at the end of treatment)</th>
<th>Secondary endpoint (improvement/normalization at the end of treatment)</th>
<th>Other meds</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Tabibian et al&lt;sup&gt;36&lt;/sup&gt;</td>
<td>RCT</td>
<td>2013</td>
<td>USA</td>
<td>40</td>
<td>21</td>
<td>(25)/71%</td>
<td>ALP</td>
<td>AST, CRP, total bilirubin, MRS, pruritis, fatigue, and AEs</td>
<td>UDCA and any other investigational agent was ceased 3 mo prior to study enrolment</td>
</tr>
<tr>
<td>2</td>
<td>Rahimpour et al&lt;sup&gt;37&lt;/sup&gt;</td>
<td>RCT</td>
<td>2016</td>
<td>Iran</td>
<td>34</td>
<td>17</td>
<td>(21)/75%</td>
<td>ALP and MRS</td>
<td>ALT, GGT, AST, ESR, total and direct bilirubin, WCC, PLT, and symptoms</td>
<td>All patients were on UDCA 300 mg TDS Cessation of other antibiotics/immunosuppressants 3 mo prior to study enrolment</td>
</tr>
<tr>
<td>3</td>
<td>Färkkilä et al&lt;sup&gt;35&lt;/sup&gt;</td>
<td>RCT</td>
<td>2004</td>
<td>Finland</td>
<td>16–65</td>
<td>42</td>
<td>(65)/81%</td>
<td>NA</td>
<td>NA</td>
<td>52/80 patients took 5-ASA and 4/80 took AZA</td>
</tr>
<tr>
<td>4</td>
<td>Tabibian et al&lt;sup&gt;38&lt;/sup&gt;</td>
<td>Open label study</td>
<td>2017</td>
<td>USA</td>
<td>40</td>
<td>13</td>
<td>(13)/81%</td>
<td>ALP</td>
<td>MRS, ALT, albumin, total bilirubin, GGT, symptoms and AEs</td>
<td>Treatment with any investigational agent was ceased 3 mo prior to study enrolment</td>
</tr>
<tr>
<td>5</td>
<td>Silveria et al&lt;sup&gt;34&lt;/sup&gt;</td>
<td>Open label study</td>
<td>2003–2006</td>
<td>USA</td>
<td>50</td>
<td>(14)/88%</td>
<td>Improvement symptoms and in if Tc: ALP, AST, and total bilirubin</td>
<td>NA</td>
<td>UDCA and any other investigational agent was ceased 3 mo prior to study enrolment</td>
<td></td>
</tr>
</tbody>
</table>

Abbreviations: 5-ASA, amino salicylic acid; AEs, adverse events; ALP, alkaline phosphatase; ALT, alanine aminotransferase; AST, aspartate aminotransferase; AZA, azathioprine; BD, twice daily; ESR, erythrocyte sedimentation rate; GGT, gamma glutamyl transferase; IBD, inflammatory bowel disease; LFT, liver function test; MRS, Mayo PSC Risks Score; NA, not applicable; NS, not significant; OD, once daily; PLT, platelet count; QIDS, four times a day; RCT, randomized controlled trial; TDS, three times a day; UDCA, ursodeoxycholic acid; WCC, white cell count.
explanation for its superior effects on PSC clinical and biochemical measures.

In an open-labeled pilot study,14 children with PSC and UC treated with oral vancomycin, had significant improvement or normalization in liver function tests (LFTs) (alanine aminotransferase [ALT] and gamma glutamyl transferase [GGT]), erythrocyte sedimentation rate, and clinical symptoms, with a maximal response observed in those subjects who were not cirrhotic at the start of the treatment. Worsening of LFTs (ALT and GGT) and recurrence of clinical symptoms occurred after treatment was discontinued. Retreatment, however, again resulted in the normalization of ALT and GGT. Autoantibodies (antinuclear antibody, antismooth muscle antibody, perinuclear antineutrophil cytoplasmic antibodies) present in 4 children became negative or improved significantly while on treatment with oral vancomycin may have an influence on immunoreactivity in PSC. A subsequent study33 of the same cohort showed in addition to

Fig. 2  Forest plot showing the change in alkaline phosphatase (ALP) postantibiotic treatment in primary sclerosing cholangitis (PSC) patients ($I^2 = 44.93, p = 0.08$). CI, confidence interval.

Fig. 3  Forest plot showing the change in Mayo PSC risk score (MRS) postantibiotic treatment in primary sclerosing cholangitis (PSC) patients ($I^2 = 47.60, p = 0.06$). CI, confidence interval.
symptom resolution and normalization of liver biochemistry
an increase in peripheral CD4+FoxP3+ regulatory T (Tregs)
cells and transforming growth factor β levels in response to
the antibiotic, suggesting an immunomodulatory effect of
vancomycin. The immunomodulatory effect of vancomycin
was thought to be due to its direct effect on the T cell
inflammatory pathway via the tumor necrosis factor
(TNF)-α pathways and downstream Treg induction. This
may suggest that vancomycin has a direct or indirect immu-
omodulatory effect, via the TNF-α inflammatory pathways
and/or downstream Treg induction.

