The role of luminal factors in the recovery of gastric function and behavioral changes after chronic *Helicobacter pylori* infection

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1Intestinal Disease Research Program, McMaster University, Hamilton, Ontario, Canada; 2Advanced Research Institute for Science and Engineering, Waseda University, Tokyo, Japan; and 3Institut Rosell-Lallemand, Montreal, Quebec, Canada

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The role of luminal factors in the recovery of gastric function and behavioral changes after chronic *Helicobacter pylori* infection. *Am J Physiol Gastrointest Liver Physiol* 295: G664–G670, 2008. First published July 24, 2008; doi:10.1152/ajpgi.90316.2008.—The role of chronic infections, such as *Helicobacter pylori* (*Hp*), to produce sustained changes in gut physiology remains controversial. In this study, we investigate whether the antigenic or bacterial content of the gut, after *Hp* eradication, influences the changes in gut function induced by chronic *Hp* infection. Mice were infected with *Hp* for 4 mo and then treated with antibiotics or placebo for 2 wk. Gastric emptying was measured using videofluoroscopy, feeding behavior using a 24-h feeding system, and intestinal permeability using an isolated jejunal segment arterially perfused with an artificial oxygen carrier, hemoglobin vesicles. Immune responses were assessed by CD3+ cell counts and anti-*Hp* antibodies using ELISA. To determine the role of luminal factors in host physiology post eradication, groups of mice received the probiotics containing *Lactobacillus rhamnosus* R0011 and *L. helveticus* R0052 or placebo for 2 wk or crude *Hp* antigen weekly for 2 mo. Chronic *Hp* infection was associated with delayed gastric emptying, increased intestinal permeability, and increased gastric CD3+ cell counts. *Hp*-induced altered feeding patterns did not reverse after eradication. Probiotics accelerated the recovery of paracellular permeability and delayed gastric emptying, improved the CD3+ cell counts, and normalized altered feeding patterns post eradication. *Hp* antigen resulted in increased anti-*Hp* antibodies and increased CD3+ cell counts in the stomach and delayed recovery of gastric function. Our results suggest that the bacterial content of the gut, as well as the presence of relevant antigens, influences the rate of recovery of host pathophysiology induced by *H. pylori* infection.

**MATERIALS AND METHODS**

*Animals.* Male BALB/c mice (Harlan, Indianapolis, IN) were purchased at the age of 6–8 wk and housed in a conventional specific pathogen-free unit at McMaster University Central Animal Facility. All experiments were conducted with approval from the McMaster University Animal Care Committee.

*Chronic *H. pylori* infection.* Mice chronically infected with *H. pylori* Sydney strain for 4 mo (*n* = 64) and a group of uninfected controls were used (*n* = 27). Additional mice infected with *H. pylori* were used to monitor the establishment of a chronic infection (*n* = 14). Every 2 wk, beginning at 2 wk postinfection, 2 mice per group were euthanized, and *H. pylori* infection was verified using Warthin-Starry staining. Gastric emptying and 24-h feeding patterns were assessed at 4 mo of chronic infection. Additional mice were euthanized and used for ex vivo intestinal permeability measurements. *H. pylori* eradication therapy was administered thereafter using antibiotic-containing food pellets (Bio-Serv, Frenchtown, NJ) for 2 wk. Gastric emptying was reassessed 2 wk and 2 mo post eradication. Feeding patterns and intestinal permeability were reassessed 2 mo post eradication.

*Inflammation.* Stomach samples (Swiss rolls) were preserved in 10% formalin and then stained with hematoxylin and eosin (H & E).

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H & E-stained and Warthin-Starry-stained slides were examined under light microscopy to confirm *H. pylori* eradication after antimicrobial therapy and assess gastric inflammation. Mononuclear cell (MN) scores were graded in the corpus on a scale of 0–3 as described previously (2).

