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GIP-BASED MIXED AGONISTS FOR TREATMENT OF METABOLIC DISORDERS AND OBESITY

CROSS REFERENCE TO RELATED APPLICATIONS

This application claims priority to the following: U.S. Provisional Patent Application No. 61/073,274 filed on June 17, 2008, U.S. Provisional Patent Application No. 61/078,171 filed July 3, 2008, U.S. Provisional Patent Application No. 61/090,448 filed on August 20, 2008, and U.S. Provisional Patent Application No. 61/151,349 filed on February 10, 2009. The disclosure of each application is hereby expressly incorporated by reference in its entirety.

BACKGROUND

Pre-proglucagon is a 158 amino acid precursor polypeptide that is processed in different tissues to form a number of different proglucagon-derived peptides, including glucagon, glucagon-like peptide-1 (GLP-1), glucagon-like peptide-2 (GLP-2) and oxyntomodulin (OXM), that are involved in a wide variety of physiological functions, including glucose homeostasis, insulin secretion, gastric emptying, and intestinal growth, as well as the regulation of food intake. Glucagon is a 29-amino acid peptide that corresponds to amino acids 33 through 61 of pre-proglucagon, while GLP-1 is produced as a 37-amino acid peptide that corresponds to amino acids 72 through 108 of pre-proglucagon.

When blood glucose begins to fall, glucagon, a hormone produced by the pancreas, signals the liver to break down glycogen and release glucose, causing blood glucose levels to rise toward a normal level. GLP-1 has different biological activities compared to glucagon. Its actions include stimulation of insulin synthesis and secretion, inhibition of glucagon secretion, and inhibition of food intake. GLP-1 has been shown to reduce hyperglycemia (elevated glucose levels) in diabetics. Exendin-4, a peptide from lizard venom that shares about 50% amino acid identity with GLP-1, activates the GLP-1 receptor and likewise has been shown to reduce hyperglycemia in diabetics.

Glucose-dependent insulinotropic peptide (GIP) is a 42-amino acid gastrointestinal regulatory peptide that stimulates insulin secretion from pancreatic beta

cells in the presence of glucose. It is derived by proteolytic processing from a 133-amino acid precursor, preproGIP.

SUMMARY

As disclosed herein, glucagon peptides are provided that are analogs of native glucagon (SEQ ID NO: 1) and that exhibit GIP activity. The invention also provides methods of using such peptides.

Native glucagon does not activate the GIP receptor, and normally has about 1% of the activity of native-GLP-1 at the GLP-1 receptor. Modifications to the native glucagon sequence described herein produce glucagon peptides that can exhibit potent glucagon activity equivalent to or better than the activity of native glucagon (SEQ ID NO: 1), potent GIP activity equivalent to or better than the activity of native GIP (SEQ ID NO: 4), and/or potent GLP-1 activity equivalent to or better than the activity of native GLP-1. GLP-1(7-36) amide (SEQ ID NO: 3) or GLP-1(7-37) (acid) (SEQ ID NO: 2) are biologically potent forms of GLP-1, that demonstrate essentially equivalent activity at the GLP-1 receptor.

The data described herein show that peptides having both GIP activity and GLP-1 activity are particularly advantageous for inducing weight loss or preventing weight gain, as well as for treating hyperglycemia, including diabetes. *In vivo* data disclosed herein demonstrate that the combination of GIP agonist activity with GLP-1 agonist activity produces a greater effect on weight reduction than GLP-1 alone. This activity is particularly unexpected in view of teachings in the art that antagonizing GIP is desirable for reducing daily food intake and body weight, and increasing insulin sensitivity and energy expenditure. (Irwin et al., Diabetologia 50: 1532-1540 (2007); and Althage et al., J Biol Chem, e-publication on April 17, 2008).

Thus, in one aspect, the invention provides methods for inducing weight loss or preventing weight gain, which involve administering to a patient in need thereof an effective amount of a compound, e.g. a glucagon peptide, that exhibits activity at both the GIP receptor and the GLP-1 receptor, and that optionally also exhibits activity at the glucagon receptor. Such compounds include the GIP/GLP-1 co-agonists and glucagon/GIP/GLP-1 tri-agonists described herein.

32993-208847

Increased activity at the GIP receptor is provided by an amino acid modification at position 1. For example, His at position 1 is substituted with a large, aromatic amino acid, optionally Tyr, Phe, Trp, amino-Phe, nitro-Phe, chloro-Phe, sulfo-Phe, 4-pyridyl-Ala, methyl-Tyr, or 3-amino Tyr.

Increased activity at the GIP receptor is provided by modifications that stabilize the alpha helix structure of the C-terminal portion (amino acids 12-29) of the glucagon peptide or analog thereof. For example, an intramolecular bridge can be formed by a covalent bond between the side chains of two amino acids at positions i and i+4 or between positions j and j+3, or between positions k and k+7. In exemplary embodiments, the bridge is between positions 12 and 16, 16 and 20, 20 and 24, 24 and 28, or 17 and 20. In other embodiments, non-covalent interactions such as salt bridges can be formed between positively and negatively charged amino acids at these positions. Alternatively, for example, stabilization of the alpha helix structure in the C-terminal portion of the glucagon peptide (around amino acids 12-29) is achieved through purposeful introduction of one or more α, α-disubstituted amino acids at positions that retain the desired activity. In some embodiments, one, two, three, four or more of positions 16, 17, 18, 19, 20, 21, 24 or 29 of a glucagon peptide or analog thereof is substituted with an α, α-disubstituted amino acid. For example, substitution of position 16 of a glucagon peptide or analog thereof with amino iso-butyric acid (AIB) provides a stabilized alpha helix in the absence of a salt bridge or lactam. Such peptides are considered herein as a peptide lacking an intramolecular bridge. In specific aspects, stabilization of the alpha-helix is accomplished by introducing one or more α, α-disubstituted amino acids without introduction of a covalent intramolecular bridge, e.g., a lactam bridge, a disulfide bridge. Such peptides are considered herein as a peptide lacking a covalent intramolecular bridge. In some embodiments, one, two, three or more of positions 16, 20, 21 or 24 are substituted with AIB.

Increased activity at the GIP receptor is provided by amino acid modifications at positions 27 and/or 28, and optionally at position 29. For example, the Met at position 27 is substituted with a large aliphatic amino acid, optionally Leu, the Asn at position 28 is substituted with a small aliphatic amino acid, optionally Ala, and the Thr at position 29 is substituted with a small aliphatic amino acid, optionally Gly.

32993-208847

Increased activity at the GIP receptor is also provided by an amino acid modification at position 12. For example, position 12 is substituted with a large, aliphatic, nonpolar amino acid, optionally Ile.

Increased activity at the GIP receptor is also provided by an amino acid modification at positions 17 and/or 18. For example, position 17 is substituted with a polar residue, optionally Gln, and position 18 is substituted with a small aliphatic amino acid, optionally Ala.

Increased activity at the glucagon receptor is provided by an amino acid modification at position 16 of native glucagon (SEQ ID NO: 1) as described herein.

Reduced, maintained, or increased activity at the glucagon receptor is provided, e.g., by an amino acid modification at position 3 as described herein.

Restoration of glucagon activity which has been reduced by amino acid modifications at positions 1 and/or 2 is provided by modifications that stabilize the alpha helix structure of the C-terminal portion (amino acids 12-29) of the glucagon peptide or analog thereof. For example, an intramolecular bridge can be formed by a covalent bond between the side chains of two amino acids at positions i and i+4 or between positions j and j+3, or between positions k and k+7. In other embodiments, non-covalent interactions such as salt bridges can be formed between positively and negatively charged amino acids at these positions. In yet other embodiments, one or more α, α-disubstituted amino acids are inserted or substituted into this C-terminal portion (amino acids 12-29) at positions that retain the desired activity. For example, one, two, three or all of positions 16, 20, 21 or 24 are substituted with an α, α-disubstituted amino acid, e.g., AIB.

Increased activity at the GLP-1 receptor is provided by replacing the carboxylic acid of the C-terminal amino acid with a charge-neutral group, such as an amide or ester.

Increased activity at the GLP-1 receptor is provided by modifications that stabilize alpha-helix structure in the C-terminal portion (around amino acids 12-29) of the glucagon peptide or analog thereof. In some embodiments, an intramolecular bridge can be formed by a covalent bond between the side chains of two amino acids at positions i and i+4 or between positions j and j+3, or between positions k and k+7. In other embodiments, non-covalent interactions such as salt bridges can be formed between positively and negatively charged amino acids at these positions. In yet other

embodiments, one or more α, α-disubstituted amino acids are inserted or substituted into this C-terminal portion (amino acids 12-29) at positions that retain the desired activity. For example, one, two, three or all of positions 16, 20, 21 or 24 are substituted with an α, α-disubstituted amino acid, e.g., AIB.

Increased activity at the GLP-1 receptor is provided by an amino acid modification at position 20 as described herein.

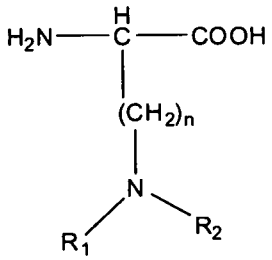
Increased activity at the GLP-1 receptor is provided by adding a C-terminal extension peptide such as GPSSGAPPPS (SEQ ID NO: 95) or XGPSSGAPPPS (SEQ ID NO: 96) to the C-terminus. GLP-1 activity in such analogs can be further increased by modifying the amino acid at position 18, 28 or 29, or at position 18 and 29, as described herein.

A further modest increase in GLP-1 potency is provided by modifying the amino acid at position 10 to be a large, aromatic amino acid residue, optionally Trp.

Reduced activity at the GLP-1 receptor is provided, e.g., by an amino acid modification at position 7, a deletion of the amino acid(s) C-terminal to the amino acid at position 27 or 28, yielding a 27- or 28-amino acid peptide, or a combination thereof, as described herein.

Preservation of activity after pegylation is provided by the addition of GPSSGAPPPS (SEQ ID NO: 95) to the C-terminus.

As demonstrated herein, maintained or increased activity at each of the glucagon receptor, GLP-1 receptor, and GIP receptor (in comparison to a lactam-containing, GIP-active, glucagon-based analog) is provided by (i) an amino acid substitution of Ser at position 16 with an amino acid of Formula IV:



[Formula IV],

wherein n is 1 to 16, or 1 to 10, or 1 to 7, or 1 to 6, or 2 to 6, or 2 or 3 or 4 or 5, each of R_1 and R_2 is independently selected from the group consisting of H, C_1-C_{18} alkyl, (C_1-C_{18}

alkyl)OH, (C_1-C_{18} alkyl)NH_2, (C_1-C_{18} alkyl)SH, (C_0-C_4 alkyl)(C_3-C_6)cycloalkyl, (C_0-C_4 alkyl)(C_2-C_5 heterocyclic), (C_0-C_4 alkyl)(C_6-C_{10} aryl)R_7, and (C_1-C_4 alkyl)(C_3-C_9 heteroaryl), wherein R_7 is H or OH, and the side chain of the amino acid of Formula IV comprises a free amino group, and (ii) an amino acid substitution of the Gln at position 20 with an alpha, alpha-disubstituted amino acid, e.g., AIB. In some embodiments, the amino acid at position 16 is Lys and the amino acid at position 20 is AIB.

The activity at each of the glucagon receptor, GLP-1 receptor, and GIP receptor of the analog comprising an amino acid of Formula IV at position 16 and an alpha, alpha di-substituted amino acid at position 20 can be further enhanced by extending the length of the peptide, e.g. by fusion to a C-terminal extension peptide, e.g. of about 1-21, about 9 to 21, about 6-18, about 9-12, or about 10 or 11 amino acids in length. In some embodiments, the C-terminus is extended by fusion to GPSSGAPPPS (SEQ ID NO: 95) or XGPSSGAPPPS (SEQ ID NO: 96), wherein X is Gly or a small, aliphatic or non-polar or slightly polar amino acid. In alternative embodiments, the C-terminus is extended by fusion to GPSSGAPPPS (SEQ ID NO: 95) and 1-11 amino acids (e.g., 1-5, or 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11 amino acids) are fused to the C-terminus of GPSSGAPPPS (SEQ ID NO: 95). The 1-11 amino acids at the C-terminus of GPSSGAPPPS (SEQ ID NO: 95) can comprise, for example, one or more small aliphatic amino acids, such as Ala or Gly. In this regard, the C-terminal extension can be, for example, $GPSSGAPPPSX_m$, wherein m is 1 to 11 (e.g., 1 to 5) and X is Ala or Gly. Alternatively, the 1 to 11 (e.g., 1 to 5) amino acids fused to the C-terminus of SEQ ID NO: 95 may be a combination of different small aliphatic amino acids. For example, the 1 to 11 (e.g., 1 to 5) amino acids may be a combination of Ala and Gly residues.

Enhancement of activity at each of the glucagon, GLP-1, and GIP receptors of a GIP-active, glucagon-based analog, including an analog comprising an amino acid of Formula IV at position 16 and an alpha, alpha disubstituted amino acid at position 20, can furthermore be achieved upon acylation or alkylation of an amino acid located within a C-terminal extension or at the C-terminal amino acid (e.g., an amino acid which is added to the C-terminus of the C-terminal extension). The acylation or alkylation can be of an amino acid located at, for example, any of positions 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, and 50. In some embodiments, the amino acid

which is acylated or alkylated is located at position 37, 38, 39, 40, 41, 42, or 43. In some embodiments, the acylated or alkylated amino acid is a Lys which is attached to an acyl or alkyl group, e.g. C10-C22. In certain embodiments, the Lys is located C-terminal to a C-terminal extension consisting of the amino acid sequence of SEQ ID NO: 95, such that the Lys is located at position 40 of the analog. Optionally, acylated, C-terminally extended peptides are also pegylated, e.g. at position 24.

Enhancement of the activity at each of the glucagon, GLP-1, and GIP receptors of a GIP-active, glucagon-based analog can moreover be achieved by acylation or alkylation of an amino acid via a spacer (e.g., an amino acid, dipeptide, tripeptide, hydrophilic bifunctional spacer, hydrophobic bifunctional spacer). In some embodiments, the GIP-active, glucagon-based analog comprises an acyl or alkyl group via a spacer, which spacer is attached to the side chain of the amino acid at position 10 or position 40 of the analog. In other embodiments, the analog comprises a C-terminal extension of 1 to 21 amino acids C-terminal to the amino acid at position 29 and the spacer, which is covalently attached to an acyl or alkyl group, is attached to an amino acid of the extension at a position corresponding to one of positions 37-43 relative to SEQ ID NO: 1. In certain embodiments, the spacer is 3 to 10 atoms in length. In specific aspects, the total length of the spacer and acyl or alkyl group is about 14 to about 28 atoms in length. Suitable spacers for purposes of increasing activity at one or more of the glucagon, GLP-1, and GIP receptors are further described herein.

Any of the modifications described above which increase or decrease GIP activity, which increase or decrease glucagon receptor activity, and which increase or decrease GLP-1 receptor activity can be applied individually or in combination. Any of the modifications described above can also be combined with other modifications that confer other desirable properties, such as increased solubility and/or stability and/or duration of action. Alternatively, any of the modifications described above can be combined with other modifications that do not substantially affect solubility or stability or activity. Exemplary modifications include but are not limited to:

(A) Improving solubility, for example, by introducing one, two, three or more charged amino acid(s) to the C-terminal portion of native glucagon, preferably at a position C-terminal to position 27. Such a charged amino acid can be introduced by

substituting a native amino acid with a charged amino acid, e.g. at positions 28 or 29, or alternatively by adding a charged amino acid, e.g. after position 27, 28 or 29. In exemplary embodiments, one, two, three or all of the charged amino acids are negatively charged. In other embodiments, one, two, three or all of the charged amino acids are positively charged. Such modifications increase solubility, e.g. provide at least 2-fold, 5-fold, 10-fold, 15-fold, 25-fold, 30-fold or greater solubility relative to native glucagon at a given pH between about 5.5 and 8, e.g., pH 7, when measured after 24 hours at 25°C.

(B) Increasing solubility and duration of action or half-life in circulation by addition of a hydrophilic moiety such as a polyethylene glycol chain, as described herein, e.g. at position 16, 17, 20, 21, 24 or 29, within a C-terminal extension, or at the C-terminal amino acid of the peptide,

(C) Increasing solubility and/or duration of action or half-life in circulation and/or delaying the onset of action by acylation or alkylation of the glucagon peptide, as described herein;

(D) Increasing duration of action or half-life in circulation through introducing resistance to dipeptidyl peptidase IV (DPP IV) cleavage by modification of the amino acid at position 1 or 2 as described herein.

(E) Increasing stability by modification of the Asp at position 15, for example, by deletion or substitution with glutamic acid, homoglutamic acid, cysteic acid or homocysteic acid. Such modifications can reduce degradation or cleavage at a pH within the range of 5.5 to 8, for example, retaining at least 75%, 80%, 90%, 95%, 96%, 97%, 98% or 99%, up to 100% of the original peptide after 24 hours at 25°C. Such modifications reduce cleavage of the peptide bond between Asp15-Ser16.

(F) Increasing stability by modification of the Ser at position 16, for example by substitution with Thr or AIB. Such modifications also reduce cleavage of the peptide bond between Asp15-Ser16.

(G) Increasing stability by modification of the methionine at position 27, for example, by substitution with leucine or norleucine. Such modifications can reduce oxidative degradation. Stability can also be increased by modification of the Gln at position 20 or 24, e.g. by substitution with Ala, Ser, Thr, or AIB. Such modifications can reduce degradation that occurs through deamidation of Gln. Stability can be increased by

modification of Asp at position 21, e.g. by substitution with Glu. Such modifications can reduce degradation that occurs through dehydration of Asp to form a cyclic succinimide intermediate followed by isomerization to iso-aspartate.

(H) Non-conservative or conservative substitutions, additions or deletions that do not substantially affect activity, for example, conservative substitutions at one or more of positions 2, 5, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 24, 27, 28 or 29; substitution of one or more of these positions with Ala; deletion of amino acids at one or more of positions 27, 28 or 29; or deletion of amino acid 29 optionally combined with a C-terminal amide or ester in place of the C-terminal carboxylic acid group; substitution of Lys at position 12 with Arg; substitution of Tyr at position 10 with Val or Phe;

In some embodiments, the glucagon peptides described herein exhibit an EC50 for GIP receptor activation activity of about 100nM or less, or about 75, 50, 25, 10, 8, 6, 5, 4, 3, 2 or 1 nM or less. In some embodiments, the glucagon peptides described herein exhibit an EC50 at the GIP receptor that is about 0.001 nM, 0.01 nM, or 0.1 nM. In some embodiments, the glucagon peptides described herein exhibit an EC50 at the GIP receptor that is no more than about 1 nM, 2 nM, 3 nM, 4 nM, 5 nM, 6 nM, 8 nM, 10 nM, 15 nM, 20 nM, 25 nM, 30 nM, 40 nM, 50 nM, 75 nM, or 100 nM. In some embodiments, the glucagon peptides exhibit an EC50 for glucagon receptor activation of about 100nM or less, or about 75, 50, 25, 10, 8, 6, 5, 4, 3, 2 or 1 nM or less. In some embodiments, the glucagon peptides described herein exhibit an EC50 at the glucagon receptor that is about 0.001 nM, 0.01 nM, or 0.1 nM. In some embodiments, the EC50 at the glucagon receptor is no more than about 1 nM, 2 nM, 3 nM, 4 nM, 5 nM, 6 nM, 8 nM, 10 nM, 15 nM, 20 nM, 25 nM, 30 nM, 40 nM, 50 nM, 75 nM, or 100 nM. In some embodiments, the glucagon peptides exhibit an EC50 for GLP-1 receptor activation of about 100 nM or less, or about 75, 50, 25, 10, 8, 6, 5, 4, 3, 2 or 1 nM or less. In some embodiments, the glucagon peptides described herein exhibit an EC50 at the GLP-1 receptor that is about 0.001 nM, 0.01 nM, or 0.1 nM. In some embodiments, the EC50 at the GLP-1 receptor is no more than about 1 nM, 2 nM, 3 nM, 4 nM, 5 nM, 6 nM, 8 nM, 10 nM, 15 nM, 20 nM, 25 nM, 30 nM, 40 nM, 50 nM, 75 nM, or 100 nM. Receptor activation can be measured by *in vitro* assays measuring cAMP induction in HEK293 cells over-expressing the

receptor, e.g. assaying HEK293 cells co-transfected with DNA encoding the receptor and a luciferase gene linked to cAMP responsive element as described in Example 16.

In some embodiments, glucagon peptides exhibit at least about 0.1%, 0.2%, 0.3%, 0.4%, 0.5%, 0.6%, 0.7%, 0.8%, 0.9%,1%, 5%, 10%, 20%, 30%, 40%, 50%, 60%, 75%, 100%, 125%, 150%, 175% or 200% or higher activity at the GIP receptor relative to native GIP (GIP potency). In some embodiments, the glucagon peptides described herein exhibit no more than 1000%, 10,000%, 100,000%, or 1,000,000% activity at the GIP receptor relative to native GIP. In some embodiments, glucagon peptides exhibit at least about 1%, 5%, 10%, 20%, 30%, 40%, 50%, 60%, 75%, 100%, 125%, 150%, 175%, 200%, 250%, 300%, 350%, 400%, 450%, or 500% or higher activity at the glucagon receptor relative to native glucagon (glucagon potency). In some embodiments, the glucagon peptides described herein exhibit no more than 1000%, 10,000%, 100,000%, or 1,000,000% activity at the glucagon receptor relative to native glucagon. In some embodiments, glucagon peptides exhibit at least about 0.1%, 0.2%, 0.3%, 0.4%, 0.5%, 0.6%, 0.7%, 0.8%, 0.9%, 1%, 5%, 10%, 20%, 30%, 40%, 50%, 60%, 75%, 100%, 125%, 150%, 175% or 200% or higher activity at the GLP-1 receptor relative to native GLP-1 (GLP-1 potency). In some embodiments, the glucagon peptides described herein exhibit no more than 1000%, 10,000%, 100,000%, or 1,000,000% activity at the GLP-1 receptor relative to native GLP-1. A glucagon peptide's activity at a receptor relative to a native ligand of the receptor is calculated as the inverse ratio of EC50s for the glucagon peptide vs. the native ligand.

Thus, one aspect of the invention provides glucagon peptides that exhibit activity at both the glucagon receptor and the GIP receptor ("glucagon/GIP co-agonists"). These glucagon peptides have lost native glucagon's selectivity for glucagon receptor compared to GIP receptor. In some embodiments, the EC50 of the glucagon peptide at the GIP receptor is less than about 50-fold, 40-fold, 30-fold or 20-fold different (higher or lower) from its EC50 at the glucagon receptor. In some embodiments, the GIP potency of the glucagon peptide is less than about 500-, 450-, 400-, 350-, 300-, 250-, 200-, 150-, 100-, 75-, 50-, 25-, 20-, 15-, 10-, or 5-fold different (higher or lower) from its glucagon potency. In some embodiments, the ratio of the EC50 of the glucagon peptide at the GIP receptor divided by the EC50 of the glucagon peptide at the glucagon receptor is less than

about 100, 75, 60, 50, 40, 30, 20, 15, 10, or 5. In some embodiments, the ratio of the EC50 at the GIP receptor divided by the EC50 at the glucagon receptor is about 1 or less than about 1 (e.g., about 0.01, 0.013, 0.0167, 0.02, 0.025, 0.03, 0.05, 0.067, 0.1, 0.2). In some embodiments, the ratio of the GIP potency of the glucagon peptide compared to the glucagon potency of the glucagon peptide is less than about 500, 450, 400, 350, 300, 250, 200, 150, 100, 75, 60, 50, 40, 30, 20, 15, 10, or 5. In some embodiments, the ratio of the potency at the GIP receptor divided by the potency at the glucagon receptor is about 1 or less than about 1 (e.g., about 0.01, 0.013, 0.0167, 0.02, 0.025, 0.03, 0.05, 0.067, 0.1, 0.2). In some embodiments, GLP-1 activity has been significantly reduced or destroyed, e.g., by an amino acid modification at position 7, a deletion of the amino acid(s) C-terminal to the amino acid at position 27 or 28, yielding a 27- or 28-amino acid peptide, or a combination thereof.

Another aspect of the invention provides glucagon peptides that exhibit activity at the glucagon, GIP and GLP-1 receptors ("glucagon/GIP/GLP-1 tri-agonists"). These glucagon peptides have lost native glucagon's selectivity for the glucagon receptor compared to both the GLP-1 and GIP receptors. In some embodiments, the EC50 of the glucagon peptide at the GIP receptor is less than about 50-fold, 40-fold, 30-fold or 20-fold different (higher or lower) from its respective EC50s at the glucagon and GLP-1 receptors. In some embodiments, the GIP potency of the glucagon peptide is less than about 500-, 450-, 400-, 350-, 300-, 250-, 200-, 150-, 100-, 75-, 50-, 25-, 20-, 15-, 10-, or 5-fold different (higher or lower) from its glucagon and GLP-1 potencies. In some embodiments, the ratio of the EC50 of the tri-agonist at the GIP receptor divided by the EC50 of the tri-agonist at the GLP-1 receptor is less than about 100, 75, 60, 50, 40, 30, 20, 15, 10, or 5. In some embodiments, the ratio of the EC50 at the GIP receptor divided by the EC50 at the GLP-1 receptor is about 1 or less than about 1 (e.g., about 0.01, 0.013, 0.0167, 0.02, 0.025, 0.03, 0.05, 0.067, 0.1, 0.2). In some embodiments, the ratio of the GIP potency of the tri-agonist compared to the GLP-1 potency of the tri-agonist is less than about 100, 75, 60, 50, 40, 30, 20, 15, 10, or 5. In some embodiments, the ratio of the potency at the GIP receptor divided by the potency at the GLP-1 receptor is about 1 or less than about 1 (e.g., about 0.01, 0.013, 0.0167, 0.02, 0.025, 0.03, 0.05, 0.067, 0.1, 0.2). In related embodiments, the ratio of the EC50 of the tri-agonist at the GIP receptor

divided by the EC50 of the tri-agonist at the glucagon receptor is less than about 100, 75, 60, 50, 40, 30, 20, 15, 10, or 5. In some embodiments, the ratio of the EC50 at the GIP receptor divided by the EC50 at the glucagon receptor is about 1 or less than about 1 (e.g., about 0.01, 0.013, 0.0167, 0.02, 0.025, 0.03, 0.05, 0.067, 0.1, 0.2). In some embodiments, the ratio of the GIP potency of the tri-agonist compared to the glucagon potency of the tri-agonist is less than about 500, 450, 400, 350, 300, 250, 200, 150, 100, 75, 60, 50, 40, 30, 20, 15, 10, or 5. In some embodiments, the ratio of the potency at the GIP receptor divided by the potency at the glucagon receptor is about 1 or less than about 1 (e.g., about 0.01, 0.013, 0.0167, 0.02, 0.025, 0.03, 0.05, 0.067, 0.1, 0.2). In some embodiments, the ratio of the EC50 of the tri-agonist at the GLP-1 receptor divided by the EC50 of the tri-agonist at the glucagon receptor is less than about 100, 75, 60, 50, 40, 30, 20, 15, 10, or 5. In some embodiments, the ratio of the EC50 at the GLP-1 receptor divided by the EC50 at the glucagon receptor is about 1 or less than about 1 (e.g., about 0.01, 0.013, 0.0167, 0.02, 0.025, 0.03, 0.05, 0.067, 0.1, 0.2). In some embodiments, the ratio of the GLP-1 potency of the tri-agonist compared to the glucagon potency of the tri-agonist is less than about 100, 75, 60, 50, 40, 30, 20, 15, 10, or 5. In some embodiments, the ratio of the potency at the GLP-1 receptor divided by the potency at the glucagon receptor is about 1 or less than about 1 (e.g., about 0.01, 0.013, 0.0167, 0.02, 0.025, 0.03, 0.05, 0.067, 0.1, 0.2).

Yet another aspect of the invention provides glucagon peptides that exhibit activity at the GLP-1 and GIP receptors, but in which the glucagon activity has been significantly reduced or destroyed ("GIP/GLP-1 co-agonists"), e.g., by an amino acid modification at position 3. For example, substitution at this position with an acidic, basic, or a hydrophobic amino acid (glutamic acid, ornithine, norleucine) reduces glucagon activity. In some embodiments, the EC50 of the glucagon peptide at the GIP receptor is less than about 50-fold, 40-fold, 30-fold or 20-fold different (higher or lower) from its EC50 at the GLP-1 receptor. In some embodiments, the GIP potency of the glucagon peptide is less than about 25-, 20-, 15-, 10-, or 5-fold different (higher or lower) from its GLP-1 potency. In some embodiments these glucagon peptides have about 10% or less of the activity of native glucagon at the glucagon receptor, e.g. about 1-10%, or about 0.1-10%, or greater than about 0.1% but less than about 10%. In some embodiments, the

ratio of the EC50 of the glucagon peptide at the GIP receptor divided by the EC50 of the glucagon peptide at the GLP-1 receptor is less than about 100, 75, 60, 50, 40, 30, 20, 15, 10, or 5, and no less than 1. In some embodiments, the ratio of the GIP potency of the glucagon peptide compared to the GLP-1 potency of the glucagon peptide is less than about 100, 75, 60, 50, 40, 30, 20, 15, 10, or 5, and no less than 1.

A further aspect of the invention provides glucagon peptides that exhibit activity at the GIP receptor, in which the glucagon and GLP-1 activity have been significantly reduced or destroyed ("GIP agonist glucagon peptides"), e.g., by amino acid modifications at positions 3 and 7. In some embodiments these glucagon peptides have about 10% or less of the activity of native glucagon at the glucagon receptor, e.g. about 1-10%, or about 0.1-10%, or greater than about 0.1%, 0.5%, or 1% but less than about 1%, 5%, or 10%. In some embodiments these glucagon peptides also have about 10% or less of the activity of native GLP-1 at the GLP-1 receptor, e.g. about 1-10%, or about 0.1-10%, or greater than about 0.1%, 0.5%, or 1% but less than about 1%, 5%, or 10%.

In accordance with some embodiments of the invention, the analog of glucagon (SEQ ID NO: 1) having GIP agonist activity comprises SEQ ID NO: 1 with (a) an amino acid modification at position 1 that confers GIP agonist activity, (b) a modification which stabilizes the alpha helix structure of the C-terminal portion (amino acids 12-29) of the analog, and (c) optionally, 1 to 10 (e.g., 1, 2, 3, 4, 5, 6, 7, 8, 9, 10) further amino acid modifications. In some embodiments, the analog exhibits at least about 1% activity of native GIP at the GIP receptor or any other activity level at the GIP receptor described herein. The modification which stabilizes the alpha helix structure may be any of those known in the art, such as, for example, any of those described herein. See the teachings under the section "Stabilization of the Alpha Helix Structure." In some embodiments, the modification which stabilizes the alpha helix structure is a modification selected from the group consisting of: (i) a lactam bridge between the side chains of amino acids at positions i and i+4 or between the side chains of amino acids at positions j and j+3, wherein i is 12, 13, 16, 17, 20 or 24, and wherein j is 17, and (ii) one, two, three, or all of the amino acids at positions 16, 20, 21, and 24 of the analog is substituted with an α,α-disubstituted amino acid. Such analogs of glucagon having GIP agonist activity are further described herein.

32993-208847

In some embodiments, the invention provides an analog of glucagon (SEQ ID NO: 1) having GIP agonist activity, with the following modifications:

(a) an amino acid modification at position 1,

(b) (i) a lactam bridge between the side chains of amino acids at positions i and i+4 or between the side chains of amino acids at positions j and j+3, wherein i is 12, 13, 16, 17, 20 or 24, and wherein j is 17, or (ii) an amino acid substitution with an α, α-disubstituted amino acid at one, two, three or all of positions 16, 20, 21, or 24,

(c) amino acid modifications at one, two or all of positions 27, 28 and 29, and

(d) 1, 2, 3, 4, 5, 6, or 8 further amino acid modifications,

wherein the EC50 of the analog for GIP receptor activation is about 100 nM or less.

In exemplary embodiments,

(a) the amino acid modification at position 1 is a substitution of His at position 1 with a large, aromatic amino acid, optionally Tyr, Phe, Trp, amino-Phe, nitro-Phe, chloro-Phe, sulfo-Phe, 4-pyridyl-Ala, methyl-Tyr, or 3-amino Tyr,

(b) (i) the lactam bridge is between the amino acids at positions 16 and 20, wherein one of the amino acids at positions 16 and 20 is substituted with Glu, and the other of the amino acids at positions 16 and 20 is substituted with Lys, or (ii) the α, α-disubstituted amino acid is AIB,

(c) the Met at position 27 is substituted with a large aliphatic amino acid, optionally Leu,

(d) the Asn at position 28 is substituted with a small aliphatic amino acid, optionally Ala, and

(e) the Thr at position 29 is substituted with a small aliphatic amino acid, optionally Gly.

The analog may comprise further modifications, including without limitation:

(a) amino acid modification at position 12, optionally substitution with Ile,

(b) amino acid modifications at positions 17 and 18, optionally substitution with Q at position 17 and A at position 18,

(c) addition of GPSSGAPPPS (SEQ ID NO: 95) to the C-terminus, or any combination thereof.

The analog may alternatively or in addition comprise further modifications, including without limitation:

(a) Ser at position 2 substituted with D-Ser, Ala, D-Ala, Gly, N-methyl-Ser, AIB, Val, or α-amino-N-butyric acid;

(b) Tyr at position 10 substituted with Trp, Lys, Orn, Glu, Phe, or Val;

(c) Linkage of an acyl group to a Lys at position 10;

(d) Lys at position 12 substituted with Arg;

(e) Ser at position 16 substituted with Glu, Gln, homoglutamic acid, homocysteic acid, Thr, Gly, or AIB;

(f) Arg at position 17 substituted with Gln, Lys or Glu;

(g) Arg at position 18 substituted with Ala, Ser, Thr, or Gly;

(h) Gln at position 20 substituted with Ala, Ser, Thr, Lys, Citrulline, Arg, Orn, or AIB;

(i) Asp at position 21 substituted with Glu, homoglutamic acid, homocysteic acid;

(j) Val at position 23 substituted with Ile;

(k) Gln at position 24 substituted with Asn, Ala, Ser, Thr,Glu, Lys, or AIB; and

(l) a conservative substitution at any of positions 2, 5, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 24, 27, 28, and 29,

or any combination thereof.

In some embodiments, when the glucagon peptide is not pegylated, the EC50 of the analog for GIP receptor activation is about 4, 2, 1 nM or less, or the analog has at least about 1%, 2%, 3%, 4% or 5% of the activity of native GIP at the GIP receptor. In related embodiments, the EC50 of the unpegylated analog for GLP-1 receptor activation

is about 4, 2, 1 nM or less or has at least about 1%, 2%, 3%, 4% or 5% of the activity of native GLP-1 at the GLP-1 receptor. In yet other related embodiments, the EC50 of the unpegylated analog for glucagon receptor activation is about 4, 2, 1 nM or less, or at least about 5%, 10%, 15% or 20% of the activity of native glucagon at the glucagon receptor. In some embodiments, the unpegylated analog has less than about 1% of the activity of native glucagon at the glucagon receptor. In other embodiments, the unpegylated analog has less than about 10%, 5% or 1% of the activity of native GLP-1 at the GLP-1 receptor.

In some embodiments, the glucagon peptide is covalently linked to a hydrophilic moiety at any of amino acid positions 16, 17, 20, 21, 24, or 29, after position 29 at an added amino acid (e.g., position 30) within a C-terminal extension, or at the C-terminal amino acid. In exemplary embodiments, this hydrophilic moiety is covalently linked to a Lys, Cys, Orn, homocysteine, or acetyl-phenylalanine residue at any of these positions. Exemplary hydrophilic moieties include polyethylene glycol (PEG), for example, of a molecular weight of about 1,000 Daltons to about 40,000 Daltons, or about 20,000 Daltons to about 40,000 Daltons.

In such embodiments where the analogs are linked to hydrophilic moieties such as PEG, the relative EC50s at one or more receptors may be higher, e.g., about 10-fold higher, in comparison to the analog lacking the hydrophilic moiety. For example, the EC50 of a pegylated analog for GIP receptor activation is about 10 nM or less, or the analog has at least about 0.1%, 0.2%, 0.3%, 0.4%, or 0.5% of the activity of native GIP at the GIP receptor. In related embodiments, the EC50 of a pegylated analog for GLP-1 receptor activation is about 10 nM or less or has at least about 0.1%, 0.2%, 0.3%, 0.4% or 0.5% of the activity of native GLP-1 at the GLP-1 receptor. In yet other related embodiments, the EC50 of a pegylated analog for glucagon receptor activation is about 10 nM or less, or at least about 0.5%, 1%, 1.5% or 2% of the activity of native glucagon at the glucagon receptor. In some embodiments, the analog has less than about 1% of the activity of native glucagon at the glucagon receptor. In other embodiments, the analog has less than about 10%, 5% or 1% of the activity of native GLP-1 at the GLP-1 receptor.

The glucagon peptide may be part of a dimer, trimer or higher order multimer comprising at least two, three, or more peptides bound via a linker, wherein at least one or both peptides is a glucagon peptide. The dimer may be a homodimer or heterodimer.

32993-208847

In some embodiments, the linker is selected from the group consisting of a bifunctional thiol crosslinker and a bi-functional amine crosslinker. In certain embodiments, the linker is PEG, e.g., a 5 kDa PEG, 20 kDa PEG. In some embodiments, the linker is a disulfide bond. For example, each monomer of the dimer may comprise a Cys residue (e.g., a terminal or internally positioned Cys) and the sulfur atom of each Cys residue participates in the formation of the disulfide bond. In some aspects of the invention, the monomers are connected via terminal amino acids (e.g., N-terminal or C-terminal), via internal amino acids, or via a terminal amino acid of at least one monomer and an internal amino acid of at least one other monomer. In specific aspects, the monomers are not connected via an N-terminal amino acid. In some aspects, the monomers of the multimer are attached together in a "tail-to-tail" orientation in which the C-terminal amino acids of each monomer are attached together. A conjugate moiety may be covalently linked to any of the glucagon peptides described herein, including a dimer, trimer or higher order multimer.

Any of the modifications described herein which increase glucagon receptor activity, retain partial glucagon receptor activity, improve solubility, increase stability, or reduce degradation can be applied to glucagon peptides individually or in combination. In some embodiments, the glucagon peptides are soluble at a concentration of at least 1 mg/mL at a pH between 6 and 8, or between 6 and 9, or between 7 and 9 (e.g. pH 7), and optionally retain at least 95% of the original peptide (e.g. 5% or less of the original peptide is degraded or cleaved) after 24 hours at 25°C.

Sterile pharmaceutical compositions comprising a pharmaceutically acceptable carrier or diluent and kits comprising devices are provided. Methods of reducing weight gain or inducing weight loss, comprising administering to a patient in need thereof such pharmaceutical compositions in an amount effective to reduce weight gain or induce weight loss are provided. Methods of treating diabetes, comprising administering to a patient in need thereof such pharmaceutical compositions in an amount effective to lower blood glucose levels are provided.

All therapeutic methods, pharmaceutical compositions, kits and other similar embodiments described herein contemplate that the use of the terms peptides, agonists,

co-agonists, tri-agonists, or analogs includes all pharmaceutically acceptable salts or esters thereof.

The foregoing summary is not intended to define every aspect of the invention, and additional embodiments are described in other sections, such as the Detailed Description. The entire document is intended to be related as a unified disclosure, and it should be understood that all possible combinations of features described herein may be contemplated, even if the combination of features are not found together in the same sentence, or paragraph, or section of this document.

Moreover, the invention includes any one or all embodiments of the invention that are narrower in scope in any way than the variations defined by specific paragraphs herein. For example, where certain aspects of the invention are described as a genus, it should be understood that every member of a genus is, individually, an embodiment of the invention, and that combinations of two or more members of the genus are embodiments of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 represents a graph of the % change in body weight in mice as a function of time (days) after administration of vehicle alone (open inverted triangles), chimera 2 AIB2 Cys24 (40K PEG) (closed squares), GIP antagonist Pro3 Cys24 GIP-NH_2 (1-42) 40K PEG (open diamonds), GIP agonist AIB2 Cys24 GIP (1-42) 40K PEG (open upright triangles with dotted line), or an unrelated peptide hormone (shaded inverted triangles).

Figure 2 represents a graph of the food intake (in grams) by mice as a function in time after administration of vehicle alone (open inverted triangles), chimera 2 AIB2 Cys24 40K PEG (closed squares), GIP antagonist Pro3 Cys24 GIP-NH_2 (1-42) 40K PEG (open diamonds), GIP agonist AIB2 Cys24 GIP (1-42) 40K PEG (open upright triangles with dotted line), or an unrelated peptide hormone (shaded inverted triangles).

Figure 3 represents a graph of the change in blood glucose levels (mg/dL) in mice at Day 7 after administration of vehicle alone (black bar), chimera 2 AIB2 Cys24 (40K PEG) (white bar), GIP antagonist Pro3 Cys24 GIP-NH2 (1-42) 40K PEG (shaded bar), GIP agonist AIB2 Cys24 GIP (1-42) 40K PEG (horizontal lined bar), or an unrelated peptide hormone (vertical lined bar).

32993-208847

Figure 4 represents a graph of the % change in body weight in mice as a function of time (days) after administration of vehicle alone (closed inverted triangles), chimera 2 AIB2 (open diamonds), chimera 2 AIB2 lactam (open triangles), triagonist peptide MT-170 (open squares), GIP/glucagon co-agonist peptide MT-182 (closed diamonds), GLP-1/GIP co-agonist peptide MT-178 (shaded triangles with dotted line), or GIP/glucagon co-agonist peptide MT-179 (closed squares). Note that PEGylated MT-179 acts as a triagonist.

Figure 5 is a graph of the % change in body weight in mice as a function of time (days) after administration of vehicle alone (closed upright triangles), GLP-1 E 16 agonist at 10 nmol/kg (closed inverted triangles) or 35 nmol/kg (open squares), triagonist peptide MT-170 at 10 nmol/kg (open inverted triangles) or 35 nmol/kg (closed diamonds), or GLP-1/GIP co-agonist peptide MT-178 at 10 nmol/kg (grey inverted triangles) or at 35 nmol/kg (grey squares).

Figure 6 is a graph of the change in blood glucose levels (mg/dL) in mice at Day 7 after administration of vehicle alone (black bar), GLP-1 E 16 agonist at 10 nmol/kg (white bar) or 35 nmol/kg (grey bar), triagonist peptide MT-170 at 10 nmol/kg (horizontal lined bar) or 35 nmol/kg (vertical lined bar), or GLP-1/GIP co-agonist peptide MT-178 at 10 nmol/kg (right-left diagonal lined bar) or at 35 nmol/kg (left-right diagonal lined bar).

Figure 7 represents a graph of the blood glucose levels (mg/dL) as a function of time before and after a glucose injection (administered at timepoint 0) of mice injected (at timepoint -60) with a vehicle control, a GLP-1 agonist peptide control, a lactam-containing (cyclic), pegylated, GIP-active glucagon analog ("mt-178"), or a lactam-lacking (linear), pegylated, GIP-active glucagon analog ("mt-274") at 1, 3, or 10 nmol/kg/week. The data of this figure excludes the data of four mice, as these mice exhibited aggressive behavior and substantial weight loss.

Figure 8 represents a graph of the blood glucose levels (mg/dL) as a function of time before and after a glucose injection (administered at timepoint 0) of mice injected (24 hours before the glucose injection) with a vehicle control, a GLP-1 agonist peptide control, mt-178, or mt-274 at 1, 3, or 10 nmol/kg/week. The data of this figure excludes

the data of four mice, as these mice exhibited aggressive behavior and substantial weight loss.

Figure 9 represents a graph of the blood glucose levels (mg/dL) of mice 0 or 7 days after injection with a vehicle control, a GLP-1 agonist peptide control, mt-178, or mt-274 at 1, 3, or 10 nmol/kg/week. The data of this figure excludes the data of four mice, as these mice exhibited aggressive behavior and substantial weight loss.

Figure 10 represents a graph of the percent change in body weight of mice 0, 1, 3, 5, and 7 days after injection with a vehicle control, a GLP-1 agonist peptide control, mt-178, or mt-274 at 1, 3, or 10 nmol/kg/week. The data of this figure excludes the data of four mice, as these mice exhibited aggressive behavior and substantial weight loss.

Figure 11 represents a graph of the blood glucose levels (mg/dL) of mice 0 or 7 days after injection with a vehicle control, a GLP-1 agonist peptide control, mt-178, mt-178(TE), mt-274, or mt-274(TE) at 10 or 35 nmol/kg/week. "TE" indicates a PEG group attached to the Cys at position 40.

Figure 12 represents a graph of the change in blood glucose (mg/dL) of mice 7 days after injection with a vehicle control, a GLP-1 agonist peptide control, mt-178, mt-178(TE), mt-274, or mt-274(TE) at 10 or 35 nmol/kg/week. "TE" indicates a PEG group attached to the Cys at position 40.

