Novel Expression of Gastrin (Cholecystokinin-B) Receptors in Azaserine-induced Rat Pancreatic Carcinoma: Receptor Determination and Characterization¹

Weigong Zhou, Stephen P. Povoski, Daniel S. Longnecker, and Richard H. Bell, Jr.²

Department of Surgery, University of Cincinnati College of Medicine, and Department of Veterans Affairs Medical Center, Cincinnati, Ohio 45267 [W. Z., S. P. P., R. H. B. J., and Department of Pathology, Dartmouth Medical School, Hanover, New Hampshire 03756 [D. S. L.]

ABSTRACT

Many reports have emphasized the role of gastrin as a growth factor for normal gastrointestinal mucosa and gastrointestinal cancers. Recent studies have pointed out that this model acts also as a growth factor for the pancreatic cancer cell line AR42J. This effect is mediated by gastrin [cholecystokinin (CCK)-B] receptors. In the present study, we investigated gastrin (CCK-B) receptor expression in the azaserine-induced rat pancreatic carcinoma DSL-6, comparing it to normal rat pancreas, and we also characterized CCK receptor subtypes in this tumor.

The results showed that there is extensive gastrin binding to the DSL-6 pancreatic carcinoma. No evidence of specific gastrin binding to normal pancreas was found. Analysis of the ability of gastrin-17-I to inhibit 125I-gastrin-1 binding demonstrated that gastrin bound to a single class of receptors with a Kᵢ of 0.21 ± 0.04 nM and a binding capacity of 184 ± 29 fmol/mg protein. 125I-Gastrin-1 binding was inhibited by the specific CCK-B receptor antagonist L365,260 approximately 40 times more effectively than by the specific CCK-A receptor antagonist L364,718. Analysis of the ability of cholecystokinin octapeptide (CCK-8) to inhibit 125I-Bolton-Hunter-CCK-8 binding revealed two CCK binding sites, i.e., a high affinity site and a low affinity site. The observed binding affinities of CCK-8 were then introduced into the computer analysis of the dose-inhibition curve of the ability of gastrin-17-I to inhibit binding of 125I-Bolton-Hunter-CCK-8, which was significantly better fit by a three-site model than by a two-site model. The three sites meet the criteria for CCK-B, high affinity CCK-A, and low affinity CCK-A receptors. The binding capacity of CCK-B receptors constitutes 34% of the total high affinity CCK binding sites.

This study demonstrated that DSL-6 pancreatic carcinoma expresses three subtypes of CCK receptors. Gastrin (CCK-B) receptors, which were not detected in normal rat pancreas, constitute about one third of the total high affinity CCK receptors. We suggest that novel expression of gastrin (CCK-B) receptors may be generated by gene mutation or amplification during carcinogenesis and may play an important role in promoting tumor growth.

INTRODUCTION

Adenocarcinoma of the pancreas has become the fifth most common cause of cancer death in the United States and remains nearly incurable, with an average survival from diagnosis until death of approximately 3 months (1). For this reason, there has been considerable interest in trying to identify factors involved in the growth of pancreatic cancer, particularly those factors which may be manipulated. In recent years, several experimental models of chemically induced carcinoma in the exocrine pancreas have been developed in rodents for studying pancreatic carcinogenesis (2), of which one well described example is azaserine-induced pancreatic carcinoma in the rat (3–5). In response to a single injection of the carcinogen azaserine (30 mg/kg body weight) at age 2 weeks, approximately 50% of Lewis rats develop acinar cell adenocarcinoma of the pancreas after a latency period of 18 months.

The peptide hormone gastrin, which was the first gastrointestinal hormone to be isolated and sequenced (6), has been shown to modulate the growth of normal gastrointestinal mucosa (7) and pancreas (8–10) through stimulation of protein and DNA synthesis. Recent studies have pointed out that gastrin may also act as a growth factor in gastrointestinal cancers. Gastrin stimulates the growth of colon carcinomas in vivo (11) and those transplanted into nude mice (12). In addition, it induces proliferation of colon and gastric cancer cell lines (13, 14). These effects are presumed to be receptor mediated. Indeed, in vitro studies have demonstrated the presence of gastrin receptors on gastric and colon cancer cells (15), suggesting that growth of some gastrointestinal cancers is hormonally regulated.

