TREATMENTS FOR GASTROINTESTINAL DISORDERS

FIELD OF THE INVENTION

[0001] This invention relates to peptides, compositions and methods for treating upper gastrointestinal disorders.

PRIORITY CLAIM

[0002] This application claims priority to United States Application Serial No. 61/259,264, filed November 09, 2009. The entire contents of the aforementioned application are incorporated herein by reference.

SEQUENCE LISTING

[0003] This application incorporates by reference in its entirety the Sequence Listing entitled "IW077US_ST25.txt" (6.64 kilobytes), which was created November 3, 2010 and filed electronically herewith.

BACKGROUND

[0002] Functional dyspepsia (FD) and gastroparesis (GP) are upper gastrointestinal (GI) disorders that are collectively characterized by symptoms that include bloating, epigastric (upper abdominal) pain and/or burning, nausea, vomiting and early satiation. Therapeutic options for FD and GP patients are extremely limited, due to both lack of efficacy and poor safety profiles for existing therapies. Dyspepsia is defined as the presence of one or more dyspepsia symptoms (epigastric pain, burning, bothersome postprandial fullness, and early satiation) that are considered to originate from the gastroduodenal region, in the absence of any organic, systemic, or metabolic disease that is likely to explain the symptoms (see Drossman, D.A., ed., Rome III: The Functional Gastrointestinal Disorders, 3rd Ed., McLean, VA: Degnon Associates, Inc., 2006). FD refers to dyspepsia that has no structural explanation after standard medical investigations, including upper endoscopy. Pathophysiological mechanisms that may be involved in FD include, among others, delayed gastric emptying, impaired gastric accommodation, hypersensitivity to gastric distention, altered duodenal sensitivity to lipids or acid, and abnormal duodenojejunal motility. Prolonged duodenal acid exposure is also seen in some FD and GP patients, and this exposure may slow gastric emptying and cause FD or GP-like symptoms. Dyspepsia is a common

syndrome that accounts for about 30% of cases seen by gastroenterologists, with FD representing about 60% of all such dyspepsia cases.

[0003] GP refers to abnormal gastric motility characterized by delayed gastric emptying in the absence of mechanical obstruction. GP may be idiopathic or may be caused by various conditions, including Type I or Type II diabetes mellitus, viral infection, scleroderma, nervous system disorders such as Parkinson's disease, metabolic disorders such as hypothyroidism, post-operative ileus, and certain medications, including narcotic pain medications, tricyclic antidepressants and calcium channel blockers. Treatment for cancer, including chemotherapeutic drugs and radiation to the chest and abdomen can also cause gastroparesis, either temporarily or permanently. The most common symptoms are nausea, vomiting, bloating, epigastric pain, weight loss and early satiation. Gastroparesis is a chronic condition that can lead to frequent hospitalization, decreased quality of life, and increased disability and, in severe cases, increased mortality. Severe, symptomatic GP is common in individuals suffering from diabetes, affecting from 5-10% of diabetics for a total patient population of 1 million in the U.S. alone.

[0004] Conventional treatment options for FD and GP, as well as other upper gastrointestinal disorders, have been of limited efficacy for many patients. Thus, there remains a need for new compounds and methods of treating FD, GP and other gastrointestinal disorders.

SUMMARY

[0005] The present invention features peptides, compositions, and related methods for treating upper gastrointestinal disorders and conditions (e.g., dyspepsia, GP, post-operative gastric ileus, a functional esophageal disorder, a functional gastroduodenal disorder, gastroesophageal reflux disease (GERD), or a duodenal or stomach ulcer) as well as other conditions and disorders are described herein The compositions feature peptides that activate guanylate cyclase C (GC-C) in the upper GI but activate GC-C in the lower GI much more weakly or not at all. Without being bound by any particular theory, the peptides of the invention are useful because they may alleviate symptoms of upper GI disorders (in whole or in part by increasing upper GI motility and/or reducing epigastric pain/discomfort and bloating) without causing pronounced effects in the lower GI tract (e.g., dose-limiting alterations in bowel habits, including diarrhea) at dose levels and dosing frequency sufficient to reduce upper GI symptoms. The peptides of the invention are also useful for ameliorating gastrointestinal pain and discomfort.

[0006] One aspect of the present invention provides a peptide or a pharmaceutically acceptable salt thereof, wherein the peptide comprises the amino acid sequence:

$Xaa_1\ Xaa_2\ Xaa_3\ Xaa_4\ Cys_5\ Xaa_6\ Xaa_7\ Xaa_8\ Cys_9\ Asn_{10}\ Pro_{11}\ Ala_{12}\ Cys_{13}\ Xaa_{14}\ Gly_{15}\ Xaa_{16}\ Xaa_{17}$, or a pharmaceutically acceptable salt thereof; wherein

Xaa_1 is Asn, D-Asn, Gln, D-Gln, Pro, Ala, β-Ala, D-Ala, Val, D-Val, Gly, Thr, D-Thr, Asp, D-Asp, γ-carboxylated Asp, Glu, D-Glu, γ-carboxylated Glu, α-aminosuberic acid (Asu), α-aminoadipic acid (Aad), α-aminopimelic acid (Apm), or is absent;

Xaa_2 is Asp, γ-carboxylated Asp, Glu, γ-carboxylated Glu, Asu, Aad, Apm, or is absent;

Xaa_3 is Asp, γ-carboxylated Asp, Glu, γ-carboxylated Glu, Asu, Aad, Apm, or is absent;

Xaa_4 is Cys or D-Cys;

Xaa_6 is P-Ser, P-Thr, P-homo-Ser, 4-hydroxyvaline phosphate, P-homo-Thr, P-Cys or P-Tyr;

Xaa_7 is Tyr, Leu, Phe or Ile;

Xaa_8 is Cys or D-Cys;

Xaa_{14} is Thr, Ala or Phe;

Xaa_{16} is Cys or D-Cys; and

Xaa_{17} is Tyr, D-Tyr, or is absent;

wherein:

if Xaa_1 is present, Xaa_1 may be modified on its amino group by methyl, ethanedioic acid, propanedioic acid, butanedioic acid, pentanedioic acid, hexanedioic acid, heptanedioic acid or octanedioic acid;

if Xaa_1 is absent and Xaa_2 is present, then Xaa_2 may be modified on its amino group by methyl, ethanedioic acid, propanedioic acid, butanedioic acid, pentanedioic acid, hexanedioic acid, heptanedioic acid or octanedioic acid; or

if both Xaa_1 and Xaa_2 are absent, then Xaa_3 may be modified on its amino group by methyl, ethanedioic acid, propanedioic acid, butanedioic acid, pentanedioic acid, hexanedioic acid, heptanedioic acid or octanedioic acid.

[0007] A second aspect of the present invention provides pharmaceutical compositions comprising a peptide of the present invention.

[0008] A third aspect of the present invention provides methods for treating a gastrointestinal disorder, which include administering a pharmaceutical composition according to the present invention.

[0009] The details of one or more embodiments of the invention are set forth in the accompanying description.

BRIEF DESCRIPTION OF THE FIGURES

[00010] Figure 1A illustrates the reaction of an exemplary peptide of the present invention with alkaline phosphatase.

[00011] Figure 1B illustrates the hydrolysis of the control *p*-nitrophenylphosphate by phosphatases;

[00012] Figure 2 presents an example showing that Peptide 2 and Peptide 4 promote duodenal fluid secretion.

[00013] Figure 3 presents the results of a study on the stability of Peptide 2, Dephospho-peptide 2, and Peptide 3 in mouse intestinal (jejunum) fluid;

[00014] Figure 4 presents the results of a study on the effect of Peptides 2 and 3 on liquid gastric emptying in STZ-induced diabetic rats;

[00015] These figures are provided by way of example and are not intended to limit the scope of the present invention.

DETAILED DESCRIPTION

[00016] Guanylate cyclase C (GC-C) is a transmembrane receptor that is located on the apical surface of epithelial cells in the stomach and intestine. The receptor has an extracellular ligand-binding domain, a single transmembrane region and a C-terminal guanylyl cyclase domain. When a ligand binds to the extracellular domain of GC-C, the intracellular catalytic domain catalyzes the production of cGMP from GTP. *In vivo*, this increase in intracellular cGMP initiates a cascade of events that leads to increased secretion of chloride and bicarbonate into the intestinal lumen, increased luminal pH, decreased luminal sodium absorption, increased fluid secretion, and acceleration of intestinal transit. cGMP, which is secreted bidirectionally from the epithelium into the mucosa and lumen, has also been shown to dampen afferent C fiber firing, suggesting a potential mechanism for the observed analgesic effects of GC-C agonists on visceral pain.

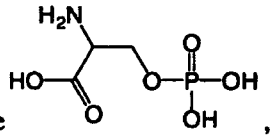
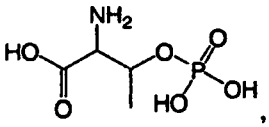
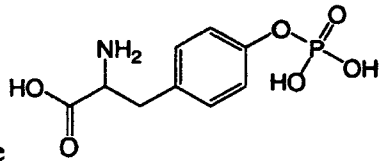
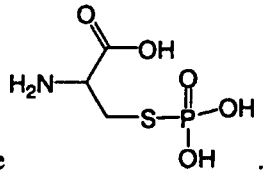
[00017] Linaclotide, a peptide GC-C agonist that is orally administered and currently in clinical trials for treatment of irritable bowel syndrome with constipation (IBS-c) and chronic constipation (CC), has numerous effects on lower GI physiology including: (1) reduced visceral pain, (2) reduced bloating, and (3) increased GI transit, which can lead to increased stool frequency and improved stool consistency. Orally administered linaclotide acts locally

by activating GC-C at the luminal surface; there are no detectable levels of linaclotide seen systemically after oral administration at therapeutic dose levels. Thus, the results from clinical trials of linaclotide, as well as preclinical studies that have been done with linaclotide and related peptides, suggest that GC-C peptide agonists may be used therapeutically.

[00018] It would be useful to have a GC-C agonist that could be used to alleviate upper GI disorders and symptoms (e.g., functional dyspepsia (FD) and gastroparesis (GP)) without promoting pronounced effects on bowel habits that could result from stimulation of GC-C in lower parts of the GI tract. Such a GC-C agonist would decrease the potential for lower GI adverse events, including altered bowel habits and diarrhea. The GC-C peptide agonists described herein are more active in the upper GI tract (e.g., the stomach and duodenum), and less active in the lower GI tract. Such agonists would have benefits in patients who suffer from upper GI disorders (e.g., FD and GP) by (1) reducing visceral pain through cGMP production and or/other mechanisms, (2) decreasing bloating, (3) increasing gastric emptying and/or upper small intestine transit (e.g., duodenal transit), and (4) neutralizing acid in the duodenum by promoting bicarbonate secretion. Importantly, these agonists, by virtue of their targeted activity to the upper GI, would be able to alleviate the symptoms of FD and GP without causing pronounced effects on bowel habits (e.g., that can result from stimulation of GC-C in lower parts of the GI tract).

[00019] In one aspect, the invention provides a novel GC-C peptide agonist useful for the treatment of gastrointestinal disorders, particularly upper GI disorders such as FD and GP. The GC-C peptide agonist is designed to be active in the upper GI, including the esophagus, stomach and upper small intestine (duodenum) but to be less active as it traverses the rest of the small intestine and large intestine. The peptides of the invention are also useful for ameliorating gastrointestinal pain and discomfort. The GC-C agonist peptide contains a phosphoamino acid, e.g., a phosphoserine, to replace a conserved glutamate or aspartate found in other GC-C agonist peptides. The phosphate of a phosphoamino acid $-OPO_3^{2-}$, such as phosphoserine, is able to act as a biomimetic for the COO^- of glutamate or aspartate such that the phosphoamino acid-containing peptide is able to bind to and activate GC-C. The phosphoamino acid-containing peptide can be dephosphorylated by intestinal alkaline phosphatases, which greatly decreases the GC-C binding and agonist activity of the peptide. Intestinal alkaline phosphatases are found throughout the GI tract, and are most active in an alkaline luminal environment, including the small intestine. The phosphoamino acid-containing peptide is able to activate GC-C in the upper GI tract, including the acidic stomach environment and upper GI tract, to promote fluid and bicarbonate secretion. As the peptide

promotes increased fluid and bicarbonate secretion in the upper GI, the intestinal lumen becomes more alkaline, thus activating the alkaline phosphatase activity. Thus, through the action of the peptide on GC-C as well as the movement of the peptide through the intestine, the peptide's phosphoamino acid is converted to the dephosphorylated amino acid, thereby decreasing its activity as a GC-C agonist as it transits from the upper to lower GI.

[00020] As used herein, the term "P-" preceding an amino acid or the three letter abbreviation thereof, refers to a phosphoamino acid. For example, the terms "P-Ser", "P-Thr", "P-Tyr", "P-Cys", "P-homo-Cys", "P-homo-Ser" and "P-homo-Thr" refer to phosphoserine, phosphothreonine, phosphotyrosine, phosphocysteine, phosphohomocysteine, phosphohomoserine, and phosphohomothreonine, respectively. As used herein, a phosphoamino acid refers to an ester or thioester of an amino acid and phosphoric acid; e.g., the hydrogen on the alcohol or thiol functional group is replaced by $-P(O)(OH)_2$. For example, P-Ser has the structure , P-Thr has the structure , P-Tyr has the structure , and P-Cys has the structure .

[00021] In one aspect, the present invention provides a peptide or a pharmaceutically acceptable salt thereof, wherein the peptide comprises the amino acid sequence

$Xaa_1\ Xaa_2\ Xaa_3\ Xaa_4\ Cys_5\ Xaa_6\ Xaa_7\ Xaa_8\ Cys_9\ Asn_{10}\ Pro_{11}\ Ala_{12}\ Cys_{13}\ Xaa_{14}\ Gly_{15}\ Xaa_{16}\ Xaa_{17}$, or a pharmaceutically acceptable salt thereof; wherein

Xaa_1 is Asn, D-Asn, Gln, D-Gln, Pro, Ala, β-Ala, D-Ala, Val, D-Val, Gly, Thr, D-Thr, Asp, D-Asp, γ-carboxylated Asp, Glu, D-Glu, γ-carboxylated Glu, α-aminosuberic acid (Asu), α-aminoadipic acid (Aad), α-aminopimelic acid (Apm), or is absent;

Xaa_2 is Asp, γ-carboxylated Asp, Glu, γ-carboxylated Glu, Asu, Aad, Apm, or is absent;

Xaa_3 is Asp, γ-carboxylated Asp, Glu, γ-carboxylated Glu, Asu, Aad, Apm, or is absent;

Xaa_4 is Cys or D-Cys;

Xaa_6 is P-Ser, P-Thr, P-homo-Ser, 4-hydroxyvaline phosphate, P-homo-Thr, P-Cys or P-Tyr;

Xaa_7 is Tyr, Leu, Phe or Ile;

Xaa_8 is Cys or D-Cys;

Xaa_{14} is Thr, Ala or Phe;

Xaa_{16} is Cys or D-Cys; and

Xaa_{17} is Tyr, D-Tyr, or is absent;

wherein:

if Xaa_1 is present, Xaa_1 may be modified on its amino group by methyl, ethanedioic acid, propanedioic acid, butanedioic acid, pentanedioic acid, hexanedioic acid, heptanedioic acid or octanedioic acid;

if Xaa_1 is absent and Xaa_2 is present, then Xaa_2 may be modified on its amino group by methyl, ethanedioic acid, propanedioic acid, butanedioic acid, pentanedioic acid, hexanedioic acid, heptanedioic acid or octanedioic acid; or

if both Xaa_1 and Xaa_2 are absent, then Xaa_3 may be modified on its amino group by methyl, ethanedioic acid, propanedioic acid, butanedioic acid, pentanedioic acid, hexanedioic acid, heptanedioic acid or octanedioic acid.