Figure 13 represents a graph of the percent change in body weight of mice 0, 1, 3, 5, 7, and 10 days after injection with a vehicle control, a GLP-1 agonist peptide control, mt-178, mt-178(TE), mt-274, or mt-274(TE) at 10 or 35 nmol/kg/week. "TE" indicates a PEG group attached to the Cys at position 40.

Figure 14 represents a graph of the percent change in body weight of mice 7 days after injection with a vehicle control, a GLP-1 agonist peptide control, mt-178, mt-178(TE), mt-274, or mt-274(TE) at 10 or 35 nmol/kg/week. "TE" indicates a PEG group attached to the Cys at position 40.

Figure 15 represents a graph of the blood glucose levels (mg/dL) of mice 0 or 7 days after injection with a vehicle control, a GLP-1 agonist peptide control, mt-178, mt-274, a linear, unpegylated, unacylated peptide ("mt-311"), a C14 fatty acylated linear peptide ("mt-309"), a C16 fatty acylated linear peptide ("mt-298"), or a C18 fatty acylated linear peptide ("mt-310") at 10 nmol/kg.

32993-208847

Figure 16 represents a graph of the percent change in body weight of mice 0, 1, 3, 5, and 7 days after injection with a vehicle control, a GLP-1 agonist peptide control, mt-178, mt-274, mt-311, mt-309, mt-298, or mt-310 at 10 nmol/kg.

Figure 17 represents a graph of the percent change in body weight of mice 7 days after injection with a vehicle control, a GLP-1 agonist peptide control, mt-178, mt-274, mt-311, mt-309, mt-298, or mt-310 at 10 nmol/kg.

Figure 18 represents a graph of the change in blood glucose levels (mg/dL) of mice 0 and 7 days after QD injections for 7 days with a vehicle control, liraglutide (an acylated GLP-1 analog), a C14 fatty acylated, unpegylated linear peptide ("mt-260"), a C16 fatty acylated, unpegylated linear peptide ("mt-261"), or a C18 fatty acylated, unpegylated linear peptide ("mt-262") at 25 or 125 nmol/kg.

Figure 19 represents a graph of the percent change in body weight of mice 0, 1, 3, 5, and 7 days after injection with a vehicle control, liraglutide, mt-260, mt-261, or mt-262 at 25 or 125 nmol/kg.

Figure 20 represents a graph of the percent change in body weight of mice 7 days after injection with a vehicle control, liraglutide, mt-260, mt-261, or mt-262 at 25 or 125 nmol/kg.

Figure 21 represents a graph of the change in body weight (g) of mice 0, 1, 3, 5, and 7 days after the first injection with a vehicle control, liraglutide (30 nmol/kg/day), or mt-261 (0.3, 1, 3, 10, or 30 nmol/kg/day).

Figure 22 represents a graph of the fat mass of mice 7 days after the first injection with a vehicle control, liraglutide (30 nmol/kg/day), or mt-261 (0.3, 1, 3, 10, or 30 nmol/kg/day).

Figure 23 represents a graph of the blood glucose levels (mg/dL) of mice 0 and 7 days after the first injection with a vehicle control, liraglutide (30 nmol/kg/day), or mt-261 (0.3, 1, 3, 10, or 30 nmol/kg/day).

Figure 24 represents a line graph of the change in body weight (% change) as a function of time of mice injected with mt-263, Exendin-4, or a vehicle control at the doses (nmol/kg/day) indicated in ().

32993-208847

Figure 25 represents a bar graph of the total change in body weight (%) (as measured on Day 7 in comparison to Day 0) of mice injected with mt-263, Exendin-4, or a vehicle control at the doses (nmol/kg/day) indicated in ().

Figure 26 represents a bar graph of the change in blood glucose levels (mg/dL) (as measured on Day 7 in comparison to Day 0) of mice injected with mt-263, Exendin-4, or a vehicle control at the doses (nmol/kg/day) indicated in ().

Figure 27 represents a graph of the % change in body weight of mice 0, 1, 3, 5, and 7 days after the first injection with a vehicle control, liraglutide, mt-277, mt-278, or mt-279.

Figure 28 represents a graph of the blood glucose levels (mg/dL) of mice 0 and 7 days after the first injection with a vehicle control, liraglutide, mt-277, mt-278, or mt-279.

Figure 29 represents a graph of the total change in body weight (%) of mice as measured 7 days after administration of mt-331, mt-311, or a vehicle control. Doses (nmol/kg) are indicated in ().

Figure 30 represents a graph of the total food intake (g) by mice as measured 7 days after administration of mt-331, mt-311, or a vehicle control. Doses (nmol/kg) are indicated in ().

Figure 31 represents a graph of the total change in blood glucose levels of mice as measured 7 days after administration of mt-331, mt-311, or a vehicle control. Doses (nmol/kg) are indicated in ().

Figure 32 represents a graph of the total change in body weight of mice as measured 7 days after administration of mt-331, mt-353, or a vehicle control at the indicated dose (nmol/kg) shown in ().

Figure 33 represents a graph of the total food intake (g) by mice as measured 7 days after administration of mt-331, mt-353, or a vehicle control at the indicated dose (nmol/kg) shown in ().

Figure 34 represents a graph of the change in blood glucose levels (mg/dL) of mice as measured 7 days after administration of mt-331, mt-353, or a vehicle control at the indicated dose (nmol/kg) shown in ().

32993-208847

Figure 35 represents a graph of the total change in body weight (%) of mice as measured 7 days after the first administration of mt-277, mt-278, mt-279, or a vehicle control.

Figure 36 represents a graph of the total change in body weight (%) of mice as measured 6 days after the first administration of mt-261, mt-309, or a vehicle control.

Figure 37 represents a graph of the blood glucose levels (mg/dL) of mice as measured 6 days after the first administration of mt-261, mt-309, or a vehicle control. The first bar of each pair of bars of the same pattern is the blood glucose levels as measured on Day 0 and the second bar of each pair is the levels on Day 6.

Figure 38 represents a bar graph of the total change in body weight (%)as measured 6 days after the first administration of mt-261 (in comparison to the body weight as measured on the first day of administration) of mice injected with a vehicle control or mt-261 as further described herein.

DETAILED DESCRIPTION

DEFINITIONS

In describing and claiming the invention, the following terminology will be used in accordance with the definitions set forth below.

The term "about" as used herein means greater or lesser than the value or range of values stated by 10 percent, but is not intended to designate any value or range of values to only this broader definition. Each value or range of values preceded by the term "about" is also intended to encompass the embodiment of the stated absolute value or range of values.

As used herein, the term "pharmaceutically acceptable carrier" includes any of the standard pharmaceutical carriers, such as a phosphate buffered saline solution, water, emulsions such as an oil/water or water/oil emulsion, and various types of wetting agents. The term also encompasses any of the agents approved by a regulatory agency of the US Federal government or listed in the US Pharmacopeia for use in animals, including humans.

As used herein the term "pharmaceutically acceptable salt" refers to salts of compounds that retain the biological activity of the parent compound, and which are not

biologically or otherwise undesirable. Many of the compounds disclosed herein are capable of forming acid and/or base salts by virtue of the presence of amino and/or carboxyl groups or groups similar thereto.

Pharmaceutically acceptable base addition salts can be prepared from inorganic and organic bases. Salts derived from inorganic bases, include by way of example only, sodium, potassium, lithium, ammonium, calcium and magnesium salts. Salts derived from organic bases include, but are not limited to, salts of primary, secondary and tertiary amines.

Pharmaceutically acceptable acid addition salts may be prepared from inorganic and organic acids. Salts derived from inorganic acids include hydrochloric acid, hydrobromic acid, sulfuric acid, nitric acid, phosphoric acid, and the like. Salts derived from organic acids include acetic acid, propionic acid, glycolic acid, pyruvic acid, oxalic acid, malic acid, malonic acid, succinic acid, maleic acid, fumaric acid, tartaric acid, citric acid, benzoic acid, cinnamic acid, mandelic acid, methanesulfonic acid, ethanesulfonic acid, p-toluene-sulfonic acid, salicylic acid, and the like.

As used herein, the term "treating" includes prophylaxis of the specific disorder or condition, or alleviation of the symptoms associated with a specific disorder or condition and/or preventing or eliminating said symptoms. For example, as used herein the term "treating diabetes" will refer in general to altering glucose blood levels in the direction of normal levels and may include increasing or decreasing blood glucose levels depending on a given situation.

As used herein an "effective" amount or a "therapeutically effective amount" of a glucagon peptide refers to a nontoxic but sufficient amount of the peptide to provide the desired effect. For example one desired effect would be the prevention or treatment of hypoglycemia, as measured, for example, by an increase in blood glucose level. An alternative desired effect for the glucagon peptides of the present disclosure would include treating hyperglycemia, e.g., as measured by a change in blood glucose level closer to normal, or inducing weight loss/preventing weight gain, e.g., as measured by reduction in body weight, or preventing or reducing an increase in body weight, or normalizing body fat distribution. The amount that is "effective" will vary from subject to subject, depending on the age and general condition of the individual, mode of

administration, and the like. Thus, it is not always possible to specify an exact "effective amount." However, an appropriate "effective" amount in any individual case may be determined by one of ordinary skill in the art using routine experimentation.

The term, "parenteral" means not through the alimentary canal but by some other route such as subcutaneous, intramuscular, intraspinal, or intravenous.

As used herein, the term "purified" and like terms relate to the isolation of a molecule or compound in a form that is substantially free of contaminants normally associated with the molecule or compound in a native or natural environment. As used herein, the term "purified" does not require absolute purity; rather, it is intended as a relative definition. The term "purified polypeptide" is used herein to describe a polypeptide which has been separated from other compounds including, but not limited to nucleic acid molecules, lipids and carbohydrates.

The term "isolated" requires that the referenced material be removed from its original environment (e.g., the natural environment if it is naturally occurring). For example, a naturally-occurring polynucleotide present in a living animal is not isolated, but the same polynucleotide, separated from some or all of the coexisting materials in the natural system, is isolated.

As used herein, the term "peptide" encompasses a sequence of 3 or more amino acids and typically less than 50 amino acids, wherein the amino acids are naturally occurring or non-naturally occurring amino acids. Non-naturally occurring amino acids refer to amino acids that do not naturally occur in vivo but which, nevertheless, can be incorporated into the peptide structures described herein.

As used herein, the terms "polypeptide" and "protein" are terms that are used interchangeably to refer to a polymer of amino acids, without regard to the length of the polymer. Typically, polypeptides and proteins have a polymer length that is greater than that of "peptides."

A "glucagon peptide" as used herein includes any peptide comprising, either the amino acid sequence of SEQ ID NO: 1, or any analog of the amino acid sequence of SEQ ID NO: 1, including amino acid substitutions, additions, deletions or post translational modifications (e.g., methylation, acylation, alkylation, ubiquitination, intramolecular covalent bonding such as lactam bridge formation, PEGylation, and the like) of the

peptide, wherein the analog stimulates glucagon or GLP-1 or GIP receptor activity, e.g., as measured by cAMP production using the assay described in Example 16.

The term "glucagon agonist" refers to a complex comprising a glucagon peptide that stimulates glucagon receptor activity, e.g., as measured by cAMP production using the assay described in Example 16.

As used herein an amino acid "modification" refers to a substitution, addition or deletion of an amino acid, and includes substitution with or addition of any of the 20 amino acids commonly found in human proteins, as well as atypical or non-naturally occurring amino acids. Throughout the application, all references to a particular amino acid position by number (e.g. position 28) refer to the amino acid at that position in native glucagon (SEQ ID NO:1) or the corresponding amino acid position in any analogs thereof. For example, a reference herein to "position 28" would mean the corresponding position 27 for a glucagon analog in which the first amino acid of SEQ ID NO: 1 has been deleted. Similarly, a reference herein to "position 28" would mean the corresponding position 29 for a glucagon analog in which one amino acid has been added before the N-terminus of SEQ ID NO: 1. Commercial sources of atypical amino acids include Sigma-Aldrich (Milwaukee, WI), ChemPep Inc. (Miami, FL), and Genzyme Pharmaceuticals (Cambridge, MA). Atypical amino acids may be purchased from commercial suppliers, synthesized de novo, or chemically modified or derivatized from other amino acids.

As used herein the term "native glucagon" refers to a peptide consisting of the sequence of SEQ ID NO: 1, the term "native GIP" refers to a peptide consisting of the sequence of SEQ ID NO: 4, and the term "native GLP-1" is a generic term that designates GLP-1(7-36) amide (consisting of the sequence of SEQ ID NO: 3), GLP-1(7-37) acid (consisting of the sequence of SEQ ID NO: 2) or a mixture of those two compounds. As used herein, a general reference to "glucagon" or "GIP" or "GLP-1" in the absence of any further designation is intended to mean native glucagon or native GIP or native GLP-1, respectively.

As used herein an amino acid "substitution" refers to the replacement of one amino acid residue by a different amino acid residue.

32993-208847

As used herein, the term "conservative amino acid substitution" is defined herein as exchanges within one of the following five groups:

I. Small aliphatic, nonpolar or slightly polar residues:
Ala, Ser, Thr, Pro, Gly;

II. Polar, negatively charged residues and their amides and esters:
Asp, Asn, Glu, Gln, cysteic acid and homocysteic acid;

III. Polar, positively charged residues:
His, Arg, Lys; Ornithine (Orn)

IV. Large, aliphatic, nonpolar residues:
Met, Leu, Ile, Val, Cys, Norleucine (Nle), homocysteine

V. Large, aromatic residues:
Phe, Tyr, Trp, acetyl phenylalanine

As used herein the general term "polyethylene glycol chain" or "PEG chain", refers to mixtures of condensation polymers of ethylene oxide and water, in a branched or straight chain, represented by the general formula $H(OCH_2CH_2)_nOH$, wherein n is at least 9. Absent any further characterization, the term is intended to include polymers of ethylene glycol with an average total molecular weight selected from the range of 500 to 40,000 Daltons. "polyethylene glycol chain" or "PEG chain" is used in combination with a numeric suffix to indicate the approximate average molecular weight thereof. For example, PEG-5,000 refers to polyethylene glycol chain having a total molecular weight average of about 5,000.

As used herein the term "pegylated" and like terms refers to a compound that has been modified from its native state by linking a polyethylene glycol chain to the compound. A "pegylated glucagon peptide" is a glucagon peptide that has a PEG chain covalently bound to the glucagon peptide.

As used herein a general reference to a peptide is intended to encompass peptides that have modified amino and carboxy termini. For example, an amino acid chain comprising an amide group in place of the terminal carboxylic acid is intended to be encompassed by an amino acid sequence designating the standard amino acids.

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As used herein a "linker" is a bond, molecule or group of molecules that binds two separate entities to one another. Linkers may provide for optimal spacing of the two entities or may further supply a labile linkage that allows the two entities to be separated from each other. Labile linkages include photocleavable groups, acid-labile moieties, base-labile moieties and enzyme-cleavable groups.

As used herein a "dimer" is a complex comprising two subunits covalently bound to one another via a linker. The term dimer, when used absent any qualifying language, encompasses both homodimers and heterodimers. A homodimer comprises two identical subunits, whereas a heterodimer comprises two subunits that differ, although the two subunits are substantially similar to one another.

As used herein the term "charged amino acid" refers to an amino acid that comprises a side chain that is negatively charged (i.e., de-protonated) or positively charged (i.e., protonated) in aqueous solution at physiological pH. For example negatively charged amino acids include aspartic acid, glutamic acid, cysteic acid, homocysteic acid, and homoglutamic acid, whereas positively charged amino acids include arginine, lysine and histidine. Charged amino acids include the charged amino acids among the 20 amino acids commonly found in human proteins, as well as atypical or non-naturally occurring amino acids.

As used herein the term "acidic amino acid" refers to an amino acid that comprises a second acidic moiety, including for example, a carboxylic acid or sulfonic acid group.

As used herein, the term "selectivity" of a molecule for a first receptor relative to a second receptor refers to the following ratio: EC50 of the molecule at the second receptor divided by the EC50 of the molecule at the first receptor. For example, a molecule that has an EC50 of 1 nM at a first receptor and an EC50 of 100 nM at a second receptor has 100-fold selectivity for the first receptor relative to the second receptor.

As used herein, "glucagon potency" of a molecule refers to the ratio of the EC50 of the molecule at glucagon receptor divided by the EC50 of native glucagon at glucagon receptor.

As used herein, "GIP potency" of a molecule refers to the ratio of the EC50 of the molecule at GIP receptor divided by the EC50 of native GIP at GIP receptor.

32993-208847

As used herein, "GLP-1 potency" of a molecule refers to the ratio of the EC50 of the molecule at GLP-1 receptor divided by the EC50 of native GLP-1 at GLP-1 receptor.

As used herein, the term "alkyl" refers to a linear or branched hydrocarbon containing the indicated number of carbon atoms. Exemplary alkyls include methyl, ethyl, and linear propyl groups.

As used herein, the term "heteroalkyl" refers to a linear or branched hydrocarbon containing the indicated number of carbon atoms and at least one heteroatom in the backbone of the structure. Suitable heteroatoms for purposes herein include but are not limited to N, S, and O.

As used herein, the term "cycloalkyl" refers to a cyclic hydrocarbon group containing the indicated number of carbon atoms, e.g., cyclopropyl, cyclobutyl, cyclohexyl, and cyclopentyl.

As used herein, the term "heterocyclic" refers to a cyclic hydrocarbon group containing the indicated number of carbon atoms and one to three heteroatoms independently selected from the group consisting of oxygen, nitrogen, and sulfur. Nonlimiting examples of heterocycloalkyl groups include piperdine, tetrahydrofuran, tetrahydropyran, dihydrofuran, morpholine, thiophene, and the like.

As used herein, the term "aryl" refers to a monocyclic or polycyclic aromatic group, preferably a monocyclic or bicyclic aromatic group, e.g., phenyl or naphthyl, containing the indicated number of carbon atoms. Unless otherwise indicated, an aryl group can be unsubstituted or substituted.

As used herein, the term "heteroaryl" refers to a monocyclic or polycyclic aromatic group containing the indicated number of carbon atoms and at least one heteroatom selected from the group consisting of oxygen, nitrogen, and sulfur. Unless otherwise indicated, an aryl group can be unsubstituted or substituted.

EMBODIMENTS

The modifications disclosed herein permit the manipulation of glucagon (SEQ ID NO: 1) to create glucagon peptides that exhibit increased GIP activity, glucagon activity, and/or GLP-1 activity. Other modifications disclosed herein prolong the half-life, increase solubility, or increase stability of the resulting peptide. Yet other modifications

disclosed herein have no effect on activity, or can be made without destroying the desired activity or activities. Any of the combinations that serve the same purpose (e.g. increasing GIP activity) can be applied individually or in combination. Any of the single or sets of combinations that confer enhanced properties can be applied individually or in combination, e.g. increased GIP and/or GLP-1 activity can be combined with increased half-life.

In exemplary embodiments, the glucagon peptide may comprise a total of 1, up to 2, up to 3, up to 4, up to 5, up to 6, up to 7, up to 8, up to 9, or up to 10 amino acid modifications relative to the native glucagon sequence. In some embodiments, such glucagon peptides retain at least 22, 23, 24, 25, 26, 27 or 28 of the naturally occurring amino acids at the corresponding positions in native glucagon (e.g. have 1-7, 1-5 or 1-3 modifications relative to naturally occurring glucagon). In related embodiments, 1, 2, 3, 4, 5, 6 or more of the amino acid modifications may be non-conservative substitutions, additions or deletions. In some embodiments, 1, 2, 3, 4, 5, 6 or more of the amino acid modifications may be conservative substitutions. In some embodiments 1, 2, 3, 4 or 5 non-conservative substitutions are carried out at any of positions 2, 5, 7, 10, 11, 12, 13, 14, 17, 18, 19, 20, 21, 24, 27, 28 or 29 and up to 5 further conservative substitutions are carried out at any of these positions. In some embodiments 1, 2, or 3 amino acid modifications are carried out within amino acids at positions 1-16, and 1, 2 or 3 amino acid modifications are carried out within amino acids at positions 17-26.

Modifications that affect GIP activity

Enhanced activity at the GIP receptor is provided by an amino acid modification at position 1. For example, His at position 1 is substituted with a large, aromatic amino acid, optionally Tyr, Phe, Trp, amino-Phe, nitro-Phe, chloro-Phe, sulfo-Phe, 4-pyridyl-Ala, methyl-Tyr, or 3-amino Tyr. Unexpectedly, the combination of Tyr at position 1 with stabilization of the alpha helix within the region corresponding to amino acids 12-29 provided a glucagon peptide that activates GIP receptor as well as GLP-1 receptor and glucagon receptor. The alpha helix structure can be stabilized by, e.g., formation of a covalent or non-covalent intramolecular bridge, or substitution and/or insertion of amino

acids around positions 12-29 with an alpha helix-stabilizing amino acid (e.g., an α,α-disubstituted amino acid).

Enhanced activity at the GIP receptor is also provided by amino acid modifications at positions 27 and/or 28, and optionally at position 29. For example, the Met at position 27 is substituted with a large aliphatic amino acid, optionally Leu, the Asn at position 28 is substituted with a small aliphatic amino acid, optionally Ala, and the Thr at position 29 is substituted with a small aliphatic amino acid, optionally Gly. Substitution with LAG at positions 27-29 provides increased GIP activity relative to the native MNT sequence at those positions.

Enhanced activity at the GIP receptor is also provided by an amino acid modification at position 12. For example, position 12 is substituted with a large, aliphatic, nonpolar amino acid, optionally Ile.

Enhanced activity at the GIP receptor is also provided by an amino acid modification at positions 17 and/or 18. For example, position 17 is substituted with a polar residue, optionally Gln, and position 18 is substituted with a small aliphatic amino acid, optionally Ala. A substitution with QA at positions 17 and 18 provides increased GIP activity relative to the native RR sequence at those positions.

Any of the modifications described above which increase GIP receptor activity can be applied individually or in combination. Combinations of the modifications that increase GIP receptor activity generally provide higher GIP activity than any of such modifications taken alone.

Modifications that affect glucagon activity

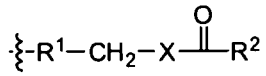
In some embodiments, analogs of glucagon are provided that have enhanced potency and optionally improved solubility and stability. In one embodiment, enhanced glucagon potency is provided by an amino acid modification at position 16 of native glucagon (SEQ ID NO: 1). By way of nonlimiting example, such enhanced potency can be provided by substituting the naturally occurring serine at position 16 with glutamic acid or with another negatively charged amino acid having a side chain with a length of 4 atoms, or alternatively with any one of glutamine, homoglutamic acid, or homocysteic acid, or a charged amino acid having a side chain containing at least one heteroatom, (e.g.

N, O, S, P) and with a side chain length of about 4 (or 3-5) atoms. In some embodiments the glucagon peptide retains its original selectivity for the glucagon receptor relative to the GLP-1 receptors.

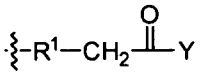
Glucagon receptor activity can be reduced by an amino acid modification at position 3, e.g. substitution of the naturally occurring glutamine at position 3, with an acidic, basic, or a hydrophobic amino acid. For example substitution at position 3 with glutamic acid, ornithine, or norleucine substantially reduces or destroys glucagon receptor activity.

Maintained or enhanced activity at the glucagon receptor may be achieved by modifying the Gln at position 3 with a glutamine analog. For example, a glucagon peptide comprising a glutamine analog at position 3 may exhibit about 5%, about 10%, about 20%, about 50%, or about 85% or greater the activity of native glucagon (SEQ ID NO: 1) at the glucagon receptor. In some embodiments a glucagon peptide comprising a glutamine analog at position 3 may exhibit about 20%, about 50%, about 75%, about 100%, about 200% or about 500% or greater the activity of a corresponding glucagon peptide having the same amino acid sequence as the peptide comprising the glutamine analog, except for the modified amino acid at position 3 (e.g. SEQ ID NO: 250 or SEQ ID NO: 251) at the glucagon receptor. In some embodiments, a glucagon peptide comprising a glutamine analog at position 3 exhibits enhanced activity at the glucagon receptor, but the enhanced activity is no more than 1000%, 10,000%, 100,000%, or 1,000,000% of the activity of native glucagon or of a corresponding glucagon peptide having the same amino acid sequence as the peptide comprising the glutamine analog, except for the modified amino acid at position 3.

In some embodiments, the glutamine analog is a naturally occurring or a non-naturally occurring amino acid comprising a side chain of Structure I, II or III:

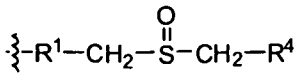


Structure I



Structure II

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Structure III

wherein R^1 is C_{0-3} alkyl or C_{0-3} heteroalkyl; R^2 is NHR^4 or C_{1-3} alkyl; R^3 is C_{1-3} alkyl; R^4 is H or C_{1-3} alkyl; X is NH, O, or S; and Y is NHR^4, SR^3, or OR^3. In some embodiments, X is NH or Y is NHR^4. In some embodiments, R^1 is C_{0-2} alkyl or C_1 heteroalkyl. In some embodiments, R^2 is NHR^4 or C_1 alkyl. In some embodiments, R^4 is H or C^1 alkyl. In exemplary embodiments, an amino acid comprising a side chain of Structure I is provided where, R^1 is CH_2-S, X is NH, and R^2 is CH_3 (acetamidomethyl-cysteine, C(Acm)); R^1 is CH_2, X is NH, and R^2 is CH_3 (acetyldiaminobutanoic acid, Dab(Ac)); R^1 is C_0 alkyl, X is NH, R^2 is NHR^4, and R^4 is H (carbamoyldiaminopropanoic acid, Dap(urea)); or R^1 is CH_2-CH_2, X is NH, and R^2 is CH_3 (acetylornithine, Orn(Ac)). In exemplary embodiments, an amino acid comprising a side chain of Structure II is provided where, R^1 is CH_2, Y is NHR^4, and R^4 is CH_3 (methylglutamine, Q(Me)); In exemplary embodiments, an amino acid comprising a side chain of Structure III is provided where, R^1 is CH_2 and R^4 is H (methionine-sulfoxide, M(O)); In specific embodiments, the amino acid at position 3 is substituted with Dab(Ac). For example, glucagon agonists can comprise the amino acid sequence of any of SEQ ID NOs: 243-248, 250, 251, and 253-256.

Modifications that affect GLP-1 activity

Enhanced activity at the GLP-1 receptor is provided by replacing the carboxylic acid of the C-terminal amino acid with a charge-neutral group, such as an amide or ester.

Enhanced activity at the GLP-1 receptor is also provided by stabilizing the alpha-helix structure in the C-terminal portion of glucagon (around amino acids 12-29), e.g., through formation of an intramolecular bridge between the side chains of two amino acids, or substitution and/or insertion of amino acids around positions 12-29 with an alpha helix-stabilizing amino acid (e.g., an α,α-disubstituted amino acid). The side chains of these amino acids can be linked to one another through hydrogen-bonding or ionic interactions, such as the formation of salt bridges, or by covalent bonds. In some embodiments, the bridge is formed between amino acids that are separated by three

intervening amino acids, i.e. an amino acid at position "i" and an amino acid at position "i+4", wherein i is any integer from 12 to 25 (e.g., 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24 or 25). In exemplary embodiments, the side chains of the amino acid pairs 12 and 16, 13 and 17, 16 and 20 , 17 and 21, 20 and 24 or 24 and 28 (amino acid pairs in which i = 12, 16, 20, or 24) are linked to one another and thus stabilize the glucagon alpha helix.

In other embodiments, the bridge is formed between amino acids that are separated by two intervening amino acids, i.e. an amino acid at position "j" and an amino acid at position "j+3", wherein j is any integer from 12 to 26 (e.g., 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25 or 26). In exemplary embodiments, j is 17. In further embodiments, the bridge is formed between amino acids that are separated by six intervening amino acids, i.e. an amino acid at position "k" and an amino acid at position "k+7", wherein k is any integer from 12 to 22 (e.g., 12, 13, 14, 15, 16, 17, 18, 19, 20, 21 or 22). In one embodiment, k is 17.

In some embodiments, the bridge or linker is about 8 (or about 7-9) atoms in length, particularly when the bridge is between positions i and i+4. In some embodiments, the bridge or linker is about 6 (or about 5-7) atoms in length, particularly when the bridge is between positions j and j+3.

In some embodiments, intramolecular bridges are formed by (a) substituting the naturally occurring serine at position 16 with glutamic acid or with another negatively charged amino acid having a side chain with a length of 4 atoms, or alternatively with any one of glutamine, homoglutamic acid, or homocysteic acid, or a charged amino acid having a side chain containing at least one heteroatom, (e.g. N, O, S, P) and with a side chain length of about 4 (or 3-5) atoms, and (b) substituting the naturally occurring glutamine at position 20 with another hydrophilic amino acid having a side chain that is either charged or has an ability to hydrogen-bond, and is at least about 5 (or about 4-6) atoms in length, for example, lysine, citrulline, arginine, or ornithine. The side chains of such amino acids at positions 16 and 20 can form a salt bridge or can be covalently linked.

In one embodiment the two amino acids are bound to one another to form a lactam ring. The size of the lactam ring can vary depending on the length of the amino acid side chains, and in one embodiment the lactam is formed by linking the side chains

of a lysine amino acid to a glutamic acid side chain. The order of the amide bond in the lactam ring can be reversed (e.g., a lactam ring can be formed between the side chains of a Lys12 and a Glu16 or alternatively between a Glu 12 and a Lys16)

In some embodiments, stabilization of the alpha helix structure in the C-terminal portion of the glucagon peptide is achieved through the formation of an intramolecular bridge other than a lactam bridge. For example, suitable covalent bonding methods include any one or more of olefin metathesis, lanthionine-based cyclization, disulfide bridge or modified sulfur-containing bridge formation, the use of α, ω-diaminoalkane tethers, the formation of metal-atom bridges, and other means of peptide cyclization are used to stabilize the alpha helix.

Potency at the GLP-1 receptor can be further enhanced by an alanine substitution for the native arginine at position 18.

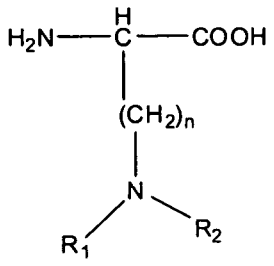
Any of the modifications described above which increase GLP-1 receptor activity can be applied individually or in combination. Combinations of the modifications that increase GLP-1 receptor activity generally provide higher GLP-1 activity than any of such modifications taken alone. For example, the invention provides glucagon peptides that comprise modifications at position 16, at position 20, and at the C-terminal carboxylic acid group, optionally with a covalent bond between the amino acids at positions 16 and 20; glucagon peptides that comprise modifications at position 16 and at the C-terminal carboxylic acid group; glucagon peptides that comprise modifications at positions 16 and 20, optionally with a covalent bond between the amino acids at positions 16 and 20; and glucagon peptides that comprise modifications at position 20 and at the C-terminal carboxylic acid group.

GLP-1 activity may be reduced by comprising (i) a C-terminal alpha carboxylate group, (ii) a substitution of the Thr at position 7 with an amino acid lacking a hydroxyl group, e.g., Abu or Ile, (iii) a deletion of the amino acid(s) C-terminal to the amino acid at position 27 or 28 (e.g., deletion of the amino acid at position 28, deletion of the amino acid at positions 28 and 29) to yield a peptide 27 or 28 amino acids in length, or (iv) a combination thereof.

32993-208847

Modifications That Affect Activity At Each Of The Glucagon, GLP-1, And GIP Receptors

Enhanced activity at each of the glucagon receptor, GLP-1 receptor, and GIP receptor is provided by (i) an amino acid substitution of Ser at position 16 with an amino acid of Formula IV:



[Formula IV],

wherein n is 1 to 16, or 1 to 10, or 1 to 7, or 1 to 6, or 2 to 6, or 2 or 3 or 4 or 5, each of R_1 and R_2 is independently selected from the group consisting of H, C_1-C_{18} alkyl, (C_1-C_{18} alkyl)OH, (C_1-C_{18} alkyl)NH_2, (C_1-C_{18} alkyl)SH, (C_0-C_4 alkyl)(C_3-C_6)cycloalkyl, (C_0-C_4 alkyl)(C_2-C_5 heterocyclic), (C_0-C_4 alkyl)(C_6-C_{10} aryl)R_7, and (C_1-C_4 alkyl)(C_3-C_9 heteroaryl), wherein R_7 is H or OH, and the side chain of the amino acid of Formula IV comprises a free amino group, and (ii) an amino acid substitution of the Gln at position 20 with an alpha, alpha-disubstituted amino acid, e.g., AIB. In some embodiments, the amino acid at position 16 is Orn, Dab, Lys, or homoLys, and the amino acid at position 20 is AIB. In specific embodiments, the amino acid at position 16 is Lys and the amino acid at position 20 is AIB.

The activity at each of the glucagon receptor, GLP-1 receptor, and glucagon receptor of the analog comprising an amino acid of Formula IV at position 16 and an alpha, alpha di-substituted amino acid at position 20 can be further enhanced by extending the length of the peptide, e.g. by fusion to a C-terminal extension peptide, e.g. of about 1-21, about 9 to 21, about 6-18, about 9-12, or about 10 or 11 amino acids in length. In some embodiments, the C-terminus is extended by fusion to GPSSGAPPPS (SEQ ID NO: 95) or XGPSSGAPPPS (SEQ ID NO: 96), wherein X is Gly or a small, aliphatic or non-polar or slightly polar amino acid. In alternative embodiments, the C-terminus is extended by fusion to GPSSGAPPPS (SEQ ID NO: 95) and 1-11 amino acids are fused to the C-terminus of GPSSGAPPPS (SEQ ID NO: 95). For example, the C-

terminal extension of the analog can comprise GPSSGAPPPS (SEQ ID NO: 95) followed by 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, or 11 additional amino acids at the C-terminus of SEQ ID NO: 95. The 1-11 additional amino acids can be, for example, a small aliphatic amino acid, such as Ala. In this regard, the C-terminal extension can, for example, comprise the amino acid sequence of $GPSSGAPPPSA_m$, wherein m is 1 to 11.

Enhancement of activity at each of the glucagon, GLP-1, and GIP receptors of a GIP-active, glucagon-based analog, including an analog comprising an amino acid of Formula IV at position 16 and an alpha, alpha disubstituted amino acid at position 20, can furthermore be achieved upon acylation or alkylation of an amino acid located within a C-terminal extension or at the C-terminal amino acid (e.g., an amino acid which is added to the C-terminus of the C-terminal extension). The acylation or alkylation can be of an amino acid located, for example, at any of positions 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, and 50 of the C-terminally extended analog. In some embodiments, the amino acid which is acylated or alkylated is located at position 37, 38, 39, 40, 41, 42, or 43 of the C-terminally extended analog. In some embodiments, the acylated or alkylated amino acid is an amino acid of Formula I, II, or III, e.g., Lys, which is attached to an acyl or alkyl group, e.g. C10-C22. In certain embodiments, the Lys is located C-terminal to a C-terminal extension consisting of SEQ ID NO: 95, such that the Lys, Dab, Orn, or homoLys is located at position 40 of the analog. Optionally, C-terminally extended peptides are also pegylated, e.g. at any of the positions described herein (e.g., position 24).

Enhancement of the activity at each of the glucagon, GLP-1, and GIP receptors of a GIP-active, glucagon-based analog can moreover be achieved by acylation or alkylation of an amino acid via a spacer (e.g., an amino acid, dipeptide, tripeptide, hydrophilic bifunctional spacer, hydrophobic bifunctional spacer). In some embodiments, the GIP-active, glucagon-based analog comprises an acyl or alkyl group via a spacer, which spacer is attached to the side chain of the amino acid at position 10 of the analog. In other embodiments, the analog comprises a C-terminal extension of 1 to 21 amino acids (e.g., an extension comprising the amino acid sequence of SEQ ID NO: 95 or 96) C-terminal to the amino acid at position 29 and the spacer, which is covalently attached to an acyl or alkyl group, is attached to an amino acid of the extension at a position

corresponding to one of positions 37-43 relative to SEQ ID NO: 1. In specific embodiments, the spacer is attached to the amino acid at position 40 relative to SEQ ID NO: 1. In certain embodiments, the spacer is 3 to 10 atoms in length. In specific aspects, the total length of the spacer and acyl or alkyl group is about 14 to about 28 atoms in length. For example, the spacer can be an amino acid, including, but not limited to, any of those described herein. Also, for example, the spacer may be a dipeptide or tripeptide comprising amino acids described herein. The spacer in specific aspects is one of the following dipeptides: Ala-Ala, βAla-βAla, or γGlu-γGlu. Additional suitable spacers for purposes of increasing activity at one or more of the glucagon, GLP-1, and GIP receptors are further described herein.

Modifications that improve DPP-IV resistance

Modifications at position 1 and/or 2 can increase the peptide's resistance to dipeptidyl peptidase IV (DPP IV) cleavage. For example, the amino acid at position 2 may be substituted with D-serine, D-alanine, valine, glycine, N-methyl serine, N-methyl alanine, or amino isobutyric acid. In some embodiments, the amino acid at position 1 may be substituted with D-histidine, desaminohistidine, hydroxyl-histidine, acetyl-histidine, homo-histidine, N-methyl histidine, alpha-methyl histidine, imidazole acetic acid, or alpha, alpha-dimethyl imidiazole acetic acid (DMIA).

It was observed that modifications at position 2 (e.g. AIB at position 2) and in some cases modifications at position 1 (e.g., DMIA at position 1) may reduce glucagon activity, sometimes significantly; surprisingly, this reduction in glucagon activity can be restored by stabilizing the alpha-helix structure in the C-terminal portion of glucagon (around amino acids 12-29), e.g., through formation of a covalent bond between the side chains of two amino acids, as described herein. In some embodiments, the covalent bond is between amino acids at positions "i" and "i+4", or positions "j" and "j+3", e.g., between positions 12 and 16, 16 and 20, 20 and 24, 24 and 28, or 17 and 20. In exemplary embodiments, this covalent bond is a lactam bridge between a glutamic acid at position 16 and a lysine at position 20. In some embodiments, this covalent bond is an intramolecular bridge other than a lactam bridge. For example, suitable covalent bonding methods (i.e., means of forming a covalent intramolecular bridge) include any one or more of olefin metathesis, lanthionine-based cyclization, disulfide bridge or modified

sulfur-containing bridge formation, the use of α, ω-diaminoalkane tethers, the formation of metal-atom bridges, and other means of peptide cyclization.

Modifications that reduce degradation

In yet further exemplary embodiments, any of the glucagon peptides can be further modified to improve stability by modifying the amino acid at position 15 and/or 16 of SEQ ID NO: 1 to reduce degradation of the peptide over time, especially in acidic or alkaline buffers. Such modifications reduce cleavage of the Asp15-Ser16 peptide bond. In exemplary embodiments, the amino acid modification at position 15 is a deletion or substitution of Asp with glutamic acid, homoglutamic acid, cysteic acid or homocysteic acid. In other exemplary embodiments, the amino acid modification at position 16 is a deletion or substitution of Ser with Thr or AIB. In other exemplary embodiments, Ser at position 16 is substituted with glutamic acid or with another negatively charged amino acid having a side chain with a length of 4 atoms, or alternatively with any one of glutamine, homoglutamic acid, or homocysteic acid.

In some embodiments the methionine residue present at position 27 of the native peptide is modified, e.g. by deletion or substitution. Such modifications may prevent oxidative degradation of the peptide. In some embodiments, the Met at position 27 is substituted with leucine, isoleucine or norleucine. In some specific embodiments, Met at position 27 is substituted with leucine or norleucine.

In some embodiments, the Gln at position 20 and/or 24 is modified, e.g. by deletion or substitution. Such modifications can reduce degradation that occurs through deamidation of Gln. In some embodiments, the Gln at position 20 and/or 24 is substituted with Ala or AIB. In some embodiments the Gln at position 20 and/or 24 is substituted with Lys, Arg, Orn, or Citrulline.

In some embodiments, the Asp at position 21 is modified, e.g. by deletion or substitution. Such modifications can reduce degradation that occurs through dehydration of Asp to form a cyclic succinimide intermediate followed by isomerization to iso-aspartate. In some embodiments, position 21 is substituted with Glu, homoglutamic acid or homocysteic acid. In some specific embodiments, position 21 is substituted with Glu.

Other modifications

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Some positions of the native glucagon peptide can be modified while retaining at least some of the activities of the parent peptide. Accordingly, applicants anticipate that one or more of the amino acids located at positions at positions 2, 5, 10, 11, 12, 13, 14, 17, 18, 19, 20, 21, 24, 27, 28 or 29 can be substituted with an amino acid different from that present in the native glucagon peptide, and still retain activity at the glucagon receptor.

In some embodiments, position 18 is substituted with an amino acid selected from the group consisting of Ala, Ser, or Thr. In some embodiments the amino acid at position 20 is substituted with Ser, Thr, Lys, Arg, Orn, Citrulline or AIB. In some embodiments, position 21 is substituted with Glu, homoglutamic acid or homocysteic acid. In some embodiments, the glucagon peptide comprises 1 to 10 amino acid modifications selected from positions 16, 17, 18, 20, 21, 23, 24, 27, 28 and 29. In exemplary embodiments, the modifications are one or more amino acid substitutions selected from the group consisting of Gln17, Ala18, Glu21, Ile23, Ala24, Val27 and Gly29. In some embodiments, 1 to 2 amino acids selected from positions 17-26 differ from the parent peptide. In other embodiments, 1 to 2 amino acids selected from positions 17-22 differ from the parent peptide. In yet other embodiments, the modifications are Gln17, Ala18, Glu21, Ile23 and Ala24.

In some embodiments, one or more amino acids is added to the carboxy terminus of the glucagon peptide. The amino acid is typically selected from one of the 20 common amino acids, and in some embodiments the amino acid has an amide group in place of the carboxylic acid of the native amino acid. In exemplary embodiments the added amino acid is selected from the group consisting of glutamic acid and aspartic acid and glycine.

Other modifications that do not destroy activity include W10 or R20.

In some embodiments, the glucagon peptides disclosed herein are modified by truncation of the C-terminus by one or two amino acid residues yet retain similar activity and potency at the glucagon, GLP-1 and/or GIP receptors. In this regard, the amino acid at position 29 and/or 28 can be deleted.

Stabilization of the Alpha Helix Structure

Stabilization of the alpha-helix structure in the C-terminal portion of the glucagon peptide (around amino acids 12-29) provides enhanced GLP-1 and/or GIP activity and

restores glucagon activity which has been reduced by amino acid modifications at positions 1 and/or 2. The alpha helix structure can be stabilized by, e.g., formation of a covalent or non-covalent intramolecular bridge, or substitution and/or insertion of amino acids around positions 12-29 with an alpha helix-stabilizing amino acid (e.g., an α,α-disubstituted amino acid).

In some embodiments, an intramolecular bridge is formed between two amino acid side chains to stabilize the three dimensional structure of the carboxy terminal portion (e.g., amino acids 12-29) of the glucagon peptide. The two amino acid side chains can be linked to one another through non-covalent bonds, e.g., hydrogen-bonding, ionic interactions, such as the formation of salt bridges, or by covalent bonds. When the two amino acid side chains are linked to one another through one or more covalent bonds, the peptide may be considered herein as comprising a covlent intramolecular bridge. When the two amino acid side chains are linked to one another through non-covalent bonds, e.g., hydrogen bonds, ionic interactions, the peptide may be considered herein as comprising a non-covalent intramolecular bridge.

In some embodiments, the intramolecular bridge is formed between two amino acids that are 3 amino acids apart, e.g., amino acids at positions i and i+4, wherein i is any integer between 12 and 25 (e.g., 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, and 25). More particularly, the side chains of the amino acid pairs 12 and 16, 16 and 20 , 20 and 24 or 24 and 28 (amino acid pairs in which i = 12, 16, 20, or 24) are linked to one another and thus stabilize the glucagon alpha helix. Alternatively, i can be 17.

In some specific embodiments, wherein the amino acids at positions i and i+4 are joined by an intramolecular bridge, the size of the linker is about 8 atoms, or about 7-9 atoms.

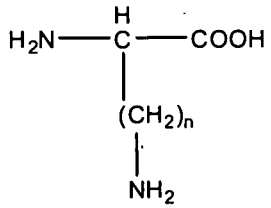
In other embodiments, the intramolecular bridge is formed between two amino acids that are two amino acids apart, e.g., amino acids at positions j and j+3, wherein j is any integer between 12 and 26 (e.g., 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, and 26). In some specific embodiments, j is 17.

In some specific embodiments, wherein amino acids at positions j and j+3 are joined by an intramolecular bridge, the size of the linker is about 6 atoms, or about 5 to 7 atoms.

32993-208847

In yet other embodiments, the intramolecular bridge is formed between two amino acids that are 6 amino acids apart, e.g., amino acids at positions k and k+7, wherein k is any integer between 12 and 22 (e.g., 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, and 22). In some specific embodiments, k is 12, 13, or 17. In an exemplary embodiment, k is 17.

