(19) DANMARK

Patent- og Varemærkestyrelsen

(10) **DK/EP 3248610 T5**

(12) Rettet oversættelse af europæisk patentskrift

(51) Int.Cl.: ***A 61 K 38/18 (2006.01)*** ***A 61 K 38/00 (2006.01)*** ***C 07 K 14/50 (2006.01)***

(45) Oversættelsen bekendtgjort den: **2024-10-07**

(80) Dato for Den Europæiske Patentmyndigheds bekendtgørelse om meddelelse af patentet: **2023-12-20**

(86) Europæisk ansøgning nr.: **17167682.8**

(86) Europæisk indleveringsdag: **2010-05-04**

(87) Den europæiske ansøgnings publiceringsdag: **2017-11-29**

(30) Prioritet: **2009-05-05 US 175736 P** **2009-12-09 US 285118 P**

(62) Stamansøgningsnr: **10718381.6**

(84) Designerede stater: **AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO SE SI SK SM TR**

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(54) Benævnelse: **FGF21-MUTANTER OG ANVENDELSER DERAF**

(56) Fremdragne publikationer:
WO-A2-2006/028595
WO-A2-2006/065582
WO-A2-2009/149171

DESCRIPTION

[0001] This application claims the benefit of U.S. Provisional Application No. 61/175,736 filed May 5, 2009 and U.S. Provisional Application No. 61/285,118 filed December 9, 2009,

FIELD OF THE INVENTION

[0002] The invention relates to nucleic acid molecules encoding FGF21 mutant polypeptides, FGF21 mutant polypeptides, pharmaceutical compositions comprising FGF21 mutant polypeptides, and methods for treating metabolic disorders using such nucleic acids, polypeptides, or pharmaceutical compositions.

BACKGROUND OF THE INVENTION

[0003] FGF21 is a secreted polypeptide that belongs to a subfamily of fibroblast growth factors (FGFs) that includes FGF19, FGF21, and FGF23 (Itoh et al., 2004, Trend Genet. 20: 563-69). FGF21 is an atypical FGF in that it is heparin independent and functions as a hormone in the regulation of glucose, lipid, and energy metabolism.

[0004] FGF21 was isolated from a liver cDNA library as a hepatic secreted factor. It is highly expressed in liver and pancreas and is the only member of the FGF family to be primarily expressed in liver. Transgenic mice overexpressing FGF21 exhibit metabolic phenotypes of slow growth rate, low plasma glucose and triglyceride levels, and an absence of age-associated type 2 diabetes, islet hyperplasia, and obesity. Pharmacological administration of recombinant FGF21 protein in rodent and primate models results in normalized levels of plasma glucose, reduced triglyceride and cholesterol levels, and improved glucose tolerance and insulin sensitivity. In addition, FGF21 reduces body weight and body fat by increasing energy expenditure, physical activity, and metabolic rate. Experimental research provides support for the pharmacological administration of FGF21 for the treatment of type 2 diabetes, obesity, dyslipidemia, and other metabolic conditions or disorders in humans.

[0005] Human FGF21 has a short half-life *in vivo.* In mice, the half-life of human FGF21 is 1 to 2 hours, and in *cynomolgus* monkeys, the half-life is 2.5 to 3 hours. In developing an FGF21 protein for use as a therapeutic in the treatment of type 2 diabetes, an increase in half-life would be desirable. FGF21 proteins having an enhanced half-life would allow for less frequent dosing of patients being administered the protein. Such proteins are described herein.
WO2006/028595 and WO2006/065582 disclose FGF21 mutants at position 167 and 121.

SUMMARY OF THE INVENTION

[0006] A polypeptide comprising an amino acid sequence of SEQ ID NO: 4 comprising: (a) an amino acid substitution at position 180; and (b) one amino acid substitution selected from the group consisting of: (i) a substitution at position 171; and (ii) a substitution at position 98; as specified in the appended claims.