[00022] In some embodiments, both Xaa_2 and Xaa_3 are absent. In other embodiments, Xaa_2 is Asp or Glu and Xaa_3 is absent. In yet other embodiments, Xaa_2 is Asp or Glu and Xaa_3 is Asp or Glu.

[00023] In some embodiments, Xaa_7 is Tyr or Leu.

[00024] In some embodiments, Xaa_{14} is Thr.

[00025] In some embodiments, Xaa_{17} is Tyr or is absent.

[00026] In some embodiments, Xaa_1 is Asn, D-Asn, Gln, D-Gln, Pro, Ala, β-Ala, D-Ala, Val, D-Val, Gly, Thr, D-Thr, Asp, D-Asp, Glu or D-Glu. In further embodiments, Xaa_1 is Asp, D-Asp, Glu or D-Glu.

[00027] In some embodiments, Xaa_6 is P-Ser or P-Thr. In further embodiments, Xaa_6 is P-Ser.

[00028] In some embodiments, Xaa_1, Xaa_2 and Xaa_3 are absent and Xaa_4 is D-Cys or Cys. In further embodiments, Xaa_7 is Tyr or Leu. In further embodiments, Xaa_{14} is Thr. In further embodiments, Xaa_{17} is Tyr or is absent. In further embodiments, Xaa_6 is P-Ser.

[00029] In some embodiments, at least one of Xaa_4, Xaa_8 or Xaa_{16} is Cys. In some embodiments, at least two of Xaa_4, Xaa_8 or Xaa_{16} are Cys. In some embodiments, all of

Xaa_4, Xaa_8 and Xaa_{16} are Cys. In some embodiments, at least one of Xaa_4, Xaa_8 or Xaa_{16} is D-Cys. In some embodiments, at least two of Xaa_4, Xaa_8 or Xaa_{16} are D-Cys. In some embodiments, all of Xaa_4, Xaa_8 and Xaa_{16} are D-Cys.

[00030] In some embodiments, a peptide or pharmaceutically acceptable salt thereof is provided, wherein the peptide comprises the amino acid sequence

Cys_4 Cys_5 P-Ser_6 Xaa_7 Cys_8 Cys_9 Asn_{10} Pro_{11} Ala_{12} Cys_{13} Thr_{14} Gly_{15} Cys_{16} Xaa_{17}, wherein Xaa_7 is Tyr or Leu.

[00031] In some embodiments, a peptide or pharmaceutically acceptable salt thereof is provided, wherein the peptide comprises the amino acid sequence

Asp Asp Cys Cys P-Ser Leu Cys Cys Asn Pro Ala Cys Thr Gly Cys Tyr;

Asp Asp Cys Cys P-Ser Leu Cys Cys Asn Pro Ala Cys Thr Gly Cys;

Asp Asp Cys Cys P-Ser Tyr Cys Cys Asn Pro Ala Cys Thr Gly Cys Tyr;

Asp Asp Cys Cys P-Ser Tyr Cys Cys Asn Pro Ala Cys Thr Gly Cys;

Cys Cys P-Ser Leu Cys Cys Asn Pro Ala Cys Thr Gly Cys Tyr;

Cys Cys P-Ser Leu Cys Cys Asn Pro Ala Cys Thr Gly Cys;

Cys Cys P-Ser Tyr Cys Cys Asn Pro Ala Cys Thr Gly Cys Tyr; or

Cys Cys P-Ser Tyr Cys Cys Asn Pro Ala Cys Thr Gly Cys.

[00032] In some embodiments, a peptide or pharmaceutically acceptable salt thereof is provided, wherein the peptide comprises peptide comprises no more than 50, 40, 30 or 20 amino acids. In further embodiments, the peptide comprises no more than 19, 18, 17, 16, 15 or 14 amino acids.

[00033] In another aspect, the present invention provides a peptide or a pharmaceutically acceptable salt thereof, wherein the peptide consists of the amino acid sequence

Xaa_1 Xaa_2 Xaa_3 Xaa_4 Cys_5 Xaa_6 Xaa_7 Xaa_8 Cys_9 Asn_{10} Pro_{11} Ala_{12} Cys_{13} Xaa_{14} Gly_{15} Xaa_{16} Xaa_{17}, or a pharmaceutically acceptable salt thereof; wherein

Xaa_1 is Asn, D-Asn, Gln, D-Gln, Pro, Ala, β-Ala, D-Ala, Val, D-Val, Gly, Thr, D-Thr, Asp, D-Asp, γ-carboxylated Asp, Glu, D-Glu, γ-carboxylated Glu, α-aminosuberic acid (Asu), α-aminoadipic acid (Aad), α-aminopimelic acid (Apm), or is absent;

Xaa_2 is Asp, γ-carboxylated Asp, Glu, γ-carboxylated Glu, Asu, Aad, Apm, or is absent;

Xaa_3 is Asp, γ-carboxylated Asp, Glu, γ-carboxylated Glu, Asu, Aad, Apm, or is absent;

Xaa_4 is Cys or D-Cys;

Xaa_6 is P-Ser, P-Thr, P-homo-Ser, 4-hydroxyvaline phosphate, P-homo-Thr, P-Cys or P-Tyr;

Xaa_7 is Tyr, Leu, Phe or Ile;

Xaa_8 is Cys or D-Cys;

Xaa_{14} is Thr, Ala or Phe;

Xaa_{16} is Cys or D-Cys; and

Xaa_{17} is Tyr, D-Tyr, or is absent;

wherein:

if Xaa_1 is present, Xaa_1 may be modified on its amino group by methyl, ethanedioic acid, propanedioic acid, butanedioic acid, pentanedioic acid, hexanedioic acid, heptanedioic acid or octanedioic acid;

if Xaa_1 is absent and Xaa_2 is present, then Xaa_2 may be modified on its amino group by methyl, ethanedioic acid, propanedioic acid, butanedioic acid, pentanedioic acid, hexanedioic acid, heptanedioic acid or octanedioic acid; or

if both Xaa_1 and Xaa_2 are absent, then Xaa_3 may be modified on its amino group by methyl, ethanedioic acid, propanedioic acid, butanedioic acid, pentanedioic acid, hexanedioic acid, heptanedioic acid or octanedioic acid.

[00034] In some embodiments, both Xaa_2 and Xaa_3 are absent. In other embodiments, Xaa_2 is Asp or Glu and Xaa_3 is absent. In yet other embodiments, wherein Xaa_2 is Asp or Glu and Xaa_3 is Asp or Glu.

[00035] In some embodiments, Xaa_7 is Tyr or Leu.

[00036] In some embodiments, Xaa_{14} is Thr.

[00037] In some embodiments, Xaa_{17} is Tyr or is absent.

[00038] In some embodiments, Xaa_1 is Asn, D-Asn, Gln, D-Gln, Pro, Ala, β-Ala, D-Ala, Val, D-Val, Gly, Thr, D-Thr, Asp, D-Asp, Glu or D-Glu. In further embodiments, Xaa_1 is Asp, D-Asp, Glu or D-Glu.

[00039] In some embodiments, Xaa_6 is P-Ser or P-Thr. In further embodiments, Xaa_6 is P-Ser.

[00040] In some embodiments, Xaa_1, Xaa_2 and Xaa_3 are absent and Xaa_4 is D-Cys or Cys. In further embodiments, Xaa_7 is Tyr or Leu. In further embodiments, Xaa_{14} is Thr. In further embodiments, Xaa_{17} is Tyr or is absent. In further embodiments, Xaa_6 is P-Ser.

[00041] In some embodiments, a peptide or pharmaceutically acceptable salt thereof is provided, wherein the peptide consists of the amino acid sequence

Cys_4 Cys_5 P-Ser_6 Xaa_7 Cys_8 Cys_9 Asn_{10} Pro_{11} Ala_{12} Cys_{13} Thr_{14} Gly_{15} Cys_{16} Xaa_{17}, wherein Xaa_7 is Tyr or Leu.

[00042] In some embodiments, a peptide or pharmaceutically acceptable salt thereof is provided, wherein the peptide consists of the amino acid sequence

Asp Asp Cys Cys P-Ser Leu Cys Cys Asn Pro Ala Cys Thr Gly Cys Tyr;

Asp Asp Cys Cys P-Ser Leu Cys Cys Asn Pro Ala Cys Thr Gly Cys;

Asp Asp Cys Cys P-Ser Tyr Cys Cys Asn Pro Ala Cys Thr Gly Cys Tyr;

Asp Asp Cys Cys P-Ser Tyr Cys Cys Asn Pro Ala Cys Thr Gly Cys;

Cys Cys P-Ser Leu Cys Cys Asn Pro Ala Cys Thr Gly Cys Tyr;

Cys Cys P-Ser Leu Cys Cys Asn Pro Ala Cys Thr Gly Cys;

Cys Cys P-Ser Tyr Cys Cys Asn Pro Ala Cys Thr Gly Cys Tyr; or

Cys Cys P-Ser Tyr Cys Cys Asn Pro Ala Cys Thr Gly Cys.

[00043] In some instances, the peptide is isolated. In others, the peptide is purified.

[00044] In some embodiments, Xaa_6 is any amino acid that may be phosphorylated.

[00045] In some embodiments, a pharmaceutically acceptable salt of the peptide is provided. In some instances, the pharmaceutically acceptable salt is a chloride salt.

Variant peptides

[00046] In some circumstances it can be desirable to treat patients with a variant peptide that binds to and activates intestinal GC-C receptors, but is less active or more active than the non-variant form of the peptide. Reduced activity can arise from reduced affinity for the receptor or a reduced ability to activate the receptor once bound or reduced stability of the peptide. Increased activity can arise from increased affinity for the receptor or an increased ability to activate the receptor once bound or increased stability of the peptide.

[00047] In some peptides one or both members of one or both pairs of Cys residues which normally form a disulfide bond can be replaced by homocysteine, penicillamine, 3-mercaptoproline (Kolodziej et al. 1996 *Int J Pept Protein Res* 48:274); β, β–dimethylcysteine (Hunt et al. 1993 *Int J Pept Protein Res* 42:249) or diaminopropionic acid (Smith et al. 1978 *J Med Chem* 21:117) to form alternative internal cross-links at the positions of the normal disulfide bonds. In other embodiments, the disulfide bonds may be replaced by hydrocarbon crosslinking (Schafmeister et al. 2000 J Am Chem Soc 122:5891, Patgiri et al. 2008 Acc Chem Res 41:1289, Henchey et al. 2008 Curr Opin Chem Biol 12:692).

Production of peptides

[00048] In one embodiment, peptides or precursor peptides of the invention can be produced recombinantly in any known protein expression system, including, without limitation, bacteria (e.g., *E. coli* or *Bacillus subtilis*), insect cell systems (e.g., *Drosophila* Sf9

cell systems), yeast cell systems (e.g., *S. cerevisiae*, *S. saccharomyces*) or filamentous fungal expression systems, or animal cell expression systems (e.g., mammalian cell expression systems). Peptides or precursor peptides of the invention may also be chemically synthesized.

[00049] If the peptide or variant peptide is to be produced recombinantly, e.g., *E. coli*, the nucleic acid molecule encoding the peptide may also encode a leader sequence that permits the secretion of the mature peptide from the cell. Thus, the sequence encoding the peptide can include the pre sequence and the pro sequence of, for example, a naturally-occurring bacterial ST peptide. The secreted, mature peptide can be purified from the culture medium.

[00050] The sequence encoding a peptide described herein is can be inserted into a vector capable of delivering and maintaining the nucleic acid molecule in a bacterial cell. The DNA molecule may be inserted into an autonomously replicating vector (suitable vectors include, for example, pGEM3Z and pcDNA3, and derivatives thereof). The vector nucleic acid may be a bacterial or bacteriophage DNA such as bacteriophage lambda or M13 and derivatives thereof. Construction of a vector containing a nucleic acid described herein can be followed by transformation of a host cell such as a bacterium. Suitable bacterial hosts include but are not limited to, *E. coli, B. subtilis*, *Pseudomonas* and *Salmonella.* The genetic construct also includes, in addition to the encoding nucleic acid molecule, elements that allow expression, such as a promoter and regulatory sequences. The expression vectors may contain transcriptional control sequences that control transcriptional initiation, such as promoter, enhancer, operator, and repressor sequences. A variety of transcriptional control sequences are well known to those in the art. The expression vector can also include a translation regulatory sequence (e.g., an untranslated 5' sequence, an untranslated 3' sequence, or an internal ribosome entry site). The vector can be capable of autonomous replication or it can integrate into host DNA to ensure stability during peptide production.

[00051] The protein coding sequence that includes a peptide described herein can also be fused to a nucleic acid encoding a peptide affinity tag, e.g., glutathione S-transferase (GST), maltose E binding protein, protein A, FLAG tag, hexa-histidine, myc tag or the influenza HA tag, in order to facilitate purification. The affinity tag or reporter fusion joins the reading frame of the peptide of interest to the reading frame of the gene encoding the affinity tag such that a translational fusion is generated. Expression of the fusion gene results in translation of a single peptide that includes both the peptide of interest and the affinity tag. In some instances where affinity tags are utilized, DNA sequence encoding a protease recognition site will be fused between the reading frames for the affinity tag and the peptide of interest.

[00052] Genetic constructs and methods suitable for production of immature and mature forms of the peptides and variants described herein in protein expression systems other than bacteria, and well known to those skilled in the art, can also be used to produce peptides in a biological system.