Examples of amino acid pairings that are capable of covalently bonding to form a six-atom linking bridge include Orn and Asp, Glu and an amino acid of Formula I, wherein n is 2, and homoglutamic acid and an amino acid of Formula I, wherein n is 1, wherein Formula I is:



wherein n = 1 to 4

[Formula I]

Examples of amino acid pairing that are capable of covalently bonding to form a seven-atom linking bridge include Orn-Glu (lactam ring); Lys-Asp (lactam); or Homoser-Homoglu (lactone). Examples of amino acid pairings that may form an eight-atom linker include Lys-Glu (lactam); Homolys-Asp (lactam); Orn-Homoglu (lactam); 4-aminoPhe-Asp (lactam); or Tyr-Asp (lactone). Examples of amino acid pairings that may form a nine-atom linker include Homolys-Glu (lactam); Lys-Homoglu (lactam); 4-aminoPhe-Glu (lactam); or Tyr-Glu (lactone). Any of the side chains on these amino acids may additionally be substituted with additional chemical groups, so long as the three-dimensional structure of the alpha-helix is not disrupted. One of ordinary skill in the art can envision alternative pairings or alternative amino acid analogs, including chemically modified derivatives, that would create a stabilizing structure of similar size and desired effect. For example, a homocysteine-homocysteine disulfide bridge is 6 atoms in length and may be further modified to provide the desired effect. Even without covalent linkage, the amino acid pairings described above or similar pairings that one of ordinary skill in the art can envision may also provide added stability to the alpha-helix through non-

covalent bonds, for example, through formation of salt bridges or hydrogen-bonding interactions.

The size of a lactam ring can vary depending on the length of the amino acid side chains, and in one embodiment the lactam is formed by linking the side chains of a lysine amino acid to a glutamic acid side chain. Further exemplary embodiments include the following pairings, optionally with a lactam bridge: Glu at position 12 with Lys at position 16; native Lys at position 12 with Glu at position 16; Glu at position 16 with Lys at position 20; Lys at position 16 with Glu at position 20; Glu at position 20 with Lys at position 24; Lys at position 20 with Glu at position 24; Glu at position 24 with Lys at position 28; Lys at position 24 with Glu at position 28. Alternatively, the order of the amide bond in the lactam ring can be reversed (e.g., a lactam ring can be formed between the side chains of a Lys12 and a Glu16 or alternatively between a Glu 12 and a Lys16).

Intramolecular bridges other than a lactam bridge can be used to stabilize the alpha helix of the glucagon analog peptides. In one embodiment, the intramolecular bridge is a hydrophobic bridge. In this instance, the intramolecular bridge optionally is between the side chains of two amino acids that are part of the hydrophobic face of the alpha helix of the glucagon analog peptide. For example, one of the amino acids joined by the hydrophobic bridge can be the amino acid at position 10, 14, and 18.

In one specific aspect, olefin metathesis is used to cross-link one or two turns of the alpha helix of the glucagon peptide using an all-hydrocarbon cross-linking system. The glucagon peptide in this instance can comprise α-methylated amino acids bearing olefinic side chains of varying length and configured with either R or S stereochemistry at the i and i+4 or i+7 positions. For example, the olefinic side can can comprise $(CH_2)n$, wherein n is any integer between 1 to 6. In one embodiment, n is 3 for a cross-link length of 8 atoms. Suitable methods of forming such intramolecular bridges are described in the art. See, for example, Schafmeister et al., *J. Am. Chem. Soc.* 122: 5891-5892 (2000) and Walensky et al., *Science* 305: 1466-1470 (2004). Alternatively, the glucagon peptide can comprise *O*-allyl Ser residues located on adjacent helical turns, which are bridged together via ruthenium-catalyzed ring closing metathesis. Such procedures of cross-linking are described in, for example, Blackwell et al., *Angew, Chem., Int. Ed.* 37: 3281-3284 (1998).

32993-208847

In another specific aspect, use of the unnatural thio-dialanine amino acid, lanthionine, which has been widely adopted as a peptidomimetic of cystine, is used to cross-link one turn of the alpha helix. Suitable methods of lanthionine-based cyclization are known in the art. See, for instance, Matteucci et al., *Tetrahedron Letters* 45: 1399-1401 (2004); Mayer et al., *J. Peptide Res.* 51: 432-436 (1998); Polinsky et al., *J. Med. Chem.* 35: 4185-4194 (1992); Osapay et al., *J. Med. Chem.* 40: 2241-2251 (1997); Fukase et al., *Bull. Chem. Soc. Jpn.* 65: 2227-2240 (1992); Harpp et al., *J. Org. Chem.* 36: 73-80 (1971); Goodman and Shao, *Pure Appl. Chem.* 68: 1303-1308 (1996); and Osapay and Goodman, *J. Chem. Soc. Chem. Commun.* 1599-1600 (1993).

In some embodiments, α, ω-diaminoalkane tethers, e.g., 1,4-diaminopropane and 1,5-diaminopentane) between two Glu residues at positions i and i+7 are used to stabilize the alpha helix of the glucagon peptide. Such tethers lead to the formation of a bridge 9-atoms or more in length, depending on the length of the diaminoalkane tether. Suitable methods of producing peptides cross-linked with such tethers are described in the art. See, for example, Phelan et al., *J. Am. Chem. Soc.* 119: 455-460 (1997).

In yet another embodiment of the invention, a disulfide bridge is used to cross-link one or two turns of the alpha helix of the glucagon peptide. Alternatively, a modified disulfide bridge in which one or both sulfur atoms are replaced by a methylene group resulting in an isosteric macrocyclization is used to stabilize the alpha helix of the glucagon peptide. Suitable methods of modifying peptides with disulfide bridges or sulfur-based cyclization are described in, for example, Jackson et al., *J. Am. Chem. Soc.* 113: 9391-9392 (1991) and Rudinger and Jost, *Experientia* 20: 570-571 (1964).

In yet another embodiment, the alpha helix of the glucagon peptide is stabilized via the binding of metal atom by two His residues or a His and Cys pair positioned at i and i+4. The metal atom can be, for example, Ru(III), Cu(II), Zn(II), or Cd(II). Such methods of metal binding-based alpha helix stabilization are known in the art. See, for example, Andrews and Tabor, *Tetrahedron* 55: 11711-11743 (1999); Ghadiri et al., *J. Am. Chem. Soc.* 112: 1630-1632 (1990); and Ghadiri et al., *J. Am. Chem. Soc.* 119: 9063-9064 (1997).

The alpha helix of the glucagon peptide can alternatively be stabilized through other means of peptide cyclizing, which means are reviewed in Davies, *J. Peptide. Sci.* 9:

471-501 (2003). The alpha helix can be stabilized via the formation of an amide bridge, thioether bridge, thioester bridge, urea bridge, carbamate bridge, sulfonamide bridge, and the like. For example, a thioester bridge can be formed between the C-terminus and the side chain of a Cys residue. Alternatively, a thioester can be formed via side chains of amino acids having a thiol (Cys) and a carboxylic acid (e.g., Asp, Glu). In another method, a cross-linking agent, such as a dicarboxylic acid, e.g. suberic acid (octanedioic acid), etc. can introduce a link between two functional groups of an amino acid side chain, such as a free amino, hydroxyl, thiol group, and combinations thereof.

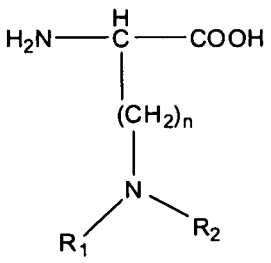
In accordance with one embodiment, the alpha helix of the glucagon peptide is stabilized through the incorporation of hydrophobic amino acids at positions i and i+4. For instance, i can be Tyr and i+4 can be either Val or Leu; i can be Phe and i+4 can be Cys or Met; I can be Cys and i+4 can be Met; or i can be Phe and i+4 can be Ile. It should be understood that, for purposes herein, the above amino acid pairings can be reversed, such that the indicated amino acid at position i could alternatively be located at i+4, while the i+4 amino acid can be located at the i position.

In accordance with other embodiments of the invention, the alpha helix is stabilized through incorporation (either by amino acid substitution or insertion) of one or more alpha helix-stabilizing amino acids at the C-terminal portion of the glucagon peptide (around amino acids 12-29). In a specific embodiment, the alpha helix-stabilizing amino acid is an α, α-disubstituted amino acid, including, but not limited to any of amino iso-butyric acid (AIB), an amino acid disubstituted with the same or a different group selected from methyl, ethyl, propyl, and n-butyl, or with a cyclooctane or cycloheptane (e.g., 1-aminocyclooctane-1-carboxylic acid). In some embodiments, one, two, three, four or more of positions 16, 17, 18, 19, 20, 21, 24 or 29 of the glucagon peptide is substituted with an α, α-disubstituted amino acid. In a specific embodiment, one, two, three or all of positions 16, 20, 21, and 24 are substituted with an α,α-disubstituted amino acid, e.g., AIB. For example, the glucagon peptide can comprise a substitution of position 16 with AIB in the absence of an intramolecular bridge, e.g., a non-covalent intramolecular bridge (e.g., a salt bridge) or a covalent intramolecular bridge (e.g., a lactam). Such peptides lacking an intramolecular bridge are advantageously easy to prepare.

32993-208847

In accordance with some embodiments, the glucagon peptide lacking an intramolecular bridge comprises one or more substitutions within amino acid positions 12-29 with an α, α-disubstituted amino acid and an acyl or alkyl group covalently attached to the side chain of an amino acid of the glucagon peptide, e.g., the amino acid at positions 10 or 40 of the glucagon peptide. In specific embodiments, the acyl or alkyl group is non-native to a naturally occurring amino acid. In certain aspects, the acyl or alkyl group is non-native to the amino acid at position 10. Such acylated or alkylated glucagon peptides lacking an intramolecular bridge exhibit enhanced activity at the GLP-1 and glucagon receptors as compared to the non-acylated counterpart peptides. Further enhancement in activity at the GLP-1 and glucagon receptors can be achieved by the acylated glucagon peptides lacking an intramolecular bridge by incorporating a spacer between the acyl or alkyl group and the side chain of the amino acid at positions 10 or 40 of the peptide. Acylation and alkylation, with or without incorporating spacers, are further described herein.

In specific embodiments, the acylated or alkylated glucagon peptide, or analog thereof, further comprises a modification which selectively reduces activity at the GLP-1 receptor. For example, the acylated or alkylated glucagon peptide, or analog thereof, comprises one or a combination of: a C-terminal alpha carboxylate, a deletion of the amino acids C-terminal to the amino acid at position 27 or 28 (e.g., deletion of the amino acid at position 29, deletion of the amino acids at positions 28 and 29), a substitution of the Thr at position 7 with a large, aliphatic, non-polar amino acid, e.g., Ile.
In some embodiments, position 16 or position 20 is substituted with an α,α-disubstituted amino acid, e.g., AIB. In some embodiments, position 20 is substituted with an α,α-disubstituted amino acid, e.g., AIB. In certain embodiments, position 20 is substituted with an α,α-disubstituted amino acid, e.g., AIB, and position 16 is substituted with an amino acid of Formula IV



32993-208847

[Formula IV],

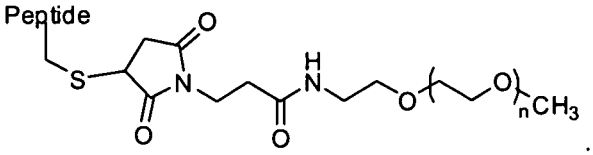
wherein n is 1 to 16, or 1 to 10, or 1 to 7, or 1 to 6, or 2 to 6, or 2 or 3 or 4 or 5, each of R_1 and R_2 is independently selected from the group consisting of H, C_1-C_{18} alkyl, (C_1-C_{18} alkyl)OH, (C_1-C_{18} alkyl)NH_2, (C_1-C_{18} alkyl)SH, (C_0-C_4 alkyl)(C_3-C_6)cycloalkyl, (C_0-C_4 alkyl)(C_2-C_5 heterocyclic), (C_0-C_4 alkyl)(C_6-C_{10} aryl)R_7, and (C_1-C_4 alkyl)(C_3-C_9 heteroaryl), wherein R_7 is H or OH, and the side chain of the amino acid of Formula IV comprises a free amino group. In particular embodiments, the amino acid of Formula IV is 2,3 diamino propionic acid (DAP), 2,4-diaminobutyric acid (DAB), Orn, Lys or homoLys. The combination of an amino acid of Formula IV at position 16 and an alpha, alpha disubstituted amino acid advantageously provides improved activity at each of the glucagon, GLP-1, and GIP receptors.

Linkage of hydrophilic moieties

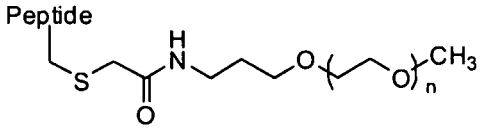
In another embodiment the solubility of the glucagon peptides disclosed herein are enhanced by the covalent linkage of a hydrophilic moiety to the peptide. Hydrophilic moieties can be attached to the glucagon peptides under any suitable conditions used to react a protein with an activated polymer molecule. Any means known in the art can be used, including via acylation, reductive alkylation, Michael addition, thiol alkylation or other chemoselective conjugation/ligation methods through a reactive group on the PEG moiety (e.g., an aldehyde, amino, ester, thiol, α-haloacetyl, maleimido or hydrazino group) to a reactive group on the target compound (e.g., an aldehyde, amino, ester, thiol, α-haloacetyl, maleimido or hydrazino group). Activating groups which can be used to link the water soluble polymer to one or more proteins include without limitation sulfone, maleimide, sulfhydryl, thiol, triflate, tresylate, azidirine, oxirane, 5-pyridyl, and alpha-halogenated acyl group (e.g., alpha-iodo acetic acid, alpha-bromoacetic acid, alpha-chloroacetic acid). If attached to the peptide by reductive alkylation, the polymer selected should have a single reactive aldehyde so that the degree of polymerization is controlled. See, for example, Kinstler et al., *Adv. Drug. Delivery Rev.* 54: 477-485 (2002); Roberts et al., *Adv. Drug Delivery Rev.* 54: 459-476 (2002); and Zalipsky et al., *Adv. Drug Delivery Rev.* 16: 157-182 (1995).

32993-208847

In a specific aspect of the invention, an amino acid residue on the glucagon peptide having a thiol is modified with a hydrophilic moiety such as PEG. In some embodiments, the thiol is modified with maleimide-activated PEG in a Michael addition reaction to result in a PEGylated peptide comprising the thioether linkage shown below:



In some embodiments, the thiol is modified with a haloacetyl-activated PEG in a nucleophilic substitution reaction to result in a PEGylated peptide comprising the thioether linkage shown below:



Suitable hydrophilic moieties include polyethylene glycol (PEG), polypropylene glycol, polyoxyethylated polyols (e.g., POG), polyoxyethylated sorbitol, polyoxyethylated glucose, polyoxyethylated glycerol (POG), polyoxyalkylenes, polyethylene glycol propionaldehyde, copolymers of ethylene glycol/propylene glycol, monomethoxy-polyethylene glycol, mono-(C1-C10) alkoxy- or aryloxy-polyethylene glycol, carboxymethylcellulose, polyacetals, polyvinyl alcohol (PVA), polyvinyl pyrrolidone, poly-1, 3-dioxolane, poly-1,3,6-trioxane, ethylene/maleic anhydride copolymer, poly (.beta.-amino acids) (either homopolymers or random copolymers), poly(n-vinyl pyrrolidone)polyethylene glycol, propropylene glycol homopolymers (PPG) and other polyakylene oxides, polypropylene oxide/ethylene oxide copolymers, colonic acids or other polysaccharide polymers, Ficoll or dextran and mixtures thereof.

The hydrophilic moiety, e.g., polyethylene glycol chain in accordance with some embodiments has a molecular weight selected from the range of about 500 to about 40,000 Daltons. In one embodiment the hydrophilic moiety, e.g. PEG, has a molecular weight selected from the range of about 500 to about 5,000 Daltons, or about 1,000 to about 5,000 Daltons. In another embodiment the hydrophilic moiety, e.g., PEG, has a molecular weight of about 10,000 to about 20,000 Daltons. In yet other exemplary

embodiments the hydrophilic moiety, e.g., PEG, has a molecular weight of about 20,000 to about 40,000 Daltons.

In one embodiment dextrans are used as the hydrophilic moiety. Dextrans are polysaccharide polymers of glucose subunits, predominantly linked by α1-6 linkages. Dextran is available in many molecular weight ranges, e.g., about 1 kD to about 100 kD, or from about 5, 10, 15 or 20 kD to about 20, 30, 40, 50, 60, 70, 80 or 90 kD.

Linear or branched polymers are contemplated. Resulting preparations of conjugates may be essentially monodisperse or polydisperse, and may have about 0.5, 0.7, 1, 1.2, 1.5 or 2 polymer moieties per peptide.

In one embodiment the hydrophilic moiety is a polyethylene glycol (PEG) chain, optionally linked to the peptide at one or more of positions 16, 17, 21, 24, 29, a position within a C-terminal extension, e.g., 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, or at the C-terminal amino acid (e.g., 40). In some embodiments, the native amino acid at that position is substituted with an amino acid having a side chain suitable for crosslinking with hydrophilic moieties, to facilitate linkage of the hydrophilic moiety to the peptide. In exemplary embodiments, the native amino acid at that position is substituted with Lys, Cys, Orn, homocysteine, or acetyl-phenylalanine residue. In other embodiments, an amino acid modified to comprise a hydrophilic group is added to the peptide at the C-terminus.

Other modifications that enhance solubility

In another embodiment the solubility of any of the glucagon peptides can be improved by amino acid substitutions and/or additions that introduce a charged amino acid into the C-terminal portion of the peptide, preferably at a position C-terminal to position 27 of SEQ ID NO: 1. Optionally, one, two or three charged amino acids may be introduced within the C-terminal portion, preferably C-terminal to position 27. In some embodiments the native amino acid(s) at positions 28 and/or 29 are substituted with one or two charged amino acids, and/or in a further embodiment one to three charged amino acids are also added to the C-terminus of the peptide. In exemplary embodiments, one, two or all of the charged amino acids are negatively charged. In some embodiments, the negatively charged (acidic amino acid) is aspartic acid or glutamic acid.

32993-208847

Additional modifications, e.g. conservative substitutions, may be made to the glucagon peptide that still allow it to retain GIP activity (and optionally GLP-1 activity and/or glucagon activity).

Conjugates and fusions

The present disclosure also encompasses other conjugates in which glucagon peptides of the invention are linked, optionally via covalent bonding and optionally via a linker, to a conjugate moiety. Linkage can be accomplished by covalent chemical bonds, physical forces such electrostatic, hydrogen, ionic, van der Waals, or hydrophobic or hydrophilic interactions. A variety of non-covalent coupling systems may be used, including biotin-avidin, ligand/receptor, enzyme/substrate, nucleic acid/nucleic acid binding protein, lipid/lipid binding protein, cellular adhesion molecule partners; or any binding partners or fragments thereof which have affinity for each other.

The peptide can be linked to conjugate moieties via direct covalent linkage by reacting targeted amino acid residues of the peptide with an organic derivatizing agent that is capable of reacting with selected side chains or the N- or C-terminal residues of these targeted amino acids. Reactive groups on the peptide or conjugate include, e.g., an aldehyde, amino, ester, thiol, α-haloacetyl, maleimido or hydrazino group. Derivatizing agents include, for example, maleimidobenzoyl sulfosuccinimide ester (conjugation through cysteine residues), N-hydroxysuccinimide (through lysine residues), glutaraldehyde, succinic anhydride or other agents known in the art. Alternatively, the conjugate moieties can be linked to the peptide indirectly through intermediate carriers, such as polysaccharide or polypeptide carriers. Examples of polysaccharide carriers include aminodextran. Examples of suitable polypeptide carriers include polylysine, polyglutamic acid, polyaspartic acid, co-polymers thereof, and mixed polymers of these amino acids and others, e.g., serines, to confer desirable solubility properties on the resultant loaded carrier.

Cysteinyl residues are most commonly are reacted with α-haloacetates (and corresponding amines), such as chloroacetic acid, chloroacetamide to give carboxymethyl or carboxyamidomethyl derivatives. Cysteinyl residues also are derivatized by reaction with bromotrifluoroacetone, alpha-bromo-β-(5-imidozoyl)propionic acid, chloroacetyl

phosphate, N-alkylmaleimides, 3-nitro-2-pyridyl disulfide, methyl 2-pyridyl disulfide, p-chloromercuribenzoate, 2-chloromercuri-4-nitrophenol, or chloro-7-nitrobenzo-2-oxa-1,3-diazole.

Histidyl residues are derivatized by reaction with diethylpyrocarbonate at pH 5.5-7.0 because this agent is relatively specific for the histidyl side chain. Para-bromophenacyl bromide also is useful; the reaction is preferably performed in 0.1 M sodium cacodylate at pH 6.0.

Lysinyl and amino-terminal residues are reacted with succinic or other carboxylic acid anhydrides. Derivatization with these agents has the effect of reversing the charge of the lysinyl residues. Other suitable reagents for derivatizing alpha-amino-containing residues include imidoesters such as methyl picolinimidate, pyridoxal phosphate, pyridoxal, chloroborohydride, trinitrobenzenesulfonic acid, O-methylisourea, 2,4-pentanedione, and transaminase-catalyzed reaction with glyoxylate.

Arginyl residues are modified by reaction with one or several conventional reagents, among them phenylglyoxal, 2,3-butanedione, 1,2-cyclohexanedione, and ninhydrin. Derivatization of arginine residues requires that the reaction be performed in alkaline conditions because of the high pK_a of the guanidine functional group. Furthermore, these reagents may react with the groups of lysine as well as the arginine epsilon-amino group.

The specific modification of tyrosyl residues may be made, with particular interest in introducing spectral labels into tyrosyl residues by reaction with aromatic diazonium compounds or tetranitromethane. Most commonly, N-acetylimidizole and tetranitromethane are used to form O-acetyl tyrosyl species and 3-nitro derivatives, respectively.

Carboxyl side groups (aspartyl or glutamyl) are selectively modified by reaction with carbodiimides (R-N.dbd.C.dbd.N-R'), where R and R' are different alkyl groups, such as 1-cyclohexyl-3-(2-morpholinyl-4-ethyl) carbodiimide or 1-ethyl-3-(4-azonia-4,4-dimethylpentyl) carbodiimide. Furthermore, aspartyl and glutamyl residues are converted to asparaginyl and glutaminyl residues by reaction with ammonium ions.

Other modifications include hydroxylation of proline and lysine, phosphorylation of hydroxyl groups of seryl or threonyl residues, methylation of the alpha-amino groups

of lysine, arginine, and histidine side chains (T. E. Creighton, Proteins: Structure and Molecular Properties, W.H. Freeman & Co., San Francisco, pp. 79-86 (1983)), deamidation of asparagines or glutamine, acetylation of the N-terminal amine, and/or amidation or esterification of the C-terminal carboxylic acid group.

Another type of covalent modification involves chemically or enzymatically coupling glycosides to the peptide. Sugar(s) may be attached to (a) arginine and histidine, (b) free carboxyl groups, (c) free sulfhydryl groups such as those of cysteine, (d) free hydroxyl groups such as those of serine, threonine, or hydroxyproline, (e) aromatic residues such as those of tyrosine, or tryptophan, or (f) the amide group of glutamine. These methods are described in WO87/05330 published 11 Sep. 1987, and in Aplin and Wriston, CRC Crit. Rev. Biochem., pp. 259-306 (1981).

Exemplary conjugate moieties that can be linked to any of the glucagon peptides described herein include but are not limited to a heterologous peptide or polypeptide (including for example, a plasma protein), a targeting agent, an immunoglobulin or portion thereof (e.g. variable region, CDR, or Fc region), a diagnostic label such as a radioisotope, fluorophore or enzymatic label, a polymer including water soluble polymers, or other therapeutic or diagnostic agents. In one embodiment a conjugate is provided comprising a glucagon peptide of the present invention and a plasma protein, wherein the plasma protein is selected form the group consisting of albumin, transferin, fibrinogen and globulins.

In some embodiments, the linker comprises a chain of atoms from 1 to about 60, or 1 to 30 atoms or longer, 2 to 5 atoms, 2 to 10 atoms, 5 to 10 atoms, or 10 to 20 atoms long. In some embodiments, the chain atoms are all carbon atoms. In some embodiments, the chain atoms in the backbone of the linker are selected from the group consisting of C, O, N, and S. Chain atoms and linkers may be selected according to their expected solubility (hydrophilicity) so as to provide a more soluble conjugate. In some embodiments, the linker provides a functional group that is subject to cleavage by an enzyme or other catalyst or hydrolytic conditions found in the target tissue or organ or cell. In some embodiments, the length of the linker is long enough to reduce the potential for steric hindrance. If the linker is a covalent bond or a peptidyl bond and the conjugate is a polypeptide, the entire conjugate can be a fusion protein. Such peptidyl linkers may

be any length. Exemplary linkers are from about 1 to 50 amino acids in length, 5 to 50, 3 to 5, 5 to 10, 5 to 15, or 10 to 30 amino acids in length. Such fusion proteins may alternatively be produced by recombinant genetic engineering methods known to one of ordinary skill in the art.

As noted above, in some embodiments, the glucagon peptides are conjugated, e.g., fused to an immunoglobulin or portion thereof (e.g. variable region, CDR, or Fc region). Known types of immunoglobulins (Ig) include IgG, IgA, IgE, IgD or IgM. The Fc region is a C-terminal region of an Ig heavy chain, which is responsible for binding to Fc receptors that carry out activities such as recycling (which results in prolonged half-life), antibody dependent cell-mediated cytotoxicity (ADCC), and complement dependent cytotoxicity (CDC).

For example, according to some definitions the human IgG heavy chain Fc region stretches from Cys226 to the C-terminus of the heavy chain. The "hinge region" generally extends from Glu216 to Pro230 of human IgG1 (hinge regions of other IgG isotypes may be aligned with the IgG1 sequence by aligning the cysteines involved in cysteine bonding). The Fc region of an IgG includes two constant domains, CH2 and CH3. The CH2 domain of a human IgG Fc region usually extends from amino acids 231 to amino acid 341. The CH3 domain of a human IgG Fc region usually extends from amino acids 342 to 447. References made to amino acid numbering of immunoglobulins or immunoglobulin fragments, or regions, are all based on Kabat et al. 1991, Sequences of Proteins of Immunological Interest, U.S. Department of Public Health, Bethesda, Md. In a related embodiments, the Fc region may comprise one or more native or modified constant regions from an immunoglobulin heavy chain, other than CH1, for example, the CH2 and CH3 regions of IgG and IgA, or the CH3 and CH4 regions of IgE.

Suitable conjugate moieties include portions of immunoglobulin sequence that include the FcRn binding site. FcRn, a salvage receptor, is responsible for recycling immunoglobulins and returning them to circulation in blood. The region of the Fc portion of IgG that binds to the FcRn receptor has been described based on X-ray crystallography (Burmeister et al. 1994, Nature 372:379). The major contact area of the Fc with the FcRn is near the junction of the CH2 and CH3 domains. Fc-FcRn contacts are all within a single Ig heavy chain. The major contact sites include amino acid residues

248, 250-257, 272, 285, 288, 290-291, 308-311, and 314 of the CH2 domain and amino acid residues 385-387, 428, and 433-436 of the CH3 domain.

Some conjugate moieties may or may not include FcγR binding site(s). FcγR are responsible for ADCC and CDC. Examples of positions within the Fc region that make a direct contact with FcγR are amino acids 234-239 (lower hinge region), amino acids 265-269 (B/C loop), amino acids 297-299 (C'/E loop), and amino acids 327-332 (F/G) loop (Sondermann et al., Nature 406: 267-273, 2000). The lower hinge region of IgE has also been implicated in the FcRI binding (Henry, et al., Biochemistry 36, 15568-15578, 1997). Residues involved in IgA receptor binding are described in Lewis et al., (J Immunol. 175:6694-701, 2005). Amino acid residues involved in IgE receptor binding are described in Sayers et al. (J Biol Chem. 279(34):35320-5, 2004).

Amino acid modifications may be made to the Fc region of an immunoglobulin. Such variant Fc regions comprise at least one amino acid modification in the CH3 domain of the Fc region (residues 342-447) and/or at least one amino acid modification in the CH2 domain of the Fc region (residues 231-341). Mutations believed to impart an increased affinity for FcRn include T256A, T307A, E380A, and N434A (Shields et al. 2001, J. Biol. Chem. 276:6591). Other mutations may reduce binding of the Fc region to FcγRI, FcγRIIA, FcγRIIB, and/or FcγRIIIA without significantly reducing affinity for FcRn. For example, substitution of the Asn at position 297 of the Fc region with Ala or another amino acid removes a highly conserved N-glycosylation site and may result in reduced immunogenicity with concomitant prolonged half-life of the Fc region, as well as reduced binding to FcγRs (Routledge et al. 1995, Transplantation 60:847; Friend et al. 1999, Transplantation 68:1632; Shields et al. 1995, J. Biol. Chem. 276:6591). Amino acid modifications at positions 233-236 of IgG1 have been made that reduce binding to FcγRs (Ward and Ghetie 1995, Therapeutic Immunology 2:77 and Armour et al. 1999, Eur. J. Immunol. 29:2613). Some exemplary amino acid substitutions are described in US Patents 7,355,008 and 7,381,408, each incorporated by reference herein in its entirety.

The present disclosure also encompasses glucagon fusion peptides or proteins wherein a second peptide or polypeptide has been fused to a terminus, e.g., the carboxy terminus of the glucagon peptide. In some embodiments the second peptide added to the carboxy terminus of the glucagon peptide is SEQ ID NO: 95 (GPSSGAPPPS), SEQ ID

NO: 97 (KRNRNNIA) or SEQ ID NO: 98 (KRNR) linked to amino acid 29 of the glucagon peptide. In other embodiments, the second peptide is XGPSSGAPPPS (SEQ ID NO: 96), wherein X is selected from one of the 20 common amino acids, e.g., glutamic acid, aspartic acid or glycine. In one embodiment X represents an amino acid, for example Cys, that further comprises a hydrophilic moiety covalently linked to the side chain of that amino acid. Such C-terminal extensions improve solubility and also can improve GIP or GLP-1 activity. In some embodiments wherein the glucagon peptide further comprises a carboxy terminal extension, the carboxy terminal amino acid of the extension ends in an amide group or an ester group rather than a carboxylic acid.

In some embodiments, e.g., in glucagon peptides which comprise the C-terminal extension, the threonine at position 29 of the native glucagon peptide is replaced with a glycine. For example, a glucagon peptide having a glycine substitution for threonine at position 29 and comprising the C-terminal extension of GPSSGAPPPS (SEQ ID NO: 95) is four times as potent at the GLP-1 receptor as native glucagon modified to comprise the same C-terminal extension. This T29G substitution can be used in conjunction with other modifications disclosed herein to enhance the affinity of the glucagon peptides for the GLP-1 receptor. For example, the T29G substitution can be combined with the S16E and N20K amino acid substitutions, optionally with a lactam bridge between amino acids 16 and 20, and optionally with addition of a PEG chain as described herein.

In some embodiments an amino acid is added to the C-terminus, and the additional amino acid is selected from the group consisting of glutamic acid, aspartic acid and glycine.

The present disclosure also encompasses multimers of the modified glucagon peptides disclosed herein. Two or more of the modified glucagon peptides can be linked together using standard linking agents and procedures known to those skilled in the art. For example, dimers can be formed between two modified glucagon peptides through the use of bifunctional thiol crosslinkers and bi-functional amine crosslinkers, particularly for the glucagon peptides that have been substituted with cysteine, lysine ornithine, homocysteine or acetyl phenylalanine residues.

Acylation and alkylation

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In accordance with some embodiments, the glucagon peptides disclosed herein are modified to comprise an acyl group or an alkyl group, e.g., an acyl or alkyl group which is non-native to a naturally-occurring amino acid. Acylation or alkylation can increase the half-life of the glucagon peptides in circulation. Acylation or alkylation can advantageously delay the onset of action and/or extend the duration of action at the glucagon and/or GLP-1 receptors and/or improve resistance to proteases such as DPP-IV and/or improve solubility. Activity at the glucagon and/or GLP-1 and/or GIP receptors of the glucagon peptide may be maintained after acylation. In some embodiments, the potency of the acylated glucagon peptides is comparable to the unacylated versions of the glucagon peptides. In alternative embodiments, the potency of the acylated glucagon peptides is increased as compared to that of the unacylated version of the glucagon peptides.

In some embodiments, the invention provides a glucagon peptide modified to comprise an acyl group or alkyl group covalently linked to the amino acid at position 10 of the glucagon peptide. The glucagon peptide may further comprise a spacer between the amino acid at position 10 of the glucagon peptide and the acyl group or alkyl group. In some embodiments, the acyl group is a fatty acid or bile acid, or salt thereof, e.g. a C4 to C30 fatty acid, a C8 to C24 fatty acid, cholic acid, a C4 to C30 alkyl, a C8 to C24 alkyl, or an alkyl comprising a steroid moiety of a bile acid. The spacer is any moiety with suitable reactive groups for attaching acyl or alkyl groups. In exemplary embodiments, the spacer comprises an amino acid, a dipeptide, a tripeptide, a hydrophilic bifunctional, or a hydrophobic bifunctional spacer. In some embodiments, the spacer is selected from the group consisting of: Trp, Glu, Asp, Cys and a spacer comprising $NH_2(CH_2CH_2O)n(CH_2)mCOOH$, wherein m is any integer from 1 to 6 and n is any integer from 2 to 12. Such acylated or alkylated glucagon peptides may also further comprise a hydrophilic moiety, optionally a polyethylene glycol. Any of the foregoing glucagon peptides may comprise two acyl groups or two alkyl groups, or a combination thereof.

Acylation can be carried out at any position within the glucagon peptide, including any of positions 1-29, a position within a C-terminal extension, or the N- or C-terminal amino acid, provided that GIP activity (and optionally GLP-1 and/or glucagon

activity) is retained, if not enhanced. Acylation may occur, for example, at any amino acid which is added to the glucagon sequence (SEQ ID NO: 1), e.g., at the N- or C-terminus. Nonlimiting examples include positions 1, 5, 10, 11, 12, 13, 14, 16, 17, 18, 19, 20, 21, 24, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, or 50 of the glucagon peptide. The acyl group can be covalently linked directly to an amino acid of the glucagon peptide, or indirectly to an amino acid of the glucagon peptide via a spacer, wherein the spacer is positioned between the amino acid of the glucagon peptide and the acyl group. Glucagon peptides may be acylated at the same amino acid position where a hydrophilic moiety is linked, or at a different amino acid position. Nonlimiting examples include acylation at position 10 or position 40 and pegylation at one or more positions in the C-terminal portion of the glucagon peptide, e.g., position 24, 28 or 29, within a C-terminal extension, or at the C-terminus (e.g., through adding a C-terminal Cys).

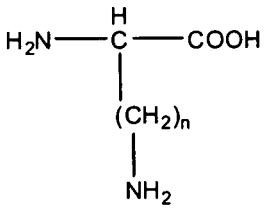
In some embodiments, the glucagon peptide is modified to comprise an extension of about 1 to about 21 amino acids C-terminal to the glucagon peptide of SEQ ID NO: 1 or an analog thereof and at least one of the amino acids of the extension is acylated or alkylated. For example, the modified glucagon peptide may comprise an extension of about 1 to about 21 amino acids C-terminal to the amino acid at position 29 of the glucagon peptide of SEQ ID NO: 1 or analog thereof. Alternatively, if the glucagon peptide or analog thereof is truncated by one or two amino acids, the extension of about 1 to about 21 amino acids may be C-terminal to the amino acid at position 27 or 28 of the glucagon peptide or analog thereof. Accordingly, the acylated or alkylated amino acid within the C-terminal extension can be, for example, any of the amino acids at position 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, or 50 of the C-terminally extended glucagon peptide. The C-terminal extension in some embodiments comprises the amino acid sequence of SEQ ID NO: 95 or 96. In some embodiments, the glucagon peptide comprises a C-terminal extension comprising the amino acid sequence of SEQ ID NO: 95 and 1 to 11 additional amino acids at the C-terminus of SEQ ID NO: 95, which additional amino acid(s) is/are acylated or alkylated, as described herein. In specific embodiments, the acylated or alkylated amino acid is a

Dab, Orn, Lys, or homoLys residue and is located at position 40 of the C-terminally extended glucagon peptide or analog thereof.

In accordance with one embodiment, the glucagon peptide is modified to comprise an acyl group which is attached to the glucagon peptide via an ester, thioester, or amide linkage for purposes of prolonging half-life in circulation and/or delaying the onset of and/or extending the duration of action and/or improving resistance to proteases such as DPP-IV.

In a specific aspect of the invention, the glucagon peptide is modified to comprise an acyl group by direct acylation of an amine, hydroxyl, or thiol of a side chain of an amino acid of the glucagon peptide. In some embodiments, the glucagon peptide is directly acylated through the side chain amine, hydroxyl, or thiol of an amino acid. In some embodiments, acylation is at position 10, 20, 24, 29, or 40. In this regard, the acylated glucagon peptide can comprise the amino acid sequence of SEQ ID NO : 1, or a modified amino acid sequence thereof comprising one or more of the amino acid modifications described herein, with at least one of the amino acids at positions 10, 20, 24, 29, and 40 modified to any amino acid comprising a side chain amine, hydroxyl, or thiol. In some specific embodiments of the invention, the direct acylation of the glucagon peptide occurs through the side chain amine, hydroxyl, or thiol of the amino acid at position 10 or 40.

In some embodiments, the amino acid comprising a side chain amine is an amino acid of Formula I:



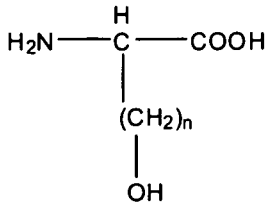
wherein n = 1 to 4

[Formula I]

In some exemplary embodiments, the amino acid of Formula I, is the amino acid wherein n is 4 (Lys) or n is 3 (Orn).

32993-208847

In other embodiments, the amino acid comprising a side chain hydroxyl is an amino acid of Formula II:

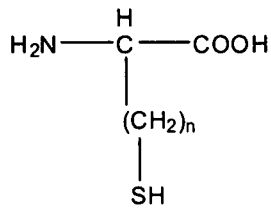


wherein n = 1 to 4

[Formula II]

In some exemplary embodiments, the amino acid of Formula II is the amino acid wherein n is 1 (Ser).

In yet other embodiments, the amino acid comprising a side chain thiol is an amino acid of Formula III:



wherein n = 1 to 4

[Formula III]

In some exemplary embodiments, the amino acid of Formula II is the amino acid wherein n is 1 (Cys).

In yet other embodiments, the amino acid comprising a side chain amine, hydroxyl, or thiol is a disubstituted amino acid comprising the same structure of Formula I, Formula II, or Formula III, except that the hydrogen bonded to the alpha carbon of the amino acid of Formula I, Formula II, or Formula III is replaced with a second side chain.

In one embodiment of the invention, the acylated glucagon peptide comprises a spacer between the peptide and the acyl group. In some embodiments, the glucagon peptide is covalently bound to the spacer, which is covalently bound to the acyl group.

32993-208847

The amino acid to which the spacer is attached can be any amino acid (e.g., a singly or doubly α-substituted amino acid) comprising a moiety which permits linkage to the spacer. For example, an amino acid comprising a side chain NH_2, –OH, or –COOH (e.g., Lys, Orn, Ser, Asp, or Glu) is suitable. In this respect, the acylated glucagon peptide can comprise the amino acid sequence of SEQ ID NO: 1, or a modified amino acid sequence thereof comprising one or more of the amino acid modifications described herein, with at least one of the amino acids at positions 10, 20, 24, 29, and 40 modified to any amino acid comprising a side chain amine, hydroxyl, or carboxylate.

In some embodiments, the spacer is an amino acid comprising a side chain amine, hydroxyl, or thiol, or a dipeptide or tripeptide comprising an amino acid comprising a side chain amine, hydroxyl, or thiol.

When acylation occurs through an amine group of a spacer the acylation can occur through the alpha amine of the amino acid or a side chain amine. In the instance in which the alpha amine is acylated, the spacer amino acid can be any amino acid. For example, the spacer amino acid can be a hydrophobic amino acid, e.g., Gly, Ala, Val, Leu, Ile, Trp, Met, Phe, Tyr, 6-amino hexanoic acid, 5-aminovaleric acid, 7-aminoheptanoic acid, and 8-aminooctanoic acid. Alternatively, the spacer amino acid can be an acidic residue, e.g., Asp and Glu.

In the instance in which the side chain amine of the spacer amino acid is acylated, the spacer amino acid is an amino acid comprising a side chain amine, e.g., an amino acid of Formula I (e.g., Lys or Orn). In this instance, it is possible for both the alpha amine and the side chain amine of the spacer amino acid to be acylated, such that the glucagon peptide is diacylated. Embodiments of the invention include such diacylated molecules.

When acylation occurs through a hydroxyl group of a spacer, the amino acid or one of the amino acids of the dipeptide or tripeptide can be an amino acid of Formula II. In a specific exemplary embodiment, the amino acid is Ser.

When acylation occurs through a thiol group of a spacer, the amino acid or one of the amino acids of the dipeptide or tripeptide can be an amino acid of Formula III. In a specific exemplary embodiment, the amino acid is Cys.

In some embodiments, the spacer is a hydrophilic bifunctional spacer. In certain embodiments, the hydrophilic bifunctional spacer comprises two or more reactive groups,

e.g., an amine, a hydroxyl, a thiol, and a carboxyl group or any combinations thereof. In certain embodiments, the hydrophilic bifunctional spacer comprises a hydroxyl group and a carboxylate. In other embodiments, the hydrophilic bifunctional spacer comprises an amine group and a carboxylate. In other embodiments, the hydrophilic bifunctional spacer comprises a thiol group and a carboxylate. In specific embodiments, the spacer comprises an amino poly(alkyloxy)carboxylate. In this regard, the spacer can comprise, for example, $NH_2(CH_2CH_2O)_n(CH_2)_mCOOH$, wherein m is any integer from 1 to 6 and n is any integer from 2 to 12, such as, e.g., 8-amino-3,6-dioxaoctanoic acid, which is commercially available from Peptides International, Inc. (Louisville, KY).

In some embodiments, the spacer is a hydrophobic bifunctional spacer. Hydrophobic bifunctional spacers are known in the art. See, e.g., *Bioconjugate Techniques*, G. T. Hermanson (Academic Press, San Diego, CA, 1996), which is incorporated by reference in its entirety In certain embodiments, the hydrophobic bifunctional spacer comprises two or more reactive groups, e.g., an amine, a hydroxyl, a thiol, and a carboxyl group or any combinations thereof. In certain embodiments, the hydrophobic bifunctional spacer comprises a hydroxyl group and a carboxylate. In other embodiments, the hydrophobic bifunctional spacer comprises an amine group and a carboxylate. In other embodiments, the hydropholic bifunctional spacer comprises a thiol group and a carboxylate. Suitable hydrophobic bifunctional spacers comprising a carboxylate, and a hydroxyl group or a thiol group are known in the art and include, for example, 8-hydroxyoctanoic acid and 8-mercaptooctanoic acid.

In some embodiments, the bifunctional spacer is not a dicarboxylic acid comprising an unbranched, methylene of 1-7 carbon atoms between the carboxylate groups. In some embodiments, the bifunctional spacer is a dicarboxylic acid comprising an unbranched, methylene of 1-7 carbon atoms between the carboxylate groups.

The spacer (e.g., amino acid, dipeptide, tripeptide, hydrophilic bifunctional, or hydrophobic bifunctional spacer) in specific embodiments is 3 to 10 atoms (e.g., 6 to 10 atoms, (e.g., 6, 7, 8, 9, or 10 atoms) in length. In more specific embodiments, the spacer is about 3 to 10 atoms (e.g., 6 to 10 atoms) in length and the acyl group is a C12 to C18 fatty acyl group, e.g., C14 fatty acyl group, C16 fatty acyl group, such that the total length of the spacer and acyl group is 14 to 28 atoms, e.g., about 14, 15, 16, 17, 18, 19,

20, 21, 22, 23, 24, 25, 26, 27, or 28 atoms. In some embodiments, the length of the spacer and acyl group is 17 to 28 (e.g., 19 to 26, 19 to 21) atoms.