Immunostaining for CD3+ cells was performed on stomach paraffin sections using a modified method described previously (2). Rabbit anti-mouse CD3 (1:300; Dako, Glostrup, Denmark) was used as primary antibody followed by biotinylated swine anti-rabbit (1:300, Dako) and streptavidin peroxidase conjugate (1:600, Dako). The antibodies were visualized using 3-amoio-9-ethylcarbazole and counterstaining with Mayer’s hematoxylin. Negative controls were performed in the absence of primary antibody. CD3+ cells were counted in two slides per mouse (n = 12/group) and averaged. CD3+ cells present in three randomly selected fields in the corpus and antrum separately (x63, mucosa and submucosa) were counted. Samples from the jejunal loop were obtained at the end of each permeability experiment to test for tissue viability. Samples were fixed in 10% formalin, stained with H & E, and examined for tissue damage as a result of hypoxia using light microscopy. Gross villous architecture and the presence of cell desquamation and edema at villi tips were investigated.

### *H. pylori* antibody measurement. Levels of anti-*H. pylori* IgG1 and IgG2A were measured at 2 mo post eradication by ELISA using biotinylated goat anti-mouse IgG2a and IgG1 (Southern Biotechnology Associates, Birmingham, AL) as described previously (9). Biotinylated goat anti-mouse IgG2a and IgG1 (Southern Biotechnologies, Birmingham, AL) were added to samples and incubated at room temperature. Plates were washed and streptavidin peroxidase conjugate (1:600, Dako) was added to the wells (Promega, Madison, WI) according to manufacturer’s instructions. PCR amplification was performed in a DNA Thermal Cycler 480 (Perkin Elmer, Boston, MA) as described previously (9). Primers were designed to target a conserved segment of the *H. pylori* genome (24958–24985) that was absent in our selected probiotics. The first PCR product was sequenced to verify design accuracy (2). PCR amplification was performed in a DNA Thermal Cycler 480 (Perkin Elmer, Boston, MA) as described previously (9).

### Detection of *L. rhamnosus* R0011 and *L. helveticus* R0052 in feces. Fresh fecal pellets were collected aseptically from the anal region into a sterile tube and placed in a custom-made restrainer. Videofluorescent images of stomach were taken at 0 and 4 min and stored for offline analysis using VCR (Panasonic). Video images were then digitized and analyzed using public domain NIH Image 1.62 software (developed at the U.S. National Institutes of Health). Gastric emptying was calculated by multiplying the area of stomach by mean optical density of the gastric area and was expressed as a percentage of barium expelled in 4 min.

### Twenty-four-hour feeding patterns. Twenty-four-hour feeding patterns were assessed individually in mice placed in the separate cages. Food pellets were fastened on the feeding tray positioned 5 cm above the bottom of the cage, which was connected to the strain cage gauge placed above the cage. The weight of the feeding tray with food pellets was continuously recorded by computer. Data acquisition and analysis were performed using custom designed software (written by N. Al-Mutawaly). The number of feeding episodes, amount of food per episode, and total amount of food consumed was calculated. An eating bout was defined as an episode of food consumption lasting more than 20 s; two bouts were considered to be independent from each other if the interval of quiescence was longer than 5 min.

### Intestinal permeability. Intestinal permeability ex vivo was investigated using an isolated arterially perfused jejunal loop (1,22). Briefly, a 4-cm segment of the distal jejunum was selected, and a terminal branch of the superior mesenteric artery was cannulated with a polyethylene catheter under intraperitoneal ketamine/xylazine anesthesia. Tissue oxygenation was maintained by perfusion of the arterial branch with hemoglobin vesicles (Waseda University, Tokyo, Japan) (17a) using a peristaltic pump (Ismatec, Zurich, Switzerland). Luminal ends of the jejunal segment were cannulated using polyethylene cannulas. Following gentle washing of the lumen with saline to remove food residue, the jejunal loop was dissected and transferred to a custom-built organ chamber containing saline at 37°C. The loop was then perfused intraluminally with saline at 5 ml/h by using a syringe infusion pump (Harvard University, Boston, MA). All preparations were allowed to equilibrate for 5 min before collection of venous outflow, which was sampled continuously for the entire duration of the experiment (36 min) in 3-min fractions. Intestinal segment was perfused luminally with isosmotic mixture of 53Cr-EDTA (0.6 μCi/ml) and 14C-mannitol (0.1 μCi/ml) (Perkin Elmer, Boston, MA) solution for 9 min at 37°C. After the end of each experiment, two full-thickness tissue samples were excised from proximal and distal regions of the loop and fixed in formalin for later microscopic examination. Concentration of the radiolabeled macromolecules in the venous outflow was detected using a liquid scintillation Beta counter (LS 5801; Beckman Coulter, Mississauga, ON, Canada). The recovery of radioactivity in each venous outflow fraction is expressed as a proportion of that found in an identical volume of the luminal perfusate.