[00053] Peptides produced recombinantly may be phosphorylated using methods known to those skilled in the art. In some embodiments, a peptide is recombinantly produced, isolated from the cell in which it was expressed, and then phosphorylated using a protein kinase, e.g., a serine/threonine kinase or a tyrosine kinase. A large number of kinases are known in the art and may be used for this purpose. One skilled in the art will recognize that different kinases have differing substrate specificities and will pick a kinase to use based upon the sequence of the peptide. In other embodiments, a peptide is recombinantly produced in a cell that also expresses a serine/threonine kinase or tyrosine kinase that will phosphorylate the peptide. In other embodiments, peptides may be recombinantly produced by incorporating a phosphoamino acid. Methods for modifying tRNA including, but not limited to, modifying the anti-codon, the amino acid attachment site, and/or the accepter stem to allow incorporation of unnatural and/or arbitrary amino acids are known in the art (Biochem. Biophys. Res. Comm. (2008) 372: 480-485; Chem. Biol. (2009) 16:323-36; Nat. Methods (2007) 4:239-44; Nat. Rev. Mol. Cell Biol. (2006) 7:775-82; Methods (2005) 36:227-238; Methods (2005) 36:270-278; Annu. Rev. Biochem. (2004) 73:147-176; Nuc. Acids Res. (2004) 32:6200-6211; Proc. Natl. Acad. Sci. USA (2003) 100:6353-6357; Royal Soc. Chem. (2004) 33:422-430).

[00054] In some embodiments, peptides may be chemically produced. Peptides can be synthesized by a number of different methods including solution and solid phase synthesis using traditional BOC or FMOC protection. For example, the peptide can be synthesized on 2-Chlorotritylchloride or Wang resin using consecutive amino acid couplings. The following protecting groups can be used: Fluorenylmethyloxycarbonyl or *tert*-butyloxycarbonyl (alpha-amino groups, N-terminus); trityl or *tert*-butyl (thiol groups of Cy); *tert*-butyl (γ-carboxyl of glutamic acid and the hydroxyl group of threonine, if present); trityl (β-amid function of the asparagine side chain and the phenolic group of tyrosine, if present); trityl or *tert*-butyldimethylsilyl (hydroxygroup of serine, if present) and *tert*-Butyloxycarbonyl (N-terminus prior to subsequent side chain modifications). Coupling can be effected with DIC and HOBt in the presence of a tertiary amine, and the peptide can be deprotected and cleaved from the solid support in using cocktail K (trifluoroacetic acid 81%, phenol 5%, thioanisole 5%, 1,2-ethanedithiol 2.5%, water 3%, dimethylsulphide 2%, ammonium iodide 1.5% w/w).

After removal of trifluoroacetic acid and other volatiles the peptide can be precipitated using an organic solvent. Disulfide bonds between Cys residues can be formed using dimethyl sulfoxide (Tam et al. (1991) J. Am. Chem. Soc. 113:6657-62) or using an air oxidation strategy. The resulting peptide can be purified by reverse-phase chromatography and lyophilized.

[00055] A phosphoamino acid, e.g., a phosphoserine, may be introduced into a peptide by any method known to one skilled in the art (see, e.g., G.K.Toth et al. (2007), Current Organic Chemistry 11: 409-426). In some embodiments, a protected phosphoamino acid analogue, e.g., a phosphoserine amino acid analogue, can be introduced as part of the peptide assembly on solid phase; e.g. as Fmoc-Ser[PO(OBzl)OH]-OH (T. Wakamiya et al. (1997), Bioorganic and Medicinal Chemistry 5: 135-145, 1997) or as Fmoc-Ser[PO(OAryl/Alkyl)$_2$]-OH (G.K.Toth et al. (2007) Current Organic Chemistry, 11: 409-426). In another embodiment, a protected amino acid analogue, e.g., a protected serine amino acid analogue, can be introduced as part of the peptide assembly on solid phase (e.g. Fmoc-protected serine with a trityl protection for the hydroxyl side chain). After full assembly of the peptide chain Ser[Trt] or Ser[SiMe$_2$*t*Bu] can be selectively deprotected and the phosphate group can be introduced using a phosphoramidite / oxidation strategy (G. Shapiro et al. (1994) Tetrahedron Letters 35: 869-872; P. Hormozdiari et al. (1996) Tetrahedron Letters, 37: 8227-8230). In other embodiments, a chemically produced peptide may be phosphorylated using a serine/threonine kinase or tyrosine kinase as described above.

[00056] Peptides can be made, isolated or used either in form of the free base or as pharmaceutically acceptable salts thereof. Examples of salts include, without limitation, acetate, chloride, sulfate and phosphate salts of the peptide.

Compositions of peptides and GC-C receptor agonists

[00057] In another aspect, compositions are provided wherein the peptides, alone or in combination, can be combined with any pharmaceutically acceptable carrier or medium. The peptides can be combined with materials that do not produce an adverse, allergic or otherwise unwanted reaction when administered to a patient. The carriers or mediums used can include solvents, dispersants, coatings, absorption promoting agents, controlled release agents, and one or more inert excipients (which include starches, polyols, granulating agents, microcrystalline cellulose (e.g., celphere, Celphere beads®), diluents, lubricants, binders, disintegrating agents, and the like), etc. If desired, tablet dosages of the disclosed compositions may be coated by standard aqueous or nonaqueous techniques.

[00058] Examples of excipients for use as the pharmaceutically acceptable carriers and the pharmaceutically acceptable inert carriers and the aforementioned additional ingredients include, but are not limited to binders, fillers, disintegrants, lubricants, anti-microbial agents, and coating agents.

[00059] As used herein, the term "binder" refers to any pharmaceutically acceptable binder that may be used in the practice of the invention. Examples of pharmaceutically acceptable binders include, without limitation, a starch (e.g., corn starch, potato starch and pre-gelatinized starch (e.g., STARCH 1500® and STARCH 1500 LM®, sold by Colorcon, Ltd.) and other starches), maltodextrin, gelatin, natural and synthetic gums such as acacia, powdered tragacanth, guar gum, cellulose and its derivatives (e.g., methylcellulose, hydroxyethyl cellulose, hydroxyethyl methylcellulose, hydroxypropyl cellulose and hydroxypropyl methylcellulose (hypromellose), ethyl cellulose, cellulose acetate, carboxymethyl cellulose calcium, sodium carboxymethyl cellulose, carboxymethylcellulose, powdered cellulose, microfine cellulose, microcrystalline cellulose (e.g. AVICEL™, such as, AVICEL-PH-101™, -103™ and -105™, sold by FMC Corporation, Marcus Hook, PA, USA)), polyvinyl alcohol, polyvinyl pyrrolidone (e.g., polyvinyl pyrrolidone K30), and mixtures thereof.

[00060] Examples of binders that may be particularly used in pharmaceutical compositions include polyvinyl alcohol, polyvinylpyrrolidone (povidone), a starch, maltodextrin or a cellulose ether (such as, for example, methylcellulose, ethylcellulose, carboxymethylcellulose, hydroxyethyl cellulose, hydroxyethyl methylcellulose, hydroxypropyl cellulose and hydroxypropyl methylcellulose).

[00061] As used herein, the term "filler" refers to any pharmaceutically acceptable filler that may be used in the practice of the invention. Examples of pharmaceutically acceptable fillers include, without limitation, talc, calcium carbonate (e.g., granules or powder), dibasic calcium phosphate, tribasic calcium phosphate, calcium sulfate (e.g., granules or powder), microcrystalline cellulose (e.g., Avicel PH101 or Celphere CP-305), microfine cellulose, powdered cellulose, dextrates, kaolin, mannitol, silicic acid, sorbitol, starch (e.g., Starch 1500), pre-gelatinized starch, lactose, glucose, fructose, galactose, trehalose, sucrose, maltose, isomalt, raffinose, maltitol, melezitose, stachyose, lactitol, palatinite, xylitol, myoinositol, and mixtures thereof.

[00062] Examples of pharmaceutically acceptable fillers that may be particularly used for coating the peptides include, without limitation, talc, microcrystalline cellulose (e.g., Avicel PH101 or Celphere CP-305), powdered cellulose, dextrates, kaolin, mannitol, silicic acid,

sorbitol, starch, pre-gelatinized starch, lactose, glucose, fructose, galactose, trehalose, sucrose, maltose, isomalt, dibasic calcium phosphate, raffinose, maltitol, melezitose, stachyose, lactitol, palatinite, xylitol, mannitol, myoinositol, and mixtures thereof.

[00063] As used herein, the term "additives" refers to any pharmaceutically acceptable additive. Pharmaceutically acceptable additives include, without limitation, disintegrants, dispersing additives, lubricants, glidants, antioxidants, coating additives, diluents, surfactants, flavoring additives, humectants, absorption promoting additives, controlled release additives, anti-caking additives, anti-microbial agents (e.g., preservatives), colorants, desiccants, plasticizers and dyes. As used herein, an "excipient" is any pharmaceutically acceptable additive, filler, binder or agent.

[00064] Compositions of the present invention may also optionally include other therapeutic ingredients, anti-caking agents, preservatives, sweetening agents, colorants, flavors, desiccants, plasticizers, dyes, glidants, anti-adherents, anti-static agents, surfactants (wetting agents), anti-oxidants, film-coating agents, and the like. Any such optional ingredient must be compatible with the compound described herein to insure the stability of the formulation. The composition may contain other additives as needed, including for example lactose, glucose, fructose, galactose, trehalose, sucrose, maltose, raffinose, maltitol, melezitose, stachyose, lactitol, palatinite, starch, xylitol, mannitol, myoinositol, and the like, and hydrates thereof, and amino acids, for example alanine, glycine and betaine, and peptides and proteins, for example albumen.

[00065] The compositions can include, for example, various additional solvents, dispersants, coatings, absorption promoting additives, controlled release additives, and one or more inert additives (which include, for example, starches, polyols, granulating additives, microcrystalline cellulose, diluents, lubricants, binders, disintegrating additives, and the like), etc. If desired, tablet dosages of the disclosed compositions may be coated by standard aqueous or non-aqueous techniques. Compositions can also include, for example, anti-caking additives, preservatives, sweetening additives, colorants, flavors, desiccants, plasticizers, dyes, and the like.

[00066] Suitable disintegrants include, for example, agar-agar, calcium carbonate, microcrystalline cellulose, croscarmellose sodium, crospovidone, povidone, polacrilin potassium, sodium starch glycolate, potato or tapioca starch, other starches, pre-gelatinized starch, clays, other algins, other celluloses, gums, and mixtures thereof.

[00067] Suitable lubricants include, for example, calcium stearate, magnesium stearate, mineral oil, light mineral oil, glycerin, sorbitol, mannitol, polyethylene glycol, other glycols,

stearic acid, sodium lauryl sulfate, talc, hydrogenated vegetable oil (e.g., peanut oil, cottonseed oil, sunflower oil, sesame oil, olive oil, corn oil and soybean oil), zinc stearate, ethyl oleate, ethyl laurate, agar, syloid silica gel (AEROSIL 200, W.R. Grace Co., Baltimore, MD USA), a coagulated aerosol of synthetic silica (Evonik Degussa Co., Plano, TX USA), a pyrogenic silicon dioxide (CAB-O-SIL, Cabot Co., Boston, MA USA), and mixtures thereof.

[00068] Suitable glidants include, for example, leucine, colloidal silicon dioxide, magnesium trisilicate, powdered cellulose, starch, talc, and tribasic calcium phosphate.

[00069] Suitable anti-caking additives include, for example, calcium silicate, magnesium silicate, silicon dioxide, colloidal silicon dioxide, talc, and mixtures thereof.

[00070] Suitable anti-microbial additives that may be used, e.g., as a preservative for the peptides compositions, include, for example, benzalkonium chloride, benzethonium chloride, benzoic acid, benzyl alcohol, butyl paraben, cetylpyridinium chloride, cresol, chlorobutanol, dehydroacetic acid, ethylparaben, methylparaben, phenol, phenylethyl alcohol, phenoxyethanol, phenylmercuric acetate, phenylmercuric nitrate, potassium sorbate, propylparaben, sodium benzoate, sodium dehydroacetate, sodium propionate, sorbic acid, thimersol, thymo, and mixtures thereof.

[00071] Suitable antioxidants include, for example, BHA (butylated hydroxyanisole), BHT (butylated hydroxytoluene), vitamin E, propyl gallate, ascorbic acid and salts or esters thereof, tocopherol and esters thereof, alpha-lipoic acid and beta-carotene.

[00072] Suitable coating additives include, for example, sodium carboxymethyl cellulose, cellulose acetate phthalate, ethylcellulose, gelatin, pharmaceutical glaze, hydroxypropyl cellulose, hydroxypropyl methylcellulose, hydroxypropyl methyl cellulose phthalate, methylcellulose, polyethylene glycol, polyvinyl acetate phthalate, shellac, sucrose, titanium dioxide, carnauba wax, microcrystalline wax, and mixtures thereof. Suitable protective coatings include Aquacoat (e.g., Aquacoat Ethylcellulose Aquaeous Dispersion, 15% w/w, FMC Biopolymer, ECD-30), Eudragit (e.g., Eudragit E PO PE-EL, Roehm Pharma Polymers) and Opadry (e.g Opadry AMB dispersion, 20% w/w, Colorcon).

[00073] In certain embodiments, suitable additives for the peptides composition include one or more of sucrose, talc, magnesium stearate, crospovidone or BHA.