In accordance with certain foregoing embodiments, the bifunctional spacer can be a synthetic or naturally occurring amino acid (including, but not limited to, any of those described herein) comprising an amino acid backbone that is 3 to 10 atoms in length (e.g., 6-amino hexanoic acid, 5-aminovaleric acid, 7-aminoheptanoic acid, and 8-aminooctanoic acid). Alternatively, the spacer can be a dipeptide or tripeptide spacer having a peptide backbone that is 3 to 10 atoms (e.g., 6 to 10 atoms) in length. Each amino acid of the dipeptide or tripeptide spacer can be the same as or different from the other amino acid(s) of the dipeptide or tripeptide and can be independently selected from the group consisting of: naturally-occurring and/or non-naturally occurring amino acids, including, for example, any of the D or L isomers of the naturally-occurring amino acids (Ala, Cys, Asp, Glu, Phe, Gly, His, Ile, Lys, Leu, Met, Asn, Pro, Arg, Ser, Thr, Val, Trp, Tyr), or any D or L isomers of the non-naturally occurring amino acids selected from the group consisting of: β-alanine (β-Ala), N-α-methyl-alanine (Me-Ala), aminobutyric acid (Abu), γ-aminobutyric acid (γ-Abu), aminohexanoic acid (ε-Ahx), aminoisobutyric acid (Aib), aminomethylpyrrole carboxylic acid, aminopiperidinecarboxylic acid, aminoserine (Ams), aminotetrahydropyran-4-carboxylic acid, arginine N-methoxy-N-methyl amide, β-aspartic acid (β-Asp), azetidine carboxylic acid, 3-(2-benzothiazolyl)alanine, α-*tert*-butylglycine, 2-amino-5-ureido-n-valeric acid (citrulline, Cit), β-Cyclohexylalanine (Cha), acetamidomethyl-cysteine, diaminobutanoic acid (Dab), diaminopropionic acid (Dpr), dihydroxyphenylalanine (DOPA), dimethylthiazolidine (DMTA), γ-Glutamic acid (γ-Glu), homoserine (Hse), hydroxyproline (Hyp), isoleucine N-methoxy-N-methyl amide, methyl-isoleucine (MeIle), isonipecotic acid (Isn), methyl-leucine (MeLeu), methyl-lysine, dimethyl-lysine, trimethyl-lysine, methanoproline, methionine-sulfoxide (Met(O)), methionine-sulfone (Met(O_2)), norleucine (Nle), methyl-norleucine (Me-Nle), norvaline (Nva), ornithine (Orn), para-aminobenzoic acid (PABA), penicillamine (Pen), methylphenylalanine (MePhe), 4-Chlorophenylalanine (Phe(4-Cl)), 4-fluorophenylalanine (Phe(4-F)), 4-nitrophenylalanine (Phe(4-NO_2)), 4-cyanophenylalanine ((Phe(4-CN)), phenylglycine (Phg), piperidinylalanine, piperidinylglycine, 3,4-dehydroproline, pyrrolidinylalanine, sarcosine (Sar),

selenocysteine (Sec), O-Benzyl-phosphoserine, 4-amino-3-hydroxy-6-methylheptanoic acid (Sta), 4-amino-5-cyclohexyl-3-hydroxypentanoic acid (ACHPA), 4-amino-3-hydroxy-5-phenylpentanoic acid (AHPPA), 1,2,3,4,-tetrahydro-isoquinoline-3-carboxylic acid (Tic), tetrahydropyranglycine, thienylalanine (Thi) , O-benzyl-phosphotyrosine, O-Phosphotyrosine, methoxytyrosine, ethoxytyrosine, O-(bis-dimethylamino-phosphono)-tyrosine, tyrosine sulfate tetrabutylamine, methyl-valine (MeVal), and alkylated 3-mercaptopropionic acid.

In some embodiments, the spacer comprises an overall negative charge, e.g., comprises one or two negatively charged amino acids. In some embodiments, the dipeptide is not any of the dipeptides of general structure A-B, wherein A is selected from the group consisting of Gly, Gln, Ala, Arg, Asp, Asn, Ile, Leu, Val, Phe, and Pro, wherein B is selected from the group consisting of Lys, His, Trp. In some embodiments, the dipeptide spacer is selected from the group consisting of: Ala-Ala, β-Ala- β-Ala, Leu-Leu, Pro-Pro, γ-aminobutyric acid- γ-aminobutyric acid, and γ-Glu- γ-Glu.

In some exemplary embodiments, the glucagon peptide is modified to comprise an acyl group by acylation of an amine, hydroxyl, or thiol of a spacer, which spacer is attached to a side chain of an amino acid at position 10, 20, 24, 29, or 40, or at the C-terminal amino acid of the glucagon peptide.

In yet more specific embodiments, the acyl group is attached to the amino acid at position 10 or 40 of the glucagon peptide and, optionally, the length of the spacer and acyl group is 14 to 28 atoms. The amino acid at position 10 or 40, in some aspects, is an amino acid of Formula I, e.g., Lys, or a disubstituted amino acid related to Formula I. In more specific embodiments, the glucagon peptide lacks an intramolecular bridge, e.g., a covalent intramolecular bridge. The glucagon peptide, for example, can be a peptide comprising one or more alpha, alpha-disubstituted amino acids, e.g., AIB, for stabilizing the alpha helix of the peptide. As shown herein, such peptides comprising an acylated spacer covalently attached to the side chain of the amino acid at position 40 exhibit enhanced potency at the GIP, GLP-1, and glucagon receptors.

Suitable methods of peptide acylation via amines, hydroxyls, and thiols are known in the art. See, for example, Example 19 (for methods of acylating through an amine), Miller, *Biochem Biophys Res Commun* 218: 377-382 (1996); Shimohigashi and

Stammer, *Int J Pept Protein Res* 19: 54-62 (1982); and Previero et al., *Biochim Biophys Acta* 263: 7-13 (1972) (for methods of acylating through a hydroxyl); and San and Silvius, *J Pept Res* 66: 169-180 (2005) (for methods of acylating through a thiol); *Bioconjugate Chem.* "Chemical Modifications of Proteins: History and Applications" pages 1, 2-12 (1990); Hashimoto et al., *Pharmacuetical Res.* "Synthesis of Palmitoyl Derivatives of Insulin and their Biological Activity" Vol. 6, No: 2 pp.171-176 (1989)..

The acyl group of the acylated glucagon peptide can be of any size, e.g., any length carbon chain, and can be linear or branched. In some specific embodiments of the invention, the acyl group is a C4 to C30 fatty acid. For example, the acyl group can be any of a C4 fatty acid, C6 fatty acid, C8 fatty acid, C10 fatty acid, C12 fatty acid, C14 fatty acid, C16 fatty acid, C18 fatty acid, C20 fatty acid, C22 fatty acid, C24 fatty acid, C26 fatty acid, C28 fatty acid, or a C30 fatty acid. In some embodiments, the acyl group is a C8 to C20 fatty acid, e.g., a C14 fatty acid or a C16 fatty acid.

In an alternative embodiment, the acyl group is a bile acid. The bile acid can be any suitable bile acid, including, but not limited to, cholic acid, chenodeoxycholic acid, deoxycholic acid, lithocholic acid, taurocholic acid, glycocholic acid, and cholesterol acid.

In some embodiments of the invention, the glucagon peptide is modified to comprise an acyl group by acylation of a long chain alkane by the glucagon peptide. In specific aspects, the long chain alkane comprises an amine, hydroxyl, or thiol group (e.g. octadecylamine, tetradecanol, and hexadecanethiol) which reacts with a carboxyl group, or activated form thereof, of the glucagon peptide. The carboxyl group, or activated form thereof, of the glucagon peptide can be part of a side chain of an amino acid (e.g., glutamic acid, aspartic acid) of the glucagon peptide or can be part of the peptide backbone.

In certain embodiments, the glucagon peptide is modified to comprise an acyl group by acylation of the long chain alkane by a spacer which is attached to the glucagon peptide. In specific aspects, the long chain alkane comprises an amine, hydroxyl, or thiol group which reacts with a carboxyl group, or activated form thereof, of the spacer. Suitable spacers comprising a carboxyl group, or activated form thereof, are described herein and include, for example, bifunctional spacers, e.g., amino acids, dipeptides, tripeptides, hydrophilic bifunctional spacers and hydrophobic bifunctional spacers.

32993-208847

As used herein, the term "activated form of a carboxyl group" refers to a carboxyl group with the general formula R(C=O)X, wherein X is a leaving group and R is the glucagon peptide or the spacer. For example, activated forms of a carboxyl groups may include, but are not limited to, acyl chlorides, anhydrides, and esters. In some embodiments, the activated carboxyl group is an ester with a N-hydroxysuccinimide ester (NHS) leaving group.

With regard to these aspects of the invention, in which a long chain alkane is acylated by the glucagon peptide or the spacer, the long chain alkane may be of any size and can comprise any length of carbon chain. The long chain alkane can be linear or branched. In certain aspects, the long chain alkane is a C4 to C30 alkane. For example, the long chain alkane can be any of a C4 alkane, C6 alkane, C8 alkane, C10 alkane, C12 alkane, C14 alkane, C16 alkane, C18 alkane, C20 alkane, C22 alkane, C24 alkane, C26 alkane, C28 alkane, or a C30 alkane. In some embodiments, the long chain alkane comprises a C8 to C20 alkane, e.g., a C14 alkane, C16 alkane, or a C18 alkane.

Also, in some embodiments, an amine, hydroxyl, or thiol group of the glucagon peptide is acylated with a cholesterol acid. In specific embodiments, the glucagon peptide is linked to the cholesterol acid through a modified Cys spacer.

The acylated glucagon peptides described herein can be further modified to comprise a hydrophilic moiety. In some specific embodiments the hydrophilic moiety can comprise a polyethylene glycol (PEG) chain. The incorporation of a hydrophilic moiety can be accomplished through any suitable means, such as any of the methods described herein. In this regard, the acylated glucagon peptide can comprise SEQ ID NO: 1, including any of the modifications described herein, in which at least one of the amino acids at position 10, 20, 24, 29, and 40 comprise an acyl group and at least one of the amino acids at position 16, 17, 21, 24, 29, or 40, a position within a C-terminal extension, or the C-terminal amino acid are modified to a Cys, Lys, Orn, homo-Cys, or Ac-Phe, and the side chain of the amino acid is covalently bonded to a hydrophilic moiety (e.g., PEG). In some embodiments, the acyl group is attached to position 10 or 40, optionally via a spacer comprising Cys, Lys, Orn, homo-Cys, or Ac-Phe, and the hydrophilic moiety is incorporated at a Cys residue at position 24.

Alternatively, the acylated glucagon peptide can comprise a spacer, wherein the

spacer is both acylated and modified to comprise the hydrophilic moiety. Nonlimiting examples of suitable spacers include a spacer comprising one or more amino acids selected from the group consisting of Cys, Ac-Cys, Lys, Orn, homo-Cys, and Ac-Phe.

In a specific aspect of the invention, the acylated glucagon peptide comprises the amino acid sequence of any of SEQ ID NOs:101-106, 113-115, 117-119, 123-125, 128-130, 132-134, 136-138, 141-145, 148, 151, 152, 154, 156, 158, 160, 162, 163, 165, 166, 231, 234-239, 257, and 258.

In accordance with some embodiments, the glucagon peptide is modified to comprise an alkyl group, e.g., an alkyl group which is not naturally-occuring on an amino acid (e.g., an alkyl group which is non-native to a naturally-occurring amino acid). Without being held to any particular theory, it is believed that alkylation of glucagon peptides will achieve similar, if not the same, effects as acylation of the glucagon peptides, e.g., a prolonged half-life in circulation, a delayed onset of action, an extended duration of action, an improved resistance to proteases, such as DPP-IV, and increased potency at the GLP-1, GIP, and glucagon receptors.

Alkylation can be carried out at any positions within the glucagon peptide, including any of positions 1-29, a position within a C-terminal extension, or the N- or C-terminal amino acid, provided that the GIP activity (and optionally GIP and/or glucagon activity) is retained, if not enhanced. Alkylation may occur, for example, at any amino acid which is added to the glucagon sequence (SEQ ID NO: 1), e.g., at the N- or C-terminus. Nonlimiting examples include positions 1, 5, 10, 11, 12, 13, 14, 16, 17, 18, 19, 20, 21, 24, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, or 50. The alkyl group can be covalently linked directly to an amino acid of the glucagon peptide, or indirectly to an amino acid of the glucagon peptide via a spacer, wherein the spacer is positioned between the amino acid of the glucagon peptide and the alkyl group. Glucagon peptides may be alkylated at the same amino acid position where a hydrophilic moiety is linked, or at a different amino acid position. Nonlimiting examples include alkylation at position 10 or 40 and pegylation at one or more positions in the C-terminal portion of the glucagon peptide, e.g., position 24, 28 29, or 40, within a C-terminal extension, or at the C-terminus (e.g., through adding a C-terminal Cys).

32993-208847

In a specific aspect of the invention, the glucagon peptide is modified to comprise an alkyl group by direct alkylation of an amine, hydroxyl, or thiol of a side chain of an amino acid of the glucagon peptide. In some embodiments, the glucagon peptide is directly alkylated through the side chain amine, hydroxyl, or thiol of an amino acid. In some embodiments, alkylation is at position 10, 20, 24, 29, or 40. In this regard, the alkylated glucagon peptide can comprise the amino acid sequence of SEQ ID NO : 1, or a modified amino acid sequence thereof comprising one or more of the amino acid modifications described herein, with at least one of the amino acids at positions 10, 20, 24, 29, and 40 modified to any amino acid comprising a side chain amine, hydroxyl, or thiol. In some specific embodiments of the invention, the direct alkylation of the glucagon peptide occurs through the side chain amine, hydroxyl, or thiol of the amino acid at position 10.

In some embodiments, the amino acid comprising a side chain amine is an amino acid of Formula I. In some exemplary embodiments, the amino acid of Formula I, is the amino acid wherein n is 4 (Lys) or n is 3 (Orn).

In other embodiments, the amino acid comprising a side chain hydroxyl is an amino acid of Formula II. In some exemplary embodiments, the amino acid of Formula II is the amino acid wherein n is 1 (Ser).

In yet other embodiments, the amino acid comprising a side chain thiol is an amino acid of Formula III. In some exemplary embodiments, the amino acid of Formula III is the amino acid wherein n is 1 (Cys).

In yet other embodiments, the amino acid comprising a side chain amine, hydroxyl, or thiol is a disubstituted amino acid comprising the same structure of Formula I, Formula II, or Formula III, except that the hydrogen bonded to the alpha carbon of the amino acid of Formula I, Formula II, or Formula III is replaced with a second side chain.

In one embodiment of the invention, the alkylated glucagon peptide comprises a spacer between the peptide and the alkyl group. In some embodiments, the glucagon peptide is covalently bound to the spacer, which is covalently bound to the alkyl group. In some exemplary embodiments, the glucagon peptide is modified to comprise an alkyl group by alkylation of an amine, hydroxyl, or thiol of a spacer, which spacer is attached to a side chain of an amino acid at position 10, 20, 24, 29, or 40 of the glucagon peptide.

32993-208847

The amino acid to which the spacer is attached can be any amino acid (e.g., a singly α-substituted amino acid or an α,α-disubstituted amino acid) comprising a moiety which permits linkage to the spacer. For example, an amino acid comprising a side chain NH_2, –OH, or –COOH (e.g., Lys, Orn, Ser, Asp, or Glu) is suitable. In this respect, the alkylated glucagon peptide can comprise the amino acid sequence of SEQ ID NO: 1, or a modified amino acid sequence thereof comprising one or more of the amino acid modifications described herein, with at least one of the amino acids at positions 10, 20, 24, 29, and 40 modified to any amino acid comprising a side chain amine, hydroxyl, or carboxylate.

In some embodiments, the spacer is an amino acid comprising a side chain amine, hydroxyl, or thiol or a dipeptide or tripeptide comprising an amino acid comprising a side chain amine, hydroxyl, or thiol.

When alkylation occurs through an amine group of a spacer the alkylation can occur through the alpha amine of the amino acid or a side chain amine. In the instance in which the alpha amine is alkylated, the spacer amino acid can be any amino acid. For example, the spacer amino acid can be a hydrophobic amino acid, e.g., Gly, Ala, Val, Leu, Ile, Trp, Met, Phe, Tyr, 6-amino hexanoic acid, 5-aminovaleric acid, 7-aminoheptanoic acid, and 8-aminooctanoic acid. Alternatively, the spacer amino acid can be an acidic residue, e.g., Asp and Glu, provided that the alkylation occurs on the alpha amine of the acidic residue. In the instance in which the side chain amine of the spacer amino acid is alkylated, the spacer amino acid is an amino acid comprising a side chain amine, e.g., an amino acid of Formula I (e.g., Lys or Orn). In this instance, it is possible for both the alpha amine and the side chain amine of the spacer amino acid to be alkylated, such that the glucagon peptide is dialkylated. Embodiments of the invention include such dialkylated molecules.

When alkylation occurs through a hydroxyl group of a spacer, the amino acid or one of the amino acids of the dipeptide or tripeptide can be an amino acid of Formula II. In a specific exemplary embodiment, the amino acid is Ser.

When acylation occurs through a thiol group of spacer, the amino acid or one of the amino acids of the dipeptide or tripeptide can be an amino acid of Formula III. In a specific exemplary embodiment, the amino acid is Cys.

32993-208847

In some embodiments, the spacer is a hydrophilic bifunctional spacer. In certain embodiments, the hydrophilic bifunctional spacer comprises two or more reactive groups, e.g., an amine, a hydroxyl, a thiol, and a carboxyl group or any combinations thereof. In certain embodiments, the hydrophilic bifunctional spacer comprises a hydroxyl group and a carboxylate. In other embodiments, the hydrophilic bifunctional spacer comprises an amine group and a carboxylate. In other embodiments, the hydrophilic bifunctional spacer comprises a thiol group and a carboxylate. In a specific embodiment, the spacer comprises an amino poly(alkyloxy)carboxylate. In this regard, the spacer can comprise, for example, $NH_2(CH_2CH_2O)_n(CH_2)_mCOOH$, wherein m is any integer from 1 to 6 and n is any integer from 2 to 12, such as, e.g., 8-amino-3,6-dioxaoctanoic acid, which is commercially available from Peptides International, Inc. (Louisville, KY).

In some embodiments, the spacer is a hydrophobic bifunctional spacer. In certain embodiments, the hydrophobic bifunctional spacer comprises two or more reactive groups, e.g., an amine, a hydroxyl, a thiol, and a carboxyl group or any combinations thereof. In certain embodiments, the hydrophobic bifunctional spacer comprises a hydroxyl group and a carboxylate. In other embodiments, the hydropholic bifunctional spacer comprises an amine group and a carboxylate. In other embodiments, the hydropholic bifunctional spacer comprises a thiol group and a carboxylate. Suitable hydrophobic bifunctional spacers comprising a carboxylate, and a hydroxyl group or a thiol group are known in the art and include, for example, 8-hydroxyoctanoic acid and 8-mercaptooctanoic acid.

The spacer (e.g., amino acid, dipeptide, tripeptide, hydrophilic bifunctional, or hydrophobic bifunctional spacer) in specific embodiments is 3 to 10 atoms (e.g., 6 to 10 atoms, (e.g., 6, 7, 8, 9, or 10 atoms)) in length. In more specific embodiments, the spacer is about 3 to 10 atoms (e.g., 6 to 10 atoms) in length and the alkyl is a C12 to C18 alkyl group, e.g., C14 alkyl group, C16 alkyl group, such that the total length of the spacer and alkyl group is 14 to 28 atoms, e.g., about 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, or 28 atoms. In some embodiments, the length of the spacer and alkyl is 17 to 28 (e.g., 19 to 26, 19 to 21) atoms.

In accordance with certain foregoing embodiments, the bifunctional spacer can be a synthetic or non-naturally occurring amino acid comprising an amino acid backbone

that is 3 to 10 atoms in length (e.g., 6-amino hexanoic acid, 5-aminovaleric acid, 7-aminoheptanoic acid, and 8-aminooctanoic acid). Alternatively, the spacer can be a dipeptide or tripeptide spacer having a peptide backbone that is 3 to 10 atoms (e.g., 6 to 10 atoms) in length. The dipeptide or tripeptide spacer can be composed of naturally-occurring and/or non-naturally occurring amino acids, including, for example, any of the amino acids taught herein. In some embodiments, the spacer comprises an overall negative charge, e.g., comprises one or two negatively charged amino acids. In some embodiments, the dipeptide spacer is selected from the group consisting of: Ala-Ala, β-Ala- β-Ala, Leu-Leu, Pro-Pro,. γ-aminobutyric acid- γ-aminobutyric acid, and γ-Glu- γ-Glu.

Suitable methods of peptide alkylation via amines, hydroxyls, and thiols are known in the art. For example, a Williamson ether synthesis can be used to form an ether linkage between a hydroxyl group of the glucagon peptide and the alkyl group. Also, a nucleophilic substitution reaction of the peptide with an alkyl halide can result in any of an ether, thioether, or amino linkage.

The alkyl group of the alkylated glucagon peptide can be of any size, e.g., any length carbon chain, and can be linear or branched. In some embodiments of the invention, the alkyl group is a C4 to C30 alkyl. For example, the alkyl group can be any of a C4 alkyl, C6 alkyl, C8 alkyl, C10 alkyl, C12 alkyl, C14 alkyl, C16 alkyl, C18 alkyl, C20 alkyl, C22 alkyl, C24 alkyl, C26 alkyl, C28 alkyl, or a C30 alkyl. In some embodiments, the alkyl group is a C8 to C20 alkyl, e.g., a C14 alkyl or a C16 alkyl.

In some specific embodiments, the alkyl group comprises a steroid moiety of a bile acid, e.g., cholic acid, chenodeoxycholic acid, deoxycholic acid, lithocholic acid, taurocholic acid, glycocholic acid, and cholesterol acid.

In some embodiments of the invention, the glucagon peptide is modified to comprise an alkyl group by reacting a nucleophilic, long chain alkane with the glucagon peptide, wherein the glucagon peptide comprises a leaving group suitable for nucleophilic substitution. In specific aspects, the nucleophilic group of the long chain alkane comprises an amine, hydroxyl, or thiol group (e.g. octadecylamine, tetradecanol, and hexadecanethiol). The leaving group of the glucagon peptide can be part of a side chain

of an amino acid or can be part of the peptide backbone. Suitable leaving groups include, for example, N-hydroxysuccinimide, halogens, and sulfonate esters.

In certain embodiments, the glucagon peptide is modified to comprise an alkyl group by reacting the nucleophilic, long chain alkane with a spacer which is attached to the glucagon peptide, wherein the spacer comprises the leaving group. In specific aspects, the long chain alkane comprises an amine, hydroxyl, or thiol group. In certain embodiments, the spacer comprising the leaving group can be any spacer discussed herein, e.g., amino acids, dipeptides, tripeptides, hydrophilic bifunctional spacers and hydrophobic bifunctional spacers further comprising a suitable leaving group.

With regard to these aspects of the invention, in which a long chain alkane is alkylated by the glucagon peptide or the spacer, the long chain alkane may be of any size and can comprise any length of carbon chain. The long chain alkane can be linear or branched. In certain aspects, the long chain alkane is a C4 to C30 alkane. For example, the long chain alkane can be any of a C4 alkane, C6 alkane, C8 alkane, C10 alkane, C12 alkane, C14 alkane, C16 alkane, C18 alkane, C20 alkane, C22 alkane, C24 alkane, C26 alkane, C28 alkane, or a C30 alkane. In some embodiments, the long chain alkane comprises a C8 to C20 alkane, e.g., a C14 alkane, C16 alkane, or a C18 alkane.

Also, in some embodiments, alkylation can occur between the glucagon peptide and a cholesterol moiety. For example, the hydroxyl group of cholesterol can displace a leaving group on the long chain alkane to form a cholesterol-glucagon peptide product.

The alkylated glucagon peptides described herein can be further modified to comprise a hydrophilic moiety. In some specific embodiments the hydrophilic moiety can comprise a polyethylene glycol (PEG) chain. The incorporation of a hydrophilic moiety can be accomplished through any suitable means, such as any of the methods described herein. In this regard, the alkylated glucagon peptide can comprise SEQ ID NO: 1, or a modified amino acid sequence thereof comprising one or more of the amino acid modifications described herein, in which at least one of the amino acids at position 10, 20, 24, 29, and 40 comprise an alkyl group and at least one of the amino acids at position 16, 17, 21, 24, 29, and 40, a position within a C-terminal extension or the C-terminal amino acid are modified to a Cys, Lys, Orn, homo-Cys, or Ac-Phe, and the side chain of the amino acid is covalently bonded to a hydrophilic moiety (e.g., PEG). In

some embodiments, the alkyl group is attached to position 10 or 40, optionally via a spacer comprising Cys, Lys, Orn, homo-Cys, or Ac-Phe, and the hydrophilic moiety is incorporated at a Cys residue at position 24.

Alternatively, the alkylated glucagon peptide can comprise a spacer, wherein the spacer is both alkylated and modified to comprise the hydrophilic moiety. Nonlimiting examples of suitable spacers include a spacer comprising one or more amino acids selected from the group consisting of Cys, Lys, Orn, homo-Cys, and Ac-Phe.

Exemplary Embodiments

In accordance with some embodiments of the invention, the analog of glucagon (SEQ ID NO: 1) having GIP agonist activity comprises SEQ ID NO: 1 with (a) an amino acid modification at position 1 that confers GIP agonist activity, (b) a modification which stabilizes the alpha helix structure of the C-terminal portion (amino acids 12-29) of the analog, and (c) optionally, 1 to 10 (e.g., 1, 2, 3, 4, 5, 6, 7, 8, 9, 10) further amino acid modifications. In some embodiments, the analog exhibits at least about 1% activity of native GIP at the GIP receptor or any other activity level at the GIP receptor described herein.

In certain embodiments, the modification which stabilizes the alpha helix structure is one which provides or introduces an intramolecular bridge, including, for example, a covalent intramolecular bridge, such as any of those described herein. The covalent intramolecular bridge in some embodiments is a lactam bridge. The lactam bridge of the analog of these embodiments can be a lactam bridge as described herein. See, e.g., the teachings of lactam bridges under the section "Stabilization of the Alpha Helix Structure." For example, the lactam bridge may be one which is between the side chains of amino acids at positions i and i+4 or between the side chains of amino acids at positions j and j+3, wherein i is 12, 13, 16, 17, 20 or 24, and wherein j is 17. In certain embodiments, the lactam bridge can be between the amino acids at positions 16 and 20, wherein one of the amino acids at positions 16 and 20 is substituted with Glu and the other of the amino acids at positions 16 and 20 is substituted with Lys.

In alternative embodiments, the modification which stabilizes the alpha helix structure is the introduction of one, two, three, or four α,α-disubstituted amino acids at

position(s) 16, 20, 21, and 24 of the analog. In some embodiments, the α,α-disubstituted amino acid is AIB. In certain aspects, the α,α-disubstituted amino acid (e.g., AIB) is at position 20 and the amino acid atposition 16 is substituted with a positive-charged amino acid, such as, for example, an amino acid of Formula IV, which is described herein. The amino acid of Formula IV may be homoLys, Lys, Orn, or 2,4-diaminobutyric acid (Dab).

In specific aspects of the invention, the amino acid modification at position 1 is a substitution of His with an amino acid lacking an imidazole side chain, e.g. a large, aromatic amino acid (e.g., Tyr).

In certain aspects, the analog of glucagon comprises amino acid modifications at one, two or all of positions 27, 28 and 29. For example, the Met at position 27 can be substituted with a large aliphatic amino acid, optionally Leu, the Asn at position 28 can be substituted with a small aliphatic amino acid, optionally Ala, the Thr at position 29 can be substituted with a small aliphatic amino acid, optionally Gly, or a combination of two or three of the foregoing. In specific embodiments, the analog of glucagon comprises Leu at position 27, Ala at position 28, and Gly or Thr at position 29.

In certain embodiments of the invention, the analog of glucagon comprises an extension of 1 to 21 amino acids C-terminal to the amino acid at position 29. The extension can comprise the amino acid sequence of SEQ ID NO: 95 or 96, for instance. Additionally or alternatively, the analog of glucagon can comprise an extension of which 1-6 amino acids of the extension are positive-charged amino acids. The positive-charged amino acids may be amino acids of Formula IV, including, but not limited to Lys, homoLys, Orn, and Dab.

The analog of glucagon in some embodiments is acylated or alkylated as described herein. For instance, the acyl or alkyl group may be attached to the analog of glucagon, with or without a spacer, at position 10 or 40 of the analog, as further described herein. The analog may additionally or alternatively be modified to comprise a hydrophilic moiety as further described herein. Furthermore, in some embodiments, the analog comprises any one or a combination of the following modifications:

(a) Ser at position 2 substituted with D-Ser, Ala, D-Ala, Gly, N-methyl-Ser, AIB, Val, or α-amino-N-butyric acid;

(b) Tyr at position 10 substituted with Trp, Lys, Orn, Glu, Phe, or Val:

(c) Linkage of an acyl group to a Lys at position 10;

(d) Lys at position 12 substituted with Arg or Ile;

(e) Ser at position 16 substituted with Glu, Gln, homoglutamic acid, homocysteic acid, Thr, Gly, or AIB;

(f) Arg at position 17 substituted with Gln;

(g) Arg at position 18 substituted with Ala, Ser, Thr, or Gly;

(h) Gln at position 20 substituted with Ser, Thr, Ala, Lys, Citrulline, Arg, Orn, or AIB;

(i) Asp at position 21 substituted with Glu, homoglutamic acid, homocysteic acid;

(j) Val at position 23 substituted with Ile;

(k) Gln at position 24 substituted with Asn, Ser, Thr, Ala, or AIB;

(l) and a conservative substitution at any of positions 2 5, 9, 10, 11; 12. 13, 14, 15, 16, 8 19 20, 21. 24, 27, 28, and 29.

In exemplary embodiments, the analog of glucagon (SEQ ID NO: 1) having GIP agonist activity comprises the following modifications:

(a) an amino acid modification at position 1 that confers GIP agonist activity,

(b) a lactam bridge between the side chains of amino acids at positions i and i+4 or between the side chains of amino acids at positions j and j+3, wherein i is 12, 13, 16, 17, 20 or 24, and wherein j is 17,

(c) amino acid modifications at one, two or all of positions 27, 28 and 29, e.g., amino acid modifications at position 27 and/or 28, and

(d) 1-9 or 1-6 further amino acid modifications, e.g. 1, 2, 3, 4, 5, 6, 7, 8 or 9 further amino acid modifications,

and the EC50 of the analog for GIP receptor activation is about 10 nM or less.

The lactam bridge of the analog of these embodiments can be a lactam bridge as described herein. See, e.g., the teachings of lactam bridges under the section "Stabilization of the Alpha Helix Structure." For example, the lactam bridge can be between the amino acids at positions 16 and 20, wherein one of the amino acids at positions 16 and 20 is substituted with Glu and the other of the amino acids at positions 16 and 20 is substituted with Lys.

In accordance with these embodiments, the analog can comprise, for example, the amino acid sequence of any of SEQ ID NOs: 5-94.

In other exemplary embodiments, the analog of glucagon (SEQ ID NO: 1) having GIP agonist activity comprises the following modifications:

(a) an amino acid modification at position 1 that confers GIP agonist activity,

(b) one, two, three, or all of the amino acids at positions 16, 20, 21, and 24 of the analog is substituted with an α,α-disubstituted amino acid,

(c) amino acid modifications at one, two or all of positions 27, 28 and 29, e.g., amino acid modifications at position 27 and/or 28, and

(d) 1-9 or 1-6 further amino acid modifications, e.g. 1, 2, 3, 4, 5, 6, 7, 8 or 9 further amino acid modifications,

and the EC50 of the analog for GIP receptor activation is about 10 nM or less.

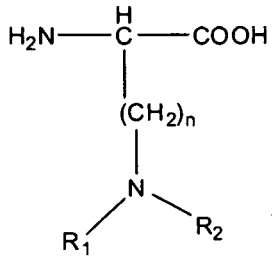
The α,α-disubstituted amino acid of the analog of these embodiments can be any α,α-disubstituted amino acid, including, but not limited to, amino iso-butyric acid (AIB), an amino acid disubstituted with the same or a different group selected from methyl, ethyl, propyl, and n-butyl, or with a cyclooctane or cycloheptane (e.g., 1-aminocyclooctane-1-carboxylic acid). In certain embodiments, the α,α-disubstituted amino acid is AIB. In certain embodiments, the amino acid at position 20 is substituted with an α,α-disubstituted amino acid, e.g., AIB.

In accordance with these embodiments, the analog can comprise, for example, the amino acid sequence of any of SEQ ID NOs: 99-141, 144-164, 166-169, and 173-178.

In yet other exemplary embodiments, the analog of glucagon (SEQ ID NO: 1) having GIP agonist activity comprises the following modifications:

(a) an amino acid modification at position 1 that confers GIP agonist activity,

(b) an amino acid substitution of Ser at position 16 with an amino acid of Formula IV:



[Formula IV],

wherein n is 1 to 16, or 1 to 10, or 1 to 7, or 1 to 6, or 2 to 6, each of R_1 and R_2 is independently selected from the group consisting of H, C_1-C_{18} alkyl, (C_1-C_{18} alkyl)OH, (C_1-C_{18} alkyl)NH_2, (C_1-C_{18} alkyl)SH, (C_0-C_4 alkyl)(C_3-C_6)cycloalkyl, (C_0-C_4 alkyl)(C_2-C_5 heterocyclic), (C_0-C_4 alkyl)(C_6-C_{10} aryl)R_7, and (C_1-C_4 alkyl)(C_3-C_9 heteroaryl), wherein R_7 is H or OH, and the side chain of the amino acid of Formula IV comprises a free amino group,

(c) an amino acid substitution of the Gln at position 20 with an alpha, alpha-disubstituted amino acid,

(d) amino acid modifications at one, two or all of positions 27, 28 and 29, e.g., amino acid modifications at position 27 and/or 28, and

(e) 1-9 or 1-6 further amino acid modifications, e.g. 1, 2, 3, 4, 5, 6, 7, 8 or 9 further amino acid modifications,

and the EC50 of the analog for GIP receptor activation is about 10 nM or less.

The amino acid of Formula IV of the analog of these embodiments may be any amino acid, such as, for example, the amino acid of Formula IV, wherein n is 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, or 16. In certain embodiments, n is 2, 3, 4, or 5, in which case, the amino acid is Dab, Orn, Lys, or homoLys respectively.

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The alpha, alpha-disubstituted amino acid of the analog of these embodiments may be any alpha, alpha-disubstituted amino acid, including, but not limited to, amino iso-butyric acid (AIB), an amino acid disubstituted with the same or a different group selected from methyl, ethyl, propyl, and n-butyl, or with a cyclooctane or cycloheptane (e.g., 1-aminocyclooctane-1-carboxylic acid). In certain embodiments, the alpha, alpha-disubstituted amino acid is AIB.

In accordance with these embodiments, the analog can comprise, for example, the amino acid sequence of any of SEQ ID NOs: 99-165.

In yet other exemplary embodiments, the analog of glucagon (SEQ ID NO: 1) having GIP agonist activity comprises:

(a) an amino acid modification at position 1 that confers GIP agonist activity, and

(b) an extension of about 1 to about 21 amino acids C-terminal to the amino acid at position 29, wherein at least one of the amino acids of the extension is acylated or alkylated,

wherein the EC50 of the analog for GIP receptor activation is about 10 nM or less.

In some embodiments, the acylated or alkylated amino acid is an amino acid of Formula I, II, or III. In more specific embodiments, the amino acid of Formula I is Dab, Orn, Lys, or homoLys. Also, in some embodiments, the extension of about 1 to about 21 amino acids comprises the amino acid sequence of GPSSGAPPPS (SEQ ID NO: 95) or XGPSSGAPPPS (SEQ ID NO: 96), wherein X is any amino acid, or GPSSGAPPPK (SEQ ID NO: 170) or XGPSSGAPPPK (SEQ ID NO: 171) or XGPSSGAPPPSK (SEQ ID NO: 172), wherein X is Gly or a small, aliphatic or non-polar or slightly polar amino acid. In some embodiments, the about 1 to about 21 amino acids may comprise sequences containing one or more conservative substitutions relative to SEQ ID NO: 95, 96, 170, 171 or 172. In some embodiments, the acylated or alkylated amino acid is located at position 37, 38, 39, 40, 41, 42, or 43 of the C-terminally-extended analog. In certain embodiments, the acylated or alkylated amino acid is located at position 40 of the C-terminally extended analog.

32993-208847

In some embodiments, the analog having GIP agonist activity further comprises amino acid modifications at one, two or all of positions 27, 28 and 29, e.g., amino acid modifications at position 27 and/or 28.

In any of the above exemplary embodiments, the amino acid modification at position 1 that confers GIP agonist activity can be a substitution of His with an amino acid lacking an imidazole side chain. The amino acid modification at position 1 can, for example, be a substitution of His with a large, aromatic amino acid. In some embodiments, the large, aromatic amino acid is any of those described herein, including, for example, Tyr.

Also, with regard to the above exemplary embodiments, amino acid modifications at one, two, or all of positions 27, 28, and 29 can be any of the modifications at these positions described herein. For example, the Met at position 27 can be substituted with a large aliphatic amino acid, optionally Leu, the Asn at position 28 can be substituted with a small aliphatic amino acid, optionally Ala, and/or the Thr at position 29 can be substituted with a small aliphatic amino acid, optionally Gly. Alternatively, the analog can comprise such amino acid modifications at position 27 and/or 28.

The analog of the above exemplary embodiments can further comprise 1-9 or 1-6 further, additional amino acid modifications, e.g. 1, 2, 3, 4, 5, 6, 7, 8 or 9 further amino acid modifications, such as, for example, any of the modifications described herein which increase or decrease the activity at any of the GIP, GLP-1, and glucagon receptors, improve solubility, improve duration of action or half-life in circulation, delay the onset of action, or increase stability. The analog can further comprise, for example, an amino acid modification at position 12, optionally, a substitution with Ile, and/or amino acid modifications at positions 17 and 18, optionally substitution with Q at position 17 and A at position 18, and/or an addition of GPSSGAPPPS (SEQ ID NO: 95) or XGPSSGAPPPS (SEQ ID NO: 96), or sequences containing one or more conservative substitutions relative to SEQ ID NO: 95 or 96, to the C-terminus. The analog can comprise one or more of the following modifications:

(i) Ser at position 2 substituted with D-Ser, Ala, D-Ala, Gly, N-methyl-Ser, AIB, Val, or α-amino-N-butyric acid;

(ii) Tyr at position 10 substituted with Trp, Lys, Orn, Glu, Phe, or Val;

(iii) Linkage of an acyl group to a Lys at position 10;

(iv) Lys at position 12 substituted with Arg;

(v) Ser at position 16 substituted with Glu, Gln, homoglutamic acid, homocysteic acid, Thr, Gly, or AIB;

(vi) Arg at position 17 substituted with Gln;

(vii) Arg at position 18 substituted with Ala, Ser, Thr, or Gly;

(viii) Gln at position 20 substituted with Ala, Ser, Thr, Lys, Citrulline, Arg, Orn, or AIB;

(ix) Asp at position 21 substituted with Glu, homoglutamic acid, homocysteic acid;

(x) Val at position 23 substituted with Ile;

(xi) Gln at position 24 substituted with Asn, Ala, Ser, Thr, or AIB; and

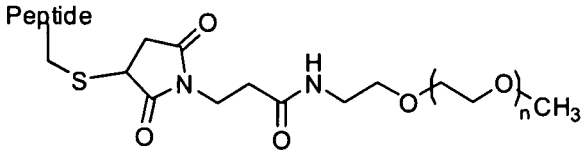
(xii) a conservative substitution at any of positions 2, 5, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 24, 27, 28, and 29.

The analog in some embodiments comprise a combination of the modifications (i) through (xii). Alternatively or additionally, the analog can comprise an amino acid modification at position 3 (e.g., an amino acid substitution of Gln with Glu), wherein the analog has less than 1% of the activity of glucagon at the glucagon receptor. Alternatively or additionally, the analog can comprise an amino acid modification at position 7 (e.g., an amino acid substitution of Thr with an amino acid lacking a hydroxyl group, e.g., Abu or Ile), wherein the analog has less than about 10% of the activity of GLP-1 at the GLP-1 receptor.

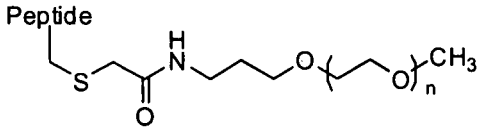
With regard to the exemplary embodiments, the analog can be covalently linked to a hydrophilic moiety. In some embodiments, the analog is covalently linked to the hydrophilic moiety at any of amino acid positions 16, 17, 20, 21, 24, 29, 40, or the C-terminus. In certain embodiments, the analog comprises a C-terminal extension (e.g., an amino acid sequence of SEQ ID NO: 95) and an addition of an amino acid comprising the hydrophilic moiety, such that the hydrophilic moiety is covalently linked to the analog at position 40.

In some embodiments, the hydrophilic moiety is covalently linked to a Lys, Cys, Orn, homocysteine, or acetyl-phenylalanine of the analog. The Lys, Cys, Orn,

homocysteine, or acetyl-phenylalanine may be an amino acid that is native to the glucagon sequence (SEQ ID NO: 1) or it may be an amino acid which is replacing a native amino acid of SEQ ID NO: 1. In some embodiments, wherein the hydrophilic moiety is attached to a Cys, the linkage to the hydrophilic moiety can comprise the structure



or



With regard to the analogs comprising a hydrophilic moiety, the hydrophilic moiety may be any of those described herein. See, e.g., the teachings under the section "Linkage of hydrophilic moieties." In some embodiments, the hydrophilic moiety is a polyethylene glycol (PEG). The PEG in certain embodiments has a molecular weight of about 1,000 Daltons to about 40,000 Daltons, e.g., about 20,000 Daltons to about 40,000 Daltons.

With regard to the exemplary embodiments, the analog can comprise a modified amino acid in which the side chain is covalently linked to an acyl or alkyl group (e.g., an acyl or alkyl group which is non-native to a naturally-occurring amino acid). The acylated or alkylated analog can be in accordance with acylated or alkylated peptides described in the section "Acylation and alkylation." In some embodiments, the acyl group is a C4 to a C30 fatty acyl group, such as, for example, a C10 fatty acyl or alkyl group, a C12 fatty acyl or alkyl group, a C14 fatty acyl or alkyl group, a C16 fatty acyl or alkyl group, a C18 fatty acyl or alkyl group, a C20 acyl or alkyl group, or a C22 acyl or alkyl group. The acyl or alkyl group may be covalently attached to any amino acid of the analog, including, but not limited to the amino acid at position 10 or 40, or the C-terminal amino acid. In certain embodiments, the analog comprises a C-terminal extension (e.g., an amino acid sequence of SEQ ID NO: 95) and an addition of an amino acid comprising the acyl or alkyl group, such that the acyl or alkyl group is covalently linked to the analog at position 40. In some embodiments, the acyl or alkyl group is covalently linked to the

side chain of an amino acid of Formula I, II, or III, e.g., a Lys residue. The acyl or alkyl group may be covalently linked to an amino acid which is native to the glucagon sequence (SEQ ID NO: 1) or may be linked to an amino acid which is added to the sequence of SEQ ID NO: 1 or to the sequence of SEQ ID NO: 1 followed by SEQ ID NO: 95 (at the N- or C-terminus) or may be linked to an amino acid which replaces a native amino acid, e.g., the Tyr at position 10 of SEQ ID NO: 1.

In the above exemplary embodiments, wherein the analog comprises an acyl or alkyl group, the analog may be attached to the acyl or alkyl group via a spacer, as described herein. The spacer, for example, may be 3 to 10 atoms in length and may be, for instance, an amino acid (e.g., 6-amino hexanoic acid, any amino acid described herein), a dipeptide (e.g., Ala-Ala, βAla-βAla, Leu-Leu, Pro-Pro, γGlu-γGlu), a tripeptide, or a hydrophilic or hydrophobic bifunctional spacer. In certain aspects, the total length of the spacer and the acyl or alkyl group is about 14 to about 28 atoms.

In still further exemplary embodiments, the analog of glucagon having GIP agonist activity comprises the amino acid sequence according to any one of SEQ ID NOs: 227, 228, 229 or 230 that further comprises the following modifications:

(a) optionally, an amino acid modification at position 1 that confers GIP agonist activity,

(b) an extension of about 1 to about 21 amino acids C-terminal to the amino acid at position 29, wherein at least one of the amino acids of the extension is acylated or alkylated, and

(d) up to 6 further amino acid modifications,

wherein the EC50 of the analog for GIP receptor activation is about 10 nM or less.

In some aspects, the acylated or alkylated amino acid is an amino acid of Formula I, II, or III. In more specific embodiments, the amino acid of Formula I is Dab, Orn, Lys, or homoLys. Also, in some embodiments, the about 1 to about 21 amino acids comprises the amino acid sequence of GPSSGAPPPS (SEQ ID NO: 95) or XGPSSGAPPPS (SEQ ID NO: 96), wherein X is any amino acid, or GPSSGAPPPK (SEQ ID NO: 170) or XGPSSGAPPPK (SEQ ID NO: 171) or XGPSSGAPPPSK (SEQ ID NO: 172), wherein X is Gly or a small, aliphatic or non-polar or slightly polar amino acid. In some embodiments, the about 1 to about 21 amino acids may comprise sequences containing

one or more conservative substitutions relative to SEQ ID NO: 95, 96, 170, 171 or 172. In some embodiments, the acylated or alkylated amino acid is located at position 37, 38, 39, 40, 41, 42, or 43 of the C-terminally-extended analog. In certain embodiments, the acylated or alkylated amino acid is located at position 40 of the C-terminally extended analog.

In any of the above exemplary embodiments, the amino acid at position 1 that confers GIP agonist activity can be an amino acid lacking an imidazole side chain. The amino acid at position 1 can, for example, be a large, aromatic amino acid. In some embodiments, the large, aromatic amino acid is any of those described herein, including, for example, Tyr.