Pancreatic acinar cells from guinea pig have been shown to possess three classes of CCK¹ receptors (16). The high affinity CCK-A receptor, having a high affinity for CCK and a low affinity for gastrin peptides, is involved in pancreatic enzyme secretion. By contrast, the CCK-B receptor does not discriminate between CCK and gastrin peptides. The third receptor is a low affinity CCK-A receptor that has a low affinity for CCK and gastrin. The biological events related to CCK-B and the third receptor subtype are still poorly documented.

It has been previously reported that the rat pancreatic carcinoma cell line AR42J possesses both CCK-A and CCK-B receptor subtypes (17). It has also been demonstrated that occupancy of CCK-B receptors by gastrin stimulates early events associated with cell proliferation, such as ornithine decarboxylase activity (18), [3H]thymidine incorporation (19), and the Na⁺/H⁺ antiporter (20).

We have previously demonstrated the overexpression of high affinity CCK receptors in the azaserine-induced rat pancreatic carcinoma DSL-6 (21). In the present study, we looked for the presence of gastrin binding sites (CCK-B receptors) by competitive binding assays. If, compared to normal pancreas, pancreatic tumors possess an enhanced ability to bind gastrin, this may imply that there is a gene mutation or amplification during carcinogenesis and that gastrin may play an important role in pancreatic tumor promotion and progression.

MATERIALS AND METHODS

Chemicals. MES and leupeptin were from Boehringer Mannheim GmbH (Penzburg, Germany). NaCl, KCl, MgCl₂, ethylene glycol bis(β-aminoethylether)-N,N,N',N'-tetraacetic acid, N-[2-hydroxyethyl]-piperazine-N'-[2-ethanesulfonic acid], bacitracin, chymostatin, and bovine albumin were from Sigma Chemical Company (St. Louis, MO). Gelatin was from Mathesc i Coleman & Bell Manufacturing Chemists (Norwood, OH). Azaserine was from Calbiochem-Behring (La Jolla, CA). ³H-thymidine incorporation (19), and the Na⁺/H⁺ antiporter (20).

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Gastrin-17-I and CCK-8 were from BACHEM, Inc. (Torrance, CA). L365,260 and L364,718 were gifts from Dr. William Friedinger, Merck Sharp & Dohme Research Laboratories (Rahway, NJ). 125I-Gastrin-I (2200 Ci/mmol) and 125I-BH-CCK-8 (2200 Ci/mmol) were from DuPont NEN Research Products (Boston, MA). Bio-Rad protein assay reagent was from Bio-Rad Laboratories (Richmond, CA).

Preparation of Tissue Sections for Binding Studies. DSL-6 was harvested from donor animals, minced, and injected s.c. in the interscapular area of 1-2-month-old male Lewis rats (Charles River Breeding Laboratories, Wilmington, MA). After the implanted tumor had grown to 1-2 cm in diameter, animals were decapitated under ether anesthesia and the tumor was harvested. At the same time, normal pancreas from tumor-bearing animals was harvested via a midline laparotomy (n = 6). All tissues were immediately frozen on dry ice and were then transferred to a -70°C freezer. For binding assays, tissue sections (20 μm) were cut at -20°C on a cryostat microtome, mounted on gelatin-coated microscope slides, and dried for 18 h at -22°C.