[00074] The compositions of the present invention can also include other excipients, agents, and categories thereof including but not limited to L-histidine, Pluronic®, Poloxamers (such as Lutrol® and Poloxamer 188), ascorbic acid, glutathione, permeability enhancers (e.g., lipids, sodium cholate, acylcarnitine, salicylates, mixed bile salts, fatty acid micelles, chelators, fatty acid, surfactants, medium chain glycerides), protease inhibitors (e.g., soybean

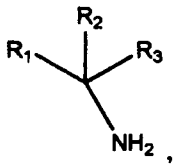
trypsin inhibitor, organic acids), pH lowering agents and absorption enhancers effective to promote bioavailability (including but not limited to those described in US 6086918 and US 5912014), materials for chewable tablets (like dextrose, fructose, lactose monohydrate, lactose and aspartame, lactose and cellulose, maltodextrin, maltose, mannitol, microcrystalline cellulose and guar gum, sorbitol crystalline); parenterals (like mannitol and povidone); plasticizers (like dibutyl sebacate, plasticizers for coatings, polyvinylacetate phthalate); powder lubricants (like glyceryl behenate); soft gelatin capsules (like sorbitol special solution); spheres for coating (like sugar spheres); spheronization agents (like glyceryl behenate and microcrystalline cellulose); suspending/gelling agents (like carrageenan, gellan gum, mannitol, microcrystalline cellulose, povidone, sodium starch glycolate, xanthan gum); sweeteners (like aspartame, aspartame and lactose, dextrose, fructose, honey, maltodextrin, maltose, mannitol, molasses, sorbitol crystalline, sorbitol special solution, sucrose); wet granulation agents (like calcium carbonate, lactose anhydrous, lactose monohydrate, maltodextrin, mannitol, microcrystalline cellulose, povidone, starch), caramel, carboxymethylcellulose sodium, cherry cream flavor and cherry flavor, citric acid anhydrous, citric acid, confectioner's sugar, D&C Red No. 33, D&C Yellow #10 Aluminum Lake, disodium edetate, ethyl alcohol 15%, FD& C Yellow No. 6 aluminum lake, FD&C Blue #1 Aluminum Lake, FD&C Blue No. 1, FD&C blue no. 2 aluminum lake, FD&C Green No.3, FD&C Red No. 40, FD&C Yellow No. 6 Aluminum Lake, FD&C Yellow No. 6, FD&C Yellow No.10, glycerol palmitostearate, glyceryl monostearate, indigo carmine, lecithin, manitol, methyl and propyl parabens, mono ammonium glycyrrhizinate, natural and artificial orange flavor, pharmaceutical glaze, poloxamer 188, Polydextrose, polysorbate 20, polysorbate 80, polyvidone, pregelatinized corn starch, pregelatinized starch, red iron oxide, saccharin sodium, sodium carboxymethyl ether, sodium chloride, sodium citrate, sodium phosphate, strawberry flavor, synthetic black iron oxide, synthetic red iron oxide, titanium dioxide, and white wax.

[00075] In some embodiments, there is provided a pharmaceutical composition comprising a peptide described herein and one or more stabilizing agents selected from Mg^{2+}, Ca^{2+}, Zn^{2+}, Mn^{2+}, K^{+}, Na^{+} or Al^{3+}, a combination thereof, and/or a sterically hindered primary amine. In further embodiments, the agent is Mg^{2+}, Ca^{2+} or Zn^{2+} or a combination thereof In some embodiments, the cation is provided, without limitation, as magnesium acetate, magnesium chloride, magnesium phosphate, magnesium sulfate, calcium acetate, calcium chloride, calcium phosphate, calcium sulfate, zinc acetate, zinc chloride, zinc phosphate, zinc sulfate, manganese acetate, manganese chloride, manganese phosphate, manganese sulfate,

potassium acetate, potassium chloride, potassium phosphate, potassium sulfate, sodium acetate, sodium chloride, sodium phosphate, sodium sulfate, aluminum acetate, aluminum chloride, aluminum phosphate or aluminum sulfate. In further embodiments, the cation is provided as magnesium chloride, calcium chloride, calcium phosphate, calcium sulfate, zinc acetate, manganese chloride, potassium chloride, sodium chloride or aluminum chloride. In other embodiments, the cation is provided as calcium chloride, magnesium chloride or zinc acetate.

[00076] In another embodiment, the stabilizing agent is a sterically hindered primary amine. In a further embodiment, the sterically hindered primary amine is an amino acid. In yet a further embodiment, the amino acid is a naturally-occurring amino acid. In a still further embodiment, the naturally-occurring amino acid is selected from the group consisting of: histidine, phenylalanine, alanine, glutamic acid, aspartic acid, glutamine, leucine, methionine, asparagine, tyrosine, threonine, isoleucine, tryptophan, glycine and valine; yet further, the naturally-occurring amino acid is leucine, isoleucine, alanine or methionine. In another embodiment, the sterically hindered primary amine is a non-naturally occurring amino acid (e.g., 1-aminocyclohexane carboxylic acid). In a further embodiment, the sterically hindered primary amine is cyclohexylamine, 2-methylbutylamine or a polymeric amine such as chitosan. In another embodiment, one or more sterically hindered primary amines may be used in a composition.

[00077] In some cases, the sterically hindered primary amine has the formula:



, wherein R_1, R_2 and R_3 are independently selected from: H, C(O)OH, C_1-C_6 alkyl, C_1-C_6 alkylether, C_1-C_6 alkylthioether, C_1-C_6 alkyl carboxylic acid, C_1-C_6 alkyl carboxylamide and alkylaryl, wherein any group can be singly or multiply substituted with: halogen or amino, and provided that no more than two of R_1, R_2 and R_3 are H. In another embodiment, no more than one of R_1, R_2 and R_3 is H.

[00078] In other embodiments, there is provided a pharmaceutical composition comprising a pharmaceutically acceptable carrier, peptide, a cation selected from Mg^{2+}, Ca^{2+}, Zn^{2+}, Mn^{2+}, K^+, Na^+ or Al^{3+}, or a mixture thereof, and a sterically hindered primary amine. In one embodiment, the cation is Mg^{2+}, Ca^{2+} or Zn^{2+} or a mixture thereof.. In a further embodiment, the pharmaceutical composition further comprises a pharmaceutically acceptable binder and/or a pharmaceutically acceptable glidant, lubricant or additive that acts as both a glidant

and lubricant and/or an antioxidant. In some embodiments, the pharmaceutical composition is applied to a carrier. In some embodiments, the carrier is a filler.

[00079] In some cases the molar ratio of cation:sterically hindered primary amine: peptide in the aqueous solution applied to the carrier is 5-100:5-50:1. In some cases, the molar ratio of cation:sterically hindered primary amine may be equal to or greater than 2:1 (e.g., between 5:1 and 2:1). Thus, in some cases the molar ratio of cation:sterically hindered primary amine: peptide applied to the carrier is 100:50:1, 100:30:1, 80:40:1, 80:30:1, 80:20:1, 60:30:1, 60:20:1, 50:30:1, 50:20:1, 40:20:1, 20:20:1, 10:10:1, 10:5:1 or 5:10:1. When binder, e.g., methylcellulose, is present in the GC-C agonist peptide solution applied to the carrier it can be present at 0.5% - 2.5% by weight (e.g., 0.7%-1.7% or 0.7% - 1% or 1.5% or 0.7%).

[00080] It has been found that a cation selected from Mg^{2+}, Ca^{2+}, Zn^{2+}, Mn^{2+}, K^{+}, Na^{+} and $Al^{3+}$is useful for suppressing the formation of an oxidation product of GC-C receptor agonist polypeptides during storage. It has also been found that a sterically hindered primary amine is useful for suppressing the formation of a formaldehyde imine adduct ("formaldehyde imine product") of the GC-C receptor agonist polypeptides during storage. Thus, the GC-C receptor agonist polypeptide formulations comprising a cation selected from Mg^{2+}, Ca^{2+}, Zn^{2+}, Mn^{2+}, K^{+}, Na^{+} or Al^{3+}—for example, a divalent cation selected from Zn^{2+}, Mg^{2+} and Ca^{2+}—and/or a sterically hindered primary amine, such as an amino acid, have a sufficient shelf life (as measured by chromatographic purity and/or by a weight/weight assay) for manufacturing, storing and distributing the drug. Further, while the presence of a sterically hindered amine alone can increase the formation of a hydrolysis product of linaclotide during storage, the combination of a sterically hindered primary amine and a cation, e.g., but not limited to, the combination of leucine and Ca^{2+}, suppresses the formation of the hydrolysis product of the GC-C receptor agonist polypeptide as well as the oxidation product of GC-C receptor agonist polypeptide during storage, leading to an even greater overall stability as determined by a weight/weight assay and/or by chromatographic purity.

[00081] In a further embodiment, the pharmaceutical composition further comprises a pharmaceutically acceptable binder or additive, and/or a pharmaceutically acceptable glidant, lubricant or additive that acts as both a glidant and lubricant and/or an antioxidant.

[00082] Suitable pharmaceutical compositions in accordance with the invention will generally include an amount of the active compound(s) with an acceptable pharmaceutical diluent or excipient, such as a sterile aqueous solution, to give a range of final concentrations, depending on the intended use. The techniques of preparation are generally well known in

the art, as exemplified by Remington's Pharmaceutical Sciences (18th Edition, Mack Publishing Company, 1995).

[00083] For treatment of gastrointestinal disorders, the peptides described herein are preferably administered orally, e.g., as a tablet, capsule, sachet containing a predetermined amount of the active ingredient pellet, gel, paste, syrup, bolus, electuary, slurry, powder, lyophilized powder, granules, as a solution or a suspension in an aqueous liquid or a non-aqueous liquid; as an oil-in-water liquid emulsion or a water-in-oil liquid emulsion, via a liposomal formulation (see, e.g., EP 736299) or in some other form. Orally administered compositions can include binders, lubricants, inert diluents, lubricating, surface active or dispersing agents, flavoring agents, and humectants. Orally administered formulations such as tablets may optionally be coated or scored and may be formulated so as to provide sustained, delayed or controlled release of the active ingredient therein. The peptides can be co-administered with other agents used to treat gastrointestinal disorders including but not limited to the agents described herein.

[00084] In another aspect, suitable pharmaceutical compositions may comprise one or more other therapeutic agents. Such therapeutic agents include, without limitation, analgesic agents; anti-secretory agents, including proton pump inhibitors, acid pump antagonists, H2 receptor antagonists; PDE5 inhibitors; GABA-B antagonists; bile acid sequestrants; prokinetic and promotility agents; antidepressants; antibiotics; antiemetics; and mucosal-protecting agents.

Methods of Treatment

[00085] In some embodiments of the invention, a method of treatment is provided for gastrointestinal disorders.

[00086] In some embodiments, the gastrointestinal disorder is an upper GI disorder. In a further embodiment, the disorder is GP, post-operative gastric ileus, a functional esophageal disorder, a functional gastroduodenal disorder, gastroesophageal reflux disease (GERD), celiac disease, mucositis, or a duodenal or stomach ulcer.

[00087] In some embodiments, the gastrointestinal disorder is GP. In further embodiments, the GP is idiopathic, diabetic or post-surgical GP.

[00088] In some embodiments, the gastrointestinal disorder is post-operative gastric ileus.

[00089] In some embodiments, the gastrointestinal disorder is a functional esophageal disorder.

[00090] In some embodiments, the functional esophageal disorder is functional heartburn, functional chest pain of presumed esophageal origin, functional dysphagia or globus.

[00091] In some embodiments, the gastrointestinal disorder is a functional gastroduodenal disorder.

[00092] In some embodiments, the functional gastroduodenal disorder is FD, a belching disorder, a nausea or vomiting disorder, or rumination syndrome. In a further embodiment, the functional gastroduodenal disorder is FD. In some embodiments, the FD is postprandial distress syndrome or epigastric pain syndrome. In some embodiments, the belching disorder is aerophagia or unspecified excessive belching. In some embodiments, the nausea or vomiting disorder is chronic idiopathic nausea, functional vomiting or cyclic vomiting syndrome.

[00093] In some embodiments, the gastrointestinal disorder is gastroesophageal reflux disease (GERD).

[00094] In some embodiments, the gastrointestinal disorder is celiac disease.

[00095] In some embodiments, the gastrointestinal disorder is mucositis.

[00096] In some embodiments, the gastrointestinal disorder is a duodenal or stomach ulcer.

[00097] The peptides and agonists described herein can be used alone or in combination therapy for the treatment, prevention or reduction of visceral pain associated with a upper gastrointestinal disorder or pain associated with another disorder as described herein.

[00098] The GC-C receptor agonists described herein can be administered in combination with other agents. For example, the peptides can be administered with an analgesic peptide or compound. The analgesic peptide or compound can be covalently attached to a peptide described herein or it can be a separate agent that is administered together with or sequentially with a peptide described herein in a combination therapy. The GC-C receptor agonists described herein may also be administered in combination with other agents used to treat upper GI disorders including antidepressants, promotility or prokinetic agents, antiemetics, antibiotics, proton pump inhibitors, acid blockers (e.g., histamine H2 receptor antagonists), acid pump antagonists, PDE5 inhibitors, GABA-B agonists, bile acid sequestrants, and mucosal protecting agents.

[00099] In some embodiments, useful analgesic agents that may be used with the peptides described herein include Ca channel blockers (e.g., ziconotide), 5HT receptor antagonists

(e.g., 5HT3, 5HT4 and 5HT1 receptor antagonists), 5HT4 agonists (e.g., tegaserod (Zelnorm®), mosapride, metoclopramide, zacopride, cisapride, renzapride, benzimidazolone derivatives such as BIMU 1 and BIMU 8, and lirexapride), 5HT1 agonists (e.g., sumatriptan and buspirone), opioid receptor agonists (e.g., loperamide, fedotozine, enkephalin pentapeptide, morphine, diphenyloxylate, frakefamide, trimebutine and fentanyl), CCK receptor agonists (e.g., loxiglumide and dexloxiglumide), NK1 receptor antagonists (e.g., aprepitant, vofopitant, ezlopitant, R-673 (Hoffmann-La Roche Ltd), SR-48968 and SR-14033, (Sanofi Synthelabo), CP-122,721 (Pfizer, Inc.), GW679769 (Glaxo Smith Kline) and TAK-637 (Takeda/Abbot)), NK2 receptor antagonists (e.g., nepadutant, saredutant, GW597599 (Glaxo Smith Kline), SR-144190 (Sanofi-Synthelabo) and UK-290795 (Pfizer Inc)), NK3 receptor antagonists (e.g., osanetant (SR-142801; Sanofi-Synthelabo), SR-241586 and talnetant), norepinephrine-serotonin reuptake inhibitors (NSRI) (e.g., milnacipran), vanilloid and cannabanoid receptor agonists, sialorphin and sialorphin-related peptides. Analgesic agents in the various classes are described in the literature.

[000100] In some embodiments, one or more other therapeutic agents may be used in combination with the peptides described herein. Such agents include antidepressants, promotility or prokinetic agents, antiemetics, antibiotics, proton pump inhibitors, acid blockers (e.g., histamine H2 receptor antagonists), acid pump antagonists, PDE5 inhibitors, GABA-B agonists, bile acid sequestrants, and mucosal protecting agents.

[000101] Examples of antidepressants include, without limitation, tricyclic antidepressants such as amitriptyline (Elavil®), desipramine (Norpramin®), imipramine (Tofranil®), amoxapine (Asendin®), nortriptyline; the selective serotonin reuptake inhibitors (SSRI's) such as paroxetine (Paxil®), fluoxetine (Prozac®), sertraline (Zoloft®), and citralopram (Celexa®); and others such as doxepin (Sinequan®) and trazodone (Desyrel®).

[000102] Examples of promotility and prokinetic agents include, without limitation, itopride, octreotide, bethanechol, metoclopramide (Reglan®), domperidone (Motilium®), erythromycin (and derivatives thereof) and cisapride (Propulsid®). An example of antiemetics includes, without limitation, prochlorperazine.

