Long-Term Antibiotic Treatment for Crohn’s Disease: Systematic Review and Meta-Analysis of Placebo-Controlled Trials

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Background. We investigated the effectiveness of long-term antibiotic treatment in patients with Crohn’s disease.

Methods. We performed a systematic review and meta-analysis of randomized clinical trials. Data sources were Medline (from 1966 through June 2009), EMBASE (from 1980 through June 2009), Cochrane Central Register of Controlled Trials (issue 3, 2009), and references from relevant publications. Trials that compared antibiotic therapy during at least 3 months with placebo were included. Outcomes were remission in patients with active disease and relapse in patients with inactive disease. Results from intention-to-treat analyses were combined in a random-effects meta-analysis, stratified by class of drug. Odds ratios (ORs) >1 indicate superiority of antibacterial treatment over placebo. Numbers needed to treat for 1 year to keep 1 additional patient in remission were calculated.

Results. Sixteen trials that examined 13 treatment regimens in 865 patients were included in the meta-analysis. The median duration of treatment was 6 months (range, 3–24 months). Three trials of nitroimidazoles showed benefit, with a combined OR of 3.54 (95% confidence interval [CI], 1.94–6.47). Similarly, the combined OR from 4 trials of clofazimine was 2.86 (95% CI, 1.67–4.88). For patients with active disease, the number needed to treat was 3.4 (95% CI, 2.3–7.0) for nitroimidazoles and 4.2 (95% CI, 2.7–9.3) for clofazimine. The corresponding numbers needed to treat for inactive disease were 6.1 (95% CI, 5.0–9.7) and 6.9 (95% CI, 5.4–12.0). No benefit was evident for classic drugs against tuberculosis (3 trials; OR, 0.58; 95% CI, 0.29–1.18). Results for clarithromycin were heterogeneous (I² = 77%; P = .005) and not combined in the meta-analysis.

Conclusions. Long-term treatment with nitroimidazoles or clofazimine appears to be effective in patients with Crohn’s disease.

The defect underlying the pathogenesis of Crohn’s disease may be impaired innate immunity [1]. This hypothesis is supported by the association of Crohn’s disease with variants of the CARD15/NOD2 gene [2–4]. Defective CARD15/NOD2 variants lead to decreased macrophage activation in response to intracellular lipopolysaccharides, which in turn could result in the activation of other inflammatory pathways [2]. Independent of the CARD15/NOD2 genotype, impaired innate immunity could lead to intestinal content breaching the mucosal barrier of the bowel wall [5]. In the absence of adequate numbers of functional neutrophils to clear bacteria, these may be ingested by macrophages to form the granulomata and chronic inflammation typical of Crohn’s disease. Consequently, there is renewed interest in the microbes associated with Crohn’s disease. Several bacteria have been implicated, including, for example, Listeria monocytogenes, Yersinia enterocolitica, Mycobacterium avium subspecies paratuberculosis, or Escherichia coli [6–12].

If microbes are involved in the development and persistence of inflammation in Crohn’s disease, then treatment with antibacterial drugs should be beneficial. However, at present, guidelines and opinion leaders consider antibiotics appropriate only in the management of some complications, such as sepsis, symptoms...
attributable to bacterial overgrowth, or perianal disease [13–15]. Despite this, there have been a number of trials of long-term antibacterial therapy that examined their effect on the course of Crohn’s disease independent of such complications. With the exception of a meta-analysis of trials of antimycobacterial therapy [16], these trials have never been comprehensively reviewed. We therefore performed a systematic review and meta-analysis of randomized, placebo-controlled clinical trials to assess the effectiveness of long-term antibiotic treatment in patients with Crohn’s disease.