The analog of the above exemplary embodiments can further comprise 1-6 further amino acid modifications, such as, for example, any of the modifications described herein which increase or decrease the activity at any of the GIP, GLP-1, and glucagon receptors, improve solubility, improve duration of action or half-life in circulation, delay the onset of action, or increase stability.

In certain aspects, glucagon analogs described in the above exemplary embodiment, comprise further amino acid modifications at one, two or all of positions 27, 28 and 29. Modifications at these positions can be any of the modifications described herein relative to these positions. For example, relative to SEQ ID NO: 227, 228, 229 or 230, position 27 can be substituted with a large aliphatic amino acid (e.g., Leu, Ile or norleucine) or Met, position 28 can be substituted with another small aliphatic amino acid (e.g., Gly or Ala) or Asn, and/or position 29 can be substituted with another small aliphatic amino acid (e.g., Ala or Gly) or Thr. Alternatively, the analog can comprise such amino acid modifications at position 27 and/or 28.

The analog can further comprise one or more of the following additional modifications:

(i) the amino acid at position 2 is any one of D-Ser, Ala, D-Ala, Gly, N-methyl-Ser, AIB, Val, or α-amino-N-butyric acid;

(ii) the amino acid at position 10 is Tyr, Trp, Lys, Orn, Glu, Phe, or Val;

(iii) linkage of an acyl group to a Lys at position 10;

(iv) the amino acid at position 12 is Ile, Lys or Arg;

(v) the amino acid at position 16 is any one of Ser, Glu, Gln, homoglutamic acid, homocysteic acid, Thr, Gly, or AIB;

(vi) the amino acid at position 17 is Gln or Arg;

(vii) the amino acid at position 18 is any one of Ala, Arg, Ser, Thr, or Gly;

(viii) the amino acid at position 20 is any one of Ala, Ser, Thr, Lys, Citrulline, Arg, Orn, or AIB or another alpha, alpha-disubstituted amino acid;

(ix) the amino acid at position 21 is any one of Glu, Asp, homoglutamic acid, homocysteic acid;

(x) the amino acid at position 23 is Val or Ile;

(xi) the amino acid at position 24 is any one of Gln, Asn, Ala, Ser, Thr, or AIB; and

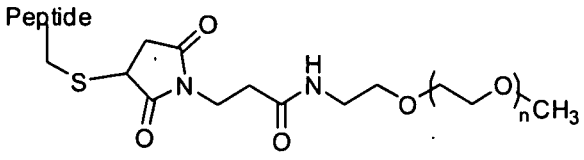
(xii) one or more conservative substitutions at any of positions 2, 5, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 24, 27, 28, and 29.

The analog in some embodiments comprise a combination of the modifications (i) through (xii). Alternatively or additionally, the analog can comprise an amino acid modification at position 3 (e.g., an amino acid substitution of Gln with Glu), wherein the analog has less than 1% of the activity of glucagon at the glucagon receptor. Alternatively or additionally, the analog can comprise an amino acid modification at position 7 (e.g., an amino acid substitution of Thr with an amino acid lacking a hydroxyl group, e.g., Abu or Ile), wherein the analog has less than about 10% of the activity of GLP-1 at the GLP-1 receptor.

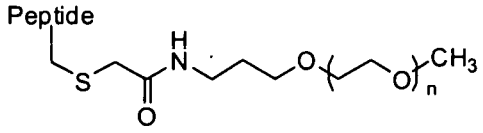
With regard to the exemplary embodiments, the analog can be covalently linked to a hydrophilic moiety. In some embodiments, the analog is covalently linked to the hydrophilic moiety at any of amino acid positions 16, 17, 20, 21, 24, 29, 40, or the C-terminus. In certain embodiments, the analog comprises a hydrophilic moiety covalently linked to the analog at position 24.

In some embodiments, the hydrophilic moiety is covalently linked to a Lys, Cys, Orn, homocysteine, or acetyl-phenylalanine of the analog. The Lys, Cys, Orn,

homocysteine, or acetyl-phenylalanine may be an amino acid that is native to SEQ ID NO: 1, 227, 228, 229 or 230 or it may be a substituted amino acid. In some embodiments, wherein the hydrophilic moiety is linked to a Cys, the linkage may comprise the structure



or



With regard to the analogs comprising a hydrophilic moiety, the hydrophilic moiety may be any of those described herein. See, e.g., the teachings under the section "Linkage of hydrophilic moieties." In some embodiments, the hydrophilic moiety is a polyethylene glycol (PEG). The PEG in certain embodiments has a molecular weight of about 1,000 Daltons to about 40,000 Daltons, e.g., about 20,000 Daltons to about 40,000 Daltons.

With regard to the exemplary embodiments, the analog can comprise a modified amino acid within the C-terminal extension in which the side chain is covalently linked to an acyl or alkyl group. The acylated or alkylated analog can be in accordance with acylated or alkylated peptides described in the section "Acylation and alkylation." In some embodiments, the acyl group is a C4 to a C30 fatty acyl group, such as, for example, a C10 fatty acyl or alkyl group, a C12 fatty acyl or alkyl group, a C14 fatty acyl or alkyl group, a C16 fatty acyl or alkyl group, a C18 fatty acyl or alkyl group, a C20 acyl or alkyl group, or a C22 acyl or alkyl group. The acyl or alkyl group may be covalently attached to any amino acid of the analog, including, but not limited to the amino acid at position 10 or 40, or the C-terminal amino acid. In some embodiments, the acyl or alkyl group is covalently linked to the side chain of an amino acid of Formula I, II, or III, e.g., a Lys residue. The acyl or alkyl group is covalently linked to an amino acid which is native to SEQ ID NO: 1, 227, 228, 229 or 230 or it may be linked to a substituted amino acid. The acyl or alkyl group is covalently linked to an amino acid which is native to SEQ ID NO: 95, 96, 171 or 172, or it may be linked to a substituted amino acid.

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In the above exemplary embodiments, wherein the analog comprises an acyl or alkyl group, the analog may be attached to the acyl or alkyl group via a spacer, as described herein. The spacer, for example, may be 3 to 10 atoms in length and may be, for instance, an amino acid (e.g., 6-amino hexanoic acid, any amino acid described herein), a dipeptide (e.g., Ala-Ala, βAla-βAla, Leu-Leu, Pro-Pro, γGlu-γGlu), a tripeptide, or a hydrophilic or hydrophobic bifunctional spacer. In certain aspects, the total length of the spacer and the acyl or alkyl group is about 14 to about 28 atoms.

In some very specific embodiments, an analog of the invention comprises an amino acid sequence selected from the group consisting of SEQ ID NOs: 99-141, 144-164, 166, 192-207, 209-221 and 223 or selected from the group consisting of SEQ ID NOs: 167-169,173-178 and 225.

Further, specific examples of analogs of the invention include but are not limited to, any of those referenced in Tables 1-3.

In still further exemplary embodiments, the analog of glucagon having GIP agonist activity comprises an acyl or alkyl group (e.g., an acyl or alkyl group which is non-native to a naturally occurring amino acid), wherein the acyl or alkyl group is attached to a spacer, wherein (i) the spacer is attached to the side chain of the amino acid at position 10 of the analog; or (ii) the analog comprises an extension of 1 to 21 amino acids C-terminal to the amino acid at position 29 and the spacer is attached to the side chain of an amino acid corresponding to one of positions 37-43 relative to SEQ ID NO: 1, wherein the EC50 of the analog for GIP receptor activation is about 10 nM or less.

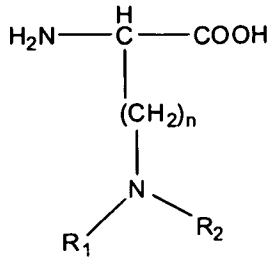
In such embodiments, the analog may comprise an amino acid sequence of SEQ ID NO: 1 with (i) an amino acid modification at position 1 that confers GIP agonist activity, (ii) amino acid modifications at one, two, or all of positions 27, 28, and 29, (iii) at least one of:

(A) the analog comprises a lactam bridge between the side chains of amino acids at positions i and i+4 or between the side chains of amino acids at positions j and j+3, wherein i is 12, 13, 16, 17, 20 or 24, and wherein j is 17;

(B) one, two, three, or all of the amino acids at positions 16, 20, 21, and 24 of the analog is substituted with an α,α-disubstituted amino acid; or

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(C) the analog comprises (i) an amino acid substitution of Ser at position 16 with an amino acid of Formula IV:



[Formula IV],

wherein n is 1 to 7, wherein each of R1 and R2 is independently selected from the group consisting of H, C_1-C_{18} alkyl, (C_1-C_{18} alkyl)OH, (C_1-C_{18} alkyl)NH_2, (C_1-C_{18} alkyl)SH, (C_0-C_4 alkyl)(C_3-C_6)cycloalkyl, (C_0-C_4 alkyl)(C_2-C_5 heterocyclic), (C_0-C_4 alkyl)(C_6-C_{10} aryl)R_7, and (C_1-C_4 alkyl)(C_3-C_9 heteroaryl), wherein R_7 is H or OH, and the side chain of the amino acid of Formula IV comprises a free amino group; and (ii) an amino acid substitution of the Gln at position 20 with an alpha, alpha-disubstituted amino acid.

and (iv) up to 6 further amino acid modifications.

The alpha, alpha-disubstituted amino acid of the analog of these embodiments may be any alpha, alpha-disubstituted amino acid, including, but not limited to, amino iso-butyric acid (AIB), an amino acid disubstituted with the same or a different group selected from methyl, ethyl, propyl, and n-butyl, or with a cyclooctane or cycloheptane (e.g., 1-aminocyclooctane-1-carboxylic acid). In certain embodiments, the alpha, alpha-disubstituted amino acid is AIB.

The amino acid of Formula IV of the analog of these embodiments may be any amino acid, such as, for example, the amino acid of Formula IV, wherein n is 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, or 16. In certain embodiments, n is 2, 3, 4, or 5, in which case, the amino acid is Dab, Orn, Lys, or homoLys respectively.

In any of the above exemplary embodiments, the amino acid modification at position 1 that confers GIP agonist activity can be a substitution of His with an amino

acid lacking an imidazole side chain. The amino acid modification at position 1 can, for example, be a substitution of His with a large, aromatic amino acid. In some embodiments, the large, aromatic amino acid is any of those described herein, including, for example, Tyr.

Also, with regard to the above exemplary embodiments, amino acid modifications at one, two, or all of positions 27, 28, and 29 can be any of the modifications at these positions described herein. For example, the Met at position 27 can be substituted with a large aliphatic amino acid, optionally Leu, the Asn at position 28 can be substituted with a small aliphatic amino acid, optionally Ala, and/or the Thr at position 29 can be substituted with a small aliphatic amino acid, optionally Gly. Alternatively, the analog can comprise such amino acid modifications at position 27 and/or 28.

The analog of the above exemplary embodiments can further comprise 1-9 or 1-6 further, additional amino acid modifications, e.g. 1, 2, 3, 4, 5, 6, 7, 8 or 9 further amino acid modifications, such as, for example, any of the modifications described herein which increase or decrease the activity at any of the GIP, GLP-1, and glucagon receptors, improve solubility, improve duration of action or half-life in circulation, delay the onset of action, or increase stability. The analog can further comprise, for example, an amino acid modification at position 12, optionally, a substitution with Ile, and/or amino acid modifications at positions 17 and 18, optionally substitution with Q at position 17 and A at position 18, and/or an addition of GPSSGAPPPS (SEQ ID NO: 95) or XGPSSGAPPPS (SEQ ID NO: 96), or sequences containing one or more conservative substitutions relative to SEQ ID NO: 95 or 96, to the C-terminus. The analog can comprise one or more of the following modifications:

(i) Ser at position 2 substituted with D-Ser, Ala, D-Ala, Gly, N-methyl-Ser, AIB, Val, or α-amino-N-butyric acid;

(ii) Tyr at position 10 substituted with Trp, Lys, Orn, Glu, Phe, or Val;

(iii) Linkage of an acyl group to a Lys at position 10;

(iv) Lys at position 12 substituted with Arg;

(v) Ser at position 16 substituted with Glu, Gln, homoglutamic acid, homocysteic acid, Thr, Gly, Lys, or AIB;

(vi) Arg at position 17 substituted with Gln;

(vii) Arg at position 18 substituted with Ala, Ser, Thr, or Gly;

(viii) Gln at position 20 substituted with Ala, Ser, Thr, Lys, Citrulline, Arg, Orn, or AIB;

(ix) Asp at position 21 substituted with Glu, homoglutamic acid, homocysteic acid;

(x) Val at position 23 substituted with Ile;

(xi) Gln at position 24 substituted with Asn, Ala, Ser, Thr, or AIB; and

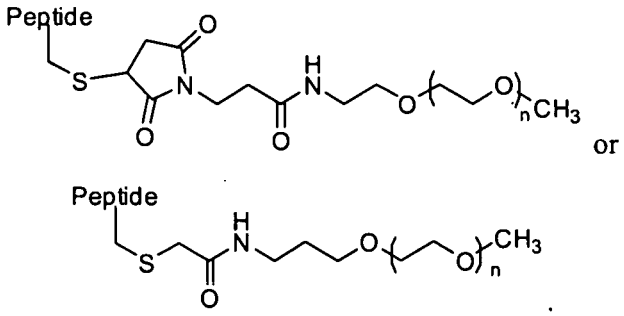
(xii) a conservative substitution at any of positions 2, 5, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 24, 27, 28, and 29.

The analog in some embodiments comprise a combination of the modifications (i) through (xii). Alternatively or additionally, the analog can comprise an amino acid modification at position 3 (e.g., an amino acid substitution of Gln with Glu), wherein the analog has less than 1% of the activity of glucagon at the glucagon receptor. Alternatively or additionally, the analog can comprise an amino acid modification at position 7 (e.g., an amino acid substitution of Thr with an amino acid lacking a hydroxyl group, e.g., Abu or Ile), a deletion of the amino acid(s) C-terminal to the amino acid at position 27 or 28, yielding a 27- or 28-amino acid peptide, or a combination thereof, wherein the analog has less than about 10% of the activity of GLP-1 at the GLP-1 receptor.

With regard to the exemplary embodiments, the analog can be covalently linked to a hydrophilic moiety. In some embodiments, the analog is covalently linked to the hydrophilic moiety at any of amino acid positions 16, 17, 20, 21, 24, 29, 40, or the C-terminus. In certain embodiments, the analog comprises a C-terminal extension (e.g., an amino acid sequence of SEQ ID NO: 95) and an addition of an amino acid comprising the hydrophilic moiety, such that the hydrophilic moiety is covalently linked to the analog at position 40.

In some embodiments, the hydrophilic moiety is covalently linked to a Lys, Cys, Orn, homocysteine, or acetyl-phenylalanine of the analog. The Lys, Cys, Orn, homocysteine, or acetyl-phenylalanine may be an amino acid that is native to the glucagon sequence (SEQ ID NO: 1) or it may be an amino acid which is replacing a native amino acid of SEQ ID NO: 1. In some embodiments, wherein the hydrophilic

moiety is attached to a Cys, the linkage to the hydrophilic moiety can comprise the structure



or

With regard to the analogs comprising a hydrophilic moiety, the hydrophilic moiety may be any of those described herein. See, e.g., the teachings under the section "Linkage of hydrophilic moieties." In some embodiments, the hydrophilic moiety is a polyethylene glycol (PEG). The PEG in certain embodiments has a molecular weight of about 1,000 Daltons to about 40,000 Daltons, e.g., about 20,000 Daltons to about 40,000 Daltons.

In the exemplary embodiments, wherein the analog comprises an acyl or alkyl group, which is attached to the analog via a spacer, the spacer can be any spacer as described herein. The spacer, for example, may be 3 to 10 atoms in length and may be, for instance, an amino acid (e.g., 6-amino hexanoic acid, any amino acid described herein), a dipeptide (e.g., Ala-Ala, βAla-βAla, Leu-Leu, Pro-Pro, γGlu-γGlu), a tripeptide, or a hydrophilic or hydrophobic bifunctional spacer. In certain aspects, the total length of the spacer and the acyl or alkyl group is about 14 to about 28 atoms.

The acyl or alkyl group is any acyl or alkyl group as described herein, such as an acyl or alkyl group which is non-native to a naturally occurring amino acid. The acyl or alkyl group in some embodiments is a C4 to C30 fatty acyl group, such as, for example, a C10 fatty acyl or alkyl group, a C12 fatty acyl or alkyl group, a C14 fatty acyl or alkyl group, a C16 fatty acyl or alkyl group, a C18 fatty acyl or alkyl group, a C20 acyl or alkyl group, or a C22 acyl or alkyl group, or a C4 to C30 alkyl group. In specific embodiments, the acyl group is a C12 to C18 fatty acyl group (e.g., a C14 or C16 fatty acyl group).

In some embodiments, the extension of about 1 to about 21 amino acids C-terminal to the amino acid at position 29 of the analog comprises the amino acid sequence of GPSSGAPPPS (SEQ ID NO: 95) or XGPSSGAPPPS (SEQ ID NO: 96),

wherein X is any amino acid, or GPSSGAPPPK (SEQ ID NO: 170) or XGPSSGAPPPK (SEQ ID NO: 171) or XGPSSGAPPPSK (SEQ ID NO: 172), wherein X is Gly or a small, aliphatic or non-polar or slightly polar amino acid. In some embodiments, the about 1 to about 21 amino acids may comprise sequences containing one or more conservative substitutions relative to SEQ ID NO: 95, 96, 170, 171 or 172. In some embodiments, the acylated or alkylated amino acid is located at position 37, 38, 39, 40, 41, 42, or 43 of the C-terminally-extended analog. In certain embodiments, the acylated or alkylated amino acid is located at position 40 of the C-terminally extended analog.

Pharmaceutical compositions and treatment methods

In some aspects, the invention provides a pharmaceutical composition comprising any of the novel glucagon peptides disclosed herein, preferably sterile and preferably at a purity level of at least 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98% or 99%, and a pharmaceutically acceptable diluent, carrier or excipient. Such compositions may contain a glucagon peptide at a concentration of at least A, wherein A is 0.001 mg/ml, 0.01 mg/ml, 0.1 mg/ml, 0.5 mg/ml, 1 mg/ml, 2 mg/ml, 3 mg/ml, 4 mg/ml, 5 mg/ml, 6 mg/ml, 7 mg/ml, 8 mg/ml, 9 mg/ml, 10 mg/ml, 11 mg/ml, 12 mg/ml, 13 mg/ml, 14 mg/ml, 15 mg/ml, 16 mg/ml, 17 mg/ml, 18 mg/ml, 19 mg/ml, 20 mg/ml, 21 mg/ml, 22 mg/ml, 23 mg/ml, 24 mg/ml, 25 mg/ml or higher. In other embodiments, such compositions may contain a glucagon peptide at a concentration of at most B, wherein B is 30 mg/ml, 25 mg/ml, 24 mg/ml, 23, mg/ml, 22 mg/ml, 21 mg/ml, 20 mg/ml, 19 mg/ml, 18 mg/ml, 17 mg/ml, 16 mg/ml, 15 mg/ml, 14 mg/ml, 13 mg/ml, 12 mg/ml, 11 mg/ml 10 mg/ml, 9 mg/ml, 8 mg/ml, 7 mg/ml, 6 mg/ml, 5 mg/ml, 4 mg/ml, 3 mg/ml, 2 mg/ml, 1 mg/ml, or 0.1 mg/ml. In some embodiments, the compositions may contain a glucagon peptide at a concentration range of A to B mg/ml, for example, 0.001 to 30.0 mg/ml. In one embodiment the pharmaceutical compositions comprise aqueous solutions that are sterilized and optionally stored within various containers. The compounds of the present invention can be used in some embodiments to prepare pre-formulated solutions ready for injection. In other embodiments the pharmaceutical compositions comprise a lyophilized powder. The pharmaceutical compositions can be further packaged as part of a kit that includes a disposable device for administering the composition to a patient. The

containers or kits may be labeled for storage at ambient room temperature or at refrigerated temperature.

The glucagon peptides can be administered to a patient using any standard route of administration, including parenterally, such as intravenously, intraperitoneally, subcutaneously or intramuscularly, intrathecally, transdermally, rectally, orally, nasally or by inhalation. In one embodiment the composition is administered subcutaneously or intramuscularly.

In one embodiment the kit is provided with a device for administering the glucagon composition to a patient, e.g. syringe needle, pen device, jet injector or other needle-free injector. The kit may alternatively or in addition include one or more containers, *e.g.*, vials, tubes, bottles, single or multi-chambered pre-filled syringes, cartridges, infusion pumps (external or implantable), jet injectors, pre-filled pen devices and the like, optionally containing the glucagon peptide in a lyophilized form or in an aqueous solution. Preferably, the kits will also include instructions for use. In some embodiments the device of the kit is an aerosol dispensing device, wherein the composition is prepackaged within the aerosol device. In another embodiment the kit comprises a syringe and a needle, and in one embodiment the sterile glucagon composition is prepackaged within the syringe.

In accordance with one embodiment a pharmaceutical composition is provided wherein the composition comprises a GIP active glucagon analog of the present disclosure, or pharmaceutically acceptable salt thereof, and a pharmaceutically acceptable carrier. The pharmaceutical composition can comprise any pharmaceutically acceptable ingredient, including, for example, acidifying agents, additives, adsorbents, aerosol propellants, air displacement agents, alkalizing agents, anticaking agents, anticoagulants, antimicrobial preservatives, antioxidants, antiseptics, bases, binders, buffering agents, chelating agents, coating agents, coloring agents, desiccants, detergents, diluents, disinfectants, disintegrants, dispersing agents, dissolution enhancing agents, dyes, emollients, emulsifying agents, emulsion stabilizers, fillers, film forming agents, flavor enhancers, flavoring agents, flow enhancers, gelling agents, granulating agents, humectants, lubricants, mucoadhesives, ointment bases, ointments, oleaginous vehicles, organic bases, pastille bases, pigments, plasticizers, polishing agents, preservatives,

sequestering agents, skin penetrants, solubilizing agents, solvents, stabilizing agents, suppository bases, surface active agents, surfactants, suspending agents, sweetening agents, therapeutic agents, thickening agents, tonicity agents, toxicity agents, viscosity-increasing agents, water-absorbing agents, water-miscible cosolvents, water softeners, or wetting agents.

In some embodiments, the pharmaceutical composition comprises any one or a combination of the following components: acacia, acesulfame potassium, acetyltributyl citrate, acetyltriethyl citrate, agar, albumin, alcohol, dehydrated alcohol, denatured alcohol, dilute alcohol, aleuritic acid, alginic acid, aliphatic polyesters, alumina, aluminum hydroxide, aluminum stearate, amylopectin, α-amylose, ascorbic acid, ascorbyl palmitate, aspartame, bacteriostatic water for injection, bentonite, bentonite magma, benzalkonium chloride, benzethonium chloride, benzoic acid, benzyl alcohol, benzyl benzoate, bronopol, butylated hydroxyanisole, butylated hydroxytoluene, butylparaben, butylparaben sodium, calcium alginate, calcium ascorbate, calcium carbonate, calcium cyclamate, dibasic anhydrous calcium phosphate, dibasic dehydrate calcium phosphate, tribasic calcium phosphate, calcium propionate, calcium silicate, calcium sorbate, calcium stearate, calcium sulfate, calcium sulfate hemihydrate, canola oil, carbomer, carbon dioxide, carboxymethyl cellulose calcium, carboxymethyl cellulose sodium, β-carotene, carrageenan, castor oil, hydrogenated castor oil, cationic emulsifying wax, cellulose acetate, cellulose acetate phthalate, ethyl cellulose, microcrystalline cellulose, powdered cellulose, silicified microcrystalline cellulose, sodium carboxymethyl cellulose, cetostearyl alcohol, cetrimide, cetyl alcohol, chlorhexidine, chlorobutanol, chlorocresol, cholesterol, chlorhexidine acetate, chlorhexidine gluconate, chlorhexidine hydrochloride, chlorodifluoroethane (HCFC), chlorodifluoromethane, chlorofluorocarbons (CFC)chlorophenoxyethanol, chloroxylenol, corn syrup solids, anhydrous citric acid, citric acid monohydrate, cocoa butter, coloring agents, corn oil, cottonseed oil, cresol, m-cresol, o-cresol, p-cresol, croscarmellose sodium, crospovidone, cyclamic acid, cyclodextrins, dextrates, dextrin, dextrose, dextrose anhydrous, diazolidinyl urea, dibutyl phthalate, dibutyl sebacate, diethanolamine, diethyl phthalate, difluoroethane (HFC), dimethyl-β-cyclodextrin, cyclodextrin-type compounds such as Captisol®, dimethyl ether, dimethyl phthalate, dipotassium edentate, disodium edentate, disodium hydrogen

32993-208847

phosphate, docusate calcium, docusate potassium, docusate sodium, dodecyl gallate, dodecyltrimethylammonium bromide, edentate calcium disodium, edtic acid, eglumine, ethyl alcohol, ethylcellulose, ethyl gallate, ethyl laurate, ethyl maltol, ethyl oleate, ethylparaben, ethylparaben potassium, ethylparaben sodium, ethyl vanillin, fructose, fructose liquid, fructose milled, fructose pyrogen-free, powdered fructose, fumaric acid, gelatin, glucose, liquid glucose, glyceride mixtures of saturated vegetable fatty acids, glycerin, glyceryl behenate, glyceryl monooleate, glyceryl monostearate, self-emulsifying glyceryl monostearate, glyceryl palmitostearate, glycine, glycols, glycofurol, guar gum, heptafluoropropane (HFC), hexadecyltrimethylammonium bromide, high fructose syrup, human serum albumin, hydrocarbons (HC), dilute hydrochloric acid, hydrogenated vegetable oil, type II, hydroxyethyl cellulose, 2-hydroxyethyl-β-cyclodextrin, hydroxypropyl cellulose, low-substituted hydroxypropyl cellulose, 2-hydroxypropyl-β-cyclodextrin, hydroxypropyl methylcellulose, hydroxypropyl methylcellulose phthalate, imidurea, indigo carmine, ion exchangers, iron oxides, isopropyl alcohol, isopropyl myristate, isopropyl palmitate, isotonic saline, kaolin, lactic acid, lactitol, lactose, lanolin, lanolin alcohols, anhydrous lanolin, lecithin, magnesium aluminum silicate, magnesium carbonate, normal magnesium carbonate, magnesium carbonate anhydrous, magnesium carbonate hydroxide, magnesium hydroxide, magnesium lauryl sulfate, magnesium oxide, magnesium silicate, magnesium stearate, magnesium trisilicate, magnesium trisilicate anhydrous, malic acid, malt, maltitol, maltitol solution, maltodextrin, maltol, maltose, mannitol, medium chain triglycerides, meglumine, menthol, methylcellulose, methyl methacrylate, methyl oleate, methylparaben, methylparaben potassium, methylparaben sodium, microcrystalline cellulose and carboxymethylcellulose sodium, mineral oil, light mineral oil, mineral oil and lanolin alcohols, oil, olive oil, monoethanolamine, montmorillonite, octyl gallate, oleic acid, palmitic acid, paraffin, peanut oil, petrolatum, petrolatum and lanolin alcohols, pharmaceutical glaze, phenol, liquified phenol, phenoxyethanol, phenoxypropanol, phenylethyl alcohol, phenylmercuric acetate, phenylmercuric borate, phenylmercuric nitrate, polacrilin, polacrilin potassium, poloxamer, polydextrose, polyethylene glycol, polyethylene oxide, polyacrylates, polyethylene-polyoxypropylene-block polymers, polymethacrylates, polyoxyethylene alkyl ethers, polyoxyethylene castor oil derivatives, polyoxyethylene sorbitol fatty acid

esters, polyoxyethylene stearates, polyvinyl alcohol, polyvinyl pyrrolidone, potassium alginate, potassium benzoate, potassium bicarbonate, potassium bisulfite, potassium chloride, postassium citrate, potassium citrate anhydrous, potassium hydrogen phosphate, potassium metabisulfite, monobasic potassium phosphate, potassium propionate, potassium sorbate, povidone, propanol, propionic acid, propylene carbonate, propylene glycol, propylene glycol alginate, propyl gallate, propylparaben, propylparaben potassium, propylparaben sodium, protamine sulfate, rapeseed oil, Ringer's solution, saccharin, saccharin ammonium, saccharin calcium, saccharin sodium, safflower oil, saponite, serum proteins, sesame oil, colloidal silica, colloidal silicon dioxide, sodium alginate, sodium ascorbate, sodium benzoate, sodium bicarbonate, sodium bisulfite, sodium chloride, anhydrous sodium citrate, sodium citrate dehydrate, sodium chloride, sodium cyclamate, sodium edentate, sodium dodecyl sulfate, sodium lauryl sulfate, sodium metabisulfite, sodium phosphate, dibasic, sodium phosphate, monobasic, sodium phosphate, tribasic, anhydrous sodium propionate, sodium propionate, sodium sorbate, sodium starch glycolate, sodium stearyl fumarate, sodium sulfite, sorbic acid, sorbitan esters (sorbitan fatty esters), sorbitol, sorbitol solution 70%, soybean oil, spermaceti wax, starch, corn starch, potato starch, pregelatinized starch, sterilizable maize starch, stearic acid, purified stearic acid, stearyl alcohol, sucrose, sugars, compressible sugar, confectioner's sugar, sugar spheres, invert sugar, *Sugartab*, Sunset Yellow FCF, synthetic paraffin, talc, tartaric acid, tartrazine, tetrafluoroethane (HFC), theobroma oil, thimerosal, titanium dioxide, alpha tocopherol, tocopheryl acetate, alpha tocopheryl acid succinate, beta-tocopherol, delta-tocopherol, gamma-tocopherol, tragacanth, triacetin, tributyl citrate, triethanolamine, triethyl citrate, trimethyl-β-cyclodextrin, trimethyltetradecylammonium bromide, tris buffer, trisodium edentate, vanillin, type I hydrogenated vegetable oil, water, soft water, hard water, carbon dioxide-free water, pyrogen-free water, water for injection, sterile water for inhalation, sterile water for injection, sterile water for irrigation, waxes, anionic emulsifying wax, carnauba wax, cationic emulsifying wax, cetyl ester wax, microcrystalline wax, nonionic emulsifying wax, suppository wax, white wax, yellow wax, white petrolatum, wool fat, xanthan gum, xylitol, zein, zinc propionate, zinc salts, zinc stearate, or any excipient in the *Handbook of Pharmaceutical Excipients*, Third Edition, A. H. Kibbe (Pharmaceutical Press, London,

UK, 2000), which is incorporated by reference in its entirety. *Remington's Pharmaceutical Sciences*, Sixteenth Edition, E. W. Martin (Mack Publishing Co., Easton, Pa., 1980), which is incorporated by reference in its entirety, discloses various components used in formulating pharmaceutically acceptable compositions and known techniques for the preparation thereof. Except insofar as any conventional agent is incompatible with the pharmaceutical compositions, its use in pharmaceutical compositions is contemplated. Supplementary active ingredients also can be incorporated into the compositions.

The pharmaceutical formulations disclosed herein may be designed to be short-acting, fast-releasing, long-acting, or sustained-releasing as described below. The pharmaceutical formulations may also be formulated for immediate release, controlled release or for slow release. The instant compositions may further comprise, for example, micelles or liposomes, or some other encapsulated form, or may be administered in an extended release form to provide a prolonged storage and/or delivery effect. The disclosed pharmaceutical formulations may be administered according to any regime including, for example, daily (1 time per day, 2 times per day, 3 times per day, 4 times per day, 5 times per day, 6 times per day), every two days, every three days, every four days, every five days, every six days, weekly, bi-weekly, every three weeks, monthly, or bi-monthly.

In some embodiments, the foregoing component(s) may be present in the pharmaceutical composition at any concentration, such as, for example, at least A, wherein A is 0.0001% w/v, 0.001% w/v, 0.01% w/v, 0.1% w/v, 1% w/v, 2% w/v, 5% w/v, 10% w/v, 20% w/v, 30% w/v, 40% w/v, 50% w/v, 60% w/v, 70% w/v, 80% w/v, or 90% w/v. In some embodiments, the foregoing component(s) may be present in the pharmaceutical composition at any concentration, such as, for example, at most B, wherein B is 90% w/v, 80% w/v, 70% w/v, 60% w/v, 50% w/v, 40% w/v, 30% w/v, 20% w/v, 10% w/v, 5% w/v, 2% w/v, 1% w/v, 0.1% w/v, 0.001% w/v, or 0.0001%. In other embodiments, the foregoing component(s) may be present in the pharmaceutical composition at any concentration range, such as, for example from about A to about B. In some embodiments, A is 0.0001% and B is 90%.

32993-208847

The pharmaceutical compositions may be formulated to achieve a physiologically compatible pH. In some embodiments, the pH of the pharmaceutical composition may be at least 5, at least 5.5, at least 6, at least 6.5, at least 7, at least 7.5, at least 8, at least 8.5, at least 9, at least 9.5, at least 10, or at least 10.5 up to and including pH 11, depending on the formulation and route of administration. In certain embodiments, the pharmaceutical compositions may comprise buffering agents to achieve a physiological compatible pH. The buffering agents may include any compounds capabale of buffering at the desired pH such as, for example, phosphate buffers (e.g. PBS), triethanolamine, Tris, bicine, TAPS, tricine, HEPES, TES, MOPS, PIPES, cacodylate, MES, and others. In certain embodiments, the strength of the buffer is at least 0.5 mM, at least 1 mM, at least 5 mM, at least 10 mM, at least 20 mM, at least 30 mM, at least 40 mM, at least 50 mM, at least 60 mM, at least 70 mM, at least 80 mM, at least 90 mM, at least 100 mM, at least 120 mM, at least 150 mM, or at least 200 mM. In some embodiments, the strength of the buffer is no more than 300 mM (e.g. at most 200 mM, at most 100 mM, at most 90 mM, at most 80 mM, at most 70 mM, at most 60 mM, at most 50 mM, at most 40 mM, at most 30 mM, at most 20 mM, at most 10 mM, at most 5 mM, at most 1 mM).

Glucagon peptides that are GIP/GLP-1 co-agonists, glucagon/GIP co-agonists and glucagon/GIP/GLP-1 tri-agonists may be used in any indication for which each of their activities has been previously described as useful. For example, glucagon activity can increase glucose levels, for insulin buffering, or to decrease gut motility during radiological examination. GLP-1 activity can lower glucose levels, an activity useful for treating hyperglycemia, e.g. diabetes. GLP-1 activity can also induce weight loss or prevent weight gain, e.g. through decreasing appetite. GIP activity can also lower glucose levels, an activity useful for treating hyperglycemia, e.g. diabetes.

GIP/GLP-1 co-agonists and glucagon/GIP/GLP-1 tri-agonists are particularly advantageous for inducing weight loss or preventing weight gain, as well as for treating hyperglycemia, including diabetes. *In vivo* data disclosed herein demonstrates that the combination of GIP agonist activity with GLP-1 agonist activity produces a greater effect on weight reduction than GLP-1 alone. This activity is particularly unexpected in view of teachings in the art that antagonizing GIP is desirable for reducing daily food intake and body weight, and increasing insulin sensitivity and energy expenditure. (Irwin et al.,

Diabetologia 50: 1532-1540 (2007); and Althage et al., J Biol Chem, e-publication on April 17, 2008).

In vivo data disclosed herein also demonstrates that the combination of GIP agonist activity with GLP-1 agonist activity reduces glucose levels.

Thus, the glucagon peptides described herein are expected to be used to reduce or maintain body weight, or to treat hyperglycemia, or to reduce blood glucose level, or to normalize and/or stabilize blood glucose level.

In some embodiments, a method of treating hyperglycemia, or a method of reducing weight gain or inducing weight loss is provided, which involves administering an effective amount of an aqueous solution comprising a glucagon peptide of the invention. In further embodiments, methods of treating diabetes involving co-administering a conventional dose or a reduced dose of insulin and a glucagon peptide of the invention are provided. Methods of treating diabetes with a glucagon peptide of the invention, without co-administering insulin are also provided.

Such methods for treating hyperglycemia are expected to be useful for a variety of types of hyperglycemia, including diabetes, diabetes mellitus type I, diabetes mellitus type II, or gestational diabetes, either insulin-dependent or non-insulin-dependent, and reducing complications of diabetes including nephropathy, retinopathy and vascular disease.

Methods for reducing appetite or promoting loss of body weight are expected to be useful in reducing body weight, preventing weight gain, or treating obesity of various causes, including drug-induced obesity, and reducing complications associated with obesity including vascular disease (coronary artery disease, stroke, peripheral vascular disease, ischemia reperfusion, etc.), hypertension, onset of diabetes type II, hyperlipidemia and musculoskeletal diseases.

Metabolic Syndrome, also known as metabolic syndrome X, insulin resistance syndrome or Reaven's syndrome, is a disorder that affects over 50 million Americans. Metabolic Syndrome is typically characterized by a clustering of at least three or more of the following risk factors: (1) abdominal obesity (excessive fat tissue in and around the abdomen), (2) atherogenic dyslipidemia (blood fat disorders including high triglycerides, low HDL cholesterol and high LDL cholesterol that enhance the accumulation of plaque

in the artery walls), (3) elevated blood pressure, (4) insulin resistance or glucose intolerance, (5) prothrombotic state (e.g. high fibrinogen or plasminogen activator inhibitor-1 in blood), and (6) pro-inflammatory state (e.g. elevated C-reactive protein in blood). Other risk factors may include aging, hormonal imbalance and genetic predisposition.

Metabolic Syndrome is associated with an increased the risk of coronary heart disease and other disorders related to the accumulation of vascular plaque, such as stroke and peripheral vascular disease, referred to as atherosclerotic cardiovascular disease (ASCVD). Patients with Metabolic Syndrome may progress from an insulin resistant state in its early stages to full blown type II diabetes with further increasing risk of ASCVD. Without intending to be bound by any particular theory, the relationship between insulin resistance, Metabolic Syndrome and vascular disease may involve one or more concurrent pathogenic mechanisms including impaired insulin-stimulated vasodilation, insulin resistance-associated reduction in NO availability due to enhanced oxidative stress, and abnormalities in adipocyte-derived hormones such as adiponectin (Lteif and Mather, Can. J. Cardiol. 20 (suppl. B):66B-76B (2004)).

According to the 2001 National Cholesterol Education Program Adult Treatment Panel (ATP III), any three of the following traits in the same individual meet the criteria for Metabolic Syndrome: (a) abdominal obesity (a waist circumference over 102 cm in men and over 88 cm in women); (b) serum triglycerides (150 mg/dl or above); (c) HDL cholesterol (40 mg/dl or lower in men and 50 mg/dl or lower in women); (d) blood pressure (130/85 or more); and (e) fasting blood glucose (110 mg/dl or above). According to the World Health Organization (WHO), an individual having high insulin levels (an elevated fasting blood glucose or an elevated post meal glucose alone) with at least two of the following criteria meets the criteria for Metabolic Syndrome: (a) abdominal obesity (waist to hip ratio of greater than 0.9, a body mass index of at least 30 kg/m^2, or a waist measurement over 37 inches); (b) cholesterol panel showing a triglyceride level of at least 150 mg/dl or an HDL cholesterol lower than 35 mg/dl; (c) blood pressure of 140/90 or more, or on treatment for high blood pressure). (Mathur, Ruchi, "Metabolic Syndrome," ed. Shiel, Jr., William C., MedicineNet.com, May 11, 2009).

32993-208847

For purposes herein, if an individual meets the criteria of either or both of the criteria set forth by the 2001 National Cholesterol Education Program Adult Treatment Panel or the WHO, that individual is considered as afflicted with Metabolic Syndrome.

Without being bound to any particular theory, glucagon peptides described herein are useful for treating Metabolic Syndrome. Accordingly, the invention provides a method of preventing or treating Metabolic Syndrome, or reducing one, two, three or more risk factors thereof, in a subject, comprising administering to the subject a glucagon peptide described herein in an amount effective to prevent or treat Metabolic Syndrome, or the risk factor thereof.

Nonalcoholic fatty liver disease (NAFLD) refers to a wide spectrum of liver disease ranging from simple fatty liver (steatosis), to nonalcoholic steatohepatitis (NASH), to cirrhosis (irreversible, advanced scarring of the liver). All of the stages of NAFLD have in common the accumulation of fat (fatty infiltration) in the liver cells (hepatocytes). Simple fatty liver is the abnormal accumulation of a certain type of fat, triglyceride, in the liver cells with no inflammation or scarring. In NASH, the fat accumulation is associated with varying degrees of inflammation (hepatitis) and scarring (fibrosis) of the liver. The inflammatory cells can destroy the liver cells (hepatocellular necrosis). In the terms "steatohepatitis" and "steatonecrosis", *steato* refers to fatty infiltration, hepatitis refers to inflammation in the liver, and necrosis refers to destroyed liver cells. NASH can ultimately lead to scarring of the liver (fibrosis) and then irreversible, advanced scarring (cirrhosis). Cirrhosis that is caused by NASH is the last and most severe stage in the NAFLD spectrum. (Mendler, Michel, "Fatty Liver: Nonalcoholic Fatty Liver Disease (NAFLD) and Nonalcoholic Steatohepatitis (NASH)," ed. Schoenfield, Leslie J., MedicineNet.com, August 29, 2005).

Alcoholic Liver Disease, or Alcohol-Induced Liver Disease, encompasses three pathologically distinct liver diseases related to or caused by the excessive consumption of alcohol: fatty liver (steatosis), chronic or acute hepatitis, and cirrhosis. Alcoholic hepatitis can range from a mild hepatitis, with abnormal laboratory tests being the only indication of disease, to severe liver dysfunction with complications such as jaundice (yellow skin caused by bilirubin retention), hepatic encephalopathy (neurological dysfunction caused by liver failure), ascites (fluid accumulation in the abdomen),

bleeding esophageal varices (varicose veins in the esophagus), abnormal blood clotting and coma. Histologically, alcoholic hepatitis has a characteristic appearance with ballooning degeneration of hepatocytes, inflammation with neutrophils and sometimes Mallory bodies (abnormal aggregations of cellular intermediate filament proteins). Cirrhosis is characterized anatomically by widespread nodules in the liver combined with fibrosis. (Worman, Howard J., "Alcoholic Liver Disease", Columbia University Medical Center website).

Without being bound to any particular theory, glucagon peptides described herein are useful for the treatment of Alcoholic Liver Disease, NAFLD, or any stage thereof, including, for example, steatosis, steatohepatitis, hepatitis, hepatic inflammation, NASH, cirrhosis, or complications thereof. Accordingly, the invention provides a method of preventing or treating Alcoholic Liver Disease, NAFLD, or any stage thereof, in a subject comprising administering to a subject a glucagon peptide described herein in an amount effective to prevent or treat Alcoholic Liver Disease, NAFLD, or the stage thereof. Such treatment methods include reduction in one, two, three or more of the following: liver fat content, incidence or progression of cirrhosis, incidence of hepatocellular carcinoma, signs of inflammation, e.g. abnormal hepatic enzyme levels (e.g., aspartate aminotransferase AST and/or alanine aminotransferase ALT, or LDH), elevated serum ferritin, elevated serum bilirubin, and/or signs of fibrosis, e.g. elevated TGF-beta levels. In preferred embodiments, the glucagon peptides are used treat patients who have progressed beyond simple fatty liver (steatosis) and exhibit signs of inflammation or hepatitis. Such methods may result, for example, in reduction of AST and/or ALT levels.

The glucagon peptides of the invention may be administered alone or in combination with other anti-diabetic or anti-obesity agents. Anti-diabetic agents known in the art or under investigation include insulin, sulfonylureas, such as tolbutamide (Orinase), acetohexamide (Dymelor), tolazamide (Tolinase), chlorpropamide (Diabinese), glipizide (Glucotrol), glyburide (Diabeta, Micronase, Glynase), glimepiride (Amaryl), or gliclazide (Diamicron); meglitinides, such as repaglinide (Prandin) or nateglinide (Starlix); biguanides such as metformin (Glucophage) or phenformin; thiazolidinediones such as rosiglitazone (Avandia), pioglitazone (Actos), or troglitazone (Rezulin), or other PPARγ inhibitors; alpha glucosidase inhibitors that inhibit carbohydrate digestion, such

as miglitol (Glyset), acarbose (Precose/Glucobay); exenatide (Byetta) or pramlintide; Dipeptidyl peptidase-4 (DPP-4) inhibitors such as vildagliptin or sitagliptin; SGLT (sodium-dependent glucose transporter 1) inhibitors; glucokinase activators (GKA); glucagon receptor antagonists (GRA); or FBPase (fructose 1,6-bisphosphatase) inhibitors.

Anti-obesity agents known in the art or under investigation include, Leptin and Fibroblast Growth Factor 21 (FGF-21), appetite suppressants, such as phenethylamine type stimulants, phentermine (optionally with fenfluramine or dexfenfluramine), diethylpropion (Tenuate®), phendimetrazine (Prelu-2®, Bontril®), benzphetamine (Didrex®), sibutramine (Meridia®, Reductil®); rimonabant (Acomplia®), other cannabinoid receptor antagonists; oxyntomodulin; fluoxetine hydrochloride (Prozac); Qnexa (topiramate and phentermine), Excalia (bupropion and zonisamide) or Contrave (bupropion and naltrexone); or lipase inhibitors, similar to xenical (Orlistat) or Cetilistat (also known as ATL-962), or GT 389-255.