[0007] In one embodiment the isolated polypeptide comprises a substitution at position 98 and a substitution at position 180 and wherein: (a) the substitution at position 98 is arginine, and (b) the substitution at position 180 is selected from the group consisting of glycine, proline, serine or glutamic acid In one embodiment the residue at position 98 is arginine and the residue at position 180 is glutamic acid. Also provided is a fusion polypeptide comprising the isolated polypeptide fused to a heterologous amino acid sequence. In one embodiment the heterologous amino acid sequence is an Fc domain or fragment thereof, and can comprise the amino acid sequence of SEQ ID NO:11. In another embodiment the polypeptide is fused to the Fc domain via a linker and in yet another embodiment the linker comprises GGGGSGGGGSGGGGS (SEQ ID NO:31). Also disclosed is a multimer comprising two or more of the fusion polypeptides. A pharmaceutical composition comprising the isolated polypeptide and a pharmaceutically acceptable formulation agent, such as a hydrogel, is also disclosed. In another aspect, a method of treating a metabolic disorder is provided and in one embodiment comprises administering to a human patient in need thereof a pharmaceutical composition provided herein. In one embodiment the metabolic disorder is diabetes and in another the metabolic disorder is obesity. Nucleic acids encoding the isolated polypeptide are also provided The nucleic acid can be present in a vector, which can itself be present in a host cell. In still another embodiment the polypeptide comprises: (a) an amino-terminal truncation of no more than 8 amino acid residues, wherein the polypeptide is capable of lowering blood glucose in a mammal; (b) a carboxyl-terminal truncation of no more than 12 amino acid residues, wherein the polypeptide is capable of lowering blood glucose in a mammal; or (c) an amino-terminal truncation of no more than 8 amino acid residues and a carboxyl-terminal truncation of no more than 12 amino acid residues, wherein the polypeptide is capable of lowering blood glucose in a mammal. In still other embodiments the polypeptide is covalently linked to one or more polymers, such as PEG.

[0008] In another embodiment the isolated polypeptide comprises a substitution at position 171 and a substitution at position 180 and wherein: (a) the substitution at position 180 is selected from the group consisting of glycine, proline, serine and glutamic acid; (b) the substitution at position 171 is glycine, In one embodiment the residue at position 171 is glycine and the residue at position 180 is glutamic acid. Also provided is a fusion polypeptide comprising the isolated polypeptide fused to a heterologous amino acid sequence. In one embodiment the heterologous amino acid sequence is an Fc domain or fragment thereof, and can comprise the amino acid sequence of SEQ ID NO:11. In another embodiment the polypeptide is fused to the Fc domain via a linker and in yet another embodiment the linker comprises GGGGSGGGGSGGGGS (SEQ ID NO:31). Also disclosed is a multimer comprising two or more of the fusion polypeptides. A pharmaceutical composition comprising the isolated polypeptide and a pharmaceutically acceptable formulation agent, such as a hydrogel, is also disclosed. In another aspect, a method of treating a metabolic disorder is provided and in one embodiment comprises administering to a human patient in need thereof a pharmaceutical composition provided herein. In one embodiment the metabolic disorder is diabetes and in another the metabolic disorder is obesity. Nucleic acids encoding the isolated polypeptide are also provided The nucleic acid can be present in a vector, which can itself be present in a host cell. In still another embodiment the polypeptide comprises: (a) an amino-terminal truncation of no more than 8 amino acid residues, wherein the polypeptide is capable of lowering blood glucose in a mammal; (b) a carboxyl-terminal truncation of no more than 12 amino acid residues, wherein the polypeptide is capable of lowering blood glucose in a mammal; or (c) an amino-terminal truncation of no more than 8 amino acid residues and a carboxyl-terminal truncation of no more than 12 amino acid residues, wherein the polypeptide is capable of lowering blood glucose in a mammal. In still other embodiments the polypeptide is covalently linked to one or more polymers, such as PEG.