METHODS

Literature search. We searched the Medline database from 1966 through June 2009 using keywords that denote Crohn’s disease or inflammatory bowel diseases and antibacterial and antimycobacterial drugs. The results from this search were combined with the search strategy for controlled clinical trials of the Cochrane Collaboration [17]. Similar searches were performed in EMBASE for the period from 1980 through June 2009 and the Cochrane Central Register of Controlled Trials (issue 3, 2009). No language restrictions were applied. Finally, we checked references from relevant publications and review articles.

Eligibility criteria. Clinical trials were included if they used random allocation of patients to treatment groups and compared antibacterial agents, including combination regimens, with placebo in patients with Crohn’s disease. The duration of treatment had to be at least 3 months to exclude studies of short-term antibiotic therapy in the management of bacterial complications during flare-ups of the disease. Studies administering concomitant steroids or other drugs were included if regimens were identical in the 2 groups. We excluded trials of patients with exclusive perianal Crohn’s disease or trials that reported insufficient data to calculate odds ratios (ORs). Two reviewers (M.F. and K.H.) independently assessed the eligibility of publications. Discrepancies were resolved by consensus in consultation with a third reviewer (M.E.).

Data extraction, outcomes, and definitions. Two observers (M.F. and K.H.) independently extracted data using a standardized data extraction sheet, with differences resolved by consensus. We extracted bibliographic, sociodemographic, and clinical data, aspects of study quality, and results. Remission in patients with active disease and relapse in patients with inactive disease were the outcomes of interest. There was no single, standardized definition of outcomes, which may be explained by the fact that most trials were performed before the publication of the consensus statement on definitions of remission or relapse [18]. We used the definitions reported in the publications, including, for example, the Crohn’s Disease Activity Index [19]. If a study presented outcome data at >1 point, we analyzed the data from the latest assessment during treatment.

Ethambutol, isoniazid, and rifamycins (eg, rifampicin and rifabutin) were considered to be classic drugs against infection with Mycobacterium tuberculosis, and trials of 1 or several antituberculosis drugs were combined in the meta-analysis. Similarly, trials of drugs from other drug classes, including nitroimidazoles (metronidazole and ornidazole), macrolides (clarithromycin), and riminophenazines (clofazimine), were also analyzed together.

Statistical analysis. Data were analyzed according to the intention-to-treat principle. Patients lost to follow-up or excluded from the study for other reasons were considered treatment failures (ie, not in remission or with relapse). Study results are presented as ORs with 95% confidence intervals (CIs). For studies with continuous outcome measures, results were converted to ORs using the method described by Hasselblad and Hedges [20]. The method is based on the fact that, when assuming logistic distributions and equal variances in the 2 treatment groups, the log OR corresponds to a constant multiplied by the standardized difference between means. We coded outcomes so that ORs >1 indicated superiority of antibacterial treatments over placebo. Results were combined in a random-effects meta-analysis, stratified by drug class, if the degree of between-trial heterogeneity was moderate or low. We assessed between-trial heterogeneity by calculating the $I^2$ statistic [21]. Low, moderate, and high levels of heterogeneity correspond to $I^2$ values of 25%, 50%, and 75%, respectively. Numbers needed to treat to keep 1 additional patient in remission were based on the combined ORs and typical proportions of patients in remission after 1 year in the placebo groups, with 95% CIs calculated as suggested by Altman [22]. Publication bias was examined by inspection of funnel plots. All analyses were performed with Stata statistical software, version 10.0 (StataCorp).

RESULTS

The process of identifying eligible studies is summarized in Figure 1. Forty-three potentially eligible publications were assessed in detail, and 16 trials [23–38] met the eligibility criteria (Table 1). A list of the 27 excluded trials with reasons for exclusion is available from the authors on request. Outcome measures were continuous in 4 trials [25, 27, 37, 38] and categorical in the others. Two trials [32, 37] compared 2 dosages of the antibacterial agent to placebo: we included the comparison with the higher dosage.