### *H. pylori* antigen administration post eradication. To maintain persistence of gastric dysfunction post eradication a group of mice received crude *H. pylori* antigen (100 μg/mouse) by gavage once weekly for 2 mo starting 1 wk after *H. pylori* eradication therapy. *H. pylori* antigen was prepared from fresh *H. pylori* cultures using liquid brain-heart infusion-based media as described previously (2). The bacteria were then gently centrifuged, and pellets were resuspended in saline and homogenized/dispersed with a sonicator. The concentration of bacterial antigen was adjusted with saline (100 μl/mouse). Gastric emptying was reassessed at the end of *H. pylori* antigen administration (2 mo post eradication). Stomach samples were obtained at sacrifice and fixed in formalin for Warthin-Starry stain and for CD3+ cell counts.

### Probiotic treatment post eradication. Groups of mice received by daily gavage either 100 μl of placebo-maltodextrin dissolved in sterile water or 100 μl of 106* Lactobacillus rhamnosus* (L. rhamnosus) R0011 and *L. helveticus* R0052 (Lacidofil) for 2 wk immediately after eradication therapy. Uninfected mice received maltodextrin treatment on a daily basis for 2 wk. Gastric emptying was reassessed at the end of probiotic treatment (2 wk post eradication) and at 2 mo post eradication. Fecal pellets were obtained at 2 wk to investigate probiotic survival in the gastrointestinal tract. Twenty-four-hour feeding patterns were reexamined at 2 mo post eradication. Additional mice were euthanized for ex vivo permeability measurements at 2 mo post eradication.

### Detection of *L. rhamnosus* R0011 and *L. helveticus* R0052 in feces. Fresh fecal pellets were collected aseptically from the anal region into a sterile cryogenic tube containing 0.9% saline and 10% glycerol while the animals were kept in Plexiglas restrainers. For analysis, 100 μl of fecal solution were pipetted into 25 ml of de Man, Rogosa, and Sharpe broth (Oxoid) as described previously (9). *L. helveticus* R0052 (Lacidofil) was cultured anaerobically at 37°C. *L. rhamnosus R0011* was used as a positive control, and *L. zeae* ATCC 393 and its prophage R0052 growth and was cultured anaerobically at 37°C for 48 h.

For DNA extraction and PCR amplification, 1.5 ml of each culture solution were centrifuged, and pellets were resuspended in saline and homogenized/dispersed with a sonicator. The concentration of bacterial antigen was adjusted with saline (100 μl/mouse). Gastric emptying was reassessed at the end of probiotic treatment (2 wk post eradication) and at 2 mo post eradication. Fecal pellets were obtained at 2 wk to investigate probiotic survival in the gastrointestinal tract. Twenty-four-hour feeding patterns were reexamined at 2 mo post eradication.
prophage, LarhR11-1. Therefore, only samples that were positive for both primer sets were considered positive for R0011.

**Statistical analysis.** Data are presented as means ± SD or medians with interquartile ranges when appropriate. Data was analyzed using either two-way ANOVA, Kolmogorov-Smirnov test or non-paired t-test as appropriate. The Spearman rank correlation test was used to test the strength of association between parameters. A P value of <0.05 was considered statistically significant.