[0009] Specific embodiments of the invention will become evident from the following more detailed description of certain embodiments and the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010]

Figures 1A-1B show the results of an ELK-luciferase activity assay performed on the FGF21 truncation mutants 7-181 and 8-181 (Figure 1A) and the FGF21 truncation mutants 1-172, 1-171, 1-169, and 1-164 (Figure 1B); each panel shows the results obtained for a human FGF21 control.

Figure 2 shows the results of an ELK-luciferase activity assay performed on a human FGF21 control and the FGF21 truncation mutants 3-181, 4-181, 5-181, 7-181, 8-181, 1-180, 1-178, 1-177, 1-176, 1-175, 1-174, 1-173, 1-172, 9-181, and 1-149.

Figure 3 shows the blood glucose levels measured in mice injected with PBS (solid bar), human FGF21 control (open bar), or the FGF21 truncation mutants 8-181 (gray bar) and 9-181 (stippled bar).

Figure 4 shows the percent change in blood glucose levels measured in mice injected with PBS (solid circles), an Fc-FGF21 control (WT) (open circles), or truncated Fc-FGF21 fusion proteins comprising amino acid residues 5-181 (solid triangles) or 7-181 (open triangles).

Figure 5 shows the percent change in blood glucose levels measured in mice injected with PBS (solid circles), an FGF21-Fc control (WT) (open circles), a truncated FGF21-Fc fusion protein comprising residues 1-175 (solid triangles), or a truncated Fc-FGF21 protein comprising amino acid residues 1-171 (open triangles).

Figures 6A-6D show the results of liquid chromatography-mass spectrometry (LC-MS) analysis of a human Fc-(G5)-FGF21 (SEQ ID NO: 107) control sample (Figure 6A) and samples of Fc-

(G5)-FGF21 drawn from mice at 6 hours (Sample D6; Figure 6B), 24 hours (Sample D24; Figure 6C), and 48 hours (Sample D48; Figure 6D) after injection.

Figures 7A-7D show the results if LC-MS analysis of a mammalian-derived human FGF21-(G3)-Fc (SEQ ID NO: 105) control sample (Figure 7A) and samples of FGF21-(G3)-Fc drawn from mice at 6 hours (Sample E6; Figure 7B), 24 hours (Sample E24; Figure 7C), and 48 hours (Sample E48; Figure 7D) after injection.

Figures 8A-8D show the results of LC-MS analysis of an Fc-(L15)-FGF21 (SEQ ID NO:49) control sample (Figure 8A) and samples of Fc-(L15)-FGF21 drawn from mice at 6 hours (Figure 8B), 24 hours (Figure 8C), and 48 hours (Figure 8D) after injection.

Figures 9A-9D show the results of LC-MS analysis of an FGF21-(L15)-Fc (SEQ ID NO:41) control sample (Figure 9A) and samples of FGF21-(L15)-Fc drawn from mice at 6 hours (Figure 9B), 24 hours (Figure 9C), and 48 hours (Figure 9D) after injection.

Figures 10A-10B show the cleavage sites identified by LC-MS analysis of Fc-(L15)-FGF21 (Figure 10A, SEQ ID NO:49) and FGF21-(L15)-Fc (Figure 10B, SEQ ID NO:41) fusion proteins injected into mice.

Figure 11 shows the blood glucose levels measured in mice injected with PBS (solid bar), Fc-(L15)-FGF21 (SEQ ID NO:49) (open bar), or the Fc-(L15)-FGF21 mutants Fc-(L15)-FGF21 G170E (SEQ ID NO:51) (gray bar), Fc-(L15)-FGF21 P171A (SEQ ID NO:53) (stippled bar), Fc-(L15)-FGF21 S172L (SEQ ID NO:55) (open diagonally crosshatched bar), Fc-(L15)-FGF21(G170E, P171A, S172L) (SEQ ID NO:59) (solid horizontally crosshatched bar), or Fc-(L15)-FGF21 G151A (SEQ ID NO:61) (open diagonally crosshatched bar).