Study characteristics, definitions, and outcomes. Table 1 gives the characteristics of the 16 included trials. The median number of patients included in the trials was 48 (range, 14–213), and the median year of publication was 1995 (range, 1982–2008). Fifteen trials were parallel-group trials, and 1 trial [36] was a crossover study. The quality of reporting of study methods tended to be low. Only 4 studies [25, 30, 31, 38] described adequate methods of allocation concealment; in the...
remaining studies, this was unclear. Two studies reported
blinded outcome assessment [33, 38].

Eleven studies included only patients with active disease, 3
studies examined patients with inactive disease, and 1 study
included both types of patients; in 1 study, it was unclear
whether patients had active or inactive disease. In most studies
the diagnostic criteria for Crohn’s disease were described as
standard clinical findings, with typical radiologic, endoscopic,
or histologic lesions. Four studies did not report diagnostic
criteria [28, 29, 33, 35]. Remission or recurrence of symptoms
was the main outcome in all studies. In 15 studies, a disease
activity index was used to assess outcomes (the Crohn’s Disease
Activity Index [19] in 11 studies), and in 1 study recurrence
of lesions was the main outcome [33].

**Treatment regimens.** Thirteen different treatment regi-
mens were examined. These regimens ranged from single drugs
to combination regimens of up to 4 different drugs. The median
duration of the active study period was 6 months (range, 3–
24 months). Classic drugs against tuberculosis were used in 3
studies [25, 36, 38], nitroimidazoles were used in another 3
studies [33, 34, 37], clarithromycin was used in 4 studies [27,
28, 30, 35], and clofazimine was also used in 4 studies [23, 29,
31, 35] (Table 1). Three studies included a course of steroids,
with the same decreasing doses over time in the 2 arms [23,
31, 35]. Seven studies allowed steroids as clinically indicated,
and 4 studies explicitly excluded the use of steroids during the
study period (Table 1).

**Meta-analyses.** The forest plot of the meta-analysis strat-
ified by drug class is shown in Figure 2. The combined OR
from the 3 trials [25, 36, 38], involving 107 patients, of classic
antituberculosis drugs was 0.58 (95% CI, 0.29–1.18), indicating
no benefit, with little between-trial heterogeneity ($I^2 = 0\%$).
In contrast, the 3 trials [33, 34, 37] of nitroimidazoles, involving
206 patients, showed benefit: the combined OR was 3.54 (95%
CI, 1.94–6.47), again with little heterogeneity ($I^2 = 0\%$). The
results from the 4 studies [27, 28, 30, 35] of clarithromycin
only or clarithromycin in combination, involving 287 patients,
were highly heterogeneous ($I^2 = 77\%; P = .005$) and therefore
not combined in the meta-analysis. The trials of clofazimine
[23, 29, 31, 35], involving 322 patients, were homogenous
($I^2 = 0\%$), with a combined OR of 2.86 (95% CI, 1.67–4.88).
A trial of 6 months of ciprofloxacin [24] also showed benefit,
with an OR of 11.3, but wide CIs (95% CI, 2.60–48.8). There
was little evidence of an effect in a trial of sulfadoxine combined
with pyrimethamine [26] or a trial of rifaximin [32]. The funnel
plot of the 16 studies included in the meta-analysis was sym-
metrical (Figure 3).

On the basis of the placebo groups of included studies [23,
31, 33–35] and 1 additional large study [39], we assumed that,
after 1 year, 25% of control patients with active disease and
75% of control patients with inactive disease will be in remis-