[000103] Examples of antibiotics that may be used include those that may be used to treat *Heliobacter pylori* infections, such as amoxicillin, tetracycline, metronidazole, or clarithromycin.. Other antibiotics such as erythromycin and derivatives thereof may also be used in combination with the peptides described herein.

[000104] Examples of proton pump inhibitors include, without limitation, omeprazole (Prilosec®), esomeprazole (Nexium®), lansoprazole (Prevacid®), pantoprazole (Protonix®)

and rabeprazole (Aciphex®). Examples of H2 receptor blockers include, without limitation, including cimetidine, ranitidine, famotidine and nizatidine. Examples of acid pump antagonists include, without limitation, revaprazan, CS-526 (J. Pharmacol. Exp. Ther. (2007) 323:308-317), PF-03716556 (J. Pharmacol. Exp. Ther. (2009) 328(2):671-9), and YH1885 (Drug Metab. Dispos. (2001) 29(1):54-9).

[000105] Examples of PDE5 inhibitors include, without limitation, avanafil, lodenafil, mirodenafil, sildenafil citrate, tadalafil, vardenafil and udenafil. GABA-B agonists include, without limitation, baclofen and XP19986 (CAS Registry No. 847353-30-4). Examples of bile acid sequestrants include, without limitation, GT102-279, cholestyramine, colesevelam, colesevelam hydrochloride, ursodeoxycholic acid, colestipol, colestilan, sevelamer, polydiallylamine cross-linked with epichlorohydrin, dialkylaminoalkyl derivatives of a cross-linked dextran, andN-(cycloalkyl)alkylamines. Examples of mucosal protecting agents include, without limitation, sucralfate (Carafate), teprenone, polaprezinc, cetraxate and bismuth subsalicyclate.

[000106] Combination therapy can be achieved by administering two or more agents, e.g., a GC-C receptor agonist described herein and another therapeutic peptide or compound, each of which is formulated and administered separately, or by administering two or more agents in a single formulation. Other combinations are also encompassed by combination therapy. For example, two agents can be formulated together and administered in conjunction with a separate formulation containing a third agent. While the two or more agents in the combination therapy can be administered simultaneously, they need not be. For example, administration of a first agent (or combination of agents) can precede administration of a second agent (or combination of agents) by minutes, hours, days, or weeks. Thus, the two or more agents can be administered within minutes of each other or within 1, 2, 3, 6, 9, 12, 15, 18, or 24 hours of each other or within 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 12, 14 days of each other or within 2, 3, 4, 5, 6, 7, 8, 9, or 10 weeks of each other. In some cases even longer intervals are possible. While in many cases it is desirable that the two or more agents used in a combination therapy be present in within the patient's body at the same time, this need not be so.

Dosage

[000107] The dose range for adult humans may be generally from 5 μg to 100 mg/day orally of the GC-C peptide agonist described herein. Tablets, capsules, or other forms of presentation provided in discrete units may conveniently contain an amount of compound described herein which is effective at such dosage or as a multiple of the same, for instance,

units containing 25 μg to 2 mg or around 100 μg to 1 mg. The precise amount of compound prescribed to a patient will be the responsibility of the attendant physician. However, the dose employed will depend on a number of factors, including the age and sex of the patient, the precise disorder being treated, and its severity.

[000108] In various embodiments, the dosage unit is administered with food at anytime of the day, without food at anytime of the day, with food after an overnight fast (e.g. with breakfast), at bedtime after a low fat snack. In one particular embodiment, the dosage unit is administered prior to or subsequent to food consumption (e.g., a meal). In a further embodiment, the dosage unit is administered approximately 15 minutes to 1 hour prior to food consumption. In various embodiments, the dosage unit is administered once a day, twice a day, three times a day, four times a day, five times a day or six times a day. In certain embodiments the dosage unit and daily dose are equivalent.

[000109] In combination therapy embodiments of the present invention, the precise amount of each of the two or more active ingredients in a dosage unit will depend on the desired dosage of each component. Thus, it can be useful to create a dosage unit that will, when administered according to a particular dosage schedule (e.g., a dosage schedule specifying a certain number of units and a particular timing for administration), deliver the same dosage of each component as would be administered if the patient was being treated with only a single component. In other circumstances, it might be desirable to create a dosage unit that will deliver a dosage of one or more components that is less than that which would be administered if the patient was being treated only with a single component. Finally, it might be desirable to create a dosage unit that will deliver a dosage of one or more components that is greater than that which would be administered if the patient was being treated only with a single component.

[000110] The pharmaceutical composition can include additional ingredients including but not limited to the active ingredients and excipients described herein. In certain embodiments, one or more therapeutic agents of the dosage unit may exist in an extended or control release formulation and additional therapeutic agents may not exist in extended release formulation. For example, a peptide or agonist described herein may exist in a controlled release formulation or extended release formulation in the same dosage unit with another agent that may or may not be in either a controlled release or extended release formulation. Thus, in certain embodiments, it may be desirable to provide for the immediate release of one or more of the agents described herein, and the controlled release of one or more other agents.

[000111] The present invention has been described with reference to certain exemplary embodiments thereof. However, it will be readily apparent to those skilled in the art that it is possible to embody the invention in specific forms other than those of the exemplary embodiments described above. This may be done without departing from the spirit of the invention. The exemplary embodiments are merely illustrative and should not be considered restrictive in any way. The scope of the invention is defined by the appended claims and their equivalents, rather than by the preceding description.

EXAMPLES

[000112] The GC-C agonist peptides or pharmaceutically acceptable salts thereof as described herein were prepared by solid phase chemical synthesis and natural folding (air oxidation) by American Peptide Company (Sunnyvale, CA). The peptides and their sequences are shown below (wherein the amino acid sequence is the standard one letter code and "pS" is phosphoserine):

Peptide Name	Amino Acid Sequence
Peptide 1	CCpSLCCNPACTGCY
Dephospho-Peptide 1	CCSLCCNPACTGCY
Peptide 2	CCpSLCCNPACTGC
Dephospho-Peptide 2	CCSLCCNPACTGC
Peptide 3	CCELCCNPACTGCY
Peptide 4	CCEFCCNPACTGCY
Peptide 5	DDCCpSLCCNPACTGCY
Peptide 6	DDCCpSYCCNPACTGCY

Example 1: Alkaline and acid phosphatase effects on peptide substrates

[000113] For the alkaline phosphatase reactions, peptide stocks were prepared at 1 mg/mL in 0.1 M Tris-HCl pH 8, which were stored at -20 °C until assays were conducted. For the acid phosphatase reactions, peptide stocks were prepared at 1 mg/mL in 50 mM sodium phosphate pH 6, which was stored at -20 °C until assays were conducted.

Alkaline phosphatase reaction

[000114] Calf intestinal alkaline phosphatase (CIP) was obtained from New England BioLabs, Ipswich, MA. Cat # M0290S. The CIP reaction solution was prepared by dilution with buffer (50 mM KCl, 10 mM Tris-HCl pH 8, 1 mM $MgCl_2$, 50% glycerol) to 0.5

units/μL. The alkaline phosphatase reaction solutions were assembled in 20 μL quantities containing:

2 μL 10X CIP buffer (1M NaCl, 500 mM Tris-HCl pH 8, 100 mM $MgCl_2$)

2 μL peptide stock (1 mg/mL)

12 μL H_2O

4 μL alkaline phosphatase (0, 0.5 or 2 units)

[000115] The reaction solutions were mixed gently and incubated for 90 minutes at 37 °C. These reaction solutions were stored at -20 °C until analysis. For analysis, the reaction solutions were diluted from 7.5 μL of CIP treated peptide to 50 μL with 0.1% formic acid in water to a final concentration of 10 μM. The final solution of 20 μL was then analyzed by LCMS with conditions as shown in Table 1 below.

[000116] Control reactions were assembled for enzyme activity containing 10 mM *p*-nitrophenylphosphate in place of peptide. After incubation, the reactions were diluted with 0.1 mL of 100 mM borate buffer pH 9 and read at the absorbance of 405 nm to monitor *p*-nitrophenol appearance.

Acid phosphatase reactions

[000117] Potato acid phosphatase (PoAP) was obtained from Sigma, St. Louis, MS. Cat #P1146 and human prostate acid phosphatase (HuPrAP) was obtained from MP Biochemicals, Solon, OH. Cat # 153872. The acid phosphatases were dissolved to provide a solution containing 0.5 units AP/μL using 50 mM sodium acetate pH 5, 0.2 mM $MgCl_2$. The acid phosphatase reactions were assembled in 20 μL quantities containing:

2 μL 10X acid phosphatase buffer (500 mM sodium acetate pH 5, 2 mM $MgCl_2$)

2 μL peptide stock (1 mg/mL)

12 μL H_2O

4 μL acid phosphatase (0.5 or 2 units)

[000118] The reaction solutions were mixed gently and incubated for 90 minutes at 37 °C. The reaction solutions were stored at -20 °C for later analysis. For analysis, 7.5 μL acid phosphatase reactions were diluted to 50 μL with 0.1% formic acid in water to a final concentration of 10 μM. The final reactions of 20 μL were analyzed by LCMS with conditions as shown in Table 1 below. The control reactions for enzyme activity were assembled and diluted to 10 mM *p*-nitrophenylphosphate in place of peptide. After incubation, the reactions were diluted with 0.1 mL of 100 mM borate buffer pH 9 and read at the absorbance of 405 nm to monitor *p-nitrophenol* appearance.

Table 1: LCMS Analysis

MS:	Thermo Scientific LTQ Orbitrap Discovery		
Ion Mode:	Positive ion electrospray (ESI^+)		
Scan Range:	200 – 2000 *m/z*		
HPLC:	Waters Acquity UPLC		
Column:	Thermo Hypersil Gold aQ, 2.1 x 50 mm, 1.9 µm		
Flow Rate:	400 µL/min		
Column Temperature	40 °C		
Autosampler Temperature:	4 °C		
Injection Volume:	20 µL		
Mobile Phases:	A = 0.1% formic acid in H_2O		
	B = 0.1% formic acid in 85:15 (v/v) acetonitrile:methanol		
Gradient:	**Time (min)**	**% A**	**% B**
	0	98	2
	2.4	98	2
	25.2	20	80
	26.2	20	80
	27.2	10	90
	30.2	98	2
	35	98	2

[000119] Tables 2 and 3 show that under the conditions used for assay, 0.5 units of calf intestinal alkaline phosphatase (pH 8) and 0.5 units of either potato acid phosphatase or human prostate acid phosphatase (pH 5) efficiently hydrolyzed *p*-nitrophenylphosphate.

[000120] The sensitivity of Peptide 1 and Peptide 2 to phosphatase treatment was assessed by analyzing the reaction products by LC-MS. Tables 2 and 3 show that at pH 8 calf intestinal alkaline phosphatase efficiently dephosphorylated Peptide 1 and Peptide 2. In contrast to alkaline phosphatase, potato acid and human prostate gland acid phosphatases were very inefficient in dephosphorylating Peptide 1 under conditions where they efficiently hydrolyzed *p*-nitrophenylphosphate (Table 2). Human prostate gland acid phosphatase was also very inefficient in dephosphorylating Peptide 2 (Table 3).

[000121] As a separate control, Peptide 3 was treated with and without calf intestinal alkaline phosphatase and the resulting reactions were analyzed by LC-MS. Peptide 3 was not affected by CIP treatment (data not shown)

Table 2: Dephosphorylation of Peptide 1

Substrate	p-nitrophenylphosphate		Peptide 1	
	Remaining (%)	Dephospho (%)	Remaining (%)	Dephospho (%)
Alkaline phosphatase pH 8	0	100	0	100
Potato acid phosphatase pH 5	0	100	77.8	22.1
Human prostatic acid phosphatase pH 5	0	100	93.8	6.2

Table 3: Dephosphorylation of Peptide 2

Substrate	p-nitrophenylphosphate		Peptide 2	
	Remaining (%)	Dephospho (%)	Remaining (%)	Dephospho (%)
Alkaline phosphatase pH 8	0	100	0	100
Human prostatic acid phosphatase pH 5	0	100	95.9	4.1

Example 2: cGMP accumulation in T84 cells for analysis of GC-C activity

[000122] For the cGMP assay, 4.5 x 10^5 cells/mL of T84 cells were grown overnight in 24 well tissue culture plates. On the next day, the T84 cells were washed twice with 1 mL of DMEM + 20 mM MES (pH 5) or DMEM + 50 mM sodium bicarbonate (pH8) in which these buffers did not contain serum. After the second wash, the cells were incubated with 450 µL of 1 mM isobutylmethylxanthine (IBMX) in either the pH 5 or pH 8 buffers for 10 minutes at 37°C to inhibit any phosphodiesterase activity. The peptides were then diluted in either pH 5 or pH 8 buffer to a 10x concentration. The peptide solution of 50 µL was diluted to a final volume of 500 µL with the T84 cells, bringing each peptide concentration to 1x. An eleven point curve analysis was conducted for each peptide, with final peptide concentrations tested in each assay, in nM: 10000, 3000, 1000, 300, 100, 30, 10, 3, 1, 0.3, 0.1.

[000123] There was no peptide control used to determine endogenous levels of cGMP. Peptides were incubated for 30 minutes at 37°C. After 30 minutes, the supernatants were removed and the cells were lysed with 0.1 M HCl. The cells were lysed for 30 minutes on ice. After 30 minutes, lysates were pipetted off and placed into a 96 well HPLC plate and spun at 10,000x g for 10 minutes to remove any cell debris. Supernatants from the previous spin were removed and placed into a fresh 96 well HPLC plate. Samples were diluted with an equal volume of 1 M ammonium acetate (pH 7) to neutralize samples for better

chromatography. A 2x cGMP standard curve was prepared in 0.1 M HCl and then diluted with an equal volume of 1 M ammonium acetate, with the following final concentrations in nM: 1024, 512, 256, 128, 64, 32, 16, 8, 4, 2, 1.

[000124] cGMP concentrations were determined from each sample using the LC/MS conditions in Table 4 and a calculated standard curve. EC_{50} values were calculated from concentration-response curves generated with GraphPad Prism Software.

