MICROBIAL PATHOGENICITY

The effect of colonisation by Helicobacter pylori in Praomys (Mastomys) natalensis on the incidence of carcinoids

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An animal model of experimental gastric Helicobacter pylori infection has been developed in the Z strain of Praomys (Mastomys) natalensis; this animal has been reported to develop gastric carcinoids and adenocarcinoma spontaneously. In the present study, male and female Mastomys were killed at 1, 2, 4, 8 and 16 weeks after H. pylori inoculation. Colonisation of H. pylori was maintained in the stomachs of all animals for up to 16 weeks. H. pylori were mainly found in the antrum. Lymphoid infiltration appeared in the antral lamina propria and submucosa in all male and female animals from 4 to 16 weeks after inoculation. On microscopic examination after immunostaining for H. pylori, the organisms were detected in the antral mucus layer of the gastric epithelium. Serum immunoglobulin G specific for H. pylori could be detected 2 weeks after inoculation in female and 4 weeks after inoculation in male Mastomys, and persisted throughout the 16-week study period. At 18 months after inoculation, H. pylori positive rates for male and female Mastomys were 15 of 21 and 7 of 27, respectively. Carcinoids developed in 27 of 100 inoculated and in 49 of 100 uninoculated male, and in 5 of 100 inoculated and in 21 of 100 uninoculated female animals at 18 months after inoculation. Adenocarcinoma developed in 1 of 100 male Mastomys in both the inoculated and uninoculated groups, but in none of the female animals in either the inoculated or uninoculated groups. These results indicate that antrum-predominant colonisation by H. pylori caused the decrease in incidence of carcinoid formation in Mastomys.

Introduction

Helicobacter pylori infection is strongly associated with gastroduodenal disease [1, 2]. The site of gastritis induced by H. pylori may play a role in determining clinical outcome. Gastritis involving the antral region is associated with excessive acid production and a high risk of duodenal ulcer disease [3]. In contrast, gastritis involving the acid-secreting corpus region leads to hypochlorhydria, progressive gastric atrophy and an increased risk of gastric cancer [4].

Praomys (Mastomys) natalensis is an African rodent with a high incidence of spontaneous stomach tumours [5]. A Z strain of this species has been reported to develop carcinoids along the greater curvature of the body as well as adenocarcinoma along the lesser curvature of the antrum, the predilection site of human gastric adenocarcinoma [6]. In a study by Kumazawa et al., carcinoids were found in 80.6% of male and in 64.7% of female animals, whereas adenocarcinoma was found in 22.6% of male and in 13.2% of female animals of this Z strain at the age of 18 months [7]. In Mastomys, as in man, gastric carcinoids are mainly composed of enterochromaffin-like (ECL) cells [8]. The adenocarcinomas in Mastomys appear to proceed according to a hyperplasia-dysplasia-adenocarcinoma sequence [7]. In man, gastric cancer consists of two distinct histological subtypes: intestinal and diffuse [9]. According to Correa’s hypothesis, the intestinal type of gastric cancer develops from chronic inflammation leading to intestinal metaplasia, then dysplasia and finally cancer, while the diffuse type does not go through these precancerous conditions but moves...
straight from inflammation to cancer [10]. The type of adenocarcinoma seen in Mastomys resembles diffuse-type cancer.

ECL carcinoids in the human stomach are usually associated with chronic atrophic gastritis, Zollinger-Ellison syndrome with multiple endocrine neoplasia type 1, or pernicious anaemia [11], but are only rarely associated with H. pylori infection [12]. On the other hand, several studies have shown an epidemiological association between H. pylori and gastric cancer [13]. Thus, the World Health Organization’s IARC designated H. pylori as a definite biological carcinogen in 1994 [14]. Recent studies have suggested that the association of H. pylori and intestinal-type gastric cancer is related to gastric mucosal atrophy and intestinal metaplasia [15], but there has been no consensus regarding the relationship of H. pylori to diffuse-type cancer [16]. This study examined the influence of H. pylori infection on the incidence of carcinoids and adenocarcinoma in Mastomys.