![](cid.oxfordjournals.org/iii/primary/journals/cid/resource/50/15/figure1.png)
<table>
<thead>
<tr>
<th>Trial</th>
<th>Year</th>
<th>No. of patients</th>
<th>Intervention, duration of treatment</th>
<th>Steroid administration</th>
<th>Source of patients</th>
<th>Mean age of intervention group, years</th>
<th>Mean age of control group, years</th>
<th>Disease status</th>
<th>Outcome definition</th>
<th>Odds ratio (95% confidence interval)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Afshol et al [23]</td>
<td>1991</td>
<td>49</td>
<td>Clofazimine, 100 mg/day, 12 months</td>
<td>Mean dose at entry, 45 mg of prednisone, gradually withdrawn during first 3 months</td>
<td>Not reported</td>
<td>25</td>
<td>32</td>
<td>Active</td>
<td>Relapse of disease: Crohn’s Disease Activity Index score &gt;10</td>
<td>2.77 (0.82–9.31)</td>
</tr>
<tr>
<td>Arnold et al [24]</td>
<td>2002</td>
<td>47</td>
<td>Ciprofloxacin, 1000 mg/day, 6 months</td>
<td>If clinically indicated</td>
<td>Outpatients</td>
<td>45</td>
<td>42</td>
<td>Active</td>
<td>No. of patients with Crohn’s Disease Activity Index score &gt;150</td>
<td>11.26 (2.60–48.8)</td>
</tr>
<tr>
<td>Basilisco et al [25]</td>
<td>1989</td>
<td>15</td>
<td>Rifabutin, 300 mg/day, 6 months</td>
<td>If clinically indicated</td>
<td>Outpatients</td>
<td>37a</td>
<td>36a</td>
<td>Active</td>
<td>Reduction in Bristol Simple Index score</td>
<td>0.57 (0.08–4.02)</td>
</tr>
<tr>
<td>Elliott et al [26]</td>
<td>1982</td>
<td>51</td>
<td>Sulfadoxine, 1500 mg/week, and pyrimethamine, 75 mg/week, 12 months</td>
<td>If clinically indicated</td>
<td>Not reported</td>
<td>Not reported</td>
<td>Not reported</td>
<td>Active</td>
<td>Decrease of Crohn’s Disease Activity Index score &gt;50</td>
<td>0.70 (0.22–2.19)</td>
</tr>
<tr>
<td>Goodgame et al [27]</td>
<td>2001</td>
<td>18</td>
<td>Ethambutol, 15 mg/kg/day and clarithromycin, 1000 mg/day, 3 months</td>
<td>If clinically indicated</td>
<td>Unclear</td>
<td>39</td>
<td>45</td>
<td>Active and inactive</td>
<td>Changes in Harvey- Bradshaw index</td>
<td>0.13 (0.02–0.79)</td>
</tr>
<tr>
<td>Graham et al [28]</td>
<td>1995</td>
<td>15</td>
<td>Clarithromycin, 1000 mg/day, 3 months</td>
<td>Not reported</td>
<td>Not reported</td>
<td>Not reported</td>
<td>Not reported</td>
<td>Active</td>
<td>Crohn’s Disease Activity Index score &lt;150</td>
<td>17.50 (1.22–250.4)</td>
</tr>
<tr>
<td>Kelleher et al [29]</td>
<td>1982</td>
<td>20</td>
<td>Clofazimine (dosage not reported), 6 months</td>
<td>Not reported</td>
<td>Not reported</td>
<td>Not reported</td>
<td>Not reported</td>
<td>Inactive</td>
<td>Relapse measured with Crohn’s Disease Activity Index score</td>
<td>9.80 (0.44–219.3)</td>
</tr>
<tr>
<td>Leiper et al [30]</td>
<td>2008</td>
<td>41</td>
<td>Clarithromycin, 1000 mg/day, 3 months</td>
<td>Allowed up to 10 mg of prednisolone or 3 mg of budesonide</td>
<td>Outpatients</td>
<td>34</td>
<td>38</td>
<td>Active</td>
<td>Remission or response (Crohn’s Disease Activity Index score &lt;150 or decrease &gt;70)</td>
<td>0.95 (0.24–3.81)</td>
</tr>
</tbody>
</table>