Table 4: LC/MS Conditions:

MS:	Thermo Quantum					
Ion Mode:	ESI+					
Scan Type:	MRM					
Compound:	**Transition**	**Dwell Time (msec)**	**Collision Energy (V)**	**Tube Lens**	**Retention Time (min)**	
cGMP	346 > 152	100	28	139	1.0	
HPLC:	Agilent Technologies 1200 Series with CTC Analytics HTS PAL					
Column:	Thermo Hypersil Gold 2.1 x 50 mm 5 micron particle size					
Flow Rate:	400 uL/min					
Column Temperature:	RT					
Autosampler Temperature:	6 °C					
Injection Volume:	20 uL					
Mobile Phases:	A = 98:2 Water:Acetonitrile + 0.1% Formic Acid B = 2:98 Water:Acetonitrile + 0.1% Formic Acid					
Gradient:	**Time (min)**	**% A**	**% B**			
	0	100	0			
	0.3	30	70			
	2.00	30	70			
	2.01	100	0			
	4	100	0			

[000125] The ability of Peptide 1 and Peptide 2 and their dephosphorylated forms to stimulate cGMP synthesis in human T84 cells at pH 5 was tested by incubating the cells with the peptides followed by determination of the accumulated intracellular cGMP by LC-MS. Table 5 shows that Peptide 1 and Peptide 2 have potencies similar to that of Peptide 3 in stimulating cGMP synthesis at pH 5. However, dephosphorylated Peptide 1 and Peptide 2 were less potent in the T84 assay than Peptide 3.

Table 5: cGMP response of T84 cells

Peptide	EC_{50} at pH 5 (nM)
Peptide 3	16
Peptide 1	9.8
Dephospho-Peptide 1	128
Peptide 2	10.4
Dephospho-Peptide 2	78.1

[000126] The cGMP response of T84 cells to Peptide 5 and Peptide 6 were also measured in duplicate in a similar fashion to that described above. The EC_{50} at pH 5 for Peptide 5 was 14.7 nM and the EC_{50} at pH 5 for Peptide 6 was 39.2 nM.

Example 3: Competitive Radioligand-Binding on T84 cells

[000127] Intact human T84 cells from the American Type Culture Collection (ATCC; Manassas, VA) were used for competitive radioligand-binding experiments. The T84 cells were grown in monolayers on T-150 plastic flasks to 60-70% confluency in Dulbecco's Modified Eagle Medium: Ham's F-12 50/50 media (DMEM/F12) + 5% fetal bovine serum (FBS). The cells were harvested by gentle scraping with a cell scraper and cells collected by centrifuge at 2000 *g* for 10 minutes at 4 °C. The cells were washed twice by resuspending gently in phosphate buffered saline (PBS) and collecting them by centrifugation as above.

[000128] [^{125}I]-STp radioligand was prepared by dissolving one hundred micrograms (100 µg) of NTFYCCELCCNPACAGCY (Enterotoxin STp; Bachem H-6248) in 0.5 mL water and sent to Perkin-Elmer Life and Analytical Sciences (N. Billerica, MA) for iodination using the lactoperoxidase method recited in (Marchanolis, J.J., "An enzymic method for the trace iodination of immunoglobulins and other proteins," *Biochem. J.* 1969, *113*, 299-305). Perkin-Elmer purified the labeled tracer by HPLC using a Waters C-18 µBondapak column (25 cm) previously equilibrated with 10 mM ammonium acetate pH 5.8. A gradient from 0 to 25% acetonitrile was applied to the column in 60 min, followed by isocratic elution at 25% acetonitrile for another 20 min. This method separated two monoiodinated forms from each other and from unlabeled precursor. The second monoiodinated peak (Peak 2) which eluted after 64 min and corresponded to iodination of the fourth tyrosine, was used as the labeled tracer in the assay. The labeled tracer had a specific activity of 2200 Ci/mmol. Upon arrival, tracer was stored in aliquots at -20 °C.

[000129] The binding reactions were assembled in duplicate in 0.2 mL containing: 2.5 x 10^5 T84 cells (0.25 mg protein), 200,000 cpm [^{125}I]-STp (41 fmol, 200 pM), 0.1 to 3,000 nM

competitor, and 0.5% bovine serum albumin (BSA). The binding assays were conducted at pH 5.0 in DMEM/20 mM 2-(N-morpholino) ethanesulfonic acid (MES). The binding assays at pH 8.0 were performed in DMEM/20 mM N-2-Hydroxyethylpiperazine-N′-2-Ethane Sulfonic Acid (HEPES)/50 mM sodium bicarbonate. The control reactions did not contain a competitor (total) or no cells.

[000130] The buffer solutions were prepared first, then protease-free BSA was added to 0.5%. The radioligand was added to a final concentration of 0.001 μCi/μL. Preparation of competitor peptide stock solutions were made by dissolving peptides to 1 mg/mL in 50 mM sodium phosphate pH 6.0. Concentrations were calculated from the peptide molecular weight provided in the Certificate of Analysis. Competitor dilutions were made in 50 mM sodium phosphate pH 6.0 that contained 20 times the final concentration of peptide to be tested in the binding reaction (20X competitor).

[000131] The binding reactions were assembled in the following order:

i. Radioligand and BSA in buffer solution.

ii. 10 μL of 20X competitor.

iii. T84 cells.

The binding reactions were mixed gently and incubated at 37°C for 1 h. Separation of membrane-bound from free radioligand was conducted by applying the binding reactions to 2.5 cm Whatman GF/C glass-fiber filters (pretreated with 1% polyvinylpyrrolidone in PBS) using vacuum filtration. The filters were rinsed twice with 5 mL ice-cold PBS buffer and measurements of the trapped radioligand was conducted in a scintillation counter. The determination of specific binding was made by subtracting the bound radioactivity from a reaction that contained excess competitor (1 μM) from the bound radioactivity of each sample. The generation of competitive radioligand-binding curves were made using GraphPad Prism (GraphPad Software, San Diego, CA) and the data was analyzed with nonlinear regression to calculate the concentration of competitor that resulted in 50% radioligand bound (IC_{50}). The apparent dissociation equilibrium constant (K_i) for each competitor was obtained, from the IC_{50} values and a previously determined estimate of the dissociation constant for the radioligand, $K_d \cong 15$ nM, using the method of (Cheng and Prusoff, (1973) Biochem. Pharmacol. 22(23) 3099-3108). The radioligand concentration of 200 pM used in the assays was very small compared to its dissociation constant, the calculated IC_{50} and the K_i values (Table 5) were in effect identical.

Table 6: Competitive radioligand binding assay

Peptide	K_i at pH 5 (nM)
Peptide 3	1.2
Peptide 1	1.1
Dephospho-Peptide 1	10.5
Peptide 2	0.6
Dephospho-Peptide 2	4.5

[000132] Table 6 shows that Peptide 1 and Peptide 2 have potencies similar to that of Peptide 3 in binding at pH 5. However, dephosphorylated Peptide 1 and Peptide 2 have lower affinities for GC-C than Peptide 3 in the binding assay.

Example 4: Gastrointestinal Transit in Mice

[000133] The purpose of the assay was to test the effect of the guanylate cyclase C agonist peptides on *in vivo* gastrointestinal transit in mice. Orally-dosed guanylate cyclase C agonists have been demonstrated to increase the % Distance Travelled by a charcoal meal in mice.

[000134] For the assay, female CD-1 mice (n=10 per group) weighing 25-30 g were fasted overnight and given access to water *ad libitum*. Activated charcoal (20g; 100 mesh; Sigma cat# 242276) was suspended in 200 mL gum arabic (100 mg/mL), and stirred for at least one hour. Test peptides were prepared in a 20 mM Tris pH 6.9 vehicle.

[000135] Test peptide and vehicle were administered in 200 µL doses by oral gavage. Seven minutes after dosing the test peptides, 200 µL of the charcoal/gum arabic suspension was dosed by oral gavage. After 15 minutes, mice were sacrificed by CO_2 overdose. The gastrointestinal tract was removed from the esophagus to the caecum. The total length of the small intestine was measured from the pyloric junction to the ileocaecal junction. The distance travelled by the charcoal was measured from the pyloric junction to the charcoal front. The Distance Travelled (%) was determined as (distance travelled by charcoal/total length of the small intestine) x 100. Data were entered into the GraphPad Prism software program and analyzed by ANOVA using a Bonferroni multiple comparison test *post-hoc*. Plots of data and ED_{50} were also determined using the GraphPad Prism software package.

[000136] The dose-dependent effects of acute doses of Peptide 4, Peptide 1, Peptide 2, the dephosphorylated form of Peptide 1 and the dephosphorylated form of Peptide 2 on GI transit were determined in female CD mice. The distance traveled by the charcoal front after seven minutes, expressed as a percent of total length of small intestine was used to calculate ED_{50} values (Table 7).

Table 7: Acceleration of upper GI transit in mice

Peptide	ED_{50} (μg/kg)
Peptide 4	2.06
Peptide 1	5.61
Dephospho-Peptide 1	12.7
Peptide 2	2.47
Dephospho-Peptide 2	6.03

[000137] Table 7 shows that the dephosphorylated forms of Peptide 1 and Peptide 2 exhibited reduced potency when compared to their respective peptides when administered orally in the upper GI transit model in mice.

Example 5: Fluid secretion in rat intestinal loops

[000146] The effect of GC-C agonist peptides on secretion were studied by injecting GC-C agonist peptides described herein directly into an isolated loop in wild-type rats.

[000147] Loops were isolated by surgically ligating three loops in the small intestine of the rat. The methodology for ligated loop formation was similar to that described in (London et al., 1997, Am J Physiol, p.G93-105). The loops were roughly centered and at lengths of 1-3 cm. The loops were injected with 200 μl of either peptide/GC-C agonist (0.1-5μg) or vehicle (20 mM Tris, pH 7.5 or Krebs Ringer, 10mM Glucose, HEPES buffer (KRGH)). Following a recovery time of up to 90 minutes the loops were excised. Weights were recorded for each loop before and after removal of the fluid contained therein. The length of each loop was also recorded. A weight to length ratio (W/L) for each loop was calculated to determine the effects of the GC-C agonist peptide described herein on secretion. Loop fluid volume was also determined.

[000148] Data showing increases in fluid secretion, pH increase and bicarbonate secretion in ligated duodenal loops in rats are shown in Figure 2 and Table 8. Figure 2 shows that Peptide 2 has a potency similar to that of Peptide 4 with regard to induction of fluid accumulation in ligated rat duodenal loops. Table 8 provides the results in ligated rat duodenal loops using 2.5 μg of peptide per loop.

Table 8: Fluid secretion, pH increase, and bicarbonate secretion

Peptide	Rate of fluid accumulation µL/min/cm	pH	Rate of HCO_3^- accumulation Meq/min/cm
Vehicle	0.5	7.5	0.00002
Peptide 4	2.0	8.2	0.00008
Peptide 2	2.3	8.1	0.00008
Dephospho-Peptide 2	2.3	ND	ND
Peptide 1	1.8	7.7	0.00007
Dephospho-Peptide 1	2.0	7.7	0.00008

Example 6. In vitro Metabolism in Mouse Jejunum Loop Fluid

[000149] The purpose of this study was to determine the stability of phosphorylated peptides in mouse jejunal loop fluid. Peptide 2, dephosphorylated-peptide 2 (dephospho-peptide 2), peptide 3, and isotopically labeled peptide 2 were used in the study. The isotopically labeled peptide 2 was synthesized with ^{13}C, ^{15}N –labeled alanine and leucine (i.e., with a sequence CCpS[$^{13}C_6$, ^{15}N]LCCNP[$^{13}C_6$, ^{15}N]ACTGC).

[000150] Each peptide was synthesized by American Peptide Company, Inc., and was stored desiccated at –20°C. A 1 mg/mL solution for each of the non-labeled peptides was prepared in 1 M tris (hydroxymethyl) aminomethane hydrochloride (Tris-HCl), pH 8 just prior to conducting the mouse intestinal loop fluid assay. A 500 ng/mL solution of ^{13}C, ^{15}N –labeled peptide 2 was prepared in 0.1% formic acid in water and was utilized to dilute the jejunum samples for post-assay LC-MS/MS analysis.

[000151] To study the metabolism of peptide 2, dephospho-peptide 2, and peptide 3 in vitro, the peptides were incubated in mouse jejunum fluid extracted from loops ligated in the small intestine of mice. To collect the fluid, mice were fasted overnight with full access to water. They were then anesthetized with isofluorane for surgery and subjected to laparotomy in which the small intestine was exteriorized. Jejunum loops of 3 to 4 cm in length were made with sutures starting at 7 cm from the pyloric sphincter of the stomach. Once the loops were formed, they were injected with 200 µL of phosphate buffered saline (PBS) buffer (10 mM, pH 7.4). The abdominal wall and skin of the animals were then sutured, and the animals were allowed to recover for 30 minutes. Following recovery, the animals were sacrificed, the loops were then excised and the fluid inside was recovered and stored at –80 °C until use.

[000152] For each peptide, 25 µL of the 1 mg/mL peptide stock solution was added to 25 µL of 1 M Tris-HCl and 25 µL of 10x calf intestinal phosphatase (CIP) buffer containing 500 mM Tris-HCl, 1 M sodium chloride (NaCl), 0.1 mM magnesium chloride ($MgCl_2$), pH 8. The reactions were initiated by adding 175 µL of the mouse jejunum loop fluid or 175 µL of the 1 M Tris-HCl pH8 buffer for the control reactions. The final concentration of each peptide was 100 µg/mL. The reactions were continuously mixed and maintained at 37°C on a plate shaker. At 0, 2, 5, 10, 20, 30, 60, 90 and 120 minutes after adding the mouse intestinal loop fluid, a 25 µL aliquot was taken and added to 25 µL of 4 °C 12% trichloroacetic acid to stop the reaction. An additional 200 µL of 0.1% formic acid in water was added to these reactions for dilution purposes. These samples were then further diluted by taking 20 µL of each sample and adding it to 480 µL of 0.1% formic acid in water containing 500 ng/mL of the internal standard 13C, 15N –labeled peptide 2.

[000153] The concentration of peptide 2, dephospho-peptide 2, and peptide 3 in the samples were measured by LC-MS/MS. All samples were analyzed using an Applied Biosystems/MDS SCIEX API 4000 triple quadrupole mass spectrometer equipped with a high-performance liquid chromatography (HPLC) system. The mass spectrometer was operated in multiple reaction monitoring (MRM) mode, with resolution set to 1.2 Da. The instrument and chromatographic parameters for each compound are summarized in Table 9.