Materials and methods

Animals

Five-week-old specific-pathogen-free (SPF) male and female animals of the Z strain of Mastomys (Mastomys) natalensis (Japan SLC, Shizuoka, Japan) weighing c. 40 g were used in this study. Japan SLC established SPF Mastomys breeding colonies originating from the Z strain [17]. Mastomys were confirmed to be free of the following common pathogens: Pseudomonas aeruginosa, Mycoplasma spp., Bordetella bronchiseptica, Streptococcus pneumoniae, Corynebacterium kutscheri, Pasteurella pneumotropica, Tyzzer’s organism, Salmonella spp., Giardia spp., Spirochelus spp., Sypacia spp., Aspicularis tetraptera, Sendai virus and Pneumonia virus of mice. The presence or absence of gastric Helicobacter spp. was ascertained in the 10 male and female Mastomys before admission to the study by evaluating the animals’ stools for urease activity, by examining tissue sections for the presence of Helicobacter-like organisms [18] and by culture for Helicobacter spp. [19]. All Mastomys were negative for Helicobacter spp. in all tests. Mastomys were housed in polycarbonate cages in isolators and fed a commercial pellet diet (F-2; Funabashi Farms, Chiba, Japan) with water ad libitum. All animal experiments were carried out according to the guidelines provided by the Institutional Animal Care and Use Committee of Sankyo Co. Ltd (Tokyo, Japan).

Bacterial inocula

H. pylori strain 9818 was isolated from gastric biopsy samples from a patient with gastric ulcers and was supplied by Dr T. Fujisaka (Oita Medical University, Oita, Japan). This strain had the cagA gene and vacuolating cytotoxin, as confirmed by PCR amplification with primers specific for cagA and cytotoxin assay, respectively [20, 21]. This H. pylori strain was passaged three times in Mastomys. Stock cultures were stored at −80°C in Brucella Broth (Becton Dickinson, Cockeysville, MD, USA) supplemented with fetal bovine serum (FBS; Dainippon Pharmaceutical, Osaka, Japan) 2%.

Experimental design

Bacteria were cultured in brucella broth supplemented with FBS 2% on a gyratory shaker at 110 rpm for 40 h at 37°C under micro-aerobic conditions. The culture was harvested and the cells were suspended in brucella broth supplemented with FBS 2% to 2 × 10^8 cfu/ml. The bacterial cell counts of all inocula were done with Brain Heart Infusion Agar (Difco Laboratories, Detroit, MI, USA) supplemented with horse blood 5%. Plates were incubated at 37°C in a GasPak jar (Becton Dickinson) for 5 days with Campy Paks (Becton Dickinson). Mastomys were inoculated orally with 2 ml of bacterial suspension after 1 day of fasting. Control groups were given brucella broth supplemented with FBS 2% alone. Six inoculated animals and six unoinoculated controls were anaesthetised in a CO₂ chamber and killed by cervical dislocation at 1, 2, 4, 8 and 16 weeks after inoculation. Blood was obtained by heart puncture, and serum was stored at −20°C until testing for anti-H. pylori antibody by an enzyme-linked immunosorbent assay (ELISA) as described below. Three each of the six inoculated and unoinoculated animals were used for culture of H. pylori, and the other three inoculated and unoinoculated animals were used for microscopic examinations. Finally, 121 inoculated male, 127 inoculated female, 100 unoinoculated male and 100 unoinoculated female animals were examined for H. pylori by culture and for the incidence of gastric carcinoids and adenocarcinoma at 18 months after inoculation.

Microbiology

The stomachs were homogenised in 5 ml of brucella broth supplemented with FBS 2%, followed by dilution with the same broth; 100-μl samples of the dilutions were inoculated on to modified Skirrow’s agar plates containing vancomycin (Sigma) 10 μg/ml, bacitracin (Sigma) 8 μg/ml, polymyxin B (Pfizer Pharmaceutical, Tokyo, Japan) 0.25 μg/ml, trimethoprim (Shionogi Pharmaceutical, Osaka, Japan) 2.5 μg/ml and polymyxin B (Sigma) 5 μg/ml. Plates were incubated at 37°C under micro-aerobic conditions for 5 days and the colonies of H. pylori were counted. Bacterial counts are expressed as cfu/g of tissue.

Distribution of H. pylori in the stomach

One week after inoculation, three female Mastomys were used to study the distribution of H. pylori in the stomach. The body, antrum and duodenum of the
stomach were examined. These sections were cut separately and homogenised in 2 ml of brucella broth supplemented with FBS 2%. Viable cells of *H. pylori* were counted as described above.