Glucagon peptides of the invention that retain the glucose-raising effects of glucagon in hypoglycemic patients may be used to treat hypoglycemia, e.g., preventing or treating acute, periodic or nocturnal hypoglycemia. Such glucagon peptides can also be administered in conjunction with insulin to buffer the actions of insulin and help to maintain stable blood glucose levels in diabetics. In such embodiments an improved method of regulating blood glucose levels in insulin dependent patients is provided. The glucagon peptides of the present disclosure can be co-administered with insulin as a single composition, simultaneously administered as separate solutions, or alternatively, the insulin and the glucagon peptide can be administered at different time relative to one another. In some embodiments, the method comprises the steps of administering insulin in an amount therapeutically effective for the control of diabetes and administering a novel modified glucagon peptide of the present disclosure in an amount therapeutically effective for the prevention of hypoglycemia, wherein said administering steps are conducted within twelve hours of each other. The exact ratio of the modified glucagon peptide relative to the administered insulin will be dependent in part on determining the glucose levels of the patient and other clinical parameters. "Normalizing" blood level means that the blood glucose level is returned to normal (e.g,, lowering blood glucose level if it is higher than normal, or raising blood glucose level if it is lower than normal).

"Stabilizing" blood glucose level means reducing the maximal variation in blood glucose level over a period of time, e.g., 8 hours, 16 hours, 24 hours, 2 days, 3 days, 4 days, 5 days, 6 days or 1 week. For example, administration of glucagon peptide causes the blood glucose level over time to be maintained closer to the normal range of glucose values than it would be in the absence of administration of glucagon peptide.

Glucagon peptides of the invention that retain the desired activity can be used to induce temporary paralysis of the gut for radiological uses, or treat other metabolic diseases that result from low blood levels of glucagon. In such embodiments a method is provided for inducing the temporary paralysis of the intestinal tract. The method comprises the step of administering one or more of the glucagon peptides disclosed herein to a patient.

In a different aspect, the invention provides a method of reducing weight gain or inducing weight loss, or treating hyperglycemia, comprising co-administering to a patient in need thereof a GIP receptor agonist molecule and a GLP-1 receptor agonist molecule in amounts effective to reduce weight gain or induce weight loss or decrease appetite. The two molecules can be together in the same composition. Alternatively, a molecule that activates both GIP and GLP-1 receptors can be administered in such methods. The combination of various receptor agonist, i.e., activation, properties provides an unexpected additive or synergistic effect, or other unexpected clinical benefit(s). Administration with a conventional dose of insulin, a reduced dose of insulin, or without insulin is contemplated according to such methods. Exemplary GIP receptor agonist molecules include GIP or GIP analogs, e.g., that retain at least 50%, 60%, 70%, or 80% sequence identity upon visual inspection after alignment to maximize matches. Exemplary GLP-1 receptor agonists molecules include GLP-1, GLP-1 analogs, e.g., that retain at least 50%, 60%, 70%, or 80% sequence identity upon visual inspection after alignment to maximize matches, exendin-4 analogs, e.g., that retain at least 50%, 60%, 70%, or 80% sequence identity upon visual inspection after alignment to maximize matches or derivatives thereof. Exemplary molecules that exhibit both activities include glucagon peptides of the invention, GLP-1 analogs that activate both GLP-1 and GIP receptors, fusions of GIP and GLP-1, or fusions of GIP analogs and GLP-1 analogs, or chemically modified derivatives thereof.

32993-208847

The treatment methods in accordance with the present invention including but not limited to treatment of hypoglycemia, may comprise the steps of administering the presently disclosed glucagon peptides to a patient using any standard route of administration, including parenterally, such as intravenously, intraperitoneally, subcutaneously or intramuscularly, intrathecally, transdermally, rectally, orally, nasally or by inhalation.

In accordance with some embodiments, excluded from such methods, on a disease-by-disease basis, are any glucagon analogs or GLP-1 analogs in the prior art disclosed to be useful for treating that particular disease. In another embodiment peptides described in U.S. Patent No. 6,864,069 as acting as both a GLP-1 agonist and a glucagon antagonist for treating diabetes may also be excluded. In another embodiment, the invention may exclude the use of glucagon antagonists to treat diabetes, such as the antagonists described in Unson et al., *J. Biol. Chem.*, 264:789-794 (1989), Ahn et al., *J. Med. Chem.*, 44:3109-3116 (2001), and Sapse et al., *Mol. Med.*, 8(5):251-262 (2002). In some embodiments, oxyntomodulin or a glucagon peptide that contains the 8 C-terminal amino acids of oxyntomodulin (SEQ ID NO: 97) may be excluded.

Oxyntomodulin, a naturally occurring digestive hormone found in the small intestine, induces weight loss (see Diabetes 2005; 54:2390-2395). Oxyntomodulin is a 37 amino acid peptide that contains the 29 amino acid sequence of glucagon (i.e. SEQ ID NO: 1) followed by an 8 amino acid carboxy terminal extension of SEQ ID NO: 97 (KRNRNNIA). While the present invention contemplates that glucagon peptides described herein may optionally be joined to this 8 amino acid carboxy terminal extension (SEQ ID NO: 97), the invention in some embodiments also specifically contemplates glucagon peptides lacking the 8 contiguous carboxy amino acids of SEQ ID NO: 97.

Any one of the following peptides is excluded from the compounds of the invention, although further modifications thereto exhibiting the desired co-agonist pr tri-agonist activity, pharmaceutical compositions, kits, and treatment methods using such compounds may be included in the invention: The peptide of SEQ ID NO: 1 with an [Arg12] substitution and with a C-terminal amide; The peptide of SEQ ID NO: 1 with [Arg12,Lys20] substitutions and with a C-terminal amide; The peptide of SEQ ID NO: 1

32993-208847

with [Arg12,Lys24] substitutions and with a C-terminal amide; The peptide of SEQ ID NO: 1with [Arg12,Lys29] substitutions and with a C-terminal amide; The peptide of SEQ ID NO: 1 with a [Glu9] substitution; The peptide of SEQ ID NO: 1 missing His1, with [Glu9, Glu16, Lys29] substitutions and C-terminal amide; The peptide of SEQ ID NO: 1 with [Glu9, Glu16, Lys29] substitutions and with a C-terminal amide; The peptide of SEQ ID NO: 1 with [Lys13, Glu17] substitutions linked via lactam bridge and with a C-terminal amide; The peptide of SEQ ID NO: 1 with [Lys17, Glu21] substitutions linked via lactam bridge and with a C-terminal amide; the peptide of SEQ ID NO: 1 missing His1, with [Glu20, Lys24] substitutions linked via lactam bridge; the peptides disclosed in PCT/US2008/053857, filed February 13, 2008, PCT/US2006/017494, filed May 5, 2006; PCT/US2007/018415, filed August 17, 2007; PCT/GB2005/000710, filed February 25, 2005; PCT/GB00/01089, filed March 29, 2000; PCT/US2006/005020, filed February 10, 2006; each of which are incorporated by reference herein in its entirety.

EXAMPLES

The compounds of the invention may be prepared by standard synthetic methods, recombinant DNA techniques, or any other methods of preparing peptides and fusion proteins. Although certain non-natural amino acids cannot be expressed by standard recombinant DNA techniques, techniques for their preparation are known in the art. Compounds of the invention that encompass non-peptide portions may be synthesized by standard organic chemistry reactions, in addition to standard peptide chemistry reactions when applicable. Additional data on glucagon and GLP-1 activity of glucagon peptides is also disclosed in PCT/US2008/053857, filed February 13, 2008, incorporated by reference herein in its entirety.

EXAMPLE 1

General Synthesis Protocol:

Glucagon analogs were synthesized using HBTU-activated "Fast Boc" single coupling starting from 0.2mmole of Boc Thr(OBzl)Pam resin on a modified Applied Biosystem 430 A peptide synthesizer. Boc amino acids and HBTU were obtained from

32993-208847

Midwest Biotech (Fishers, IN). Side chain protecting groups used were: Arg(Tos), Asn(Xan), Asp(OcHex), Cys(pMeBzl), His(Bom), Lys(2Cl-Z), Ser(OBzl), Thr(OBzl), Tyr(2Br-Z), and Trp(CHO). The side-chain protecting group on the N-terminal His was Boc.

Each completed peptidyl resin was treated with a solution of 20% piperdine in dimethylformamide to remove the formyl group from the tryptophan. Liquid hydrogen fluoride cleavages were performed in the presence of p-cresol and dimethyl sulfide. The cleavage was run for 1 hour in an ice bath using an HF apparatus (Penninsula Labs). After evaporation of the HF, the residue was suspended in diethyl ether and the solid materials were filtered. Each peptide was extracted into 30-70ml aqueous acetic acid and a diluted aliquot was analyzed by HPLC [Beckman System Gold, 0.46x5cm Zorbax C8, 1ml/min, 45C, 214nm, A buffer =0.1%TFA, B=0.1%TFA/90%acetonitrile, gradient of 10% to 80%B over 10min].

Purification was done on a FPLC over a 2.2 x 25 cm Kromasil C18 column while monitoring the UV at 214nm and collecting 5 minute fractions. The homogeneous fractions were combined and lyophilized to give a product purity of >95%. The correct molecular mass and purity were confirmed using MALDI-mass spectral analysis.

EXAMPLE 2

General Pegylation Protocol: (Cys-maleimido)

Typically, the glucagon Cys analog is dissolved in phosphate buffered saline (5-10mg/ml) and 0.01M ethylenediamine tetraacetic acid is added (10-15% of total volume). Excess (2-fold) maleimido methoxyPEG reagent (Nektar) is added and the reaction stirred at room temp while monitoring reaction progress by HPLC. After 8-24hrs, the reaction mixture, is acidified and loaded onto a preparative reverse phase column for purification using 0.1%TFA/acetonitrile gradient. The appropriate fractions were combined and lyophilized to give the desired pegylated analogs.

32993-208847

EXAMPLE 3

Synthesis of Glucagon Cys^{17}(1-29) and Similar MonoCys Analogs

0.2mmole Boc Thr(OBzl) Pam resin (SynChem Inc) in a 60ml reaction vessel and the following sequence was entered and run on a modified Applied Biosystems 430A Peptide Synthesizer using FastBoc HBTU-activated single couplings.

HSQGTFTSDYSKYLDSCRAQDFVQWLMNT

The following side chain protecting groups were used: Arg(Tos), Asp(OcHex), Asn(Xan), Cys(pMeBzl), Glu(OcHex), His(Boc), Lys(2Cl-Z), Ser(Bzl), Thr(Bzl), Trp(CHO), and Tyr(Br-Z). The completed peptidyl resin was treated with 20% piperidine/dimethylformamide to remove the Trp formyl protection then transferred to an HF reaction vessel and dried in vacuo. 1.0ml p-cresol and 0.5 ml dimehyl sulfide were added along with a magnetic stir bar. The vessel was attached to the HF apparatus (Pennisula Labs), cooled in a dry ice/methanol bath, evacuated, and aprox. 10ml liquid hydrogen fluoride was condensed in. The reaction was stirred in an ice bath for 1hr then the HF was removed in vacuo. The residue was suspended in ethyl ether; the solids were filtered, washed with ether, and the peptide extracted into 50 ml aqueous acetic acid. An analytical HPLC was run [0.46 x 5 cm Zorbax C8, 1 ml/min, 45C, 214nm, A buffer of 0.1%TFA, B buffer of 0.1%TFA/90%ACN, gradient=10%B to 80%B over 10min.] with a small sample of the cleavage extract. The remaining extract was loaded onto a 2.2 x 25cm Kromasil C18 preparative reverse phase column and an acetonitrile gradient was run using a Pharmacia FPLC system. 5min fractions were collected while monitoring the UV at 214nm (2.0A). A=0.1%TFA, B=0.1%TFA/50%acetonitrile. Gradient = 30%B to 100%B over 450min.

The fractions containing the purest product (48-52) were combined frozen, and lyophilized to give 30.1mg. An HPLC analysis of the product demonstrated a purity of >90% and MALDI mass spectral analysis demonstrated the desired mass of 3429.7. Glucagon Cys^{21}, Glucagon Cys^{24}, and Glucagon Cys^{29} were similarly prepared.

32993-208847

EXAMPLE 4

Synthesis of Glucagon-Cex and Other C-Terminal Extended Analogs.

285mg (0.2mmole) methoxybenzhydrylamine resin (Midwest Biotech) was placed in a 60ml reaction vessel and the following sequence was entered and run on a modified Applied Biosystems 430A peptide synthesizer using FastBoc HBTU-activated single couplings.

HSQGTFTSDYSKYLDSRRAQDFVQWLMNTGPSSGAPPPS

The following side chain protecting groups were used: Arg(Tos), Asp(OcHex), Asn(Xan), Cys(pMeBzl), Glu(OcHex), His(Boc), Lys(2Cl-Z), Ser(Bzl), Thr(Bzl), Trp(CHO), and Tyr(Br-Z). The completed peptidyl resin was treated with 20% piperidine/dimethylformamide to remove the Trp formyl protection then transferred to HF reaction vessel and dried in vacuo. 1.0ml p-cresol and 0.5 ml dimehyl sulfide were added along with a magnetic stir bar. The vessel was attached to the HF apparatus (Pennisula Labs), cooled in a dry ice/methanol bath, evacuated, and aprox. 10ml liquid hydrogen fluoride was condensed in. The reaction was stirred in an ice bath for 1hr then the HF was removed in vacuo. The residue was suspended in ethyl ether; the solids were filtered, washed with ether, and the peptide extracted into 50 ml aqueous acetic acid. An analytical HPLC was run [0.46 x 5 cm Zorbax C8, 1 ml/min, 45C, 214nm, A buffer of 0.1%TFA, B buffer of 0.1%TFA/90%ACN, gradient=10%B to 80%B over 10min.] on an aliquot of the cleavage extract. The extract was loaded onto a 2.2 x 25cm Kromasil C18 preparative reverse phase column and an acetonitrile gradient was run for elution using a Pharmacia FPLC system. 5min fractions were collected while monitoring the UV at 214nm (2.0A). A=0.1%TFA, B=0.1%TFA/50%acetonitrile. Gradient = 30%B to 100%B over 450min. Fractions 58-65 were combined, frozen and lyophilized to give 198.1mg.

HPLC analysis of the product showed a purity of greater than 95%. MALDI mass spectral analysis showed the presence of the desired theoretical mass of 4316.7 with the product as a C-terminal amide. Oxyntomodulin and oxyntomodulin-KRNR were similarly prepared as the C-terminal carboxylic acids starting with the appropriately loaded PAM-resin.

32993-208847

EXAMPLE 5

Glucagon Cys^{17} Mal-PEG-5K

15.1mg of Glucagon Cys^{17}(1-29) and 27.3mg methoxy poly(ethyleneglycol) maleimide avg. M.W.5000 (mPEG-Mal-5000, Nektar Therapeutics) were dissolved in 3.5ml phosphate buffered saline (PBS) and 0.5ml 0.01M ethylenediamine tetraacetic acid (EDTA) was added. The reaction was stirred at room temperature and the progress of the reaction was monitored by HPLC analysis [0.46 x 5 cm Zorbax C8, 1ml/min,45C, 214nm (0.5A), A=0.1%TFA, B=0.1%TFA/90%ACN, gradient=10%B to 80%B over 10min.]. After 5 hours, the reaction mixture was loaded onto 2.2 x 25 cm Kromasil C18 preparastive reverse phase column. An acetonitrile gradient was run on a Pharmacia FPLC while monitoring the UV wavelength at 214nm and collecting 5 min fractions. A=0.1%TFA, B=0.1%TFA/50% acetonitrile, gradient= 30%B to 100%B over 450 min. The fractions corresponding to the product were combined, frozen and lyophilized to give 25.9 mg.

This product was analyzed on HPLC [0.46 x 5 cm Zorbax C8, 1 ml/min, 45C, 214nm (0.5A), A=0.1%TFA, B=0.1%TFA/90%ACN, gradient=10%B to 80%B over 10min.] which showed a purity of aprox. 90%. MALDI (matrix assisted laser desorption ionization) mass spectral analysis showed a broad mass range (typical of PEG derivatives) of 8700 to 9500. This shows an addition to the mass of the starting glucagon peptide (3429) of approximately 5,000 a.m.u.

EXAMPLE 6

Glucagon Cys^{21} Mal-PEG-5K

21.6mg of Glucagon Cys^{21}(1-29) and 24mg mPEG-MAL-5000 (Nektar Therapeutics) were dissolved in 3.5ml phosphate buffered saline (PBS) and 0.5ml 0.01M ethylene diamine tetraacetic acid (EDTA) was added. The reaction was stirred at room temp. After 2hrs, another 12.7 mg of mPEG-MAL-5000 was added. After 8hrs, the reaction mixture was loaded onto a 2.2 x 25cm Vydac C18 preparative reverse phase column and an acetonitrile gradient was run on a Pharmacia FPLC at 4 ml/min while collecting 5min fractions. A=0.1%TFA, B=0.1%TFA/50%ACN. Gradient= 20% to 80%B over 450min.

32993-208847

The fractions corresponding to the appearance of product were combined frozen and lyophilized to give 34 mg. Analysis of the product by analytical HPLC [0.46 x 5 cm Zorbax C8, 1 ml/min, 45C, 214nm (0.5A), A=0.1%TFA, B=0.1%TFA/90%ACN, gradient=10%B to 80%B over 10min.] showed a homogeneous product that was different than starting glucagon peptide. MALDI (matrix assisted laser desorption ionization) mass spectral analysis showed a broad mass range (typical of PEG analogs) of 8700 to 9700. This shows an addition to the mass of the starting glucagon peptide (3470) of approximately 5,000 a.m.u.

EXAMPLE 7

Glucagon Cys^{24} Mal-PEG-5K

20.1mg Glucagon C^{24}(1-29) and 39.5mg mPEG-Mal-5000 (Nektar Therapeutics) were dissolved in 3.5ml PBS with stirring and 0.5 ml 0.01M EDTA was added. The reaction was stirred at room temp for 7 hrs, then another 40 mg of mPEG-Mal-5000 was added. After approximately 15 hr, the reaction mixture was loaded onto a 2.2 x 25 cm Vydac C18 preparative reverse phase column and an acetontrile gradient was run using a Pharmacia FPLC. 5 min. fractions were collected while monitoring the UV at 214nm (2.0A). A buffer = 0.1%TFA, B buffer = 0.1%TFA/50%ACN, gradient = 30%B to 100%B over 450min. The fractions corresponding to product were combined, frozen and lyophilized to give 45.8mg. MALDI mass spectral analysis showed a typical PEG broad signal with a maximum at 9175.2 which is approximately 5,000 a.m.u. more than Glucagon C^{24} (3457.8).

EXAMPLE 8

Glucagon Cys^{24} Mal-PEG-20K

25.7mg of Glucagon Cys^{24}(1-29) and 40.7mg mPEG-Mal-20K (Nektar Therapeutics) were dissolved in 3.5ml PBS with stirring at room temp. and 0.5 ml 0.01M EDTA was added. After 6hrs, the ratio of starting material to product was aprox. 60:40 as determined by HPLC. Another 25.1mg of mPEG-Mal-20K was added and the reaction allowed to stir another 16hrs. The product ratio had not significantly improved, so the reaction mixture was loaded onto a 2.2 x 25 cm Kromasil C18 preparative reverse

32993-208847

phase column and purified on a Pharmacia FPLC using a gradient of 30%B to 100%B over 450min. A buffer =0.1%TFA, B buffer = 0.1%TFA/50%ACN, flow = 4ml/min, and 5 min fractions were collected while monitoring the UV at 214nm (2.0A). The fractions containing homogeneous product were combined, frozen and lyophilized to give 25.7 mg. Purity as determined by analytical HPLC was ~90%. A MALDI mass spectral analysis showed a broad peak from 23,000 to 27,000 which is approximately 20,000 a.m.u. more than starting Glucagon C^{24} (3457.8).

EXAMPLE 9

Glucagon Cys^{29} Mal-PEG-5K

20.0mg of Glucagon Cys^{29}(1-29) and 24.7 mg mPEG-Mal-5000 (Nektar Therapeutics) were dissolved in 3.5 ml PBS with stirring at room temperature and 0.5 ml 0.01M EDTA was added. After 4 hr, another 15.6 mg of mPEG-Mal-5000 was added to drive the reaction to completion. After 8 hrs, the reaction mixture was loaded onto a 2.2 x 25 cm Vydac C18 preparative reverse phase column and an acetonitrile gradient was run on a Pharmacia FPLC system. 5 min fractions were collected while monitoring the UV at 214nm (2.0A). A=0.1%TFA, B=0.1%TFA/50%ACN. Fractions 75-97 were combined frozen and lyophilized to give 40.0 mg of product that is different than recovered starting material on HPLC (fractions 58-63). Analysis of the product by analytical HPLC [0.46 x 5 cm Zorbax C8, 1 ml/min, 45C, 214nm (0.5A), A=0.1%TFA, B=0.1%TFA/90%ACN, gradient=10%B to 80%B over 10min.] showed a purity greater than 95%. MALDI mass spectral analysis showed the presence of a PEG component with a mass range of 8,000 to 10,000 (maximum at 9025.3) which is 5,540 a.m.u. greater than starting material (3484.8).

EXAMPLE 10

Glucagon Cys^{24} (2-butyrolactone)

To 24.7mg of Glucagon Cys^{24}(1-29) was added 4ml 0.05M ammonium bicarbonate/50%acetonitrile and 5.5 ul of a solution of 2-bromo-4-hydroxybutyric acid-γ-lactone (100ul in 900ul acetonitrile). After 3hrs of stirring at room temperature, another

32993-208847

105 ul of lactone solution was added to the reaction mixture which was stirred another 15hrs. The reaction mixture was diluted to 10ml with 10% aqueous acetic acid and was loaded onto a 2.2 x 25 cm Kromasil C18 preparative reverse phase column. An acetonitrile gradient (20%B to 80%B over 450min) was run on a Pharmacia FPLC while collecting 5min fractions and monitoring the UV at 214nm (2.0A). Flow =4ml/min, A=0.1%TFA, B=0.1%TFA/50%ACN. Fractions 74-77 were combined frozen and lyophilized to give 7.5mg. HPLC analysis showed a purity of 95% and MALDI mass spect analysis showed a mass of 3540.7 or 84 mass units more than starting material. This result consistent with the addition of a single butyrolactone moiety.

EXAMPLE 11

Glucagon Cys^{24}(S-carboxymethyl)

18.1mg of Glucagon Cys^{24}(1-29) was dissolved in 9.4ml 0.1M sodium phosphate buffer (pH=9.2) and 0.6ml bromoacetic acid solution (1.3mg/ml in acetonitrile) was added. The reaction was stirred at room temperature and the reaction progress was followed by analytical HPLC. After 1hr another 0.1ml bromoacetic acid solution was added. The reaction was stirred another 60min. then acidified with aqueous acetic acid and was loaded onto a 2.2 x 25cm Kromasil C18 preparative reverse phase column for purification. An acetonitrile gradient was run on a Pharmacia FPLC (flow = 4ml/min) while collecting 5min fractions and monitoring the UV at 214nm (2.0A). A=0.1%TFA, B=0.1%TFA/50%ACN. Fractions 26-29 were combined frozen and lyophilized to give several mg of product. Analytical HPLC showed a purity of 90% and MALDI mass spectral analysis confirmed a mass of 3515 for the desired product.

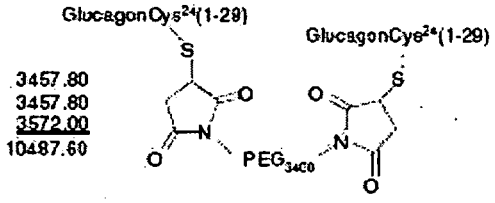
EXAMPLE 12

Glucagon Cys^{24} maleimido, PEG-3.4K-dimer

16mg Glucagon Cys^{24} and 1.02mg Mal-PEG-Mal-3400, poly(ethyleneglycol)-bis-maleimide avg. M.W. 3400, (Nektar Therpeutics) were dissolved in 3.5 phosphate buffered saline and 0.5ml 0.01M EDTA and the reaction was stirred at room temperature.

32993-208847

After 16hrs, another 16mg of Glucagon Cys^{24} was added and the stirring continued. After approximately 40hrs, the reaction mixture was loaded onto a Pharmcia PepRPC 16/10 column and an acetonitrile gradient was run on a Pharmacia FPLC while collecting 2min fractions and monitoring the UV at 214nm (2.0A). Flow=2ml/min, A=0.1%TFA, B=0.1%TFA/50%ACN. Fractions 69-74 were combined frozen and lyophilized to give 10.4mg. Analytical HPLC showed a purity of 90% and MALDI mass spectral analysis shows a component in the 9500-11,000 range which is consistent with the desired dimer.



EXAMPLE 13

Synthesis of Glucagon Lactams

285 mg (0.2 mmole) methoxybenzhydrylamine resin (Midwest Biotech) was added to a 60 mL reaction vessels and the following sequence was assembled on a modified Applied Biosystems 430A peptide synthesizer using Boc DEPBT-activated single couplings.

HSQGTFTSDYSKYLDERRAQDFVQWLMNT-NH2 (12-16 Lactam)

The following side chain protecting groups were used: Arg(Tos), Asp(OcHx), Asn(Xan), Glu(OFm), His(BOM), Lys(Fmoc), Ser(Bzl), Thr(Bzl), Trp(CHO), Tyr(Br-Z). Lys(Cl-Z) was used at position 12 if lactams were constructed from 16-20, 20-24, or 24-28. The completed peptidyl resin was treated with 20% piperidine/dimethylformamide for one hour with rotation to remove the Trp formyl group as well as the Fmoc and OFm protection from Lys12 and Glu16. Upon confirmation of removal by a positive ninhydrin test, the resin was washed with dimethylformamide, followed by dichloromethane and than again with dimethylformamide. The resin was treated with 520 mg (1 mmole) Benzotriazole-1-yl-oxy-tris-pyrrolidino-phosphonium hexafluorophosphate (PyBOP) in

dimethylformamide and diisopropylethylamine (DIEA). The reaction proceeded for 8-10 hours and the cyclization was confirmed by a negative ninhydrin reaction. The resin was washed with dimethylformamide, followed by dichloromethane and subsequently treated with trifluoroacetic acid for 10 minutes. The removal of the Boc group was confirmed by a positive ninhydrin reaction. The resin was washed with dimethylformamide and dichloromethane and dried before being transferred to a hydrofluoric acid (HF) reaction vessel. 500 μL p-cresol was added along with a magnetic stir bar. The vessel was attached to the HF apparatus (Peninsula Labs), cooled in a dry ice/methanol bath, evacuated, and approximately 10 mL of liquid hydrofluoric acid was condensed into the vessel. The reaction was stirred for 1 hour in an ice bath and the HF was subsequently removed in vacuo. The residue was suspended in ethyl ether; the solids were filtered, washed with ether, and the peptide was solubilized with 150 mL 20% acetonitrile/1% acetic acid.

An analytical HPLC analysis of the crude solubilized peptide was conducted under the following conditions [4.6 X 30 mm Xterra C8, 1.50 mL/min, 220 nm, A buffer 0.1% TFA/10% ACN, B buffer 0.1% TFA/100% ACN, gradient 5-95%B over 15 minutes]. The extract was diluted twofold with water and loaded onto a 2.2 X 25 cm Vydac C4 preparative reverse phase column and eluted using an acetonitrile gradient on a Waters HPLC system (A buffer of 0.1% TFA/10% ACN, B buffer of 0.1% TFA/10% CAN and a gradient of 0-100% B over 120 minutes at a flow of 15.00 ml/min. HPLC analysis of the purified peptide demonstrated greater than 95% purity and electrospray ionization mass spectral analysis confirmed a mass of 3506 Da for the 12-16 lactam. Lactams from 16-20, 20-24, and 24-28 were prepared similarly.

32993-208847

EXAMPLE 14

Glucagon Solubility Assays:

A solution (1mg/ml or 3mg/ml) of glucagon (or an analog) is prepared in 0.01N HCl. 100ul of stock solution is diluted to 1ml with 0.01N HCl and the UV absorbance (276nm) is determined. The pH of the remaining stock solution is adjusted to pH7 using 200-250ul 0.1M Na_2HPO_4 (pH 9.2). The solution is allowed to stand overnight at 4°C then centrifuged. 100ul of supernatant is then diluted to 1ml with 0.01N HCl, and the UV absorbance is determined (in duplicate).

The initial absorbance reading is compensated for the increase in volume and the following calculation is used to establish percent solubility:

$$\frac{\text{Final Absorbance}}{\text{Initial Absorbance}} \times 100 = \text{percent soluble}$$

EXAMPLE 15

Glucagon Receptor Binding Assay

The affinity of peptides to the glucagon receptor was measured in a competition binding assay utilizing scintillation proximity assay technology. Serial 3-fold dilutions of the peptides made in scintillation proximity assay buffer (0.05 M Tris-HCl, pH 7.5, 0.15 M NaCl, 0.1% w/v bovine serum albumin) were mixed in 96 well white/clear bottom plate (Corning Inc., Acton, MA) with 0.05 nM (3-[^{125}I]-iodotyrosyl) Tyr10 glucagon (Amersham Biosciences, Piscataway, NJ), 1-6 micrograms per well, plasma membrane fragments prepared from cells over-expressing human glucagon receptor, and 1 mg/well polyethyleneimine-treated wheat germ agglutinin type A scintillation proximity assay beads (Amersham Biosciences, Piscataway, NJ). Upon 5 min shaking at 800 rpm on a rotary shaker, the plate was incubated 12h at room temperature and then read on MicroBeta1450 liquid scintillation counter (Perkin-Elmer, Wellesley, MA). Non-specifically bound (NSB) radioactivity was measured in the wells with 4 times greater concentration of "cold" native ligand than the highest concentration in test samples and total bound radioactivity was detected in the wells with no competitor. Percent specific binding was calculated as following: % Specific Binding = ((Bound-NSB)/(Total bound-

32993-208847

NSB)) X 100. IC_{50} values were determined by using Origin software (OriginLab, Northampton, MA).

EXAMPLE 16

Functional Assay- cAMP Synthesis

The ability of glucagon analogs to induce cAMP was measured in a firefly luciferase-based reporter assay. HEK293 cells co-transfected with a receptor (glucagon receptor, GLP-1 receptor or GIP receptor) and luciferase gene linked to cAMP responsive element were serum deprived by culturing 16h in DMEM (Invitrogen, Carlsbad, CA) supplemented with 0.25% Bovine Growth Serum (HyClone, Logan, UT) and then incubated with serial dilutions of either glucagon, GLP-1, GIP or novel glucagon analogs for 5 h at 37°C, 5% CO_2 in 96 well poly-D-Lysine-coated "Biocoat" plates (BD Biosciences, San Jose, CA). At the end of the incubation 100 microliters of LucLite luminescence substrate reagent (Perkin-Elmer, Wellesley, MA) were added to each well. The plate was shaken briefly, incubated 10 min in the dark and light output was measured on MicroBeta-1450 liquid scintillation counter (Perkin-Elmer, Wellesley, MA). Effective 50% concentrations were calculated by using Origin software (OriginLab, Northampton, MA.

EXAMPLE 17

Stability Assay for glucagon Cys-maleimido PEG analogs

Each glucagon analog was dissolved in water or PBS and an initial HPLC analysis was conducted. After adjusting the pH (4, 5, 6, 7), the samples were incubated over a specified time period at 37°C and re-analyzed by HPLC to determine the integrity of the peptide. The concentration of the specific peptide of interest was determined and the percent remaining intact was calculated relative to the initial analysis.

EXAMPLE 18

Preparation of acylated and/or PEGylated peptides

Acylated and/or PEGylated peptides are prepared as follows. Peptides are synthesized on a solid support resin using either a CS Bio 4886 Peptide Synthesizer or

32993-208847

Applied Biosystems 430A Peptide Synthesizer. In situ neutralization chemistry is used as described by Schnolzer et al., *Int. J. Peptide Protein Res.* 40: 180-193 (1992). For acylated peptides, the target amino acid residue to be acylated (e.g., position ten) is substituted with an N ε -FMOC lysine residue. Treatment of the completed N-terminally BOC protected peptide with 20% piperidine in DMF for 30 minutes removes FMOC/formyl groups. Coupling to the free ε-amino Lys residue is achieved by coupling a ten-fold molar excess of either an FMOC-protected spacer amino acid (ex. FMOC-(N-BOC)-Tryptophan-OH) or acyl chain (ex. C17-COOH) and PyBOP or DEPBT coupling reagent in DMF/DIEA. Subsequent removal of the spacer amino acid's FMOC group is followed by repetition of coupling with an acyl chain. Final treatment with 100% TFA results in removal of any side chain protecting groups and the N-terminal BOC group. Peptide resins are neutralized with 5% DIEA/DMF, are dried, and then are cleaved from the support using HF/p-cresol, 95:5, at 0°C for one hour. Following ether extraction, a 5% HOAc solution is used to solvate the crude peptide. A sample of the solution is then verified to contain the correct molecular weight peptide by ESI-MS. Correct peptides are purified by RP-HPLC using a linear gradient of 10% CH3CN/0.1% TFA to 0.1% TFA in 100% CH3CN. A Vydac C18 22 mm x 250 mm protein column is used for the purification. Acylated peptide analogs generally complete elution by a buffer ratio of 20:80. Portions are pooled together and checked for purity on an analytical RP-HPLC. Pure fractions are lyophilized yielding white, solid peptides.

If a peptide comprises a lactam bridge and target residues to be acylated, acylation is carried out as described above upon addition of that amino acid to the peptide backbone.

For peptide pegylation, 40 kDa methoxy poly(ethylene glycol) maleimido-propionamide (Chirotech Technology Ltd.) is reacted with a molar equivalent of peptide in 7M Urea, 50mM Tris-HCl buffer using the minimal amount of solvent needed to dissolve both peptide and PEG into a clear solution (generally less than 2 mL for a reaction using 2-3 mg peptide). Vigorous stirring at room temperature commences for 4-6 hours and the reaction is analyzed by analytical RP-HPLC. PEGylated products appear distinctly from the starting material with decreased retention times. Purification is performed on a Vydac C4 column with conditions similar to those used for the initial

peptide purification. Elution typically occurs around buffer ratios of 50:50. Fractions of pure PEGylated peptide are collected and lyophilized.

Peptides are assayed for biological activity as described above in Example 16. Acylated peptides may exhibit increased potency at the GLP-1 receptor. Inclusion of a tryptophan spacer may provide better potency at the glucagon receptor.

While acylation can extend the half-life of a peptide to hours or more, PEGylation with repeats in tens of kDa ranges can do even more. Peptides comprising both types of modifications are prepared. These peptides are expected to exhibit extended half-life in circulation, as well as resistance to DPP-IV and other proteases.

EXAMPLE 20

Effect in vivo on weight gain, appetite and blood glucose levels

The following peptides were synthesized as essentially described above.

(A) A pegylated glucagon/GLP-1 co-agonist peptide (Chimera 2 AIB2 C24 40K PEG, which is a Chimera 2 peptide (see Example 21) further modified with an AIB at position 2, a Cys at 24 which is attached to a 40K PEG group);

(B) A pegylated GIP antagonist (Pro3 C24 GIP NH2 (1-42) 40K PEG, which is amino acids 1-42 of GIP (the sequence of native GIP is SEQ ID NO: 4) modified with a Pro at position 3, a Cys at position 24, which is attached to a 40K PEG group, and an amide in place of the C-terminal carboxylate);

(C) A GIP agonist (AIB2 C24 GIP (1-42) 40K PEG, which is amino acids 1-42 of GIP (the sequence of native GIP is SEQ ID NO: 4) modified with AIB at position 2 and a Cys at position 24, which is attached to a 40K PEG group); and

The peptides were tested *in vivo* by subcutaneously injecting diet-induced obese (DIO) mice with various peptides, or vehicle alone, QW (70 or 210 nmol/kg/week). Each group contained 8 mice, each with an initial average body weight of 50 g. Body weight, body composition, food intake, and blood glucose levels were determined periodically.

As shown in Figures 1 to 3, neither the GIP antagonist nor the GIP agonist peptide were effective at reducing body weight, cumulative food intake, and blood glucose levels in the mice, in comparison to the pegylated glucagon/GLP-1 co-agonist.

32993-208847

EXAMPLE 21

GIP, GLP-1 and glucagon activity of peptides

Peptides of SEQ ID NOs: 5-94 (each of which comprised an amide in place of the C-terminal carboxylate) were synthesized as essentially described above and tested in vitro for activity at the GIP receptor, GLP-1 receptor, and glucagon receptors by Example 16. The EC50 of each peptide are shown in Table 1.

TABLE 1

Code	SEQ ID NO:	Glucagon Receptor			GLP-1 Receptor			GIP Receptor		
		EC_{50}, nM	Std.	relative activity	EC_{50}, nM	Std.	relative activity	EC_{50}, nM	Std.	relative activity
mt-61	5	0.110	0.190	172.73%	0.180	0.040	22.22%	9.987	0.083	0.83%
mt-62	6	0.450	0.190	42.22%	0.100	0.040	40.00%	5.183	0.083	1.60%
mt-63	7	3.150	0.190	6.03%	0.310	0.040	12.90%	N/D		
mt-66	8	2.000	0.260	13.00%	0.130	0.050	38.46%	N/D		
mt-68	9	1.970	0.260	13.20%	0.820	0.050	6.10%	N/D		
mt-69	10	0.160	0.260	162.50%	0.410	0.050	12.20%	14.601	0.083	0.57%
mt-84	11	0.450	0.060	13.33%	0.160	0.080	50.00%	N/D		
mt-85	12	4.560	0.060	1.32%	0.660	0.080	12.12%	N/D		
mt-92	13	N/A	0.430		0.110	0.060	54.55%	N/D		
mt-93	14	3.000	0.430	14.33%	0.040	0.060	150.00%	N/D		
mt-95	15	280.31	0.100	0.04%	48.920	0.040	0.08%	0.465	0.049	10.54%
mt-96	16	61.70	0.180	0.29%	92.860	0.040	0.04%	0.058	0.049	84.48%
mt-97	17	4.080	0.130	3.19%	2.360	0.030	1.27%	1.745	0.049	2.81%
mt-98	18	957.07	0.100	0.01%	2.820	0.040	1.42%	0.196	0.049	25.00%
mt-99	19	23313	0.180	0.00%	4548.9	0.070	0.00%	0.049	0.049	100.00%
mt-100	20	1459	0.180	0.01%	552.43	0.060	0.01%	0.016	0.049	306.25%
mt-101	21	N/D			N/D			71.312	0.042	0.06%

Code	SEQ ID NO:	Glucagon Receptor			GLP-1 Receptor			GIP Receptor		
		EC_{50}, nM	Std.	relative activity	EC_{50}, nM	Std.	relative activity	EC_{50}, nM	Std.	relative activity
mt-102	22	798.75	0.180	0.02%	98.38	0.060	0.06%	N/A	0.025	
mt-103		>4000			26.867			.242		
mt-104	23	N/D			N/D			19.069	0.042	0.22%
mt-105	24	N/A	0.046		N/A	0.046		0.552	0.042	7.61%
mt-106	25	165	0.180	0.11%	264.4	0.060	0.02%	N/A	0.025	
mt-107	26	0.070	0.130	185.71%	24.770	0.040	0.16%	3.373	0.025	0.74%
mt-108	27	0.190	0.130	68.42%	0.320	0.040	12.50%	4.781	0.025	0.52%
mt-109	28	0.130	0.100	76.92%	3.860	0.030	0.78%	0.658	0.046	6.99%
mt-110	29	0.430	0.100	23.26%	2.020	0.030	1.49%	0.478	0.046	9.62%
mt-111	30	0.270	0.230	85.19%	0.660	0.070	10.61%	6.258	0.049	0.78%
mt-113	31	335.98	0.230	0.07%	172.66	0.070	0.04%	N/A	0.049	
mt-114	32	81.25	0.230	0.28%	143.65	0.070	0.05%	N/A	0.049	
mt-115	33	0.440	0.050	11.36%	0.150	0.030	20.00%	3.576	0.047	1.31%
mt-116	34	0.787	0.147	18.68%	3.798	0.041	1.07%	0.617	0.047	7.62%
mt-118	35	0.040	0.050	125.00%	1.280	0.030	2.34%	0.736	0.047	6.39%
mt-120	36	0.074	0.192	259.46%	0.399	0.054	13.45%	2.622	0.048	1.81%
mt-124	37	2.430	0.210	8.64%	0.040	0.040	100.00%	5.793	0.055	0.95%
mt-125	38	5.740	0.520	9.06%	1.260	0.040	3.17%	0.275	0.054	19.64%
mt-127	39	0.044	0.313	718.39%	0.055	0.048	87.75%	0.518	0.054	10.51%
mt-128	40	0.773	0.086	11.13%	0.120	0.040	33.33%	14.622	0.061	0.42%
mt-129	41	0.952	0.165	17.34%	4.073	0.046	1.12%	2.879	0.059	2.06%

Code	SEQ ID NO:	Glucagon Receptor			GLP-1 Receptor			GIP Receptor		
		EC_{50}, nM	Std.	relative activity	EC_{50}, nM	Std.	relative activity	EC_{50}, nM	Std.	relative activity
mt-139	42	0.072	0.404	561.11%	0.142	0.059	41.46%	0.569	0.070	12.22%
mt-140	43	0.149	0.196	131.15%	0.068	0.034	49.56%	0.366	0.047	12.85%
mt-141	44	0.150	0.404	269.33%	0.160	0.059	36.78%	0.747	0.075	10.04%
mt-142	45	N/A	0.427		0.041	0.067	163.41%	0.132	0.048	36.36%
mt-143	46	0.086	0.427	496.51%	1.478	0.067	4.53%	2.635	0.048	1.82%
mt-144	47	2.272	0.381	16.77%	0.036	0.051	141.67%	0.480	0.089	18.54%
mt-145	48	0.204	0.096	47.06%	9.936	0.033	0.33%	1.086	0.052	4.79%
mt-146	49	0.020	0.096	480.00%	13.093	0.033	0.25%	0.391	0.052	13.30%
mt-147	50	0.116	0.105	90.52%	0.105	0.036	33.87%	0.144	0.062	43.06%
mt-148	51	4.910	0.105	2.14%	0.098	0.036	36.22%	0.095	0.062	65.26%
mt-149	52	16.315	0.105	0.64%	0.036	0.036	97.53%	0.068	0.062	91.18%
mt-150	53	0.036	0.114	316.67%	3.474	0.038	1.09%	0.232	0.062	26.72%
mt-151	54	0.378	0.114	30.16%	0.126	0.038	30.16%	0.852	0.062	7.28%
mt-152	55	0.293	0.107	36.52%	0.016	0.027	168.75%	0.087	0.036	41.19%
mt-154	56	1.325	0.098	7.40%	2.733	0.019	0.70%	5.530	0.059	1.07%
mt-155	57	1.276	0.140	10.93%	0.025	0.025	98.99%	0.665	0.047	7.02%
mt-156	58	2.965	0.181	6.10%	0.246	0.030	12.20%	0.919	0.041	4.41%
mt-157	59	2.616	0.181	6.92%	0.081	0.030	37.04%	1.013	0.041	4.00%
mt-158	60	1.047	0.156	14.90%	0.034	0.035	102.94%	0.174	0.031	17.82%
mt-162	61	7.002	0.068	0.97%	0.011	0.012	109.09%	0.136	0.035	25.74%
mt-163	62	0.027	0.068	251.85%	0.040	0.012	30.00%	0.740	0.035	4.73%

Code	SEQ ID NO:	Glucagon Receptor			GLP-1 Receptor			GIP Receptor		
		EC_{50}, nM	Std.	relative activity	EC_{50}, nM	Std.	relative activity	EC_{50}, nM	Std.	relative activity
mt-164	63	0.151	0.166	109.93%	0.046	0.026	56.52%	0.164	0.027	16.46%
mt-165	64	0.489	0.092	18.81%	0.023	0.034	147.83%	0.074	0.020	27.03%
mt-166	65	0.875	0.086	9.83%	0.134	0.036	26.87%	0.320	0.019	5.94%
mt-167	66	0.362	0.125	34.53%	0.315	0.025	7.94%	0.399	0.020	5.01%
mt-168	67	2.607	0.125	4.79%	1.724	0.025	1.45%	6.240	0.020	0.32%
mt-169	68	0.199	0.102	51.26%	0.057	0.031	54.39%	0.142	0.021	14.79%
mt-170	69	3.447	0.041	1.19%	0.202	0.030	14.60%	1.285	0.019	1.44%
mt-172	70	9.162	0.041	0.45%	0.859	0.030	3.43%	7.542	0.019	0.25%
mt-174	71	57.546	0.037	0.06%	0.017	0.020	117.65%	0.023	0.022	95.65%
mt-175	72	2.418	0.036	1.49%	0.220	0.013	5.91%	1.930	0.018	0.93%
mt-176	73	0.141	0.037	26.24%	8.693	0.020	0.23%	0.055	0.022	40.00%
mt-177	74	0.095	0.037	38.95%	21.050	0.022	0.10%	0.114	0.022	19.30%
mt-178	75	8.251	0.035	0.42%	0.171	0.014	8.19%	0.448	0.021	4.69%
mt-179	76	1.269	0.037	2.92%	0.260	0.020	7.50%	0.473	0.018	3.74%
mt-182	77	0.212	0.037	17.45%	10.008	0.017	0.17%	0.080	0.018	22.13%
mt-186	78	1.576	0.035	2.22%	0.500	0.014	2.80%	15.209	0.021	0.14%
mt-191	79	1.460	0.063	4.32%	0.011	0.023	209.09%	0.189	0.032	16.93%
mt-192	80	N/A	0.079		47.022	0.026	0.06%	N/A	0.023	
mt-194	81	N/A	0.079		4.157	0.026	0.63%	N/A	0.023	
mt-197	82	47.664	0.063	0.13%	35.297	0.023	0.07%	N/A	0.032	
mt-198	83	11.890	0.063	0.53%	13.219	0.023	0.17%	148.63	0.032	0.02%

Code	SEQ ID NO:	Glucagon Receptor			GLP-1 Receptor			GIP Receptor		
		EC_{50}, nM	Std.	relative activity	EC_{50}, nM	Std.	relative activity	EC_{50}, nM	Std.	relative activity
mt-199	84	0.214	0.067	31.31%	2.796	0.029	1.04%	0.526	0.029	5.51%
mt-200	85	0.560	0.067	11.96%	0.021	0.029	138.10%	0.631	0.029	4.60%
mt-201	86	26.680	0.063	0.24%	0.012	0.023	191.67%	0.072	0.032	44.44%
mt-202	87	2.360	0.067	2.84%	15.725	0.029	0.18%	2.198	0.029	1.32%
mt-203	88	4.840	0.067	1.38%	0.14	0.029	20.71%	12.175	0.029	0.24%
mt-204	89	108.089	0.067	0.06%	0.018	0.029	161.11%	0.147	0.029	19.73%
mt-205	90	671.760	0.067	0.01%	0.204	0.029	14.22%	1.662	0.029	1.74%
mt-206	91	331.314	0.042	0.01%	0.095	0.031	32.63%	0.115	0.015	13.04%
mt-207	92	3.204	0.042	1.31%	0.073	0.031	42.47%	0.622	0.015	2.41%
mt-208	93	447.792	0.042	0.01%	0.262	0.031	11.83%	0.313	0.015	4.79%
mt-209	94	4.656	0.042	0.90%	2.339	0.031	1.33%	1.053	0.015	1.42%

Relative activity is activity relative to the native hormone of the indicated receptor

32993-208847

Based on these data, it was determined that Peptides mt-140, mt-147, mt-151, mt-152, mt-158, mt-164, mt-165, mt-166, mt-169, mt-170, mt-172, mt-175, and mt-179 were exemplary GLP-1/GIP/glucagon triagonist peptides, while Peptides mt-148, mt-149, mt-162, mt-174, mt-178, mt-201, and mt-204 were exemplary GLP-1/GIP co-agonist peptides, and Peptides mt-116, mt-176, mt-177, and mt-182 were exemplary GIP/glucagon co-agonist peptides.