Table 9: Peptide 2, dephospho-peptide 2 (dephosp.-Pep. 2), peptide 3, and ^{13}C, ^{15}N – labeled peptide 2 (iso-lab.-Pep. 2) LC-MS/MS Method Parameters

MS:	Applied Biosystems API 4000					
Ion Mode:	ESI+					
Scan Type:	MRM					
Compound:	**Transition**	**Dwell Time (msec)**	**Dwell Potential (V)**	**Collision Energy (V)**	**Cell Exit Potential (V)**	**Retention Time (min)**
Peptide 2	677 > 627	100	65	20	11	2.5
dephosp.-Pep. 2	636 > 627	100	65	20	11	2.5
Peptide 3	740 > 182	100	65	30	14	2.5
Iso-lab.-Pep. 2	682 > 633	100	65	20	11	2.5
HPLC:	Agilent Technologies 1200 Series					
Column:	Atlantis T3, 2.1 x 50 mm, 5 µM (PN: 186003734)					
Flow Rate:	400 uL/min					
Temperature:	40 °C					
Autosampler:	6 °C					
Injection Volume:	20 uL					
Mobile Phases:	A = 0.1% formic acid in water					
	B = 0.1% formic acid in 85:10:5 (v:v:v) acetonitrile:isopropyl alcohol:water					
Gradient:	**Time (min)**	**% A**	**% B**			
	0	98	2			
	0.5	98	2			
	0.6	20	80			
	2.0	20	80			
	2.1	98	2			
	5.0	98	2			

[000154] The LC-MS/MS data were processed using Analyst version 1.4.2 software (Applied Biosystems/MDS SCIEX). The peak area ratio (ratio of analyte peak area to internal standard peak area) was used to calculate the percent remaining of each peptide.

[000155] Figure 3 displays the percent remaining of peptide 2 and dephospho-peptide 2, and peptide 3 at the nine time points measured during the 120 minute incubation in mouse jejunum fluid and in the control reaction (1 M Tris-HCl) at 37°C. After the incubation in the mouse jejunal loop fluid, only 5.3% of peptide 2 remained after 120 minutes. The metabolite, dephospho-peptide 2, was formed in this reaction and increased in concentration for the first 20 minutes then showed a slow decrease for the remaining time. In the control reaction, peptide 2 was not metabolized and no dephospho-peptide 2 was formed. After the incubation in the mouse jejunum fluid, only 5.6% of the dephospho-peptide 2 remained after

120 minutes. In contrast, dephospho-peptide 2 was not metabolized in the control reaction. Peptide 3 was rapidly metabolized and was not detected after 90 minutes in the mouse jejunum fluid. In the control reaction, peptide 3 was not metabolized.

[000156] Peptide 2, its metabolite dephospho-peptide 2, and peptide 3 were metabolized in mouse jejunum loop fluid. Formation of dephospho-peptide 2 was observed when peptide 2 was incubated in mouse jejunum loop fluid at 37°C. Dephospho-peptide 2 and peptide 3 were degraded faster in mouse intestinal fluid than peptide 2.

Example 7: Liquid Gastric Emptying in Strepozotocin (STZ)-Induced Diabetic Rats

[000157] The effect of peptides 2 and 3 administered via oral gavage on liquid gastric emptying (LGE) in strepozotocin (STZ)-induced diabetic rats was studied.Adult male rats (Sprague-Dawley; n=60) weighing ~300 g (supplied by Taconic) were housed in controlled conditions of room temperature (22°C) and light (12:12 h light-dark cycle) with free access to food and water. Following a one-week acclimation period, the STZ protocol for inducing type I diabetes was initiated.

[000159] To induce type I diabetes in animals in the STZ experimental group (n=50), a daily regimen of intraperitoneal injections of STZ (20 mg/kg) contained in citrate buffer was administered for 5 days. A control group received an equal volume of the vehicle (n=10) over the same injection schedule. All animals were given 9 weeks to develop diabetes/recover from the injections. Blood glucose levels were monitored post 5-day STZ injection at day 0 (i.e., on day 6) and at week 1, 2 and 10 (i.e., beginning of week 10 — the day of the experiment). Blood samples were taken from the tail vein, except on the day of the Liquid Gastric Emptying (LGE) experiment (beginning of week 10), in which blood was taken directly from the heart.

[000160] The LGE procedure involved 6 groups (n=10/group) of which five groups were diabetic and one group was non-diabetic. Prior to the LGE experiment, food was withheld overnight, whereas water was withheld 2 hr before starting the gastric emptying procedure.

[000161] Peptide 3 and peptide 2 were dissolved separately in a vehicle of 20% sucrose solution containing 0.1mg/ml phenol red. The drug doses for the compounds employed were (in mg/kg): 0.1 (peptide 2 and 3), 0.3 and 1.0 (peptide 2 only). To test their effect on LGE, a

0.5 ml volume of the drug solution was then delivered via an 18-gage gavage needle (6cm in length) into the stomach either of diabetic animals or of control animals. Each animal in the diabetic experimental groups received a single drug dose of an Ironwood compound (peptide 2 or 3). In the non-diabetic group, animals were administered a similar volume of only the vehicle solution. All animals were then allowed 15 minutes for gastric emptying to occur, after which they were euthanized with isoflurane.

[000162] Following euthanasia, via a laparotomy, the stomach was accessed and ligated in each animal at the lower esophageal sphincter and the pyloric sphincter. Next, the heart was exposed through an incision in the diaphragm, a blood sample was taken and glucose level was assessed with a glucometer. The stomach was then excised from the animal and stored overnight in a 10 ml tube containing 95% ethanol. Next, the tissue was homogenized, centrifuged (twice at 40,000 *g* for 30 min) and the supernatant was tested for absorbance in a spectrophotometer (BioMate 3, Thermospectronic, Inc.) at 410nm wavelength. Results were compared to a "zero value" derived from administration of the sucrose/phenol red solution to the stomach of an animal that was immediately sacrificed and its stomach removed to determine the "percent retained" for each group.

[000163] Data were analyzed in terms of the percentage mean (± SEM) of the liquid retained in animals sacrificed at a 15 min time-point. Statistical significance was determined using ANOVA and Student-Newman-Keuls comparison *post hoc* test. Statistical significance was established at $P < 0.05$.

[000164] The fasting glucose levels of both the STZ diabetic animals and the control animals were >300mg/dL on the day of the gastric emptying experiment. The overall weights of the STZ diabetic animals were appreciably less (about 150 g on average) than the non-diabetic animals on the day of the experiment. Both groups of animals started at approximately 300 g at the time of treatment with STZ; the non-treated ammonals gained, on average, 130 g over the 10 weeks prior to LGE treatment, while the STZ diabetic animals stayed at a constant weight (~ 300 g) until fasting (about 280 g on average).

[000165] The experiments were done to determine the effect of peptides 2 and 3 on LGE in STZ-induced diabetic rats (9 wk). One dose of peptide 3 (0.1 mg/kg) and three doses of peptide 2 were evaluated. The data (Figure 4) indicates that:

[000166] STZ-induced diabetic rats exhibit a significant delay in gastric emptying of a liquid meal following 15 min of vehicle administration compared to control rats (88.24+7.12% retention compared to 45.34+7.1% in controls).

[000167] This significant difference between STZ diabetic animals and controls also extended to those diabetic animals that were administered peptide 2 and peptide 3 as calculated by the Student-Newman-Keuls multiple comparison *post hoc* test. In the case of Peptide 2, the higher two doses (0.3 and 1.0 mg/kg) significantly enhanced LGE as compared to diabetic animals that received only the vehicle solution.

[000168] The results of the present study show that there was a significant delay in the rate of LGE in STZ-induced diabetic animals (given vehicle) compared to nondiabetic controls. Furthermore, one-way analysis of variance (ANOVA) data employing *post hoc* multiple comparisons test (Student-Newman-Keuls) indicate that statistically significant differences were present in LGE between the STZ-diabetic animals that were orally administered vehicle solution compared to those that received the peptide 3 (0.1mg/kg) or peptide 2 (0.3 or 1.0 mg/kg). However, in comparison to non-diabetic controls that received only the vehicle solution, these aforementioned differences were not apparent.

[000169] These observations demonstrate that peptide 3 was effective at the dose studied (0.1mg/kg) in restoring LGE to those of non-diabetic control levels. Similarly, peptide 2 at doses 0.3 and 1.0mg/kg given orally restored LGE in STZ-induced diabetic animals to those of normal controls. At the lowest dose (0.1 mg/kg), peptide 2 did not statistically significantly restore LGE to those of normal controls, nevertheless the results showed a visual trend toward a decrease of the percent of liquid retained.

OTHER EMBODIMENTS

[000170] All publications and patents referred to in this disclosure are incorporated herein by reference to the same extent as if each individual publication or patent application were specifically and individually indicated to be incorporated by reference. Should the meaning of the terms in any of the patents or publications incorporated by reference conflict with the meaning of the terms used in this disclosure, the meaning of the terms in this disclosure are intended to be controlling. Furthermore, the foregoing discussion discloses and describes merely exemplary embodiments of the present invention. One skilled in the

art will readily recognize from such discussion and from the accompanying drawings and claims, that various changes, modifications and variations can be made therein without departing from the spirit and scope of the invention as defined in the following claims.

WHAT IS CLAIMED IS:

1. A peptide or a pharmaceutically acceptable salt thereof, wherein the peptide comprises the amino acid sequence

Xaa_1 Xaa_2 Xaa_3 Xaa_4 Cys_5 Xaa_6 Xaa_7 Xaa_8 Cys_9 Asn_{10} Pro_{11} Ala_{12} Cys_{13} Xaa_{14} Gly_{15} Xaa_{16} Xaa_{17}, or a pharmaceutically acceptable salt thereof; wherein

Xaa_1 is Asn, D-Asn, Gln, D-Gln, Pro, Ala, β-Ala, D-Ala, Val, D-Val, Gly, Thr, D-Thr, Asp, D-Asp, γ-carboxylated Asp, Glu, D-Glu, γ-carboxylated Glu, α-aminosuberic acid (Asu), α-aminoadipic acid (Aad), α-aminopimelic acid (Apm), or is absent;

Xaa_2 is Asp, γ-carboxylated Asp, Glu, γ-carboxylated Glu, Asu, Aad, Apm, or is absent;

Xaa_3 is Asp, γ-carboxylated Asp, Glu, γ-carboxylated Glu, Asu, Aad, Apm, or is absent;

Xaa_4 is Cys or D-Cys;

Xaa_6 is P-Ser, P-Thr, P-homo-Ser, 4-hydroxyvaline phosphate, P-homo-Thr, P-Cys or P-Tyr;

Xaa_7 is Tyr, Leu, Phe or Ile;

Xaa_8 is Cys or D-Cys;

Xaa_{14} is Thr, Ala or Phe;

Xaa_{16} is Cys or D-Cys; and

Xaa_{17} is Tyr, D-Tyr, or is absent;

wherein:

if Xaa_1 is present, Xaa_1 may be modified on its amino group by methyl, ethanedioic acid, propanedioic acid, butanedioic acid, pentanedioic acid, hexanedioic acid, heptanedioic acid or octanedioic acid;

if Xaa_1 is absent and Xaa_2 is present, then Xaa_2 may be modified on its amino group by methyl, ethanedioic acid, propanedioic acid, butanedioic acid, pentanedioic acid, hexanedioic acid, heptanedioic acid or octanedioic acid; or

if both Xaa_1 and Xaa_2 are absent, then Xaa_3 may be modified on its amino group by methyl, ethanedioic acid, propanedioic acid, butanedioic acid, pentanedioic acid, hexanedioic acid, heptanedioic acid or octanedioic acid.

2. The peptide or pharmaceutically acceptable salt thereof according to claim 1, wherein Xaa_2 and Xaa_3 are both absent.

3. The peptide or pharmaceutically acceptable salt thereof according to claim 1, wherein Xaa_2 is Asp or Glu and Xaa_3 is absent.

4. The peptide or pharmaceutically acceptable salt thereof according to claim 1, wherein Xaa_2 is Asp or Glu and Xaa_3 is Asp or Glu.

5. The peptide or pharmaceutically acceptable salt thereof according to any one of claims 1-4, wherein Xaa_7 is Tyr or Leu.

6. The peptide or pharmaceutically acceptable salt thereof according to any one of claims 1-5, wherein Xaa_{14} is Thr.

7. The peptide or pharmaceutically acceptable salt thereof according to any one of claims 1-6, wherein Xaa_{17} is Tyr or is absent.

8. The peptide or pharmaceutically acceptable salt thereof according to any one of claims 1-7, wherein Xaa_1 is Asn, D-Asn, Gln, D-Gln, Pro, Ala, β-Ala, D-Ala, Val, D-Val, Gly, Thr, D-Thr, Asp, D-Asp, Glu or D-Glu.

9. The peptide or pharmaceutically acceptable salt thereof according to claim 8, wherein Xaa_1 is Asp, D-Asp, Glu or D-Glu.

10. The peptide or pharmaceutically acceptable salt thereof according to any one of claims 1-9, wherein Xaa_6 is P-Ser or P-Thr.

11. The peptide or pharmaceutically acceptable salt thereof according to claim 10, wherein Xaa_6 is P-Ser.

12. The peptide or pharmaceutically acceptable salt thereof according to claim 1, wherein Xaa_1, Xaa_2 and Xaa_3 are absent.

13. The peptide or pharmaceutically acceptable salt thereof according to claim 12, wherein Xaa_7 is Tyr or Leu.

14. The peptide or pharmaceutically acceptable salt thereof according to either of claims 12 or 13, wherein Xaa_{14} is Thr.

15. The peptide or pharmaceutically acceptable salt thereof according to any one of claims 12-14, wherein Xaa_{17} is Tyr or is absent.

16. The peptide or pharmaceutically acceptable salt thereof according to any one of claims 12-15, wherein Xaa_6 is P-Ser.

17. The peptide or pharmaceutically acceptable salt thereof according to claim 16, wherein said peptide comprises the amino acid sequence

Cys_4 Cys_5 P-Ser_6 Xaa_7 Cys_8 Cys_9 Asn_{10} Pro_{11} Ala_{12} Cys_{13} Thr_{14} Gly_{15} Cys_{16} Xaa_{17},

wherein Xaa_7 is Tyr or Leu.

18. The peptide or pharmaceutically acceptable salt thereof according to claim 1, wherein said peptide comprises the amino acid sequence:

Asp Asp Cys Cys P-Ser Leu Cys Cys Asn Pro Ala Cys Thr Gly Cys Tyr;

Asp Asp Cys Cys P-Ser Leu Cys Cys Asn Pro Ala Cys Thr Gly Cys;

Asp Asp Cys Cys P-Ser Tyr Cys Cys Asn Pro Ala Cys Thr Gly Cys Tyr;

Asp Asp Cys Cys P-Ser Tyr Cys Cys Asn Pro Ala Cys Thr Gly Cys;

Cys Cys P-Ser Leu Cys Cys Asn Pro Ala Cys Thr Gly Cys Tyr;

Cys Cys P-Ser Leu Cys Cys Asn Pro Ala Cys Thr Gly Cys;

Cys Cys P-Ser Tyr Cys Cys Asn Pro Ala Cys Thr Gly Cys Tyr; or

Cys Cys P-Ser Tyr Cys Cys Asn Pro Ala Cys Thr Gly Cys.