Binding of 125I-Gastrin-I to Tissue Sections. Binding assays were performed using the method of von Schrenck et al. (22). Tissue sections were preincubated in 50 mM MES buffer containing 0.5% albumin for 20 min at pH 6.5 and 22°C. Sections were then incubated for 4 h at 22°C, pH 6.5, in 50 mM MES buffer containing 0.5% albumin, 0.025% bacitracin, 4 μg/ml leupeptin, 2 μg/ml chymostatin, 130 mM NaCl, 7.7 mM KCl, 5 mM MgCl2, 1 mM ethylene glycol bis(β-aminoethyl ether)-N,N,N′,N′-tetraacetic acid, and 25 pm 125I-gastrin-I. Incubation volume was 3 ml for four slides. For competitive binding assays, the appropriate concentrations of unlabeled ligands were added to the incubation buffer. At the conclusion of the incubation, tissue sections were rinsed three times in 50 mM MES washing buffer (pH 6.5, 4°C) with 0.5% albumin and were then wiped from the slides with a filter paper. The filter papers were then placed in tubes for counting in a gamma counter. Binding of radiolabeled ligand in the absence of unlabeled ligand was taken to represent maximum binding. Binding of labeled ligand in the presence of an excess of unlabeled ligand (1.0 x 10^-5 M) was considered to represent nonsaturable binding. Nonsaturable binding was <20% of total binding in all experiments reported below.

Binding of 125I-BH-CCK-8 to Tissue Sections. Binding of 125I-BH-CCK-8 to tissue sections was measured by using the same procedure described above, except that the pH of the preincubation, incubation, and washing buffers was 6.0 instead of 6.5.

Analysis of Binding Data. Binding parameters (Kd and Bmax) were determined for each binding site by using a nonlinear model-fitting program (LIGAND) (23). The values of Kd were determined by the method of Cheng and Prusoff (24). The number of binding sites was determined by repetitive fits with increasing numbers of sites and was established by determining the smallest number of sites that statistically best fit the data, using the F test and P < 0.05 as the level of significance. All data in the experiments described below are presented as mean ± SD unless otherwise indicated.

RESULTS

To determine the optimum conditions for binding of 125I-gastrin-I to sections of DSL-6 carcinoma and normal rat pancreas, the pH, time, and temperature dependence was determined for each tissue. For DSL-6 carcinoma, maximal binding occurred at pH 6.5 (Fig. 1). No saturable binding occurred to sections of normal pancreas. At pH 6.5, adding 10 μM gastrin-17-I decreased total binding by 97% for sections of DSL-6 carcinoma and by 6% for sections of normal pancreas. Binding of 125I-gastrin-I to DSL-6 carcinoma was time and temperature dependent (Fig. 2). At 22°C, binding was half-maximal at 1.5 h and maximal at 4 h. Binding was 65% lower at 4°C and 88% lower at 37°C than at 22°C. When 10 μM gastrin-17-I was added at 22°C binding was reduced by 94% and at 4°C binding was reduced by 86%; at 37°C, binding was not reduced. In all subsequent experiments binding was determined after 4 h at 22°C, pH 6.5.

To study the reversibility of binding of 125I-gastrin-I to DSL-6 carcinoma, tissue sections were incubated with 125I-gastrin-I for 4 h at 22°C, washed, and reincubated in incubation buffer not containing labeled or unlabeled gastrin. At 37°C, 18% of the saturably bound radioactivity dissociated from tissue sections at 1 h, 61% at 2 h, 82% at 3 h, and 96% at 4 h (Fig. 3). At 22°C, dissociation from DSL-6 carcinoma tissue sections was slower: 15% at 1 h, 20% at 2 h, 25% at 3 h, and 27% at 4 h. At 4°C, no dissociation could be found after 4 h of reincubation.

![Fig. 1. pH dependence of binding of 125I-gastrin-I to DSL-6 pancreatic carcinoma tissue sections (A) and to normal rat pancreas tissue sections (B). Sections were incubated at the indicated pH with 125I-gastrin-I alone (O) or with 10 μM unlabeled gastrin-17-I (F] with either MES (pH 5.0-6.5) or N-[2-hydroxyethyl]-piperazine-N′-[2-ethanesulfonic acid] (pH 7.0 or 7.5) buffer. Results are percentages of total radioactivity added to the incubation volume that bound to tissue sections. Results are means from at least three separate experiments. In each experiment, each value was determined in duplicate. Vertical bars, SE.](image-url)
GASTRIN RECEPTORS IN PANCREATIC CARCINOMA