Figure 12 shows the percent change in blood glucose levels measured in mice injected with PBS (solid circles), Fc-(L15)-FGF21 (SEQ ID NO:49) (open circles), or the Fc-(L15)-FGF21 mutants Fc-(L15)-FGF21 G170E (SEQ ID NO:51) (solid triangles), Fc-(L15)-FGF21 P171A (SEQ ID NO:53) (open triangles), Fc-(L15)-FGF21 S172L (SEQ ID NO:55) (solid diamonds), Fc-(L15)-FGF21(G170E, P171A, S172L) (SEQ ID NO:59) (open diamonds), or Fc-(L15)-FGF21 G151A (SEQ ID NO:61) (solid squares).

Figure 13 shows the blood glucose levels measured in mice injected with PBS (solid bar), Fc-(L15)-FGF21 (SEQ ID NO:49) (open bar), or the Fc-(L15)-FGF21 mutants Fc-(L15)-FGF21(P150A, G151A, 1152V) (gray bar), Fc-(L15)-FGF21 G170E (SEQ ID NO:51) (open diagonally crosshatched bar), Fc-(L15)-FGF21(G170E, P171A) (SEQ ID NO:63) (gray diagonally crosshatched bar), or Fc-(L15)-FGF21(G170E, S172L) (SEQ ID NO:67) (open diagonally crosshatched bar).

Figure 14 shows the percent change in blood glucose levels measured in mice injected with PBS (solid squares), Fc-(L15)-FGF21 (SEQ ID NO:49) (open squares), or the Fc-(L15)-FGF21 mutants Fc-(L15)-FGF21(P150A, G151A, I152V) (SEQ ID NO:65) (solid inverted triangles), Fc-(L15)-FGF21 G170E (SEQ ID NO:51) (open inverted triangles), Fc-(L15)-FGF21(G170E, P171A) (SEQ ID NO:63) (solid circles), or Fc-(L15)-FGF21(G170E, S172L) (SEQ ID NO:67) (open circles).

Figure 15 shows the blood glucose levels measured in mice injected with PBS (solid bar) or the Fc-(L15)-FGF21 mutants Fc-(L15)-FGF21 G170E (SEQ ID NO:51) (open bar), Fc-(L15)-FGF21 G170A (SEQ ID NO:69) (gray bar), Fc-(L15)-FGF21 G170C (SEQ ID NO:71) (open crosshatched bar), Fc-(L15)-FGF21 G170D (SEQ ID NO:73) (gray and white bar), Fc-(L15)-FGF21 G170N (SEQ ID NO:75) (solid crosshatched bar), or Fc-(L15)-FGF21 G170S (SEQ ID NO:77) (open crosshatched bar).

Figure 16 shows the percent change in blood glucose levels measured in mice injected with PBS (solid circles) or the Fc-(L15)-FGF21 mutants Fc-(L15)-FGF21 G170E (SEQ ID NO:51) (open circles), Fc-(L15)-FGF21 G170A (SEQ ID NO:69) (solid triangles), Fc-(L15)-FGF21 G170C (SEQ ID NO:71) (open triangles), Fc-(L15)-FGF21 G170D (SEQ ID NO:73) (solid diamonds), Fc-(L15)-FGF21 G170N (SEQ ID NO:75) (open diamonds), or Fc-(L15)-FGF21 G170S (SEQ ID NO:77) (inverted solid triangles).