EXAMPLE 22

A GLP-1/GIP/glucagon triagonist peptide (mt-170), GLP-1/GIP co-agonist peptide (mt-178), and two GIP/glucagon co-agonist peptides (mt-182 and mt-179) of Example 21 were tested *in vivo* by subcutaneously injecting diet-induced obese (DIO) mice with these peptides, a glucagon/GLP-1 co-agonist peptide (Chimera 2 AIB2 (native glucagon amino acid sequence (SEQ ID NO: 1) comprising the following modifications: Gln at position 17, Ala at position 18, Lys at position 20, Glu at position 21, Ile at position 23, and Ala at position 24, and a C-terminal amide ("Chimera 2") with a further modification of AIB at position 2) or Chimera 2 AIB2 lactam (same as Chimera 2 AIB2 with further modifications of Glu at position 16 and Lys at position 20, wherein a lactam bridges the side chains of Glu16 and Lys20), or vehicle alone, QW (70 or 210 nmol/kg/week). Each group contained 8 mice, each with an initial average body weight of 50 g. Body weight was determined periodically.

As shown in Figure 4, the triagonist and GLP-1/GIP co-agonist were a little more effective at reducing body weight in the mice as Chimera 2 AIB2, but not as effective as Chimera 2 AIB2 lactam, which demonstrated the best ability to reduce body weight. In contrast, both of the GIP/glucagon co-agonists, and especially mt-182, were less effective at reducing body weight.

EXAMPLE 23

A GLP-1/GIP/glucagon triagonist peptide (mt-170) and GLP-1/GIP co-agonist peptide (mt-178) were tested *in vivo* by subcutaneously injecting diet-induced obese (DIO) mice with these peptides, a GLP agonist (comprising SEQ ID NO: 3 with a Glu at position 16), or vehicle alone, QW (10 nmol/kg/week for 4 weeks or 35 nmol/kg/week

32993-208847

for 2 weeks). Each group contained 8 mice, each mouse with an initial average body weight of 49 g. Body weight and blood glucose levels were determined periodically. As shown in Figures 5 and 6, both the GLP-1/GIP co-agonist and triagonist were more effective at reducing body weight and blood glucose levels than the GLP-1 agonist.

EXAMPLE 24

The effect of stabilizing the alpha helix of glucagon-based analogs with an alpha, alpha-disubstitited amino acid in lieu of a lactam was investigated by replacing the lactam of mt-165 (SEQ ID NO: 64) and of mt-170 (SEQ ID NO: 69) with an AIB at position 16. The peptide comprising the sequence of mt-165 with an AIB at position 16 in lieu of the lactam was termed "mt-241" and had the amino acid sequence of SEQ ID NO: 167, while the peptide comprising the sequence of mt-170 with an AIB at position 16 in lieu of the lactam was termed "mt-248" and had the amino acid sequence of SEQ ID NO: 173.

Additional linear peptides lacking a lactam bridge and comprising AIB at position 16 and/or 20 were also made as essentially described above. These peptides were termed "mt-242," "mt-249," "mt-250," "mt-251," "mt-252," "mt-255," "mt-258," and "mt-259" and had the amino acid sequences of SEQ ID NOs: 168, 174-176, 107, 108, 177, and 258, respectively. The in vitro biological activity at the glucagon, GLP-1, and GIP receptors of each of these peptides were tested as essentially described in Example 16. The results are shown in Table 2.

TABLE 2

Code	SEQ ID NO:	Glucagon Receptor			GLP-1 Receptor			GIP Receptor		
		EC_{50}, nM	Std.	relative activity	EC_{50}, nM	Std.	relative activity	EC_{50}, nM	Std.	relative activity
mt-241	167	2.844	0.106	3.73%	0.023	0.030	130.43%	0.252	0.011	4.37%
mt-242	168	1.106	0.106	9.58%	0.102	0.030	29.41%	0.078	0.011	14.10%
mt-248	173	16.712	0.061	0.37%	0.103	0.010	9.71%	3.233	0.017	0.53%
mt-249	174	10.336	0.061	0.59%	0.391	0.010	2.56%	2.710	0.017	0.63%
mt-250	175	0.667	0.042	6.30%	0.033	0.021	63.64%	0.062	0.019	30.65%
mt-251	176	2.758	0.042	1.52%	0.015	0.021	140.00%	0.033	0.019	57.58%
mt-252	107	0.319	0.042	13.17%	0.018	0.021	116.67%	0.013	0.019	146.15%
mt-255	108	5.463	0.134	2.45%	0.018	0.021	116.67%	0.013	0.019	146.15%
mt-258	177	0.4873	0.0686	14.08%	0.0202	0.0119	58.91%	0.0570	0.0096	16.84%
mt-259	178	0.2967	0.0686	23.12%	0.0189	0.0119	62.96%	0.0799	0.0096	12.02%

32993-208847

As evidenced by the results in Table 2, linear peptides which do not contain a lactam provided activity at the GIP receptor, as well as the glucagon and/or GLP-1 receptors. More specifically, mt-242, mt-248, mt-249, mt-250, mt-252, mt-255, mt-258, and mt-259 exhibited activities of glucagon/GLP-1/GIP triagonists, whereas mt-251 exhibited activity of a GLP-1/GIP co-agonist. Peptide mt-252, which had a Lys at position 16 and an AIB at position 20, exhibited potency at the glucagon and GLP-1 receptors and exhibited an enhanced activity at the GIP receptor.

EXAMPLE 25

Linear peptides lacking a lactam ring and comprising a Lys or similar residue at position 16 and AIB at position 20 were made as essentially described above. The peptides had the amino acid sequences of SEQ ID NOs: 99-141, 144-164, and 166. The peptides were tested in vitro for biological activity at the glucagon, GLP-1, and GIP receptors as essentially described in Example 16. The results are shown in Table 3.

TABLE 3

Code	SEQ ID NO:	Glucagon Receptor			GLP-1 Receptor			GIP Receptor		
		EC_{50}, nM	Std.	relative activity	EC_{50}, nM	Std.	relative activity	EC_{50}, nM	Std.	relative activity
mt-252	107	0.319	0.042	13.17%	0.018	0.021	116.67%	0.013	0.019	146.15%
mt-255	108	5.463	0.134	2.45%	0.211	0.041	19.43%	0.115	0.018	15.65%
mt-256	109	58.947	0.0686	0.12%	0.0124	0.0119	95.97%	0.0034	0.0096	282.35%
mt-257	110	0.2109	0.0686	32.53%	0.0303	0.0119	39.27%	0.0232	0.0096	41.38%
mt-260	104	0.3207	0.0213	6.64%	0.0068	0.0175	257.35%	0.0018	0.0105	583.33%
mt-261	105	0.1585	0.0213	13.44%	0.0047	0.0175	372.34%	0.0015	0.0105	700.00%
mt-262	106	0.1343	0.0213	15.86%	0.0044	0.0175	397.73%	0.0027	0.0105	388.89%
mt-263	111	3.1801	0.0213	0.67%	0.0147	0.0175	119.05%	0.0031	0.0105	338.71%
mt-264	112	N/A			N/A			N/A		
mt-265	113	6.4308	0.0436	0.68%	0.9929	0.0176	1.77%	0.0624	0.0085	13.62%
mt-266	114	18.645	0.0436	0.23%	1.5334	0.0176	1.15%	0.1639	0.0085	5.19%
mt-267	115	62.010	0.0436	0.07%	2.0936	0.0176	0.84%	1.3122	0.0085	0.65%
mt-268	116	6.5002	0.0436	0.67%	0.0155	0.0176	113.55%	0.0047	0.0085	180.85%
mt-269	117	183.4936	0.1964	0.11%	0.0136	0.0197	144.85%	0.0057	0.0080	140.35%
mt-270	118	305.77	0.1964	0.06%	0.0093	0.0197	211.83%	0.0049	0.0080	163.27%
mt-271	119	112.980	0.1964	0.17%	0.0106	0.0197	185.85%	0.0056	0.0080	142.86%
mt-272	120	1060.8	0.1964	0.02%	1.2293	0.0197	1.60%	0.0241	0.0080	33.20%
mt-274	99	69.087	0.0417	0.06%	0.0916	0.0071	7.75%	0.0350	0.0139	39.71%
mt-275	121	0.0671	0.0417	62.15%	0.0068	0.0071	104.41%	0.0124	0.0139	112.10%

Code	SEQ ID NO:	Glucagon Receptor			GLP-1 Receptor			GIP Receptor		
		EC_{50}, nM	Std.	relative activity	EC_{50}, nM	Std.	relative activity	EC_{50}, nM	Std.	relative activity
mt-276	122	0.0537	0.0417	77.65%	0.0066	0.0071	107.58%	0.0080	0.0139	173.75%
mt-277	123	0.0215	0.0506	235.35%	0.0086	0.0193	224.42%	0.0052	0.0237	455.77%
mt-278	124	0.0086	0.0506	588.37%	0.0042	0.0193	459.52%	0.0028	0.0237	846.43%
mt-279	125	0.0069	0.0506	733.33%	0.0046	0.0193	419.57%	0.0045	0.0237	526.67%
mt-280	126	0.0677	0.0506	74.74%	0.0126	0.0193	153.17%	0.0149	0.0237	159.06%
mt-281	127	0.2816	0.0469	16.65%	0.2165	0.0111	5.13%	0.39996	0.0267	6.68%
mt-282	128	2.4367	0.0287	1.18%	0.0134	0.0059	44.03%	0.0133	0.0102	76.69%
mt-283	129	7.9431	0.0287	0.36%	0.0158	0.0059	37.34%	0.0122	0.0102	83.61%
mt-284	130	4.1686	0.0287	0.69%	0.0155	0.0059	38.06%	0.0186	0.0102	54.84%
mt-285	131	12.622	0.0287	0.23%	0.7844	0.0059	0.75%	0.0280	0.0102	36.43%
mt-286	132	0.0612	0.0519	84.80%	0.0225	0.0117	52.00%	0.0159	0.0109	68.55%
mt-287	133	0.0187	0.0519	277.54%	0.0124	0.0117	94.35%	0.0093	0.0109	117.20%
mt-288	134	0.0207	0.0519	250.72%	0.0138	0.0117	84.78%	0.0137	0.0109	79.56%
mt-289	135	0.0766	0.0519	67.75%	0.0144	0.0117	81.25%	0.0234	0.0109	46.58%
mt-290	136	0.0530	0.0603	113.77%	0.0117	0.0183	156.41%	0.0329	0.0078	23.71%
mt-291	137	0.0159	0.0603	379.25%	0.0057	0.0183	321.05%	0.0086	0.0078	90.70%
mt-292	138	0.0133	0.0603	453.38%	0.0044	0.0183	415.91%	0.0082	0.0078	95.12%
mt-293	139	1.6442	0.0603	3.67%	0.2223	0.0183	8.23%	0.1638	0.0078	4.76%
mt-295	140	87.2847	0.0235	0.03%	0.1143	0.0077	6.74%	0.0577	0.0110	19.06%
mt-296	141	0.4214	0.0478	11.34%	0.0124	0.0162	130.65%	0.0077	0.0163	211.69%
mt-297	142	0.0132	0.0478	362.12%	0.0129	0.0162	125.58%	0.0168	0.0163	97.02%

Code	SEQ ID NO:	Glucagon Receptor			GLP-1 Receptor			GIP Receptor		
		EC_{50}, nM	Std.	relative activity	EC_{50}, nM	Std.	relative activity	EC_{50}, nM	Std.	relative activity
mt-298	101	1.7571	0.0638	3.63%	0.0087	0.0157	180.46%	0.0051	0.0206	403.92%
mt-299	143	0.0260	0.0638	245.38%	0.0087	0.0157	180.46%	0.0439	0.0206	46.92%
mt-306	144	1.4950	0.0478	3.20%	0.0201	0.0162	80.60%	0.0064	0.0163	254.69%
mt-307	145	0.2878	0.0478	16.61%	0.0143	0.0162	113.29%	0.0127	0.0163	128.35%
mt-308	146	12.1920	0.0478	0.39%	0.0237	0.0162	68.35%	0.0057	0.0163	285.96%
mt-309	102	3.6109	0.0638	1.77%	0.0104	0.0157	150.96%	0.0091	0.0206	226.37%
mt-310	103	0.7747	0.0638	8.24%	0.0062	0.0157	253.23%	0.0075	0.0206	274.67%
mt-311	100	197.2482	0.0638	0.03%	0.2174	0.0157	7.22%	0.0545	0.0206	37.80%
mt-323	148	0.2169	0.0846	39.00%	0.0571	0.0203	35.55%	0.0084	0.0103	122.62%
mt-324	149	1.2332	0.0791	6.41%	0.2303	0.0223	9.68%	0.0387	0.0117	30.23%
mt-325	150	0.0915	0.0791	86.45%	2.6828	0.0223	0.83%	0.0105	0.0117	111.43%
mt-331	153	408.0393	0.0846	0.02%	0.4484	0.0203	4.53%	0.0968	0.0103	10.64%
mt-333	154	0.6905	0.0193	2.80%	0.0028	0.0024	85.71%	0.0034	0.0077	226.47%
mt-334	155	7.0725	0.0193	0.27%	0.0034	0.0024	70.59%	0.0041	0.0077	187.80%
mt-335	156	1.5956	0.0193	1.21%	0.0018	0.0024	133.33%	0.0047	0.0077	163.83%
mt-336	157	1561.65	0.0193	0.00%	0.0334	0.0024	7.19%	0.0395	0.0077	19.49%
mt-337	158	106.3826	0.0248	0.02%	0.0082	0.0061	74.39%	0.0080	0.0092	115.00%
mt-338	159	295.3407	0.0248	0.01%	0.2256	0.0061	2.70%	0.0234	0.0092	39.32%
mt-339	160	8.7218	0.0248	0.28%	0.0092	0.0061	66.30%	0.0040	0.0092	230.00%
mt-340	161	10.4694	0.0248	0.24%	0.0061	0.0061	100.00%	0.0028	0.0092	328.57%
mt-341	162	499.2008	0.0276	0.01%	0.0636	0.0093	14.62%	0.0566	0.0155	27.39%

Code	SEQ ID NO:	Glucagon Receptor			GLP-1 Receptor			GIP Receptor		
		EC_{50}, nM	Std.	relative activity	EC_{50}, nM	Std.	relative activity	EC_{50}, nM	Std.	relative activity
mt-343	163	41.0674	0.0276	0.07%	0.0224	0.0093	41.52%	0.0243	0.0155	63.79%
mt-344	164	159.2771	0.0276	0.02%	0.0890	0.0093	10.45%	0.0319	0.0155	48.59%
mt-345	165	0.0183	0.0353	192.90%	0.0036	0.0055	152.78%	0.0541	0.0027	4.99%
mt-353	166	12.5069	0.0210	0.17%	0.0049	0.0063	128.57%	0.0035	0.0036	102.86%

32993-208847

As shown in Table 3, the linear peptides were active at the GIP receptor and, in many cases, the peptide was additionally active at the glucagon receptor and/or the GLP-1 receptor. More specifically, all of mt-252, mt-255, mt-257, mt-260, mt-261, mt-262, mt-265, mt-266, mt-267, mt-275, mt-276, mt-277, mt-278, mt-279, mt-280, mt-286, mt-287, mt-288, mt-289, mt-290, mt-291, mt-292, mt-293, mt-295, mt-296, mt-297, mt-299, mt-306, mt-307, mt-310, mt-323, mt-324, and mt-345 exhibited activity at the GIP, GLP-1, and glucagon receptors, while the other peptides of Table 3 exhibited activity at the GIP and GLP-1 receptors (except for mt-285, which exhibited activity at only the GIP receptor, and mt-325, which exhibited activity at the glucagon and GIP receptors, but not at the GLP-1 receptor).

When comparing the data for mt-252, which comprised a C-terminal extension, to the data of mt-257, mt-258, and mt-259, which peptides did not comprise a C-terminal extension, it was apparent that the C-terminal extension enhanced the activities at all of the glucagon, GLP-1, and GIP receptors.

When comparing the data for mt-252, which comprised a Lys at position 16, to the data of mt-275 and mt-276, which peptides comprised an Orn and a Dab residue at position 16, respectively, it was apparent that the Lys could be replaced with a Lys-like residue.

Further, when comparing the data of mt-252, which comprises a Gln at position 3, to the data of mt-256 and mt-274, which peptides comprise a Glu at position 3, it becomes apparent that the substitution of Gln at position 3 with a Glu residue achieved selectivity for the GLP-1 and GIP receptors over the glucagon receptor.

The effect of acylation with C14, C16, and C18 fatty acids was evident from the data of mt-260 to mt-263 and mt-265 to mt-272. From these data, it was apparent that acylation with C16 and C18 fatty acids provided increased activity at the GLP-1 and GIP receptors. The acylation of these peptides even allowed for increased activity at the glucagon receptor even though the peptides comprised a Gln3Glu substitution. The increased activity at the glucagon receptor could also be seen from the data of the triagonists mt-277 to mt-280.

32993-208847

EXAMPLE 26

The in vivo activities of a pegylated, cyclic, lactam-containing peptide, mt-178 (SEQ ID NO: 75), and a pegylated, linear peptide lacking a lactam, mt-274 (SEQ ID NO: 99), were tested in DIO mice, and compared to the in vivo activity of a pure GLP-1 agonist control having a GLP-1-based structure of SEQ ID NO: 179. Peptides or a vehicle control were intraperitoneally injected into the mice on Day 0 at 1, 3, or 10 nmol/kg/week.

A 1-hour glucose tolerance test (GTT) was performed on the mice by intraperitoneally injecting a 25% (w/v) glucose saline solution into the mice one hour after injection with one of the peptides or vehicle control. The glucose saline solution was administered to the mice at a dose of 1.5 g per kg of mouse body weight. Blood glucose levels were measured at the time of injection of peptide or vehicle control (-60 min), at the time of glucose saline solution injection (0 min), or at 15, 30, 60, or 120 min post injection with the glucose saline solution. The results of the 1-hour GTT are shown in Figure 7.

A 24-hour GTT also was performed on the mice in the same manner as the 1-hour GTT, except that the glucose saline solution was administered to the mice 24 hours after injection with the peptide or vehicle control. The results of the 24-hour GTT are shown in Figure 8.

The total blood glucose levels of each mouse were measured 0 and 7 days after injection with peptide or vehicle control and are shown in Figure 9.

Further, the body weight of each mouse was measured at 0, 1, 3, 5, and 7 days after injection with peptide or vehicle control. The % change in body weight of the mice are shown in Figure 10.

As shown in Figure 10, mice injected with mt-178 and mt-274 at either the 3 or 10 nmol/kg/week dose lost weight to the same or greater extent of mice injected with the GLP-agonist control peptide (at a 10 nmol/kg/week dose).

As shown in Figures 7 and 8, mice injected with mt-178, mt-274, or the GLP-1 agonist control exhibited decreased levels of blood glucose, as compared to mice injected with the vehicle control. The potency of mt-178 and mt-274 appeared to be greater than that of the GLP-1 agonist control peptide, as mt-178 and mt-274 at 3 nmol/kg/week

achieved the same effect of the GLP-1 agonist control peptide at the 10 nmol/kg/week dose. mt-274 appeared to have the highest potency as this peptide at a 1 nmol/kg/week dose achieved similar results as the GLP-1 agonist control peptide at 10 nmol/kg/week.

EXAMPLE 27

The same peptides described in Example 26 were tested again in mice, except that higher doses (either 10 or 35 nmol/kg/week) of the peptides were subcutaneously injected into the mice. Two additional peptides were also tested at these doses: one peptide having the same structure as mt-178 but comprising a PEG group attached to the Cys at position 40 via a more stable thioether linkage (-SCH2CO-) formed by nucleophilic substitution as opposed to a traditional thioether linkage formed by malenimide PEG via Michael addition as found in mt-178) and a second peptide having the same structure as mt-274 but comprising a PEG group attached to the Cys at position 40 via the thioether linkage (-SCH2CO-) formed by nucleophilic substitution. These peptides are referred to herein as mt-178(TE) and mt-274(TE), respectively.

The total blood glucose levels of the mice were measured 0 and 7 days after injection with peptide or vehicle control and are shown in Figure 11. The total changes in blood glucose of the mice was measured 7 days after injection with peptide or vehicle control and are shown in Figure 12.

The body weight of each mouse was measured at 0, 1, 3, 5, 7, and 10 days after injection with peptide or vehicle control. The % changes in body weight of the mice as a function of time are shown in Figure 13, while the total changes in body weight of the mice as measured 7 days after injection with peptide or vehicle control are shown in Figure 14.

As shown in Figure 12, the total change in blood glucose decreased in all mice injected with any of the tested peptides, as compared to the mice injected with vehicle control. The most dramatic changes in blood glucose were seen in mice injected with 35 nmol/kg/week of mt-274 or mt-178(TE).

As shown in Figure 14, the total change in body weight decreased in all mice injected with any of the tested peptides, as compared to the mice injected with vehicle

control. Like the total change in blood glucose, the most dramatic changes in body weight were observed in mice injected with 35 nmol/kg/week of mt-274 or mt-178(TE).

EXAMPLE 28

The in vivo activities of the peptides described in Example 26 were compared to the in vivo activities of acylated versions of the linear mt-274 peptide. More specifically, three acylated versions of mt-274 in which the C-terminal amino acid (a Lys residue) was covalently attached to a C16 fatty acyl group, a C14 fatty acyl group, or a C18 fatty acyl group were made and tested. These peptides are referred to herein as mt-298, mt-309, and mt-310, respectively. Like the parent peptide, mt-274, the acylated peptides also comprised a 40 kDa PEG group. However, the PEG group of the acylated peptides was covalently attached to the side chain of a Cys residue at position 24 of the peptides. The amino acid sequences of the acylated peptides mt-298, mt-309, and mt-310 are provided herein as SEQ ID NOs: 101-103, respectively.

A non-acylated version of mt-298, mt-209, and mt-310 (hereinafter referred to as mt-311) was made and tested. Peptide mt-311 differed from mt-274 in that mt-311 was covalently attached to a PEG group through the side chain of a Cys residue at position 24 (as opposed to a Cys residue at the C-terminus as found in mt-274) and the C-terminal residue of mt-311 was a Lys residue, not a Cys residue, as found in mt-274.

The peptides or a vehicle control were subcutaneously injected into DIO mice on Day 0 at 10 nmol/kg for one week.

The blood glucose levels of the mice were measured 0 and 7 days after injection with peptide or vehicle control and are shown in Figure 15. The body weight of each mouse was measured at 0, 1, 3, 5, and 7 days after injection with peptide or vehicle control. The % changes in body weight of the mice as a function of time are shown in Figure 16, while the total changes in body weight of the mice as measured 7 days after injection with peptide or vehicle control are shown in Figure 17.

As shown in Figure 17, mice injected with any of the peptides exhibited a decrease in body weight as compared to mice injected with vehicle control. Mice injected with the pegylated, cyclic, lactam-containing peptide (mt-178) demonstrated the greatest loss of body weight 7 days after injection.

32993-208847

As shown in Figure 15, the blood glucose levels of mice injected with mt-178, mt-274, mt-311, or C14 or C16 acylated versions thereof decreased. Acylation with a C18 fatty acyl group did not appear to cause a decrease in blood glucose levels, suggesting that the size of the acyl group may be important for glucose lowering effects of the peptides.

EXAMPLE 29

Linear glucagon-based peptides lacking a lactam that were acylated but not pegylated were made as essentially described above. Specifcally, mt-260 comprising a C14 fatty acyl group on the C-terminal amino acid (SEQ ID NO: 104), mt-261 comprising a C16 fatty acyl group on the C-terminal amino acid (SEQ ID NO: 105) and mt-262 comprising a C18 fatty acyl group on the C-terminal amino acid (SEQ ID NO: 106) were made. The structures of each of these peptides were similar to those of mt-298, mt-309, and mt-310, but differed in that mt-260, mt-261, and mt-262 comprised an Asn residue in place of a pegylated Cys residue at position 24.

The peptides, mt-260, mt-261, or mt-262, a control peptide (Liraglutide, an acylated GLP-1 analog), or a vehicle control were injected QD into mice at a dose of 25 or 125 nmol/kg for 7 days.

The blood glucose levels of the mice were measured 0 and 7 days after injection with peptide or vehicle control and are shown in Figure 18. The body weight of each mouse was measured at 0, 1, 3, 5, and 7 days after injection with peptide or vehicle control. The % changes in body weight of the mice as a function of time are shown in Figure 19, while the total changes in body weight of the mice as measured 7 days after injection with peptide or vehicle control are shown in Figure 20.

As shown in Figure 18, the effects that the acylated, unpegylated, linear peptides (mt-260, mt-261, and mt-262) had on blood glucose levels were dramatic. At 25 nmol/kg, these peptides caused about a 50% decrease in blood glucose levels, and at the higher dose, the peptides caused a decrease in blood glucose levels that was greater than 50%.

As shown in Figure 19, each of the acylated, unpegylated, linear peptides (at either the low or high dose) caused a decrease in body weight which was more potent

than the decrease in body weight achieved by Liraglutide at the low dose. Body weight continued to decrease over the course of the 7 days of the assay.

These results suggest that acylated, unpegylated linear glucagon-based peptides that are active at the GIP and GLP-1 receptors are able to dramatically decrease blood glucose levels and body weight, thereby indicating that these peptides can be used to treat metabolic disorders, including diabetes, and for treatment of obesity.

EXAMPLE 30

The linear glucagon-based peptide mt-261 (SEQ ID NO: 105) was tested at different doses in DIO mice (N=8 per group; average initial body weight = 48 g). Mice were subcutaneously injected QD for one week with vehicle only, liraglutide (30 nmol/kg of body weight) or mt-261 (0.3, 1, 3, 10 or 30 nmol/kg of body weight).

The body weight of the mice was measured 0, 1, 3, 5, and 7 days after the first injection. As shown in Figure 21, injection with mt-261 or liraglutide caused weight loss in the mice. Peptide mt-261 exhibited a higher potency than liraglutide, as 3 nmol/kg mt-261 achieved essentially the same effect as 30 nmol/kg liraglutide (Figure 21).

The fat mass of the mice were measured 7 days after the first injection by nuclear magnetic resonance imaging. As shown in Figure 22, increasing doses of mt-261 generally correlated with decreasing fat mass. The fat mass of mice injected with 3 nmol/kg mt-261 was about the same as the fat mass of mice injected with 30 nmol/kg liraglutide, demonstrating the high potency of mt-261 in comparison to liraglutide.

Blood glucose levels of the mice were measured 0 and 7 days after the first injection. As shown in Figure 23, doses as low as 3 nmol/kg of mt-261 caused a significant decrease in blood glucose levels. Consistent with the results of the fat mass and body weight assays, the decrease in blood glucose levels of mice injected with 3 nmol/kg mt-261 was similar to the decrease of blood glucose levels of mice injected with 30 nmol/kg liraglutide, demonstrating the higher potency of mt-261 as compared to liraglutide.

In a separate experiment, the unacylated version of mt-261, namely, mt-263 (SEQ ID NO: 111) was tested in nine groups of C57BI/6 mice (8 mice per group) for its *in vivo* effects on body weight, food intake, blood glucose levels, and fat mass. The mice were

11 months old and had been on a diabetogenic diet for 9 months at the time of the study. The average body weight of the mice were 57 g. The mice were subcutaneously injected daily with 3, 10, or 30 nmol/kg mt-263 for one week. The control groups received either a vehicle control or Exendin-4 at 10 or 30 nmol/kg/day.

To assess the in vivo effects on body weight, the body weight of the mice were measured on Day 0, 1, 3, 5, and 7, wherein Day 0 is the first day of injection. As shown in Figure 24, injection of mt-263 at any of the three doses caused a steady decrease in body weight over the 7 day test period. The effect on body weight also appreared to be dose-dependent as the total change in body weight (shown in Figure 25) increased upon increasing dose of mt-263 peptide. Further, as shown in Figure 25, the total changes in body weight achieved by any of the three doses of mt-263 was substantially more than the total change in body weight achieved by injection with Exendin-4 (at either dose).

The *in vivo* effects on food intake, fat mass, and blood glucose were also determined. The total food intake and fat mass as measured on Day 7 of mice injected. with mt-263 were reduced as compared to vehicle control and Exendin-4. Further, the total changes in blood glucose levels (as measured on Day 7 compared to levels measured on Day 0) of mice injected with mt-263 were significantly reduced in comparison to mice injected with either vehicle control or Exendin-4 (Figure 26). The peptide at a 10 nmol/kg dose appeared to be the optimal dose, achieving the greatest decrease in blood glucose levels (almost -80 mg/dL).

The *in vivo* effects on body weight, food intake, and blood glucose levels of peptide mt-263 also were compared to those of peptides mt-349 (SEQ ID NO: 262), mt-280, mt-356, and mt-357, and of a vehicle control. Mice were given 30 nmol/kg/day of one of the peptides for 1 week. All peptides were effective at reducing body weight in mice as compared to vehicle control.

32993-208847

EXAMPLE 31

The in vivo effects of the linear, acylated glucagon-based peptides mt-277, mt-278, and mt-279 were tested and compared to those of liraglutide. DIO mice (8 mice per group; average initial body weight = 51.4 g) were subcutaneously injected daily for 1 week with a vehicle control or 10 nmol/kg of liraglutide, mt-277, mt-278, or mt-279.

The body weight of the mice was measured 0, 1, 3, 5, and 7 days after the first injection. As shown in Figure 27, injection with mt-277, mt-278, or mt-279 caused significant weight loss in the mice. All of these peptides further demonstrated a higher potency than liraglutide.

Blood glucose levels of the mice were measured 0 and 7 days after the first injection. As shown in Figure 28, each of mt-277, mt-278, and mt-279 caused a significant decrease in blood glucose levels, which decrease was much greater than that seen in mice injected with liraglutide.

EXAMPLE 32

A GLP-1 receptor-active, glucagon-based analog was modified to comprise a C-terminal extension of the amino acid sequence of SEQ ID NO: 95 and further modified to comprise a Lys at the C-terminus of SEQ ID NO: 95. The Lys residue which was located at position 40 of the analog was acylated with a C14 fatty acyl group. This acylated analog was tested for in vitro activity at the glucagon, GLP-1, and GIP receptors as essentially described in Example 16. The in vitro activity was compared to that of the parent GLP-1 receptor-active, glucagon-based analog lacking the C-terminal extension and acylation at position 40. The C-terminally extended, acylated analog demonstrated an approximate 15% increase of activity at the GIP receptor and an approximate 52% increase at the glucagon receptor. Activity at the GLP-1 receptor actually decreased when stimulated by the C-terminally extended, acylated analog. However, the activity was still greater than 100% of the activity achieved by native GLP-1 at the GLP-1 receptor.

32993-208847

EXAMPLE 33

Acylated glucagon analog peptides (each of which comprised an amide in place of the C-terminal carboxylate) were synthesized as essentially described above. Peptides mt-358, mt-367, mt-368, and mt-369 were acylated monomers, whereas mt-354, mt-376, and mt-377 were acylated dimers, wherein each dimer comprised two monomers linked via C-terminal Cys residues. Peptides mt-367, mt-368, and mt-369 comprised a γGlu-γGlu dipeptide spacer for purposes of attaching the acyl group, whereas mt-358 was acylated in the absence of a spacer. Peptides mt-225, mt-227, and mt-294 were pegylated monomers that comprised a lactam bridge between the glutamic acid at position 16 and the lysine at position 20. Peptides mt-225 and mt-227 comprised a dipeptide spacer for purposes of attaching the PEG, whereas mt-294 was acylated via a thioether made by a reaction with a haloacetyl. Peptides mt-356 and mt-357 served as unacylated control peptides, of which mt-357 comprised an Ile at position 7, but mt-356 comprised a Thr. All were tested for *in vitro* activity at the GIP receptor, GLP-1 receptor, and glucagon receptors as essentially described in Example 16. The EC50 (nM) and the activity relative to the native hormone of each peptide are shown in Table 4.

TABLE 4

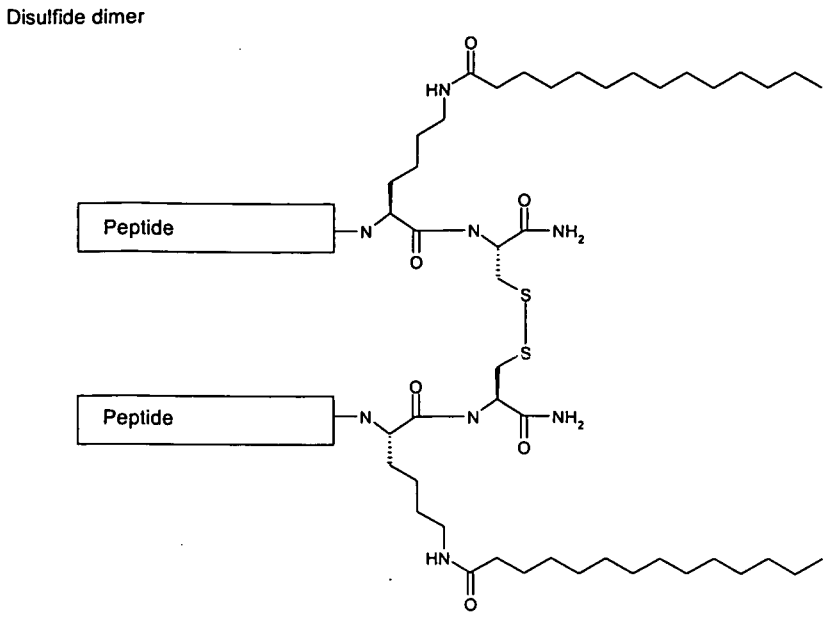
Code	Position of Acyl Group (Spacer)	SEQ ID NO:	Glucagon Receptor			GLP-1 Receptor			GIP Receptor		
			EC_{50}, nM	Std.	relative activity	EC_{50}, nM	Std.	relative activity	EC_{50}, nM	Std.	relative activity
mt-356	n/a	232	0.0869	0.1095	126.06%	0.0048	0.0108	224.02%	0.0530	0.0136	25.66%
mt-357	n/a	233	0.0420	0.1095	260.92%	1.2518	0.0108	0.86%	0.0066	0.0136	206.37%
Acylated Monomer Structures											
mt-358	40 (none)	234	0.0087	0.1095	1266.00%	0.0830	0.0108	13.04%	0.0045	0.0136	305.62%
mt-368	40 (γEγE)	236	0.0069	0.0337	491.82%	0.0038	0.0157	418.93%	0.00097	0.0029	296.07%
mt-367	40 (γEγE)	235	0.8201	0.0337	4.11%	0.0039	0.0157	405.94%	0.0014	0.0029	202.82%
mt-369	10 (γEγE)	237	2.1893	0.0337	1.54%	0.0041	0.0157	385.05%	0.0014	0.0029	204.26%
Acylated Dimer Structures											
mt-354*	40† (none)	231	2.6078	0.0378	1.45%	0.0088	0.0120	136.99%	0.0046	0.0042	91.65%
mt-376**	40† (none)	238	13.4644	0.0772	0.57%	0.0106	0.0134	126.82%	0.0068	0.0042	62.63%
mt-377**	40† (none)	239	3.9038	0.0772	1.98%	0.0076	0.0134	177.88%	0.0031	0.0042	138.11%
Pegylated, Lactamized Monomers											
mt-225	none	259	2.712	0.054	1.99%	0.098	0.029	29.59%	1.899	0.017	0.90%

Code	Position of Acyl Group (Spacer)	SEQ ID NO:	Glucagon Receptor			GLP-1 Receptor			GIP Receptor		
			EC_{50}, nM	Std.	relative activity	EC_{50}, nM	Std.	relative activity	EC_{50}, nM	Std.	relative activity
mt-227	none	260	4.244	0.054	1.27%	0.080	0.029	36.25%	1.320	0.017	1.29%
mt-294	none	261	229.996	0.0235	0.01%	0.0608	0.0077	12.66%	0.3727	0.0110	2.95%

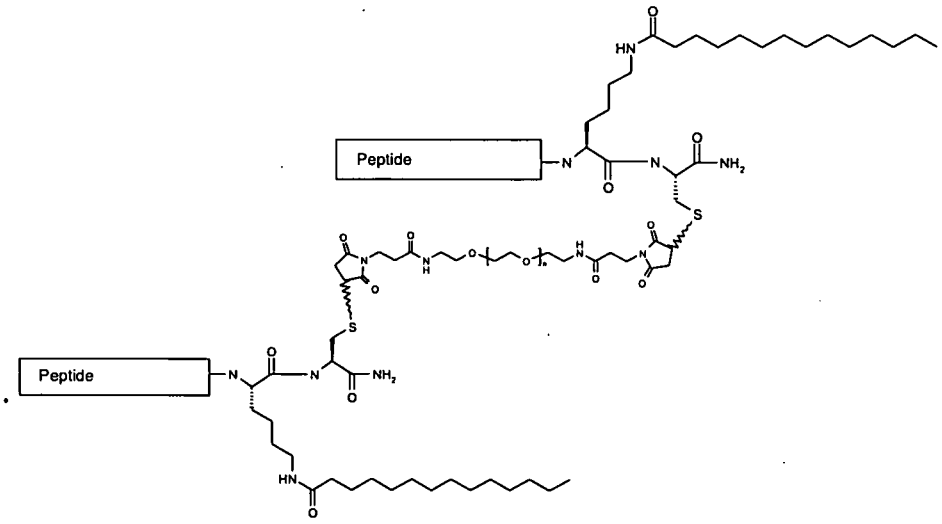
* indicates a disulfide-linked dimer structure, in which each peptide monomer is attached via a disulfide bond as shown in Structure A
** indicates a PEG-linked dimer structure, in which each peptide monomer is attached via a PEG as shown in Structure B
† each monomer of the dimer comprised acylation at position 40 of the monomer (wherein position 1 is the N-terminal amino acid).

5

32993-208847



Structure A



Structure B

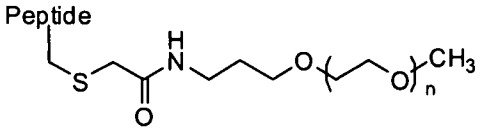
As shown in Table 4, all three acylated dimers demonstrated potent activity at the GLP-1 and GIP receptors. Also, the activity at the GLP-1 receptor exhibited by mt-368 was dramatically enhanced as compared to that demonstrated by mt-358, and the activity at the GIP receptor of mt-368 was essentially maintained in comparison to mt-358,

32993-208847

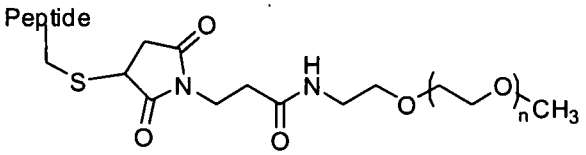
suggesting that acylation of a glucagon peptide via a spacer can increase the activity at the GLP-1 receptor, while maintaining robust activity at the GIP receptor. Acylation via a spacer at position 10 of the glucagon analog appeared to be as good a position as position 40 of the glucagon analog, since the relative activities at the GLP-1 and GIP receptors were about the same for mt-367 and mt-369.

EXAMPLE 34

Two acylated glucagon analog peptides having the same amino acid sequence but differing in the pegylation linker were made as essentially described herein: mt-331 (SEQ ID NO: 153) comprised a linkage to PEG of structure:



while mt-311 (SEQ ID NO: 100) comprised a linkage to PEG of structure:



The two peptides or a vehicle control were administered via subcutaneous injection QW for one week to multiple groups of DIO mice (6 mice per group; average body weight = 64.6 g). The peptides were administered at a dose of either 10 or 35 nmol/kg.

The body weights of the mice were measured 0, 1, 3, 5, and 7 days after administration of the peptides or the vehicle control. The body weight of the mice injected with the higher dose of either mt-311 or mt-331 steadily decreased over the course of the week. The total change in body weight (%) is shown in Figure 29. As shown in this figure, the total change in body weight was greatest for the mice injected with mt-311.

The total food intake by each group of mice was also measured 0, 1, 3, 5, and 7 days after administration of the peptides or the vehicle control. As shown in Figure 30, the total food intake by the groups of mice injected with either dose of mt-311 or mt-331 was decreased, as compared to the mice injected with a vehicle control.

32993-208847

The blood glucose levels of each group of mice were measured 0 and 7 days after administration of the peptides or the vehicle control. The blood glucose levels of the mice decreased upon administration of the higher dose of either mt-311 or mt-331. As shown in Figure 31, the decrease in blood glucose levels was greater in mice injected with 35 nmol/kg mt-331.

The fat mass of each group of mice were measured. Administration of the peptides did not appear to have an effect on the fat mass, however.

EXAMPLE 35

The *in vivo* effects of two peptides of the same amino acid sequence but differing by the absence of an acyl group attached to the Lys at position 40 (mt-331 (SEQ ID NO: 153)) or presence of a C14 fatty acyl group (mt-353 (SEQ ID NO: 166)) on body weight, food intake, blood glucose levels and fat mass were tested in 7 month old C57Bl/6 mice. The mice were on a diabetogenic diet for 5 months and the average initial body weight was 53 g. The peptides or a vehicle control were administered to the mice by subcutaneous injection for one week at a dose of 0.1, 0.3, 3, or 10 nmol/kg.

Body weight was measured 0, 1, 3, 5, and 7 days after administration of the peptide or vehicle control. As shown in Figure 32, the total change in body weight was most significant for mice injected with 10 nmol/kg of either mt-331 or mt-353.

Food intake by the mice was measured 0, 1, 3, 5, and 7 days after administration of the peptide or vehicle control. As shown in Figure 33, the total food intake by the mice injected with 3 or 10 nmol/kg of either mt-331 or mt-353 was decreased in comparison to mice administered the vehicle control.

Blood glucose levels of the mice also were monitored. As shown in Figure 34, mt-331 caused a decrease in blood glucose levels in a dose-dependent manner. The two doses of mt-353 additionally caused blood glucose levels to decrease. The fat mass levels were not significantly impacted by the administration of either peptide.