To determine the number of different binding sites on DSL-6 pancreatic carcinoma, we first used CCK-8 to inhibit binding of 125I-BH-CCK-8 (Fig. 6). The ability of CCK-8 to inhibit binding of 125I-BH-CCK-8 was analyzed by using a nonlinear model-fitting computer program (LIGAND). The dose-inhibition curve for CCK-8 was fit significantly better \( P = 0.02 \) by a two-site model than by a one-site model (Fig. 7), and a

To examine the affinity and capacity of gastrin binding to the DSL-6 carcinoma, unlabeled gastrin-17-I in graded concentrations was used to competitively inhibit binding of 125I-gastrin-1 (Fig. 4). Scatchard analysis of these data demonstrated that gastrin binds to a single class of high affinity receptors on DSL-6 carcinoma. The receptor has a \( K_d \) of 0.21 ± 0.04 nM, with a binding capacity of 184 ± 29 fmol/mg protein.

To determine if the observed high affinity binding of 125I-gastrin-I to the DSL-6 carcinoma is to a CCK-B receptor, we used the specific CCK-A receptor antagonist L364,718 (26) and the CCK-B receptor antagonist L365,260 (27) to inhibit 125I-gastrin-I binding (Fig. 5). L365,260 \( (K_i = 0.02 \pm 0.01 \mu M) \) was approximately 40 times more potent than L364,718 \( (K_i = 0.78 \pm 0.15 \mu M) \) in inhibiting 125I-gastrin-I binding to DSL-6 carcinoma tissue sections (Table 1). Thus, 125I-gastrin-I binding appeared to be to a CCK-B receptor.

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Fig. 2. Time and temperature dependence of binding of 125I-gastrin-I to DSL-6 pancreatic carcinoma tissue sections. Sections were incubated with 125I-gastrin-I for the indicated times at 22°C (A) and at the indicated temperatures for 4 h (B) with [3] or without [10 μM unlabeled gastrin-17-I. Results are percentages of total radioactivity added to the incubation volume that bound to tissue sections. Results are means of at least three separate experiments. In each experiment, each value was determined in duplicate. Vertical bars, SE.

Fig. 3. Dissociation of bound 125I-gastrin-I from DSL-6 pancreatic carcinoma tissue sections. Tissue sections were first incubated for 4 h with 125I-gastrin-I with or without 10 μM unlabeled gastrin-17-I. Sections were subsequently washed to remove free radioactivity and were reincubated in incubation buffer not containing labeled or unlabeled gastrin at 4°C (□), 22°C (○), or 37°C (▲). Results are percentages of saturably bound 125I-gastrin-I at the beginning of the second incubation, which was 4.4% of total added counts from the first incubation. Results are means from four separate experiments. In each experiment, each value was determined in duplicate.

Fig. 4. Ability of gastrin-17-I to inhibit binding of 125I-gastrin-I to DSL-6 pancreatic carcinoma tissue sections. Sections were incubated for 4 h at 22°C, pH 6.5, with 25 pm 125I-gastrin-I plus the indicated concentration of unlabeled gastrin-17-I. Saturable binding of 125I-gastrin-I is expressed as a percentage of radioactivity bound in the absence of unlabeled gastrin-17-I. Results are means from six separate experiments. In each experiment, each value was determined in duplicate. Vertical bars, SE.

Fig. 5. Time (Hour)

Fig. 6. GASTRIN CONCENTRATION (logM)
Fig. 5. Ability of L365,260 and L364,718 to inhibit binding of $^{125}$I-gastrin-I to DSL-6 pancreatic carcinoma tissue sections. Tissue sections were incubated for 4 h at 22°C, pH 6.5, with 25 pm $^{125}$I-gastrin-I alone or with the indicated concentrations of L365,260 (O) or L364,718 (■). Saturable binding is expressed as a percentage of radioactivity bound in the absence of L365,260 or L364,718. Results are means from six separate experiments. In each experiment, each value was determined in duplicate. Vertical bars, SE.