**Histopathological examination**

Histopathological examination was performed by the method of Shimizu *et al.* [22]. Each stomach was fixed in cold Carnoy’s solution (a mixture of ethanol:acetic acid:chloroform, 6:3:1, v:v:v) for 2 h at 4°C. After fixation, the stomachs were sliced longitudinally at 5-mm intervals. All tissue sections were then dehydrated in absolute alcohol, cleared in xylene and embedded in paraffin. Serial paraffin sections of 3-μm thickness were prepared. From each block, one slide was stained with haematoxylin-eosin for histopathological observation and one was immunostained for *H. pylori* by an indirect immunoperoxidase method. Histopathological findings were evaluated for the presence of lymphocyte aggregates in each section. A lymphocyte aggregate was defined as >10 lymphocytes/×400 field. After rehydration, sections fixed in Carnoy’s solution were re-fixed with buffered formalin 20% for 30 min. Before applying anti-*H. pylori* polyclonal antibody (DAKO Japan, Kobe, Japan), hydrated sections were treated with a trypsin solution (Sigma) (trypsin 0.2% and CaCl₂ 0.1% in 0.05 M Tris buffer, pH 7.6) at 37°C for 10 min. After washing with 0.05 M Tris-HCl buffered saline (pH 7.6), diluted horseradish peroxidase-conjugated anti-rabbit IgG antibody (DAKO Japan) was added. Antibody binding sites were visualised with 3,3′-diaminobenzidine tetrahydrochloride (Dojindo Laboratories, Kumamoto, Japan), and the sections were counterstained with haematoxylin.

**ELISA for *H. pylori* antibody**

Serum IgG antibody was assayed by ELISA with a commercial kit (Helico G; International Reagents, Kobe, Japan). Serial two-fold dilutions of sera from *H. pylori*-infected Mastomys were incubated for 1 h at 37°C. The secondary antibody, peroxidase-conjugated rabbit anti-mouse IgG (Chemicon International, Temecula, CA, USA) diluted 1 in 1000 in commercial buffer, was applied to the wells for 30 min at 37°C, followed by addition of substrate for 10 min, and then addition of stopping solution. OD₄₅₀ was recorded with an ELISA plate reader (MR 580; Dynatech Laboratories, Alexandria, VA, USA). The antibody titre of serum samples was prepared at a dilution with an OD₄₅₀ of 3 SD above the mean OD₄₅₀ of four negative control serum samples.

**Incidence of carcinoids and adenocarcinoma 18 months after *H. pylori* inoculation**

Inoculated (n = 100 of each sex) and uninoculated (n = 100 of each sex) Mastomys were used for the histopathological examinations, and 21 inoculated male and 27 inoculated female animals were used for culture of *H. pylori*. Carcinoids were classified according to Bilchik *et al.* [23]. All sera were tested for anti-*H. pylori* antibody by the ELISA method.

**PCR amplification and restriction fragment length polymorphism (RFLP)**

*H. pylori* were recovered from both male and female Mastomys at 16 weeks and 18 months after inoculation. The DNA samples of the recovered *H. pylori* were used. Primer sequences chosen for amplification were specific for the *H. pylori flaA* gene [24]. PCR was performed as described previously [25], with some modifications. Following PCR amplification, 15 μl of reaction mixture were removed and incubated at 37°C for 2 h, and the fragments were separated on an agarose 3% gel. The gels were stained with ethidium bromide.

**Statistical analysis**

All values are expressed as the means and SD. The incidence of gastric carcinoids and adenocarcinoma was compared by the χ² goodness of fit test. p values <0.05 were considered statistically significant.

**Results**

**Colonisation of gastric tissue with *H. pylori***

As shown in Fig. 1, *H. pylori* were continuously detected in the stomachs of all male and female Mastomys. For 1–2 weeks, the count of *H. pylori* in the stomachs of male and female animals increased, and then the count of colonies decreased, reaching one-tenth of the peak level by 16 weeks after inoculation.

**Fig. 1.** Changes in viable counts in gastric mucosa of male (○) and female (●) Mastomys after inoculation with *H. pylori* 9818. Each value indicates the mean and SD of three animals.
No *H. pylori* were isolated from the uninoculated Mastomys.

**Distribution of H. pylori in the stomach**

The bacterial counts from the body and antrum were 4.94 SD 0.56 and 5.62 SD 0.09 log10 CFU/g, respectively. The viable count of *H. pylori* colonising the antrum was five-fold higher than that in the body. No *H. pylori* were found in the duodenum.

**Histopathology**

A summary of the histopathological changes in the antrum of Mastomys inoculated or not inoculated with *H. pylori* is shown in Table 1. Inflammation was rarely present in the forestomach and body mucosa. At 1 week after inoculation in female animals or 2 weeks after inoculation in male animals, lymphoid infiltration was detected in the antral mucosa. From 4 weeks after inoculation in both male and female animals, multifocal lymphoid infiltration appeared in the lamina propria and submucosa in the pylorus (Fig. 2a, b and c). Pathological change in non-inoculated Mastomys was seen in only one male Mastomys. With immunostaining, *H. pylori* were detected in the antral mucus layer of the gastric epithelium in female Mastomys at 1 week after inoculation (Fig. 3).