Figure 17 shows the blood glucose levels measured in mice injected with PBS (solid bar) or the Fc-(L15)-FGF21 mutants Fc-(L15)-FGF21 G170E (SEQ ID NO:51) (open bar), Fc-(L15)-FGF21 P171E (SEQ ID NO:79) (gray bar), Fc-(L15)-FGF21 P171H (SEQ ID NO:81) (solid crosshatched bar), Fc-(L15)-FGF21 P171Q (SEQ ID NO:83) (open crosshatched bar), Fc-(L15)-FGF21 P171T (SEQ ID NO:85) (stippled bar), or Fc-(L15)-FGF21 P171Y (SEQ ID NO:87) (gray crosshatched bar).

Figure 18 shows the percent change in blood glucose levels measured in mice injected with PBS (solid circles) or the Fc-(L15)-FGF21 mutants Fc-(L15)-FGF21 G170E (SEQ ID NO:51) (open circles), Fc-(L15)-FGF21 P171E (SEQ ID NO:79) (solid triangles), Fc-(L15)-FGF21 P171H (SEQ ID NO:81) (open triangles), Fc-(L15)-FGF21 P171Q (SEQ ID NO:83) (solid diamonds), Fc-(L15)-FGF21 P171T (SEQ ID NO:85) (open diamonds), or Fc-(L15)-FGF21 P171Y (SEQ ID NO:87) (solid squares).

Figures 19A-19D show the results of LC-MS analysis of an Fc-(L15)-FGF21 control sample (Figure 19A, SEQ ID NO:49) and samples drawn from mice at time 6 hours (Figure 19B), 24 hours (Figure 19C), and 48 hours (Figure 19D) after injection.

Figures 20A-20D show the results of LC-MS analysis of an Fc-(L15)-FGF21 G170E control sample (Figure 20A, SEQ ID NO:51) and samples of Fc-(L15)-FGF21 G170E drawn from mice at 6 hours (Figure 20B), 24 hours (Figure 20C), and 48 hours (Figure 20D) after injection.

Figures 21A-21D show the results of LC-MS analysis of an Fc-(LI5)-FGF21 P171A control sample (Figure 21A, SEQ ID NO:53) and samples of Fc-(L15)-FGF21 P171A drawn from mice at 6 hours (Figure 21B), 24 (Figure 21C), and 48 hours (Figure 21D) after injection.

Figures 22A-22D show the results of LC-MS analysis of an Fc-(L15)-FGF21 S172L control sample (Figure 22A, SEQ ID NO:55) and samples of Fc-(L15)-FGF21 S172L drawn from mice at 6 hours (Figure 22B), 24 hours (Figure 22C), and 48 hours (Figure 22D) after injection.

Figures 23A-23D show the cleavage sites identified by LC-MS analysis of Fc-(L15)-FGF21 (Figure 23A, SEQ ID NO:49), Fc-(L15)-FGF21 G170E (Figure 23B, SEQ ID NO:51), Fc-(L15)-

FGF21 P171A (Figure 23C, SEQ ID NO:53), and Fc-(L15)-FGF21 S172L (Figure 23D, SEQ ID NO:55) fusion proteins injected in mice.

Figures 24A-24C show the results of an ELK-luciferase activity assay performed on the FGF21 mutants FGF21 L99R (SEQ ID NO:109), FGF21 L99D (SEQ ID NO:111), and FGF21 A111T (SEQ ID NO:113) (Figure 24A); the FGF21 mutants FGF21 A129D (SEQ ID NO:115), FGF21 A129Q (SEQ ID NO:117), and FGF21 A134K (SEQ ID NO:119) (Figure 24B); and the FGF21 mutants FGF21 A134Y(SEQ ID NO:121), FGF21 A134E (SEQ ID NO:123), and FGF21 A129K (SEQ ID NO:125) (Figure 24C); each panel shows the results obtained for a human FGF21 control.