Table 1. Affinities and binding capacities from dose-inhibition curves for the ability of L365,260 and L364,718 to inhibit $^{125}$I-gastrin-I binding in DSL-6 pancreatic carcinoma

| Parameter          | L365,260          | L364,718          | $^a$  
|--------------------|-------------------|-------------------|---
| $K_i$ (nM)         | 0.02 ± 0.01       | 0.78 ± 0.15       | <0.01  
| $B_{max}$ (fmol/mg protein) | 183.7 ± 19.8 | 51.0 ± 10.8 | <0.01  

$^a$ Student's t test.

Fig. 6. Ability of CCK-8 to inhibit binding of $^{125}$I-BH-CCK-8 to DSL-6 pancreatic carcinoma tissue sections. Sections were incubated at 22°C, pH 6.0, for 4 h with 25 pm $^{125}$I-BH-CCK-8. Saturable binding of $^{125}$I-BH-CCK-8 is expressed as a percentage of radioactivity bound in the absence of CCK-8. Results are means from six separate experiments. In each experiment, each value was determined in duplicate. Vertical bars, SE.

Fig. 7. Scatchard plot of ability of CCK-8 to inhibit binding of $^{125}$I-BH-CCK-8 to DSL-6 pancreatic carcinoma tissue sections. Data from Fig. 6 were analyzed by using a nonlinear model-fitting program (LIGAND), and curves were best fit by a two-binding site model. $K_d$ and $B_{max}$ for CCK-8 at these two sites are listed in Table 2.
Data were best fit by a model having two binding sites, a low affinity site.

Table 2. Affinities and binding capacities from dose-inhibition curve for the ability of CCK-8 to inhibit $^{125I}$-BH-CCK-8 binding in DSL-6 pancreatic carcinoma

<table>
<thead>
<tr>
<th>Parameter</th>
<th>High affinity</th>
<th>Low affinity</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K_d$ (nM)</td>
<td>0.51 ± 0.03</td>
<td>2.753 ± 1.153</td>
</tr>
<tr>
<td>$B_{max}$ (fmol/mg protein)</td>
<td>324 ± 63</td>
<td>3,899 ± 1,497</td>
</tr>
</tbody>
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Values represent means ± SD from six separate experiments. Data in Figs. 6 and 7 were analyzed by using a nonlinear model-fitting program (LIGAND). The data were best fit by a model having two binding sites, i.e., a high affinity site and a low affinity site.

In our study, the $^{125I}$-gastrin-I binding data indicated that gastrin (CCK-B) receptors are extensively expressed in DSL-6 pancreatic carcinoma. No saturable binding could be detected in normal pancreas, although the binding assays utilized do not rule out the possibility of the expression of a minute quantity of gastrin (CCK-B) receptors. It is our belief that these receptors are first expressed in significant amounts in DSL-6 during the process of carcinogenesis at the point of malignant transformation. The relative abilities of L365,260 and L364,718 to inhibit binding of $^{125I}$-gastrin-I further demonstrated that these receptors are of the CCK-B subtype.

### DISCUSSION

Many studies have emphasized the role of gastrin peptides as proliferative agents on cancer cells (9–12). In addition, studies using the nonpeptide gastrin receptor antagonist proglumide to prevent the growth-promoting effects of gastrin demonstrate that mediation of the effects is via a gastrin receptor (29–31).

Several investigators have previously demonstrated the presence of CCK receptors on pancreatic carcinoma cells. Logsdon (32) demonstrated high affinity CCK receptors in the AR42J cell line, which like DSL-6 is derived from an azaserine-induced acinar cell carcinoma. He also noted that CCK receptors on AR42J cells seemed to be different from those in normal rat pancreas. Scemama et al. (18) reported that AR42J cells possess both CCK-A and CCK-B receptor subtypes and that CCK-B receptor occupation is related to stimulation of ornithine decarboxylase activity. Likewise, Seva et al. (19) demonstrated that occupation of the CCK-B receptor subtype in AR42J cells led to an increase in cell proliferation as measured by $[^3H]$thymidine incorporation.