**Serum anti-*H. pylori* antibody**

Anti-*H. pylori* IgG antibody levels increased at 2 weeks after inoculation in female animals or 4 weeks after inoculation in male Mastomys. The anti-*H. pylori* IgG levels persisted throughout the 16 weeks (Fig. 4). The uninoculated control Mastomys had no antibody response specific for *H. pylori*.

**Incidence of carcinoids and adenocarcinoma 18 months after *H. pylori* inoculation**

The pathological classification and the incidence of carcinoids 18 months after *H. pylori* inoculation are shown in Table 2. The incidence of carcinoids was significantly lower (p <0.05) in animals inoculated with *H. pylori* than in uninoculated male and female animals. Microscopic examination revealed carcinoids in the body of inoculated (Fig. 5a) and uninoculated (Fig. 5b) male animals. Adenocarcinoma developed in 1 of 100 male Mastomys in both the inoculated and uninoculated groups, but in none of the female Mastomys in either the inoculated or uninoculated groups. *H. pylori* positive rates for male and female animals were 15 of 21 and 7 of 27, respectively. No serum anti-*H. pylori* antibody was detected in any of the animals.

**RFLP analysis of *H. pylori***

The identities of the isolates of *H. pylori* recovered from the experimentally inoculated Mastomys were compared by RFLP analysis of the 1.5-kb flaA gene segment with that of the infecting strain. The RFLP pattern of the flaA gene PCR product of the infecting strain was virtually identical to that of the isolates recovered from the inoculated animals (Fig. 6).

**Discussion**

These results demonstrate that Mastomys can be readily colonised by *H. pylori*. The *H. pylori*-inoculated female and male animals had mild antral gastritis within 1 and 2 weeks after inoculation, respectively, and they were persistently colonised for up to 16 weeks after inoculation. Raised antibody titres were detected within 2 weeks in female animals and within 4 weeks after inoculation in male animals. The reason for this sex difference is unknown. The most striking difference between the *H. pylori*-infected Mastomys model and man is the very low number of neutrophils and the predominant presence of lymphocytes in the inflamed mucosa of the former. A similar inflammatory response has been observed in several other models of animal infection [26–28], but the reason for this difference between animal models and man remains unclear. On the other hand, in man, lymphocyte infiltration and follicle infiltration are consistent with chronic Helicobacter-induced gastritis [29]. Therefore, the Mastomys model of *H. pylori* infection may resemble chronically infected humans. *H. pylori* colonised mainly in the antrum of the Mastomys and were detected by immunostaining. Furthermore, inflammatory cells were

<table>
<thead>
<tr>
<th>Time after challenge (weeks)</th>
<th>Male</th>
<th>Female</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Inoculated</td>
<td>Non-inoculated</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>8</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>16</td>
<td>3</td>
<td>0</td>
</tr>
</tbody>
</table>

n = 3 in each test group at each time point.
observed only in the antrum. A similar predominance of *H. pylori* colonisation in the antrum has also been reported in man [30]. The present study demonstrated that Mastomys is susceptible to gastric infection with *H. pylori*, as demonstrated by culture, immunohistochemical detection of *H. pylori*, antibody titres and histopathological findings of local inflammatory response. Moreover, the RFLP pattern of the *flaA* gene PCR product of the infecting strain was virtually identical to those of the recovered isolates. This result confirmed the lack of co-infection with other *Helicobacter* spp. Mastomys could be an ideal animal model

Fig. 2. Experimental *H. pylori* infection caused antral gastritis at (a) 4, (b) 8 and (c) 16 weeks after inoculation. At 16 weeks after inoculation, lymphoid infiltration extended throughout the antrum. Bar, 100 μm.
to study the association between *H. pylori* and carcinoids or adenocarcinoma.