Figures 25A-25D show the results of an ELK-luciferase activity assay performed on the Fc-(L15)-FGF21 mutants Fc-(L15)-FGF21 P171G (SEQ ID NO:89), Fc-(L15)-FGF21 P171S (SEQ ID NO:91), and Fc-(L15)-FGF21 P171T (SEQ ID NO:85) (Figure 25A); the Fc-(L15)-FGF21 mutants Fc-(L15)-FGF21 P171Y (SEQ ID NO:87), Fc-(L15)-FGF21 P171W (SEQ ID NO:93), and Fc-(L15)-FGF21 P171C (SEQ ID NO:95) (Figure 25B); Fc-(L15)-FGF21 (SEQ ID NO:49), Fc-(L15)-FGF21 (A45K, G170E) (SEQ ID NO:97), and FGF21 A45K (SEQ ID NO:99) (Figure 25C); and Fc-(L15)-FGF21 (SEQ ID NO:49), Fc-(L15)-FGF21 P171E (SEQ ID NO:79), and Fc-(L15)-FGF21 (A45K, G170E) (SEQ ID NO:97) (Figure 25D); each panel shows the results obtained for a human FGF21 control.

Figures 26A-B show the aggregation as a function of time for wild type mature FGF21 and various FGF21 mutants; Figure 26A shows the change in percent aggregation for an FGF21 control (WT, solid diamonds) and FGF21 A45K (solid circles) following incubation of 65 mg/mL protein at 4°C for 1, 2, and 4 days, while Figure 26B shows the change in percent aggregation for an FGF21 control (WT) (SEQ ID NO:4) and FGF21 P78C (SEQ ID NO:127), FGF21 P78R (SEQ ID NO:129), FGF21 L86T (SEQ ID NO:131), FGF21 L86C (SEQ ID NO:133), FGF21 L98C (SEQ ID NO:135), FGF21 L98R (SEQ ID NO:137), FGF21 A111T (SEQ ID NO:113), FGF21 A129D (SEQ ID NO:115), FGF21 A129Q (SEQ ID NO:117), FGF21 A129K (SEQ ID NO:125), FGF21 A134K (SEQ ID NO:119), FGF21 A134Y (SEQ ID NO:121), and FGF21 A134E (SEQ ID NO:123) (all labeled on the plot) following incubation of 65 mg/mL protein at 4°C for 1, 6, and 10 days.

Figure 27 shows the results of an ELK-luciferase activity assay performed on a human FGF21 control and the FGF21 mutants FGF21 A45K (SEQ ID NO:99), FGF21 L52T (SEQ ID NO:139), and FGF21 L58E (SEQ ID NO:141).

Figure 28A is a plot showing the change in aggregation levels for the Fc-(L15)-FGF21 mutants Fc-(L15)-FGF21(6-181, G170E) (SEQ ID NO:101) (solid diamonds), Fc-(L15)-FGF21 (A45K, G170E) (SEQ ID NO:97) (open squares), Fc-(L15)-FGF21 P171E (SEQ ID NO:79) (solid triangles), Fc-(L15)-FGF21 P171A (SEQ ID NO:53) (crosses), Fc-(L15)-FGF21 G170E (SEQ ID NO:51) (open triangles) , and an FGF21 control (solid circles) following incubation at 4°C for 1, 4, and 8 days, and Figure 28B is a bar graph also showing the results of the incubation.

Figure 29 shows the blood glucose levels measured in mice injected with PBS (vehicle) (solid circles) or the Fc-(L15)-FGF21 mutants Fc-(L15)-FGF21(A45K, G170E) (SEQ ID NO:97) (open circles), Fc-(L15)-FGF21 (A45K, P171G) (SEQ ID NO:103) (solid triangles), or Fc-(L15)-FGF21 (L98R, P171G) (SEQ ID NO:43) (open triangles).

Figure 30 is a plot showing the results of an ELK-luciferase activity assay performed on human FGF21 (solid circles, solid line), Fc-(L15)- FGF21 (SEQ ID NO:49) (open circles, solid line) and Fc-(L15) FGF21 (L98R, P171G) (SEQ ID NO:43) (solid triangles, dotted line).