Table 1. Characteristics of 16 Randomized Controlled Trials of Antibiotic Treatment for ≥3 Months Duration involving Patients with Crohn’s Disease
<table>
<thead>
<tr>
<th>Reference</th>
<th>Year</th>
<th>Patients</th>
<th>Treatment</th>
<th>Dose</th>
<th>Duration</th>
<th>Clinical Status</th>
<th>Inclusion Criteria</th>
<th>Outcome</th>
<th>Outcome Measure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prantera et al [31]</td>
<td>1994</td>
<td>40</td>
<td>Clofazimine, 50 mg/day, and ethambutol, 15 mg/kg/day, and dapsone, 600 mg/week, 9 months; rifampicin, 600 mg once</td>
<td>Methylprednisolone for 8 weeks, initially intravenously, in tapering doses, starting at 0.7–1.0 mg/kg/day</td>
<td>Not reported</td>
<td>34</td>
<td>34</td>
<td>Active</td>
<td>Maintenance of clinical remission measured with the Crohn’s Disease Activity Index</td>
</tr>
<tr>
<td>Prantera et al [32]</td>
<td>2006</td>
<td>58</td>
<td>Rifaximin, 1600 mg/day, 3 months</td>
<td>Not allowed (patients excluded)</td>
<td>Not reported</td>
<td>38</td>
<td>42</td>
<td>Active</td>
<td>Crohn’s Disease Activity Index score &lt;150</td>
</tr>
<tr>
<td>Rutgeerts et al [33]</td>
<td>1995</td>
<td>60</td>
<td>Metronidazole, 20 mg/kg/day, 3 months</td>
<td>Not allowed (tapered after inclusion and stopped within 1 month)</td>
<td>Inpatients</td>
<td>33</td>
<td>37</td>
<td>Inactive, after resection</td>
<td>Assessment of the severity of the lesions in the neoterminal ileum</td>
</tr>
<tr>
<td>Rutgeerts et al [34]</td>
<td>2005</td>
<td>80</td>
<td>Ornidazole, 1000 mg/day, 12 months</td>
<td>Not allowed (tapered after inclusion and stopped within 1 month)</td>
<td>Inpatients</td>
<td>35(^a)</td>
<td>31(^b)</td>
<td>Inactive, after resection</td>
<td>Relapse defined as Crohn’s Disease Activity Index score &gt;250</td>
</tr>
<tr>
<td>Selby et al [35]</td>
<td>2007</td>
<td>213</td>
<td>Clarithromycin, 750 mg/day, and rifabutin, 450 mg/day, and clofazimine, 50 mg/day, 24 months</td>
<td>40 mg/day of prednisolone, tapered to 0 mg during the first 16 weeks</td>
<td>Outpatients</td>
<td>37</td>
<td>35</td>
<td>Active</td>
<td>Proportion of patients with at least 1 relapse</td>
</tr>
<tr>
<td>Shaffer et al [36]</td>
<td>1984</td>
<td>14</td>
<td>Ethambutol, 15 mg/kg/day, and rifampicin, 10 mg/kg/day, 12 months</td>
<td>If clinically indicated</td>
<td>Outpatients</td>
<td>34(^a)</td>
<td>34(^b)</td>
<td>Unclear</td>
<td>Relapse, defined as rise of Crohn’s Disease Activity Index score &gt;50</td>
</tr>
<tr>
<td>Sutherland et al [37]</td>
<td>1991</td>
<td>66</td>
<td>Metronidazole, 20 mg/kg/day, 4 months</td>
<td>Not allowed (stopped before entry into study)</td>
<td>Not reported</td>
<td>Not reported</td>
<td>Not reported</td>
<td>Active</td>
<td>Decrease in Crohn’s Disease Activity Index score</td>
</tr>
<tr>
<td>Swift et al [38]</td>
<td>1994</td>
<td>78</td>
<td>Rifampicin, 450 or 600 mg/day, and isoniazid, 300 mg/day, and ethambutol, 15 mg/kg/day, 24 months</td>
<td>If clinically indicated</td>
<td>Unclear</td>
<td>37</td>
<td>36</td>
<td>Active</td>
<td>Decrease in Crohn’s Disease Activity Index score</td>
</tr>
</tbody>
</table>

\(^a\) Median value. 
\(^b\) Crossover study.
an asymmetrical funnel plot. Finally, studies will have included the 10%–15% of patients for whom the distinction between Crohn’s disease and ulcerative colitis cannot be made with certainty (inflammatory bowel disease, type unclassified), and this might have attenuated treatment effects [42].