Gastric carcinoids have been shown previously to develop in the oxyntic mucosa of aging male and female Mastomys [31]. In this study, the incidence of carcinoids in both male and female inoculated animals was significantly lower than that in uninoculated animals. It has also been shown that carcinoids develop very rapidly during H2-receptor blockade in Mastomys [23]. It was suggested that the growth of these carcinoids may have been promoted by inhibition of acid secretion [23]. According to this assumption, high acid secretion would reduce the growth of carcinoids. El-Omar *et al.* reported that individuals with gastritis predominantly localised in the antrum by *H. pylori* infection retain high acid secretion [3]. As it has also been demonstrated that gastritis in the Mastomys infection model is localised in the antrum by *H. pylori*, the incidence of carcinoids may be decreased due to high acid secretion. Solcia *et al.* reported that the incidence of *H. pylori* infection was lower in the

**Table 2.** Pathological classification and incidence of carcinoids 18 months after inoculation or non-inoculation with *H. pylori*

<table>
<thead>
<tr>
<th>Tumour type</th>
<th>Inoculated (n = 100)</th>
<th>Non-inoculated (n = 100)</th>
<th>Inoculated (n = 100)</th>
<th>Non-inoculated (n = 100)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Invasive</td>
<td>15</td>
<td>29</td>
<td>2</td>
<td>10</td>
</tr>
<tr>
<td>Mucosal</td>
<td>10</td>
<td>13</td>
<td>2</td>
<td>7</td>
</tr>
<tr>
<td>Microcarcinoid</td>
<td>2</td>
<td>7</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Total</td>
<td>27*</td>
<td>49</td>
<td>6*</td>
<td>21</td>
</tr>
</tbody>
</table>

*p <0.05 compared with the uninoculated group.*
presence of carcinoids than carcinomas and that carcinoid-associated gastritis was usually inactive or poorly active, even when human patients were *H. pylori* positive [32]. On the other hand, in a Mongolian gerbil model, *H. pylori* infection was shown to cause prominent suppression of acid secretion, which appears to be a major cause of hypergastrinaemia [33]. In consequence, ECL carcinoids developed following *H. pylori* infection in Mongolian gerbils [34].

The colonisation rate of male Mastomys tended to be higher than that of female animals at 18 months in the present study. The reasons for this sex difference remain unknown, although it was reported in another study that the rate of carcinoid formation of male Mastomys is higher than that of female animals for reasons which also remain unknown [7]. The difference in the rate of colonisation and that of carcinoid formation may be considered a sex difference. Further studies are needed to clarify the relationship between *H. pylori* infection and sex difference in Mastomys.

Adenocarcinomas of Mastomys have been shown to develop from pre-existing dysplastic glands that originate from several hyperplastic glands without gastric atrophy or metaplasia [7]. In the present study, there was no difference in the incidence of adenocarcinoma between male or female inoculated or uninoculated animals. In man, there have been discrepant results regarding the association between *H. pylori* infection and the diffuse types of gastric cancer [16, 35]. Miehlke et al. compared the gastritis parameter in the antrum and corpus in *H. pylori*-positive gastric carcinoma patients with those in *H. pylori*-positive control patients who had only gastritis [4]. In the corpus only, the grade of *H. pylori* colonisation, grade of gastritis and activity of gastritis were statistically higher in both the intestinal and diffuse types of gastric carcinomas than in the control [4]. Based on the above findings that the Mastomys infection model shows antrum-predominant colonisation and gastritis, *H. pylori* infection in Mastomys would appear not to promote adenocarcinoma. Furthermore, whether *H.
H. pylori infection increases or decreases acid secretion appears to be an important question with respect to gastric cancer.

Eighteen months after inoculation, no serum antibody against *H. pylori* was detected in any of the animals, including those positive for *H. pylori*. The levels of *H. pylori* colonisation 18 months after inoculation were lower than those 16 weeks after inoculation (data not shown); however, the reasons for this finding remain unknown. Although no difficulties appeared in determining the antibody until 16 weeks after inoculation, further work might be needed to produce an anti-Mastomys IgG antibody.

The incidence of carcinoids and adenocarcinoma in this study was lower than those previously reported [7]. As the origin of the Mastomys in this study was the same as that in the previous study, this difference may be attributed to differences in gastric flora between conventional and specific-pathogen-free conditions or differences in environmental factors.

The clinical presentation of *H. pylori* infection is thought to be influenced by the strain diversity of *H. pylori*, factors involving the host or environment, and the duration of infection [36–38]. The present study attempted to inoculate Mastomys with two strains isolated from a patient with gastric cancer, two strains from patients with gastric ulcers and one strain from a patient with duodenal ulcers, but only one of the strains from a patient with gastric ulcers successfully colonised Mastomys (data not shown). It is possible that other strains capable of inducing corpus-predominant colonisation and gastritis might show different results.

In conclusion, this study demonstrated experimental findings that the antrum-predominant colonisation of *H. pylori* caused a decrease in the incidence of carcinoid formation in Mastomys.

We thank Dr T. Takenouchi for his technical assistance.

**References**