**RESULTS**

**Effect of chronic H. pylori infection on inflammation.** Chronic *H. pylori* infection (4 mo postinfection) induced chronic active inflammation, located mainly in the submucosal layer of the proximal stomach. The mononuclear cell score in the corpus was 0.6 ± 0.6 and 2.0 ± 0.7 (P < 0.01) in uninfected controls and *H. pylori*-infected mice, respectively. CD3\(^+\) cell scores in controls were 3.8 ± 3.0 and 0.8 ± 0.9 in corpus and antrum, respectively. During *H. pylori* infection, they increased to 14.3 ± 7.1 and 4.5 ± 1.2 (both P < 0.01 vs. uninfected controls).

**Effect of chronic H. pylori infection on gastric emptying.** In accordance with previous results (3), the percentage of retained barium during *H. pylori* infection was 30% higher than in uninfected mice (Fig. 1, before eradication). Gastric emptying fully normalized at 2 mo posteradication (Fig. 1, 2 mo after eradication).

**Effect of chronic H. pylori infection on body weight.** In accordance with previous results (2, 3), there were no differences in body weight between uninfected and chronically *H. pylori*-infected mice (24.3 ± 2.6 g and 24.7 ± 3.0 g, respectively).

*H. pylori* antigen delays recovery of inflammation and gut function after bacterial eradication. In mice previously infected with *H. pylori*, administration of crude *H. pylori* antigen maintained delayed gastric emptying for up to 2 mo posteradication (Fig. 1, 2 mo posteradication). Delayed gastric emptying correlated with increased CD3\(^+\) cell counts (Spearman rank correlation test, P < 0.05). Antigen-treated mice had IgG1 and IgG2A values nine- and 23-fold higher, respectively, compared with placebo-treated mice. Antigen administration did not affect gastric emptying in uninfected mice.
Detection of L. rhamnosus R0011 and L. helveticus R0052 in feces. Figure 2 shows an example of positive detection for L. rhamnosus R0011 and L. helveticus R0052 in feces at the end of probiotic feeding. All Lacidofil-fed mice tested positive for the specific probiotics in feces at the end of the probiotic administration period. No cross contamination was observed in mice gavaged with placebo.

Probiotics improve markers of inflammation post eradication. In placebo-treated mice, there was persistent infiltration with CD3⁺ T cells in the submucosal layer of the corpus and antrum 2 mo after eradication of H. pylori. In contrast, previously infected mice treated with probiotics exhibited a 60% lower MN score in corpus compared with placebo-treated mice (2.2 ± 0.5 vs. 0.8 ± 0.4, P = 0.01). The CD3⁺ T cell infiltrate in both corpus and antrum was also reduced by probiotic therapy (Fig. 3). There was no overt inflammation in the jejunal segments of H. pylori-infected mice compared with uninfected controls.

Effect of probiotics on gastric emptying after H. pylori eradication. At 2 wk post eradication, previously H. pylori-infected mice treated with probiotics had returned to uninfected
gastric emptying values. However, there were no statistical differences between previously infected mice treated with placebo or probiotics 2 wk after eradication. Two months after eradication, previously infected mice that had been treated with probiotics tended to have faster gastric emptying than placebo-treated mice (Fig. 1).

**Probiotics improve recovery of 24-h feeding behavior after H. pylori eradication.** At 4 mo, frequency of eating bouts per 24 h was higher in *H. pylori*-infected mice compared with uninfected controls (Fig. 4). In placebo-treated mice, altered feeding patterns remained unchanged for at least 2 mo post-eradication. In contrast, previously infected mice treated with probiotics had a similar number of eating bouts per 24 h as uninfected time-point controls.

**Effect of probiotics on paracellular small intestinal permeability.** Only intestinal segments with intact morphology at the end of experiments were included in the study. Jejunal permeability to $^{51}$Cr-EDTA and $^{14}$C-mannitol was increased in *H. pylori*-infected mice compared with uninfected controls (Fig. 5). Bacterial eradication combined with probiotics tended to improve paracellular permeability to $^{51}$Cr-EDTA ($P = 0.35$ vs. uninfected controls), but this did not reach statistical significance vs. placebo-treated mice. Probiotics did not affect membrane permeability as assessed by $^{14}$C-mannitol.