EXAMPLE 36

The *in vivo* effects of three acylated triagonist peptides, mt-277, mt-278, and mt-279, having the structure of SEQ ID NOs: 123, 124, and 125, respectively, on body

weight, blood glucose levels, and food intake were tested in 8 groups of DIO mice (8 mice per group). The peptides had the same amino acid sequence but differed in the size of the fatty acyl group to which it was attached. Liraglutide at a concentration of 10 nM/kg was used as a control. The peptides or a vehicle control were administered by subcutaneous injection daily for one week.

The in vitro activities at the glucagon, GLP-1, and GIP receptors were tested and the % activity of each peptide relative to the native hormone is shown below in Table 5.

TABLE 5

Peptide	% activity at the GLP-1 receptor	% activity at the glucagon receptor	% activity at the GIP receptor
Liraglutide	138	0.04	n/a
Mt-277	224	235	446
Mt-278	460	588	846
Mt-279	420	733	527

The body weight of the mice was measured 0, 1, 3, 5, and 7 days after administration of the peptides or the vehicle control. Over the course of the week, the body weight of the mice that were injected with one of the acylated triagonist peptides dramatically decreased, as compared to the vehicle control. As shown in Figure 35, the total change in body weight (%) of the mice injected with one of the acylated triagonist peptides was approximately -15%, whereas Liraglutide achieved less than a 5% decrease in body weight.

EXAMPLE 37

The effect of dosing frequency on efficacy of a pegylated, acylated peptide (mt-309; SEQ ID NO: 102) and a non-pegylated, acylated peptide (mt-261; SEQ ID NO: 105) was tested in 7 groups of DIO mice (8 mice per group) having an average body weight of 58 g. The peptides were subcutaneously injected into the mice QD at a dose of 5 nmol/kg, every 2nd day at a dose of 10 nmol/kg, or QW at a dose of 30 nmol/kg. The study lasted for 6 days, such that each group of mice received 30 nmol/kg by the end of the study

period. Body weight and blood glucose levels were measured 0 and 6 days after the first administration.

As shown in Figure 36, the total change in body weight (%) of mice injected QW with mt-309 was approximately the same as the total change in body weight for mice injected QD with the same peptide. Also, as shown in Figure 36, the total change in body weight of mice injected QD with mt-261 was about the same as the total change in body weight of mice injected every 2nd day with this peptide.

The same trends in body weight could also be observed with blood glucose levels (Figure 37): a QW injection of mt-309 achieved the same decrease in blood glucose levels as a QD injection of this peptide, and a QD injection of mt-261 achieved the same decrease in blood glucose levels as an every 2nd day injection of this peptide.

EXAMPLE 38

The effect on dosing frequency on efficacy was tested for an acylated glucagon agonist peptide, mt-261 (SEQ ID NO: 105) by subcutaneously injecting 8 groups of DIO mice (8 mice per group) having an initial body weight of 56 g with 5 nmol/kg daily, 10 nmol/kg every 2nd day, 15 nmol/kg every 3rd day, or 30 nmol/kg for one day, such that each group received a total dose of 30 nmol/kg per week. The mice were 8 months old and had been on a diabetogenic diet for 6 months. Body weight, food intake, blood glucose levels and fat mass of each group were measured. As shown in Figure 38, the mice injected with the peptide every three days exhibited the greatest decrease in body weight. Interestingly, mice injected with the peptide daily and mice injected with the peptide every two days exhibited nearly the same decrease in body weight.

EXAMPLE 39

The following glucagon analog peptides having appreciable agonist activity at only the glucagon receptor and not the GIP receptor and comprising a backbone of Peptide J

HS-X-GTFTSDYSKYLDTRRAAEFVAWL(Nle)DE

(SEQ ID NO: 240)

or Peptide K

32993-208847

HS-X-GTFTSDYSKYLD(Aib)RRAADFVAWLMDE

(SEQ ID NO: 241)

with additional modification at position 3 were made by solid-phase peptide synthesis as essentially described herein. The peptides were tested for *in vitro* activity at the glucagon receptor as essentially described in Example 16. The EC50 (nM) of each peptide is shown in Table 6.

TABLE 6

Peptide Backbone	**Amino Acid at Position 3**	**SEQ ID NO:**	**EC_{50} at Glucagon Receptor (nM)**	**% activity***
J	Q	242	0.24	25%
J	C(Acm)	243	0.18	33%
J	Dab(Ac)	244	0.31	19%
J	Dap(urea)	245	0.48	13%
J	Q(Me)	246	0.48	13%
J	M(O)	247	0.91	7%
J	Orn(Ac)	248	0.92	7%
K	Q	249	0.39	15%
K	Dab(Ac)	250	0.07	86%
K	Q(Me)	251	0.11	55%

Q = glutamine; C(Acm) = acetamidomethyl-cysteine; Dab(Ac) = acetyldiaminobutanoic acid; Dap(urea) = carbamoyldiaminopropanoic acid; Q(Me) = methylglutamine; M(O) = methionine-sulfoxide; Orn(Ac) = acetylornithine.

32993-208847

As shown in Table 6, multiple amino acids could replace the Gln at position 3 without a substantial loss of activity at the glucagon receptor, and, in some cases, the modification actually increased the activity, e.g., Dab(Ac) and Q(Me) on the Peptide K backbone.

EXAMPLE 40

Glucagon analog peptides having appreciable activity at the glucagon receptor and not the GIP receptor and comprising Dab(Ac) at position 3 on various glucagon analog backbones were made as essentially described herein and the *in vitro* activity at the glucagon receptor was tested. The structures and activities of each peptide are shown in Table 7.

TABLE 7

Amino acid sequence	**SEQ ID NO:**	**EC_{50} (nM) at Glucagon Receptor**	**% activity***
Wildtype Glucagon	1	0.026	100
HSQGTFTSDYSKYLDSRRAQDFVQWLMDT	252	0.015	173
HSDab(Ac)GTFTSDYSKYLDAibRRAADFVAWLLDE	253	0.069	37
HSDab(Ac)GTFTSDYSKYLDAibRRAADFVAWLLDTGPSSGAPPPS amide	254	0.023	113
HSDab(Ac)GTFTSDYSKYLDAibRRASDFVSWLLDE	255	0.048	54
HSDab(Ac)GTFTSDYSKYLDAibRRATDFVTWLLDE	256	0.057	46

EXAMPLE 41

Analogs of glucagon having a C-terminal amide in place of the C-terminal alpha carboxylate were made as essentially described herein:

32993-208847

Peptides mt-367, mt-368, and mt-369 comprised the structures of SEQ ID NOs: 235, 236, and 237, resepectively. Peptide mt-384 comprised the amino acid of SEQ ID NO: 1 with the following amino acid modifications: Tyr at position 1, an AIB at position 2, Lys at position 10, wherein the Lys was covalently bound to a C16 fatty acyl group via a γ-Glu-γ-Glu dipeptide spacer, Ile at position 12, Lys at position 16, Gln at position 17, Ala at position 18, AIB at position 20, Glu at position 21, Asn at position 24, Leu at position 27, Ala at position 28, and Gly at position 29, followed by the amino acid of SEQ ID NO: 95 C-terminal to the amino acid at position 29. Peptide mt-385 comprised the same structure as Peptide mt-384 except that Thr at position 7 was changed to an Ile in mt-385.

The analogs were tested for *in vitro* activity at each of the glucagon, GLP-1, and GIP receptors as essentially described herein. The results are shown in Table 8.

TABLE 8

Peptide	% Relative activity at the Receptor for		
	Glucagon	GLP-1	GIP
mt-367	4.11	405.94	202.82
mt-368	491.82	418.93	296.07
mt-369	1.54	385.05	204.26
mt-384	227.75	349.21	807.73
mt-385	239.45	3.18	714.88

Nine groups of 8 DIO mice (strain: C57Bl6 WT) were subcutaneously injected daily for 7 days with 10 nmol/kg of one of the peptides of Table 8. The average initial body weight of the mice was 57.6 g. The mice were approximately 10 months old and had been on a high fat diet for about 8 months.

The total change in body weight was measured on Day 7. All mice injected with a peptide of Table 8 demonstrated a decrease in body weight as compared to vehicle control. Mice that were injected with mt-369 demonstrated the greatest amount of weight

loss (~25% decrease), followed by mice that were injected with mt-368 (~22% decrease) and mice that were injected with mt-384 (~21% decrease). Mice that were injected with mt-367 or mt-385 exhibited a lower but still significant weight loss (mt-367: ~18% decrease and mt-385: ~15% decrease).

32993-208847

All references, including publications, patent applications, and patents, cited herein are hereby incorporated by reference to the same extent as if each reference were individually and specifically indicated to be incorporated by reference and were set forth in its entirety herein.

The use of the terms "a" and "an" and "the" and similar referents in the context of describing the invention (especially in the context of the following claims) are to be construed to cover both the singular and the plural, unless otherwise indicated herein or clearly contradicted by context. The terms "comprising," "having," "including," and "containing" are to be construed as open-ended terms (i.e., meaning "including, but not limited to,") unless otherwise noted.

Recitation of ranges of values herein are merely intended to serve as a shorthand method of referring individually to each separate value falling within the range and each endpoint, unless otherwise indicated herein, and each separate value and endpoint is incorporated into the specification as if it were individually recited herein.

All methods described herein can be performed in any suitable order unless otherwise indicated herein or otherwise clearly contradicted by context. The use of any and all examples, or exemplary language (e.g., "such as") provided herein, is intended merely to better illuminate the invention and does not pose a limitation on the scope of the invention unless otherwise claimed. No language in the specification should be construed as indicating any non-claimed element as essential to the practice of the invention.

Preferred embodiments of this invention are described herein, including the best mode known to the inventors for carrying out the invention. Variations of those preferred embodiments may become apparent to those of ordinary skill in the art upon reading the foregoing description. The inventors expect skilled artisans to employ such variations as appropriate, and the inventors intend for the invention to be practiced otherwise than as specifically described herein. Accordingly, this invention includes all modifications and equivalents of the subject matter recited in the claims appended hereto as permitted by applicable law. Moreover, any combination of the above-described elements in all possible variations thereof is encompassed by the invention unless otherwise indicated herein or otherwise clearly contradicted by context.

What is claimed is:

1. An analog of glucagon (SEQ ID NO: 1) having GIP agonist activity, with the following modifications:

(a) an amino acid modification at position 1 that confers GIP agonist activity,

(b) a modification selected from the group consisting of:

(i) a lactam bridge between the side chains of amino acids at positions i and i+4 or between the side chains of amino acids at positions j and j+3, wherein i is 12, 13, 16, 17, 20 or 24, and wherein j is 17, and

(ii) one, two, three, or all of the amino acids at positions 16, 20, 21, and 24 of the analog is substituted with an α,α-disubstituted amino acid, and

(c) 1-10 further amino acid modifications,

wherein the analog exhibits at least 1% activity of native GIP at the GIP receptor.

2. The analog of claim 1, wherein the amino acid modification at position 1 is a substitution of His with an amino acid lacking an imidazole side chain.

3. The analog of claim 2, wherein the amino acid lacking an imidazole side chain is a large, aromatic amino acid.

4. The analog of claim 3, wherein the large, aromatic amino acid is Tyr.

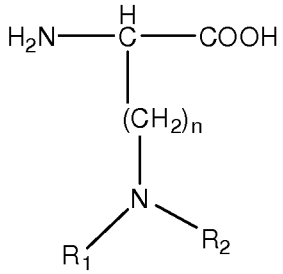
5. The analog of any of claims 1 to 4, wherein the lactam bridge is between the amino acids at positions 16 and 20, wherein one of the amino acids at positions 16 and 20 is substituted with Glu, and the other of the amino acids at positions 16 and 20 is substituted with Lys.

6. The analog of any of claims 1 to 4, wherein the α,α-disubstituted amino acid is AIB.

7. The analog of any of claims 1 to 4, and 6, wherein the amino acid at position 16 or position 20 is substituted with an α,α-disubstituted amino acid.

8. The analog of claim 7, wherein the amino acid at position 20 is AIB and the amino acid at position 16 is substituted with a positive-charged amino acid.

9. The analog of claim 8, wherein the positive-charged amino acid is an amino acid of Formula IV:



[Formula IV],

wherein n is 1 to 7, wherein each of R1 and R2 is independently selected from the group consisting of H, C_1-C_{18} alkyl, (C_1-C_{18} alkyl)OH, (C_1-C_{18} alkyl)NH_2, (C_1-C_{18} alkyl)SH, (C_0-C_4 alkyl)(C_3-C_6)cycloalkyl, (C_0-C_4 alkyl)(C_2-C_5 heterocyclic), (C_0-C_4 alkyl)(C_6-C_{10} aryl)R_7, and (C_1-C_4 alkyl)(C_3-C_9 heteroaryl), wherein R_7 is H or OH, and the side chain of the amino acid of Formula IV comprises a free amino group.

10. The analog of claim 9, wherein the amino acid of Formula IV is homoLys, Lys, Orn, or 2,4-diaminobutyric acid (Dab).

11. The analog of any of claims 1 to 10, comprising amino acid modifications at one, two or all of positions 27, 28 and 29.

12. The analog of claim 11, wherein

(a) the Met at position 27 is substituted with a large aliphatic amino acid, optionally Leu,

(b) the Asn at position 28 is substituted with a small aliphatic amino acid, optionally Ala,

(c) the Thr at position 29 is substituted with a small aliphatic amino acid, optionally Gly, or

(d) a combination of two or all of (a), (b), and (c).

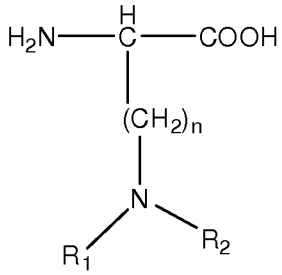
13. The analog of claim 12, comprising Leu at position 27, Ala at position 28, and Gly or Thr at position 29.

14. The analog of any of claims 1 to 13, comprising an extension of 1 to 21 amino acids C-terminal to the amino acid at position 29.

15. The analog of claim 14, wherein the extension comprises the amino acid sequence of SEQ ID NO: 95 or 96.

16. The analog of claim 14 or 15, wherein 1-6 amino acids of the extension are positive-charged amino acids.

17. The analog of claim 16, wherein the 1-6 positive-charged amino acids are of formula IV:



[Formula IV],

wherein n is 1 to 7, wherein each of R1 and R2 is independently selected from the group consisting of H, C_1-C_{18} alkyl, (C_1-C_{18} alkyl)OH, (C_1-C_{18} alkyl)NH_2, (C_1-C_{18} alkyl)SH, (C_0-C_4 alkyl)(C_3-C_6)cycloalkyl, (C_0-C_4 alkyl)(C_2-C_5 heterocyclic), (C_0-C_4 alkyl)(C_6-C_{10} aryl)R_7, and (C_1-C_4 alkyl)(C_3-C_9 heteroaryl), wherein R_7 is H

or OH, and the side chain of the amino acid of Formula IV comprises a free amino group.

18. The analog of claim 17, wherein the amino acid of formula IV is homoLys, Lys, Orn, or Dab.

19. The analog of any of claims 1 to 18, comprising an amino acid comprising a side chain covalently linked to an acyl or alkyl group, which acyl or alkyl group is non-native to a naturally-occurring amino acid.

20. The analog of claim 19, wherein the amino acid linked to the acyl or alkyl group is an amino acid of Formula I, Formula II, or Formula III.

21. The analog of claim 19, wherein the amino acid of Formula I is Lys.

22. The analog of any of claims 19 to 21, wherein the amino acid inked to the acyl or alkyl groupis located at position 10 of the analog relative to SEQ ID NO: 1.

23. The analog of any of claims 19 to 21, wherein, when the analog comprises an extension of 1 to 21 amino acids C-terminal to the amino acid at position 29, the amino acid linked to the acyl or alkyl group is located at a position corresponding to any of positions 37-43.

24. The analog of claim 23, wherein the amino acid linked to the acyl or alkyl group is located at position 40.

25. The analog of any of claims 19 to 24, wherein the acyl or alkyl group is covalently attached to the side chain of the amino acid via a spacer.

26. The analog of claim 25, wherein the spacer is 3 to 10 atoms in length.

27. The analog of claim 26, wherein the spacer is an amino acid or dipeptide.

28. The analog of claim 27, wherein the spacer is 6-amino hexanoic acid.

29. The analog of claim 27, wherein the spacer is a dipeptide selected from the group consisting of: Ala-Ala, β-Ala- β-Ala, Leu-Leu, Pro-Pro, and γ-Glu- γ-Glu.

30. The analog of any of claims 25 to 29, wherein the total length of the spacer and the acyl group is about 14 to about 28 atoms in length.

31. The analog of any of claims 19 to 30, wherein the acyl group is a C12 to C18 fatty acyl group.

32. The analog of claim 31, wherein the acyl group is a C14 or C16 fatty acyl group.

33. The analog of any of claims 1 to 32, comprising a modification selected from the group consisting of:

(a) Ser at position 2 substituted with D-Ser, Ala, D-Ala, Gly, N-methyl-Ser, AIB, Val, or α-amino-N-butyric acid;
(a) Tyr at position 10 substituted with Trp, Lys, Orn, Glu, Phe, or Val;
(b) Linkage of an acyl group to a Lys at position 10;
(c) Lys at position 12 substituted with Arg or Ile;
(d) Ser at position 16 substituted with Glu, Gln, homoglutamic acid, homocysteic acid, Thr, Gly, or AIB;
(e) Arg at position 17 substituted with Gln;
(f) Arg at position 18 substituted with Ala, Ser, Thr, or Gly;
(g) Gln at position 20 substituted with Ser, Thr, Ala, Lys, Citrulline, Arg, Orn, or AIB;
(h) Asp at position 21 substituted with Glu, homoglutamic acid, homocysteic acid;
(i) Val at position 23 substituted with Ile;
(j) Gln at position 24 substituted with Asn, Ser, Thr, Ala, or AIB; and
(k) a conservative substitution at any of positions 2, 5, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 24, 27, 28, and 29.

34. An analog of glucagon (SEQ ID NO: 1) having GIP agonist activity comprising an acyl group, wherein the acyl group is attached to a spacer, wherein:

(i) the spacer is attached to the side chain of the amino acid at position 10 of the analog; or

(ii) the analog comprises an extension of 1 to 21 amino acids C-terminal to the amino acid at position 29 and the spacer is attached to the side chain of an amino acid corresponding to one of positions 37-43 relative to SEQ ID NO: 1;

wherein the analog exhibits at least 1% activity of native GIP at the GIP receptor.

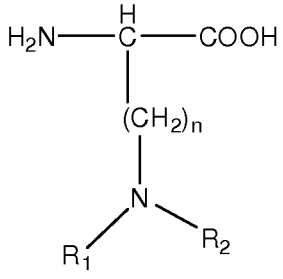
35. The analog of claim 34, comprising an amino acid sequence of SEQ ID NO: 1 with (i) an amino acid modification at position 1 that confers GIP agonist activity and (ii) at least one or both of:

(A) the analog comprises a lactam bridge between the side chains of amino acids at positions i and i+4 or between the side chains of amino acids at positions j and j+3, wherein i is 12, 13, 16, 17, 20 or 24, and wherein j is 17; and

(B) one, two, three, or all of the amino acids at positions 16, 20, 21, and 24 of the analog is substituted with an α,α-disubstituted amino acid;

and (iii) up to 6 further amino acid modifications

36. The analog of claim 35, wherein the analog comprises (i) an amino acid substitution of Ser at position 16 with an amino acid of Formula IV:



[Formula IV],

wherein n is 1 to 7, wherein each of R1 and R2 is independently selected from the group consisting of H, C_1-C_{18} alkyl, (C_1-C_{18} alkyl)OH, (C_1-C_{18} alkyl)NH_2, (C_1-C_{18} alkyl)SH, (C_0-C_4 alkyl)(C_3-C_6)cycloalkyl, (C_0-C_4 alkyl)(C_2-C_5 heterocyclic), (C_0-C_4 alkyl)(C_6-C_{10} aryl)R_7, and (C_1-C_4 alkyl)(C_3-C_9 heteroaryl), wherein R_7 is H or OH, and the side chain of the amino acid of Formula IV comprises a free amino group; and (ii) an amino acid substitution of the Gln at position 20 with an alpha, alpha-disubstituted amino acid.

37. The analog of any of claims 34 to 36, comprising amino acid modifications at one, two, or all of positions 27, 28, and 29.

38. The analog of claim 37, comprising Leu at position 27, Ala at position 28, and Gly or Thr at position 29.

39. The analog of any of claims 34 to 38, wherein the extension comprises the amino acid sequence of SEQ ID NO: 95 or 96.

40. The analog of any of claims 34 to 39, wherein the spacer is attached to the side chain of an amino acid of Formula I, Formula II, or Formula III.

41. The analog of claim 40, wherein the amino acid of Formula I is Lys.

42. The analog of any of claims 34 to 41, wherein the spacer is 3 to 10 atoms in length.

43. The analog of claim 42, wherein the spacer is an amino acid or dipeptide.

44. The analog of claim 43, wherein the spacer is 6-amino hexanoic acid.

45. The analog of claim 43, wherein the spacer is a dipeptide selected from the group consisting of: Ala-Ala, β-Ala- β-Ala, Leu-Leu, Pro-Pro, and γ-Glu- γ-Glu.

46. The analog of any of claims 34 to 45, wherein the total length of the spacer and the acyl group is about 14 to about 28 atoms in length.

47. The analog of any of claims 34 to 46, wherein the acyl group is a C12 to C18 fatty acid.

48. The analog of claim 47, wherein the acyl group is C14 or C16.

49. An analog of glucagon (SEQ ID NO: 1) having GIP agonist activity, with the following modifications:

(a) an amino acid modification at position 1 that confers GIP agonist activity,

(b) a lactam bridge between the side chains of amino acids at positions i and i+4 or between the side chains of amino acids at positions j and j+3, wherein i is 12, 13, 16, 17, 20 or 24, and wherein j is 17,

(c) amino acid modifications at one, two or all of positions 27, 28 and 29, and

(d) 1-6 further amino acid modifications,

wherein the EC50 of the analog for GIP receptor activation is about 10 nM or less.

50. The analog of claim 49 wherein the amino acid modification at position 1 is a substitution of His with an amino acid lacking an imidazole side chain.

51. The analog of claim 49 or 50 wherein

(a) the amino acid modification at position 1 is a substitution of His with a large, aromatic amino acid, optionally Tyr,

(b) the lactam bridge is between the amino acids at positions 16 and 20, wherein one of the amino acids at positions 16 and 20 is substituted with Glu, and the other of the amino acids at positions 16 and 20 is substituted with Lys, and

(c) the Met at position 27 is substituted with a large aliphatic amino acid, optionally Leu,

(d) the Asn at position 28 is substituted with a small aliphatic amino acid, optionally Ala, and

(e) the Thr at position 29 is substituted with a small aliphatic amino acid, optionally Gly.

52. The analog of any of claims 49 to 51 comprising one or more of the following modifications:

(a) amino acid modification at position 12, optionally substitution with Ile,

(b) amino acid modifications at positions 17 and 18, optionally substitution with Q at position 17 and A at position 18,

(c) addition of GPSSGAPPPS (SEQ ID NO: 95) to the C-terminus,

53. The analog of any of claims 49 to 52 comprising one or more of the following modifications:

(l) Ser at position 2 substituted with D-Ser, Ala, D-Ala, Gly, N-methyl-Ser, AIB, Val, or α-amino-N-butyric acid;

(m) Tyr at position 10 substituted with Trp, Lys, Orn, Glu, Phe, or Val;

(n) Linkage of an acyl group to a Lys at position 10;

(o) Lys at position 12 substituted with Arg;

(p) Ser at position 16 substituted with Glu, Gln, homoglutamic acid, homocysteic acid, Thr, Gly, or AIB;

(q) Arg at position 17 substituted with Gln;

(r) Arg at position 18 substituted with Ala, Ser, Thr, or Gly;

(s) Gln at position 20 substituted with Ala, Lys, Citrulline, Arg, Orn, or AIB;

(t) Asp at position 21 substituted with Glu, homoglutamic acid, homocysteic acid;

(u) Val at position 23 substituted with Ile;

(v) Gln at position 24 substituted with Asn, Ala, or AIB; and

(w) a conservative substitution at any of positions 2, 5, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 24, 27, 28, and 29.

or any combination thereof.

54. An analog of glucagon (SEQ ID NO: 1) having GIP agonist activity, with the following modifications:

(a) an amino acid modification at position 1 that confers GIP agonist activity,

(b) one, two, three, or all of the amino acids at positions 16, 20, 21, and 24 of the analog is substituted with an α,α-disubstituted amino acid,

(c) amino acid modifications at one, two or all of positions 27, 28 and 29, and

(d) 1-6 further amino acid modifications,

wherein the EC50 of the analog for GIP receptor activation is about 10 nM or less.

55. The analog of claim 54 wherein the amino acid modification at position 1 is a substitution of His with an amino acid lacking an imidazole side chain.

56. The analog of claim 54 or 55 wherein

(a) the amino acid modification at position 1 is a substitution of His with a large, aromatic amino acid, optionally Tyr,

(b) the α,α-disubstituted amino acid is AIB,

(c) the Met at position 27 is substituted with a large aliphatic amino acid, optionally Leu,

(d) the Asn at position 28 is substituted with a small aliphatic amino acid, optionally Ala, and

(e) the Thr at position 29 is substituted with a small aliphatic amino acid, optionally Gly.

57. The analog of any of claims 54 to 56 comprising one or more of the following modifications:

(a) amino acid modification at position 12, optionally substitution with Ile,

(b) amino acid modifications at positions 17 and 18, optionally substitution with Q at position 17 and A at position 18,

(c) addition of GPSSGAPPPS (SEQ ID NO: 95) to the C-terminus,

58. The analog of any of claims 54 to 57 comprising one or more of the following modifications:

(a) Ser at position 2 substituted with D-Ser, Ala, D-Ala, Gly, N-methyl-Ser, AIB, Val, or α-amino-N-butyric acid;

(b) Tyr at position 10 substituted with Trp, Lys, Orn, Glu, Phe, or Val;

(c) Linkage of an acyl group to a Lys at position 10;

(d) Lys at position 12 substituted with Arg;

(e) Ser at position 16 substituted with Glu, Gln, homoglutamic acid, homocysteic acid, Thr, Gly, or AIB;

(f) Arg at position 17 substituted with Gln;

(g) Arg at position 18 substituted with Ala, Ser, Thr, or Gly;

(h) Gln at position 20 substituted with Ala, Lys, Citrulline, Arg, Orn, or AIB;

(i) Asp at position 21 substituted with Glu, homoglutamic acid, homocysteic acid;

(j) Val at position 23 substituted with Ile;

(k) Gln at position 24 substituted with Asn, Ala, or AIB; and

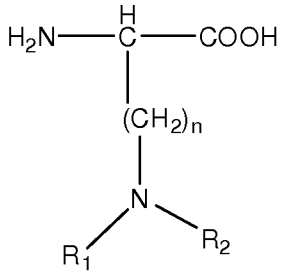
(l) a conservative substitution at any of positions 2, 5, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 24, 27, 28, and 29.

or any combination thereof.

59. An analog of glucagon (SEQ ID NO: 1) having GIP agonist activity, with the following modifications:

(a) an amino acid modification at position 1 that confers GIP agonist activity,

(b) an amino acid substitution of Ser at position 16 with an amino acid of Formula IV:



[Formula IV],

wherein n is 1 to 7, wherein each of R1 and R2 is independently selected from the group consisting of H, C_1-C_{18} alkyl, (C_1-C_{18} alkyl)OH, (C_1-C_{18} alkyl)NH_2, (C_1-C_{18} alkyl)SH, (C_0-C_4 alkyl)(C_3-C_6)cycloalkyl, (C_0-C_4 alkyl)(C_2-C_5 heterocyclic), (C_0-C_4 alkyl)(C_6-C_{10} aryl)R_7, and (C_1-C_4 alkyl)(C_3-C_9 heteroaryl), wherein R_7 is H or OH, and the side chain of the amino acid of Formula IV comprises a free amino group,

(c) an amino acid substitution of the Gln at position 20 with an alpha, alpha-disubstituted amino acid,

(d) amino acid modifications at one, two or all of positions 27, 28 and 29, and

(e) 1-6 further amino acid modifications,

wherein the EC50 of the analog for GIP receptor activation is about 10 nM or less.

60. The analog of claim 59, wherein the amino acid modification at position 1 is a substitution of His with an amino acid lacking an imidazole side chain.

61. The analog of claim 60, wherein the amino acid lacking an imidazole side chain is a large, aromatic amino acid.

62. The analog of claim 61, wherein the large, aromatic amino acid is Tyr.

63. The analog of any of claims 59 to 62, wherein the amino acid of Formula IV in (b) is homoLys, Lys, Orn, or 2,4-diaminobutyric acid (Dab).

64. The analog of any of claims 59 to 63, wherein the alpha, alpha di-substituted amino acid is AIB.

65. The analog of any of claims 59 to 64, wherein (i) the Met at position 27 is substituted with a large, aliphatic amino acid, optionally Leu, (ii) the Asn at position 28 is substituted with a small aliphatic amino acid, optionally Ala, or (iii) the Thr at position 29 is substituted with a small aliphatic amino acid, optionally Gly, or wherein the analog comprises a combination of (i), (ii), and (iii).

66. The analog of any of claims 59 to 65, further comprising the amino acid sequence of GPSSGAPPPS (SEQ ID NO: 95) or XGPSSGAPPPS (SEQ ID NO: 96) C-terminal to the amino acid at position 29.

67. The analog of any of claims 59 to 66, comprising one or more of the following modifications:

(a) Ser at position 2 substituted with D-Ser, Ala, D-Ala, Gly, N-methyl-Ser, AIB, Val, or α-amino-N-butyric acid;
(b) Gln at position 3 substituted with Glu;
(c) substitution of the amino acid Tyr at position 10 with an amino acid comprising a side chain covalently linked to an acyl group or alkyl group;
(d) addition of an amino acid comprising a side chain covalently linked to an acyl group or alkyl group as the C-terminal amino acid of the analog;
(e) Lys at position 12 substituted with Ile;
(f) Arg at position 17 substituted with Gln;
(g) Arg at position 18 substituted with Ala;
(h) Asp at position 21 substituted with Glu; and
(i) Gln at position 24 substituted with Asn;

68. The analog of claim 66 comprising (a) an amino acid modification at position 2 that confers resistance to DPP-IV, and (b) an amino acid at position 40 covalently linked to an acyl group or alkyl group.

69. The analog of claim 68 comprising a hydrophilic moiety linked to an amino acid at position 24.

70. An analog of glucagon (SEQ ID NO: 1) having GIP agonist activity, comprising:

(a) an amino acid modification at position 1 that confers GIP agonist activity, and

(b) an extension of 1 to 21 amino acids C-terminal to the amino acid at position 29, wherein at least one of the amino acids of the extension, corresponding to any of positions 37-43 relaive to SEQ ID NO: 1, is acylated or alkylated,

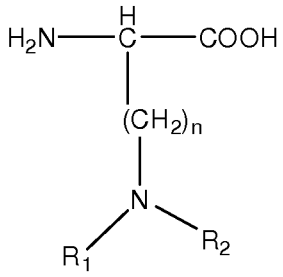
wherein the EC50 of the analog for GIP receptor activation is about 10 nM or less.

71. The analog of claims 70, wherein the analog further comprises one of the following modifications:

(A) the analog comprises a lactam bridge between the side chains of amino acids at positions i and i+4 or between the side chains of amino acids at positions j and j+3, wherein i is 12, 13, 16, 17, 20 or 24, and wherein j is 17;

(B) one, two, three, or all of the amino acids at positions 16, 20, 21, and 24 of the analog is substituted with an α,α-disubstituted amino acid; or

(C) the analog comprises (i) an amino acid substitution of Ser at position 16 with an amino acid of Formula IV:



[Formula IV],

wherein n is 1 to 7, wherein each of R1 and R2 is independently selected from the group consisting of H, C_1-C_{18} alkyl, (C_1-C_{18} alkyl)OH, (C_1-C_{18} alkyl)NH_2, (C_1-C_{18} alkyl)SH, (C_0-C_4 alkyl)(C_3-C_6)cycloalkyl, (C_0-C_4 alkyl)(C_2-C_5 heterocyclic), (C_0-C_4 alkyl)(C_6-C_{10} aryl)R_7, and (C_1-C_4 alkyl)(C_3-C_9 heteroaryl), wherein R_7 is H or OH, and the side chain of the amino acid of Formula IV comprises a free amino group; and (ii) an amino acid substitution of the Gln at position 20 with an alpha, alpha-disubstituted amino acid.

72. The analog of claim 70 or 71, comprising further amino acid modifications at one or both of positions 27 and 28.

73. The analog of any of claims 70 to 72, wherein the amino acid modification at position 1 is a substitution of His with an amino acid lacking an imidazole side chain.

74. The analog of claim 73, wherein the amino acid lacking an imidazole side chain is a large, aromatic amino acid.

75. The analog of claim 74, wherein the large, aromatic amino acid is Tyr.

76. The analog of any of claims 70 to 75, wherein the 1 to 21 amino acids comprises the amino acid sequence of GPSSGAPPPS (SEQ ID NO: 95), or XGPSSGAPPPS (SEQ ID NO: 96), wherein X is any amino acid or an amino acid sequence containing one or more conservative substitutions relative to SEQ ID NO: 95 or 96.

77. The analog of claim 76, wherein the 1 to 21 amino acids comprises the amino acid sequence of GPSSGAPPPS (SEQ ID NO: 95), or XGPSSGAPPPS (SEQ ID NO: 96), wherein X is any amino acid.

78. The analog of any of claims 70 to 77, wherein the acylated or alkylated amino acid is an amino acid of Formula I, II, or III.

79. The analog of claim 78, wherein the acylated or alkylated amino acid is Lys.

80. The analog of any of claims 70 to 79, wherein the acylated or alkylated amino acid is located at any of positions 37, 38, 39, 40, 41, 42 or 43 of the analog.

81. The analog of claim 80, wherein the acylated or alkylated amino acid is located at position 40 of the analog.

82. The analog of any of claims 70 to 81, wherein the analog comprises a lactam bridge between the amino acids at positions 16 and 20, wherein one of the amino

acids at positions 16 and 20 is substituted with Glu, and the other of the amino acids at positions 16 and 20 is substituted with Lys.

83. The analog of any of claims 70 to 81, wherein the analog comprises a substitution at one, two, three or all of the amino acids at positions 16, 20, 21 or 24 with an the α,α-disubstituted amino acid is AIB.

84. The analog of claim 83, wherein the analog comprises an AIB at position 20.

85. The analog of any of claims 70 to 81, wherein the analog comprises a homoLys, Lys, Orn, or 2,4-diaminobutyric acid (Dab) at position 16 and an AIB at position 20.

86. The analog of any of claims 70 to 85, comprising one or more of the following modifications:

(a) Ser at position 2 substituted with D-Ser, Ala, D-Ala, Gly, N-methyl-Ser, AIB, Val, or α-amino-N-butyric acid;
(b) Gln at position 3 substituted with Glu;
(c) substitution of the amino acid Tyr at position 10 with an amino acid comprising a side chain covalently linked to an acyl group or alkyl group;
(e) Lys at position 12 substituted with Ile;
(f) Arg at position 17 substituted with Gln;
(g) Arg at position 18 substituted with Ala;
(h) Asp at position 21 substituted with Glu; and
(i) Gln at position 24 substituted with Asn;

87. The analog of any of claims 70 to 86 comprising an amino acid modification at position 2 that confers resistance to DPP-IV.

88. The analog of claim 87 wherein the amino acid at position 2 is selected from the group consisting of D-Ser, Ala, D-Ala, Gly, N-methyl-Ser, AIB, Val, or α-amino-N-butyric acid.

89. The analog of any of claims 70 to 88, comprising up to 6 further amino acid modifications.

90. A glucagon analog comprising the amino acid sequence according to any one of SEQ ID NOS: 227, 228, 229 or 230 and an extension of 1 to 21 amino acids C-terminal to the amino acid at position 29,

wherein the EC50 of the analog for GIP receptor activation is about 10 nM or less.

91. The analog of claim 90, wherein the extension of 1 to 21 amino acids comprises the amino acid sequence of GPSSGAPPPS (SEQ ID NO: 95) or XGPSSGAPPPS (SEQ ID NO: 96), wherein X is any amino acid, or an amino acid sequence containing one or more conservative substitutions relative to SEQ ID NO: 95 or 96.

92. The analog of claim 90, wherein the extension of 1 to 21 amino acids comprises the amino acid sequence of GPSSGAPPPS (SEQ ID NO: 95) or XGPSSGAPPPS (SEQ ID NO: 96), wherein X is any amino acid.

93. The analog of any of claims 90 to 92, wherein at least one of the amino acids of the extension, at a position corresponding to any of positions 37-43, is acylated or alkylated.

94. The analog of claim 93, wherein the acylated or alkylated amino acid is located at position 40 of the analog.

95. The analog of any of claims 90 to 94, wherein the glucagon peptide is covalently linked to a hydrophilic moiety at amino acid position 24.

96. The analog of claim 95, wherein the hydrophilic moiety is covalently linked to Lys, Cys, Orn, homocysteine, or acetyl-phenylalanine.

97. The analog of claim 95 or 96, wherein the hydrophilic moiety is a polyethylene glycol (PEG).

98. The analog of any of claims 90 to 97, further comprising up to 6 further amino acid modifications.

99. The analog of claim 98 comprising one or more of the following modifications:

(a) the amino acid at position 2 is any one of D-Ser, Ala, D-Ala, Gly, N-methyl-Ser, AIB, Val, or α-amino-N-butyric acid;
(a) the amino acid at position 10 is Tyr, Trp, Lys, Orn, Glu, Phe, or Val;
(b) linkage of an acyl group to a Lys at position 10;
(c) the amino acid at position 12 is Ile, Lys or Arg;
(d) the amino acid at position 16 is any one of Ser, Glu, Gln, homoglutamic acid, homocysteic acid, Thr, Gly, or AIB;
(e) the amino acid at position 17 is Gln or Arg;
(f) the amino acid at position 18 is any one of Ala, Arg, Ser, Thr, or Gly;
(g) the amino acid at position 20 is any one of Ala, Lys, Citrulline, Arg, Orn, or AIB or another alpha, alpha-disubstituted amino acid;
(h) the amino acid at position 21 is any one of Glu, Asp, homoglutamic acid, homocysteic acid;
(i) the amino acid at position 23 is Val or Ile;
(j) the amino acid at position 24 is any one of Gln, Asn, Ala, or AIB; and
(k) one or more conservative substitutions at any of positions 2, 5, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 24, 27, 28, and 29.

100. An analog comprising an amino acid sequence selected from the group consisting of SEQ ID NOs: 99-141, 144-164, 166, 192-207, 209-221 and 223.

101. An analog comprising an amino acid sequence selected from the group consisting of SEQ ID NOs: 167-169,173-178 and 225.

102. An analog comprising an amino acid sequence selected from the group consisting of SEQ ID NOs: 5-94.

103. The analog of claim 53 or 58, wherein the acyl group is linked to the Lys via a spacer.

104. The analog of any of claims 67 to 69, 86, and 99, wherein the acyl group or alkyl group is linked to the amino acid side chain via a spacer.

105. The analog of any of claims 70, 93, and 94, wherein the acylated or alkylated amino acid at any of positions 37-43 relative to SEQ ID NO: 1 is covalently attached to an acyl or alkyl group via a spacer.

106. The analog of claim 105, wherein the acylated or alkylated amino acid is located at position 40 relative to SEQ ID NO: 1.

107. The analog of any of claims 100 to 102, wherein, when the analog comprises an acyl or alkyl group, the acyl or alkyl group is attached to the analog via a spacer.

108. The analog of any of claims 103 to107, wherein the spacer is 3 to 10 atoms in length.

109. The analog of claim 108, wherein the spacer is an amino acid or dipeptide.

110. The analog of claim 109, wherein the spacer is 6-amino hexanoic acid.

111. The analog of claim 109, wherein the spacer is a dipeptide selected from the group consisting of: Ala-Ala, β-Ala- β-Ala, Leu-Leu, Pro-Pro, and γ-Glu- γ-Glu.

112. The analog of any of claims 103 to 111, wherein the total length of the spacer and the acyl group is about 14 to about 28 atoms in length.

113. The analog of claim 103 to 112, wherein the acyl group is a C12 to C18 fatty acyl group.

114. The analog of claim 113, wherein the acyl group is a C14 or C16 fatty acyl group.

115. The analog of any of the preceding claims, wherein the EC50 of the analog for GIP receptor activation is about 1 nM or less.

116. The analog of any of the preceding claims, wherein the analog has at least about 4% of the activity of wild-type GIP (SEQ ID NO: 4) at the GIP receptor.

117. The analog of any of the preceding claims, wherein the EC50 of the analog for GLP-1 receptor activation is about 1 nM or less.

118. The analog of any of the preceding claims, wherein the analog has at least about 4% of the activity of GLP-1 (SEQ ID NO: 2) at the GLP-1 receptor.

119. The analog of any of the preceding claims, wherein the EC50 of the analog for glucagon receptor activation is about 1 nM or less.

120. The analog of any of the preceding claims, wherein the analog has at least about 20% of the activity of glucagon at the glucagon receptor.

121. The analog of any of the preceding claims excluding claim 120, wherein the analog comprises an amino acid modification at position 3 and has less than 1% of the activity of glucagon at the glucagon receptor.

122. The analog of any of the preceding claims excluding claims 117 and 118 , wherein the analog comprises an amino acid modification at position 7 and has less than about 10% of the activity of GLP-1 at the GLP-1 receptor.

123. The analog of any of the preceding claims, wherein the glucagon peptide is covalently linked to a hydrophilic moiety at any of amino acid positions 19, 20, 23, 24, 27, 32, 43 or the C-terminus.

124. The analog of claim 123, wherein the glucagon peptide is covalently linked to a hydrophilic moiety at amino acid position 27 or 43.

125. The analog of claim 123 or 124, wherein the hydrophilic moiety is covalently linked to Lys, Cys, Orn, homocysteine, or acetyl-phenylalanine.

126. The analog of any of claims 123 to 125, wherein the hydrophilic moiety is a polyethylene glycol (PEG).

127. The analog of claim 126, wherein the PEG has a molecular weight of about 1,000 Daltons to about 40,000 Daltons.

128. The analog of claim 126, wherein the PEG has a molecular weight of about 20,000 Daltons to about 40,000 Daltons.

129. The analog of any of claims 123 to 128 wherein the EC50 of the analog for GIP receptor activation is about 10 nM or less.

130. The analog of any of claims 123 to 128, wherein the analog has at least about 0.4% of the activity of wild-type GIP (SEQ ID NO: 4) at the GIP receptor.

131. The analog of any of claims 123 to 130, wherein the EC50 of the analog for GLP-1 receptor activation is about 10 nM or less.

132. The analog of any of claims 123 to 130, wherein the analog has at least about 0.4% of the activity of GLP-1 (SEQ ID NO: 2) at the GLP-1 receptor.

133. The analog of any of claims 123 to 132, wherein the EC50 of the analog for glucagon receptor activation is about 10 nM or less.

134. The analog of any of claims 123 to 133, wherein the analog has at least 2% of the activity of glucagon at the glucagon receptor.

135. The analog of any of the preceding claims excluding claims 122, wherein the GIP potency of the analog is within about 15-fold of GLP-1 potency of the analog.

136. The analog of any of the preceding claims excluding 121, wherein the GIP potency of the analog is within about 15-fold of the glucagon potency of the analog.

137. A dimer comprising two peptides bound via a linker, wherein at least one of the two peptides is an analog of any of claims 1 to 136.

138. The dimer of claim 137, wherein the dimer is a homodimer.

139. The dimer of claim 137 or 138, wherein the linker is selected from the group consisting of a bifunctional thiol crosslinker and a bifunctional amine crosslinker.

140. An conjugate covalently linked to an analog of any of claims 1 to 136, a dimer of any of claims 137 to 139, or a combination thereof.

141. A fusion peptide comprising an analog of any of claims 1 to 136 or a dimer of any of claims 137 to 136 fused to a second peptide.

142. A pharmaceutical composition comprising the analog of any of claims 1 to 136, a dimer of any of claims 137 to 139, a conjugate of claim 140, a fusion peptide of claim 141, or a combination thereof, and a pharmaceutically acceptable carrier.

143. A kit comprising a pharmaceutical composition of claim 142 and a device for administering said pharmaceutical composition to the patient.

144. The kit of claim 143, wherein the device comprises a syringe comprising the pharmaceutical composition.

145. A method of reducing weight gain or inducing weight loss, comprising administering to a patient in need thereof a pharmaceutical composition of claim 142 in an amount effective to reduce weight gain or induce weight loss.

146. A method of treating diabetes, comprising administering to a patient in need thereof a pharmaceutical composition of claim 142 in an amount effective to lower blood glucose levels.

147. A method of inducing temporary paralysis of the intestinal tract, comprising administering to a patient in need thereof a pharmaceutical composition of claim 142 in an amount effective to induce temporary paralysis of the intestinal tract.