Since the first description of the similarities between Crohn’s disease and Johne disease in cattle in 1913 [43], it has been suspected that *M. avium* subspecies *paratuberculosis*, which causes Johne disease, might also be a cause of Crohn’s disease [9, 44]. We found that both classic drugs against *M. tuberculosis* and clarithromycin did not appear to be efficacious. Some have argued that effective regimens should consist of at least 2 different drugs, include a macrolide and rifamycin, and be administered for at least 6 months in a dosage similar to that used in the treatment of *M. avium* complex infections [45–48]. No randomized trials of such regimens are available at present. Interestingly, clofazimine was synthesized in the 1950s as a drug against tuberculosis. Granted orphan drug status in 1986, it is an important component of the treatment of leprosy and is also used for multidrug-resistant tuberculosis and *M. avium* complex infections in patients infected with human immunodeficiency virus [49]. Our meta-analysis showed a beneficial effect of clofazimine in Crohn’s disease and found that results of the Australian trial [35] were compatible with those of the previous studies [23, 29, 31]. Of note, the published results of the Australian trial were not based on an intention-to-treat analysis and may have underestimated the beneficial effects of the drug [50].

The earlier trials of clofazimine [23, 29, 31] showed benefits in the absence of coadministered macrolides or rifamycins. The antibiotic activity of clofazimine includes some gram-positive bacteria, whereas gram-negative bacteria are uniformly resistant to clofazimine [51, 52]. Clofazimine also has immunomodulatory effects that have been attributed to the stimulation of the production of prostaglandin E2 [49]. It is unclear to what extent the beneficial effect of clofazimine might be explained.
by the immunomodulatory effects of the drug. Similarly, nitroimidazoles are widely used to treat infections by anaerobic bacteria, whereas facultative anaerobic and aerobic bacteria are uniformly resistant against nitroimidazoles [53, 54]. Anaerobic bacteria have, however, not been implicated in the pathogenesis of Crohn’s disease [7]. Immunomodulatory activities, rather than the anti-infectious effects of nitroimidazoles, might thus also explain the beneficial effects observed in Crohn’s disease [55, 56].

The current focus in the therapy of Crohn’s disease is on tumor necrosis factor α blocking agents: a recent review of the medical management of Crohn’s disease discussed this in detail but spent only 2 sentences on antibiotic therapy [15]. Nevertheless, long-term therapy with nitroimidazoles (metronidazole and ornidazole, in particular) is routinely used in some centers, outside the fairly narrow indications suggested by current guidelines [14, 15], but its efficacy has never been systematically assessed. Our review indicates that the benefit of some antibiotic regimens given for ≥3 months may be comparable to what is achieved with the anti–tumor necrosis factor α agents [57], with a potentially more favorable adverse effect profile and lower costs.

We believe that further research is justified to better define the role of antibacterial agents and combination regimens in Crohn’s disease. Future studies should focus on clazosine, alone or in combination with a macrolide and a rifamycin, as well as in combination with a nitroimidazole, and perhaps ciprofloxacin. Both pragmatic trials comparing different treatment strategies and smaller studies aiming to elucidate mechanisms of action are required. The potential role of different bacteria should be examined in such trials and interactions between drugs and potential adverse effects of long-term anti-

Figure 3. Funnel plot of 16 randomized, placebo-controlled trials using treatment regimens with antibacterial agents for at least 3 months in patients with Crohn’s disease. Asymmetry of the plot is an indication of publication bias. SE, standard error.

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