Oral vancomycin has also been effective for the treatment
of recurrent PSC after orthotopic liver transplant\textsuperscript{28}, suggesting
that the disease mechanism is not confined to the liver
and involves the intestine, for example, the backflow
of gut bacteria or gut bacteremia. Thus, it can be hypo-
thesized that oral vancomycin not only specifically suppresses
Gram-positive bacteria involved with primary bile
acid metabolism but might also be directly or indirectly
involved in attenuating the inflammatory response under-
pinning periportal inflammation and hepatic damage.

Metronidazole is the second most commonly studied
antibiotic for the treatment of PSC and associated IBD, and
two RCTs (one placebo controlled and one uncontrolled) have
evaluated the efficacy and safety of metronidazole compar-
ing it with ursodeoxycholic acid or vancomycin. Compared
with vancomycin, metronidazole had numerically higher
number of AEs leading to treatment discontinuation and
only a very modest effect on improving ALP. On the other
hand, minocycline, a semisynthetic second-generation tetracy-
cline, studied in a single open-labeled trial had a good
safety profile and was most effective among the antibiotics in
improving the total serum bilirubin and MRS and its efficacy
in improving serum ALP was similar to that observed for
vancomycin. As such, minocycline also appears to be promis-
ing, especially given its known immunomodulatory proper-
ties independent of its antibacterial effects.\textsuperscript{52–54} In contrast,
it is noteworthy that the single study evaluating rifaximin
included in this meta-analysis actually failed to have any
beneficial effect in PSC patients. While the antimicrobial
spectrum of rifaximin is considered to be very broad, its
systemic effects are limited, unlike minocycline. Taken
togther, despite the broad-spectrum antimicrobial effects
attributed to these different antibiotics, their capacity to
either directly affect host immune pathways and inflamma-
tion, as well as indirectly affect host immune and inflam-
matory response via their antimicrobial actions, needs
greater evaluation via larger RCTs and may not target gut
bacteria.

The strengths of our study include the comprehensive
literature search and a rigorous statistical approach. We
pooled the data with a random effects model, which pro-
vides a more conservative estimate of the effect of anti-
biotics on various outcome measures in PSC. We also
performed subgroup analyses to assess treatment effect of
individual antibiotics on primary and secondary outcome
measures. However, this systematic review and meta-anal-
ysis is not without limitations. First, there is a paucity of
large placebo-controlled clinical trials evaluating the effi-
cacy of antibiotics in PSC, largely due to the rarity of PSC.
Most published studies are case reports, case series, and
uncontrolled trials. Only two of the three RCTs are placebo-
controlled, limiting the conclusions that can be drawn from this review. Moreover, until recently the majority of studies assessing the impact of antimicrobial therapy in PSC were reported in the pediatric PSC populations. There was also moderate heterogeneity among the five studies included in our primary analysis, suggesting that the response to antibiotic therapy may be overestimated and could be influenced by a variety of factors. Importantly, the long-term safety profile of the antibiotics used remains unknown, but it is possible that we overestimated the rate of AEs as some of these may have been due to the underlying disease itself rather than being related to the study medication.

All trials included in this systematic review and meta-analysis have evaluated surrogate markers of PSC progression including MRS and improvement in ALP. In clinical practice, the natural history and prognosis of PSC in a patient can be established by tracking of MRS. The MRS, in turn, is used to predict survival up to 4 years. Any reduction in MRS could theoretically translate into an improvement in the natural course and the prognosis of a patient with PSC. Normalization of ALP is often used as a surrogate marker in clinical trials and is associated with improved long-term survival and decreased risk of requiring liver transplantation in patients with PSC. The degree to which a surrogate marker can simulate more definite endpoints, such as survival free of liver transplantation, is unclear and further studies are needed.

This systematic review and meta-analysis suggest that antibiotics are an effective treatment option for PSC with IBD. However, the exact mechanism(s) of action of antibiotic therapy remains to be elucidated. In addition to antimicrobial and (subsequent) anti-inflammatory effects of antibiotics, almost certainly alter the gut microbiome. Several antibiotics have been used so far without major adverse side effects; however, antibiotic drug resistance always remains a concern. A recent case series describing use of oral vancomycin to treat colitis associated with PSC in 17 children did not demonstrate the emergence of any vancomycin-resistant enterococcus that was routinely screened for in this small cohort. Vancomycin seems to be the most promising antibacterial pharmacotherapy for PSC that has been evaluated in RCTs. However, most studies in this systematic review and meta-analysis are limited by the sample sizes of the respective clinical trials. This is due to the low prevalence and incidence of PSC.

While this systematic review supports the notion that antibiotic therapy appears to be effective in improving disease activity in PSC patients, the ideal antibiotic, dose, and regimen remain largely unknown, and the use of definite primary endpoints rather than surrogate markers to define the natural history of PSC needs to be studied. Thus, adequately powered placebo-controlled RCTs are needed with a longer treatment duration and follow-up period to evaluate the effect of variable doses of vancomycin on more definite endpoints including cholangiography findings and liver transplant-free survival. In addition, state-of-the-art molecular technologies should be applied to properly explore the interdependence between the gastrointestinal microbiome, immune system, genetic profile, and response to antibiotic therapy.

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