In our study, the $^{125I}$-gastrin-I binding data indicated that gastrin (CCK-B) receptors are extensively expressed in DSL-6 pancreatic carcinoma. No saturable binding could be detected in normal pancreas, although the binding assays utilized do not rule out the possibility of the expression of a minute quantity of gastrin (CCK-B) receptors. It is our belief that these receptors are first expressed in significant amounts in DSL-6 during the process of carcinogenesis at the point of malignant transformation. The relative abilities of L365,260 and L364,718 to inhibit binding of $^{125I}$-gastrin-I further demonstrated that these receptors are of the CCK-B subtype.
Previous studies characterizing CCK receptors on dispersed pancreatic acini or pancreatic tissue sections using \(^{125}\text{I}-\text{BH-CCK-8}\) or various \(^{125}\text{I}\)-labeled carboxyl-terminal fragments or analogues of CCK have demonstrated two classes of CCK binding sites in rats, mice, guinea pigs, dogs, and the AR42J cell line (17, 33–37), one with a high affinity for CCK and the other with a low affinity. Recently, it was demonstrated that \(^{125}\text{I}-\text{BH-CCK-8}\) binds to three classes of receptors on dispersed pancreatic acini of guinea pigs, not two as reported previously (16). Two of these three classes of receptors bound CCK-8 with equal high affinity. One of these two high affinity CCK binding sites also had a high affinity for gastrin-17-I and the other had a 355-fold lower affinity for gastrin-17-I. These two sites are referred to as CCK-B and high affinity CCK-A receptor subtypes, respectively. The third class had low affinity for both CCK-8 and gastrin-17-I. In the present study, we also demonstrated two classes of receptors for CCK by computer analysis of the dose-inhibition curve of the ability of CCK-8 to inhibit the binding of \(^{125}\text{I}-\text{BH-CCK-8}\), one with high affinity for CCK-8 but low capacity and another with low affinity for CCK-8 but high capacity. Then, the binding affinities of CCK-8 were introduced into the computer analysis of the dose-inhibition curve of the ability of gastrin-17-I to inhibit binding of \(^{125}\text{I}-\text{BH-CCK-8}\), which was significantly better fit by a three-site model than by a two-site model. Two of these three sites were determined to correspond to the high affinity CCK binding site. One of them, \(R_2\) (Table 3), had the highest affinity for gastrin-17-I (\(K_a = 0.20 \pm 0.10\) nM). It appears to be the CCK-B receptor subtype. The other, \(R_3\) (Table 3), had a 1000-fold lower affinity for gastrin-17-I (\(K_a = 214 \pm 47\) nM). It appears to be the high affinity CCK-A receptor subtype. The CCK-B receptors constitute 34\% of the binding capacity of high affinity CCK receptors. In addition, a site, \(R_3\) (Table 3), with the lowest affinity for gastrin-17-I (\(K_a = 5695 \pm 2335\) nM) was found to correspond to the low affinity CCK-A binding site. It appears to be the low affinity CCK-A receptor subtype.

Carcinogenesis is a multistage process that is generally believed to include an initiation phase, in which initial cellular DNA damage and gene mutation occur, followed by promotion and progression phases. The development of carcinomas depends on further alteration in the initiated cell during the promotion phase. We surmise that the novel expression of gastrin (CCK-B) receptors in DSL-6 pancreatic carcinoma may be a result of a gene mutation or amplification during initiation and may provide a mechanism for promotion and/or progression of tumor cell growth.

In conclusion, DSL-6 pancreatic carcinoma expresses three subtypes of CCK receptors. Gastrin (CCK-B) receptors, which were not detected in normal rat pancreas, constitute about one third of the total high affinity CCK receptors in DSL-6 pancreatic carcinoma. The expression of gastrin (CCK-B) receptors may be generated by gene mutation or amplification during carcinogenesis and may play an important role in promoting tumor growth.

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