**DISCUSSION**

The aim of our study was to investigate whether the antigenic or bacterial content of the gut influences the rate of recovery of host physiology induced by chronic *H. pylori* infection after bacterial eradication.

We have previously shown that altered gastric emptying improves at 2 wk post-eradication and completely normalizes 2 mo post-eradication (3). The probiotic combination *L. rhamnosus* R0011 and *L. helveticus* R0052 administered immediately after *H. pylori* eradication accelerated recovery of gastric chronic inflammation. In contrast, previously infected mice that received *H. pylori* antigen had persistent CD3$^+$ cell counts in the stomach that correlated with persistent delayed gastric emptying post-eradication.

In the chronic model of *H. pylori* infection, the degree of neural impairment is proportional to the extent of the chronic inflammatory infiltrate (2). In the present study, we have extended this observation and showed that the degree of delayed gastric emptying is proportional to the CD3$^+$ cell counts in the stomach. Furthermore, *H. pylori* antigen-treated mice had persistent delayed gastric emptying post-eradication compared with placebo-treated controls. This was accompanied by higher anti-*H. pylori* antibody titers, suggesting a
heightened immune response after luminal *H. pylori* antigen administration. In contrast, probiotic therapy significantly decreased the number of CD3+ cells in the stomach of previously infected mice compared with placebo-treated mice in parallel with a faster recovery of gastric emptying. Thus the effect of probiotics on gastric emptying recovery may be mediated through a faster recovery of the chronic inflammatory response to *H. pylori*.

*H. pylori*-infected mice ate more frequently but smaller amounts of food per feeding bout compared with uninfected controls. This resulted in a similar total amount of food consumed per 24 h. The pattern is reminiscent of that observed frequently in patients with functional dyspepsia who have difficulty consuming regular size meals and therefore snack frequently throughout the day. Administration of probiotics normalized postinfected altered feeding behavior. It is possible that chronic inflammation in the stomach alters ascending neural pathways, resulting in abnormal feeding behavior, and that probiotics improve this through an effect on *H. pylori*-associated gastritis. However, other mechanisms such as direct modulation of neuroendocrine pathways by probiotics cannot be ruled out.

It has been shown that *H. pylori* infection alters gastric permeability in vivo and also on epithelial cell lines (6, 14, 15). The underlying mechanisms may include impaired mucus-bicarbonate barrier, disruption of tight junctions (occludin, ZO), and increase in transcellular permeability by *H. pylori*. These alterations may be long lasting and linked to chronic inflammation because bacterial eradication has been shown to improve gastric permeability only in those mice with significant improvement of chronic gastritis (14). A recent clinical study has suggested that intestinal permeability is altered in subjects with *H. pylori* infection (5). This may be more clinically relevant than changes in gastric permeability because the intestine represents a larger area of antigen and nutrient processing. The *H. pylori*-induced defect in intestinal barrier could result in chronic immune stimulation and bystander antigen stimulation even after *H. pylori* eradication. We measured permeability in ex vivo jejunal segments using a combination of two macromolecules to assess paracellular and membrane permeability. 

\[ ^{51}\text{Cr-EDTA} \]

\[ ^{14}\text{C-mannitol} \]

\[ \text{Previously infected} \]

In conclusion, using a murine model of chronic *H. pylori* infection and postinfected gut dysfunction we have shown that administration of *L. rhamnosus* R0011 and *L. helveticus* R0052 after *H. pylori* eradication accelerates recovery of gastric motor function and normalizes altered feeding behavior. This is associated with improvement in chronic gastric inflammation by probiotics but not with full recovery of intestinal barrier abnormalities. Treatment with luminal antigen related to the triggering infectious agent maintains gastric dysfunction long after bacterial eradication. The results suggest that specific probiotics may be useful in improving the rate of symptomatic relief in patients with dyspepsia after *H. pylori* eradication.

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