19. The peptide or pharmaceutically acceptable salt thereof according to any one of claims 1-18, wherein said peptide comprises no more than 50, 40, 30 or 20 amino acids.

20. The peptide or pharmaceutically acceptable salt thereof according to claim 19, wherein said peptide comprises no more than 19, 18, 17, 16, 15 or 14 amino acids.

21. A peptide consisting of the amino acid sequence

Xaa_1 Xaa_2 Xaa_3 Xaa_4 Cys_5 Xaa_6 Xaa_7 Cys_8 Cys_9 Asn_{10} Pro_{11} Ala_{12} Cys_{13} Xaa_{14} Gly_{15} Cys_{16} Xaa_{17}, or a pharmaceutically acceptable salt thereof; wherein

Xaa_1 is Asn, D-Asn, Gln, D-Gln, Pro, Ala, β-Ala, D-Ala, Val, D-Val, Gly, Thr, D-Thr, Asp, D-Asp, γ-carboxylated Asp, Glu, D-Glu, γ-carboxylated Glu, α-aminosuberic acid (Asu), α-aminoadipic acid (Aad), α-aminopimelic acid (Apm), or is absent;

Xaa_2 is Asp, γ-carboxylated Asp, Glu, γ-carboxylated Glu, Asu, Aad, Apm, or is absent;

Xaa_3 is Asp, γ-carboxylated Asp, Glu, γ-carboxylated Glu, Asu, Aad, Apm, or is absent;

Xaa_4 is Cys or D-Cys;

Xaa_6 is P-Ser, P-Thr, P-homo-Ser, 4-hydroxyvaline phosphate, P-homo-Thr, P-Cys or P-Tyr;

Xaa_7 is Tyr, Leu, Phe or Ile;

Xaa_8 is Cys or D-Cys;

Xaa_{14} is Thr, Ala or Phe;

Xaa_{16} is Cys or D-Cys; and

Xaa_{17} is Tyr, D-Tyr, or is absent;

wherein:

if Xaa_1 is present, Xaa_1 may be modified on its amino group by methyl, ethanedioic acid, propanedioic acid, butanedioic acid, pentanedioic acid, hexanedioic acid, heptanedioic acid or octanedioic acid;

if Xaa_1 is absent and Xaa_2 is present, then Xaa_2 may be modified on its amino group by methyl, ethanedioic acid, propanedioic acid, butanedioic acid, pentanedioic acid, hexanedioic acid, heptanedioic acid or octanedioic acid; or

if both Xaa_1 and Xaa_2 are absent, then Xaa_3 may be modified on its amino group by methyl, ethanedioic acid, propanedioic acid, butanedioic acid, pentanedioic acid, hexanedioic acid, heptanedioic acid or octanedioic acid.

22. The peptide or pharmaceutically acceptable salt thereof according to claim 21, wherein Xaa_2 and Xaa_3 are both absent.

23. The peptide or pharmaceutically acceptable salt thereof according to claim 21, wherein Xaa_2 is Asp or Glu and Xaa_3 is absent.

24. The peptide or pharmaceutically acceptable salt thereof according to claim 21, wherein Xaa_2 is Asp or Glu and Xaa_3 is Asp or Glu.

25. The peptide or pharmaceutically acceptable salt thereof according to any one of claims 21-24, wherein Xaa_7 is Tyr or Leu.

26. The peptide or pharmaceutically acceptable salt thereof according to any one of claims 21-25, wherein Xaa_{14} is Thr.

27. The peptide or pharmaceutically acceptable salt thereof according to any one of claims 21-26, wherein Xaa_{17} is Tyr or is absent.

28. The peptide or pharmaceutically acceptable salt thereof according to any one of claims 21-27, wherein Xaa_1 is Asn, D-Asn, Gln, D-Gln, Pro, Ala, β-Ala, D-Ala, Val, D-Val, Gly, Thr, D-Thr, Asp, D-Asp, Glu or D-Glu.

29. The peptide or pharmaceutically acceptable salt thereof according to claim 28, wherein Xaa_1 is Asp, D-Asp, Glu or D-Glu.

30. The peptide or pharmaceutically acceptable salt thereof according to any one of claims 21-29, wherein Xaa_6 is P-Ser or P-Thr.

31. The peptide or pharmaceutically acceptable salt thereof according to claim 30, wherein Xaa_6 is P-Ser.

32. The peptide or pharmaceutically acceptable salt thereof according to claim 21, wherein Xaa_1, Xaa_2 and Xaa_3 are absent.

33. The peptide or pharmaceutically acceptable salt thereof according to claim 32, wherein Xaa_7 is Tyr or Leu.

34. The peptide or pharmaceutically acceptable salt thereof according to either of claims 32 or 33, wherein Xaa_{14} is Thr.

35. The peptide or pharmaceutically acceptable salt thereof according to any one of claims 32-34, wherein Xaa_{17} is Tyr or is absent.

36. The peptide or pharmaceutically acceptable salt thereof according to any one of claims 32-35, wherein Xaa_6 is P-Ser.

37. The peptide or pharmaceutically acceptable salt thereof according to claim 36, wherein said peptide consists of the amino acid sequence

Cys_4 Cys_5 P-Ser_6 Xaa_7 Cys_8 Cys_9 Asn_{10} Pro_{11} Ala_{12} Cys_{13} Thr_{14} Gly_{15} Cys_{16} Xaa_{17},

wherein Xaa_7 is Tyr or Leu.

38. The peptide or pharmaceutically acceptable salt thereof according to claim 32, wherein said peptide consists of the amino acid sequence:

Asp Asp Cys Cys P-Ser Leu Cys Cys Asn Pro Ala Cys Thr Gly Cys Tyr;
Asp Asp Cys Cys P-Ser Leu Cys Cys Asn Pro Ala Cys Thr Gly Cys;
Asp Asp Cys Cys P-Ser Tyr Cys Cys Asn Pro Ala Cys Thr Gly Cys Tyr;
Asp Asp Cys Cys P-Ser Tyr Cys Cys Asn Pro Ala Cys Thr Gly Cys;
Cys Cys P-Ser Leu Cys Cys Asn Pro Ala Cys Thr Gly Cys Tyr;
Cys Cys P-Ser Leu Cys Cys Asn Pro Ala Cys Thr Gly Cys;
Cys Cys P-Ser Tyr Cys Cys Asn Pro Ala Cys Thr Gly Cys Tyr; or
Cys Cys P-Ser Tyr Cys Cys Asn Pro Ala Cys Thr Gly Cys.

39. The peptide or pharmaceutically acceptable salt thereof according to any one of claims 1-38, wherein said peptide or pharmaceutically acceptable salt thereof is isolated.

40. The peptide or pharmaceutically acceptable salt thereof according to claim 39, wherein said peptide or pharmaceutically acceptable salt thereof is purified.

41. A pharmaceutical composition comprising a peptide or pharmaceutically acceptable salt thereof according to any one of claims 1-40.

42. A pharmaceutical composition comprising a pharmaceutically acceptable carrier, a peptide according to any one of claims 1-40 and one or more agents selected from (i) a cation

selected from Mg^{2+}, Ca^{2+}, Zn^{2+}, Mn^{2+}, K^{+}, Na^{+} or Al^{3+}, or (ii) a sterically hindered primary amine.

43. The pharmaceutical composition according to claim 42, wherein said agent is Mg^{2+}, Ca^{2+}, Zn^{2+}, Mn^{2+}, K^{+}, Na^{+} or Al^{3+}.

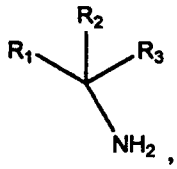
44. The pharmaceutical composition according to claim 42 or 43, wherein said Mg^{2+}, Ca^{2+}, Zn^{2+}, Mn^{2+}, K^{+}, Na^{+} or Al^{3+} is provided as magnesium acetate, magnesium chloride, magnesium phosphate, magnesium sulfate, calcium acetate, calcium chloride, calcium phosphate, calcium sulfate, zinc acetate, zinc chloride, zinc phosphate, zinc sulfate, manganese acetate, manganese chloride, manganese phosphate, manganese sulfate, potassium acetate, potassium chloride, potassium phosphate, potassium sulfate, sodium acetate, sodium chloride, sodium phosphate, sodium sulfate, aluminum acetate, aluminum chloride, aluminum phosphate or aluminum sulfate.

45. The pharmaceutical composition according to claim 42, wherein said agent is a sterically hindered primary amine.

46. The pharmaceutical composition according to claim 45, wherein the sterically hindered primary amine is an amino acid.

47. The pharmaceutical composition according to claim 46, wherein the amino acid is a naturally-occurring amino acid, a non-naturally occurring amino acid or an amino acid derivative.

48. The pharmaceutical composition according to claim 47, wherein the naturally-occurring amino acid is histidine, phenylalanine, alanine, glutamic acid, aspartic acid, glutamine, leucine, methionine, asparagine, tyrosine, threonine, isoleucine, tryptophan or valine or the non-naturally occurring amino acid is 1-aminocyclohexane carboxylic acid, lanthanine or theanine.

49. The pharmaceutical composition according to claim 42, wherein the sterically hindered primary amine has the formula: , wherein R_1, R_2 and R_3 are independently selected from: H, C(O)OH, C_1-C_6 alkyl, C_1-C_6 alkylether, C_1-C_6 alkylthioether, C_1-C_6 alkyl carboxylic acid, C_1-C_6 alkyl carboxylamide and alkylaryl, wherein any group can be singly or multiply substituted with: halogen or amino, and provided that no more than one of R_1, R_2 and R_3 is H.

50. The pharmaceutical composition according to claim 49, wherein the sterically hindered primary amine is cyclohexylamine or 2-methylbutylamine.

51. The pharmaceutical composition according to claim 42, wherein the sterically hindered primary amine is a polymeric amine.

52. The pharmaceutical composition according to claim 51, wherein the polymeric amine is chitosan.

53. The pharmaceutical composition according to any one of claims 45-52, wherein said pharmaceutical composition further comprises Mg^{2+}, Ca^{2+}, Zn^{2+}, Mn^{2+}, K^+, Na^+ or Al^{3+}.

54. The pharmaceutical composition according to claim 50, wherein said Mg^{2+}, Ca^{2+}, Zn^{2+}, Mn^{2+}, K^+, Na^+ or Al^{3+} is provided as magnesium acetate, magnesium chloride, magnesium phosphate, magnesium sulfate, calcium acetate, calcium chloride, calcium phosphate, calcium sulfate, zinc acetate, zinc chloride, zinc phosphate, zinc sulfate, manganese acetate, manganese chloride, manganese phosphate, manganese sulfate, potassium acetate, potassium chloride, potassium phosphate, potassium sulfate, sodium acetate, sodium chloride, sodium phosphate, sodium sulfate, aluminum acetate, aluminum chloride, aluminum phosphate or aluminum sulfate.

55. The pharmaceutical composition according to any one of claims 42-54, further comprising an antioxidant.

56. The pharmaceutical composition according to claim 55, wherein said antioxidant is BHA, vitamin E or propyl gallate.

57. The pharmaceutical composition according to any one of claims 42-56, further comprising a pharmaceutically acceptable binder or additive.

58. The pharmaceutical composition according to claim 57 wherein the pharmaceutically acceptable binder or additive is selected from polyvinyl alcohol, polyvinylpyrrolidone (povidone), a starch, maltodextrin or a cellulose ether.

59. The pharmaceutical composition according to claim 58, wherein the pharmaceutically acceptable binder or additive is polyvinyl alcohol.

60. The pharmaceutical composition of claim 59 wherein the pharmaceutically acceptable binder or additive is a cellulose ether.

61. The pharmaceutical composition of claim 60 wherein the cellulose ether is selected from: methylcellulose, ethylcellulose, carboxymethylcellulose, hydroxyethyl cellulose, hydroxyethyl methylcellulose, hydroxypropyl cellulose and hydroxypropyl methylcellulose.

62. The pharmaceutical composition of any of claims 42-61, further comprising a pharmaceutically acceptable filler.

63. The pharmaceutical composition according to claim 62, wherein the pharmaceutically acceptable filler is cellulose, isomalt, mannitol, lactose or dibasic calcium phosphate.

64. The pharmaceutical composition of claim 63 wherein the cellulose is selected from microfine cellulose and microcrystalline cellulose.

65. The pharmaceutical composition according to any one of claims 41-64, further comprising an additional therapeutic agent.

66. The pharmaceutical composition according to claim 65, wherein said additional therapeutic agent is selected from one or more of an analgesic agent, an antidepressant, a

promotility or prokinetic agent, an antiemetic, an antibiotic, a proton pump inhibitor, an acid blocker, a PDE5 inhibitor, an acid pump antagonist, a GABA-B agonist, a bile acid sequestrant or a mucosal protecting agent.

67. A dosage unit comprising the pharmaceutical composition according to any one of claims 41-67.

68. The dosage unit according to claim 67, wherein said dosage unit is a capsule or tablet.

69. The dosage unit according to claim 69, wherein each of said dosage units comprises 5 μg to 1 mg of said peptide.

70. A method for treating a gastrointestinal disorder comprising administering the pharmaceutical composition according to any one of claims 41-69.

71. The method according to claim 70, wherein said gastrointestinal disorder is gastroparesis, post-operative gastric ileus, a functional esophageal disorder, a functional gastroduodenal disorder, gastroesophageal reflux disease (GERD), celiac disease, mucositis, or a duodenal or stomach ulcer.

72. The method according to claim 71, wherein said gastrointestinal disorder is gastroparesis.

73. The method according to claim 72, wherein said gastroparesis is idiopathic, diabetic or post-surgical gastroparesis.

74. The method according to claim 71, wherein said gastrointestinal disorder is post-operative gastric ileus.

75. The method according to claim 71, wherein said gastrointestinal disorder is a functional esophageal disorder.

76. The method according to claim 75, wherein said functional esophageal disorder is functional heartburn, functional chest pain of presumed esophageal origin, functional dysphagia or globus.

77. The method according to claim 71, wherein said gastrointestinal disorder is a functional gastroduodenal disorder.

78. The method according to claim 77, wherein said functional gastroduodenal disorder is functional dyspepsia, a belching disorder, a nausea or vomiting disorder, or rumination syndrome.

79. The method according to claim 78, wherein said functional dyspepsia is postprandial distress syndrome or epigastric pain syndrome.

80. The method according to claim 78, wherein said belching disorder is aerophagia or unspecified excessive belching.

81. The method according to claim 78, wherein said nausea or vomiting disorder is chronic idiopathic nausea, functional vomiting or cyclic vomiting syndrome.

82. The method according to claim 71, wherein said gastrointestinal disorder is gastroesophageal reflux disease (GERD).

83. The method according to claim 71, wherein said gastrointestinal disorder is a duodenal or stomach ulcer.