Figure 31 is a plot showing the percent high molecular weight aggregates observed after nine days at room temperature (Figure 31A) and at 4°C (Figure 31B) for FGF21 (SEQ ID NO:4) (solid circles, solid line), Fc-(L15)-FGF21 (SEQ ID NO:49) (open circle, solid line) and Fc-(L15)-FGF21 (L98R, P171G) (SEQ ID NO:43) (solid triangles, dotted line).

Figure 32 is a series of MALDI mass spectrometry traces showing observed changes in Fc-(L15)-FGF21 (L98R, P171G) (SEQ ID NO:43) at various points over a 168 hour time period.

Figure 33 is a plot showing the percent change in blood glucose levels in ob/ob mice for each of a PBS vehicle control (open circles), wild-type mature FGF21 (solid squares), and the FGF21 mutants Fc-(L15)-FGF21 (L98R, P171G) (SEQ ID NO:43) (inverted solid triangles); Fc-(L15)-FGF21 (L98R, P171G, 182P) (SEQ ID NO:143) (open diamonds), and Fc-(L15)-FGF21 (L98R, P171G, 182G) (SEQ ID NO:145) (solid circles).

Figure 34 is a plot showing the percent change in blood glucose levels in ob/ob mice for each of a PBS vehicle control (solid circles), and the FGF21 mutants Fc-(L15)-FGF21 (L98R, P171G) (SEQ ID NO:43) (solid triangles); Fc-(L15)-FGF21 (L98R, P171G, 182G, 183G) (SEQ ID NO:147) (open triangles), Fc-(L15)-FGF21 (L98R, P171G, 182G) (SEQ ID NO:145) (solid diamonds) and Fc-(L15)-FGF21 (L98R, P171G, 182P) (SEQ ID NO:143) (open diamonds).

Figure 35 is a plot showing the percent change in blood glucose levels in ob/ob mice for each of a PBS vehicle control (open circles), and the FGF21 mutants Fc-(L15)-FGF21 (L98R, P171G) (SEQ ID NO:43) (solid squares); Fc-(L15)-FGF21 (L98R, P171G, Y179S) (SEQ ID NO:149) (open triangles), Fc-(L15)-FGF21 (L98R, P171G, Y179A) (SEQ ID NO:153) (inverted solid triangles), Fc-(L15)-FGF21 (L98R, P171G, A180S) (SEQ ID NO:155) (open diamonds) and Fc-(L15)-FGF21 (L98R, P171G, A180G) (SEQ ID NO:157) (solid circles).

Figure 36 is a plot showing the percent change in blood glucose levels in ob/ob mice for each of a PBS vehicle control (solid circles), and the FGF21 mutants Fc-(L15)-FGF21(L98R, P171G) (SEQ ID NO:43) (open squares); Fc-(L15)-FGF21 (L98R, P171G, Y179F) (SEQ ID NO:151) (solid triangles), and Fc-(L15)-FGF21 (L98R, P171G, A180E) (SEQ ID NO:57) (open diamonds).

Figure 37 is a diagram graphically depicting the study design for a six-week dose escalation study performed in *Rhesus* monkeys. In the figure, shaded symbols indicate blood draws in the fasted state and stippled symbols indicated blood draws in the fed state.

Figures 38A-D is a series of plots depicting how the rhesus monkeys were randomized on OGTT profiles, OGTT AUCs and body weight; Figure 38A depicts baseline glucose levels in OGTT1, solid square corresponds to group A, solid circle, solid line corresponds to group B and open circle, dashed line corresponds to group C before compounds or vehicle were assigned to each group; Figure 38B depicts baseline glucose levels in OGTT2, solid square corresponds to group A, solid circle, solid line corresponds to group B and open circle, solid line corresponds to group C before compounds or vehicle were assigned to each group; Figure 38C shows baseline glucose levels for OGTTs 1 and 2 shown in terms of AUC, the stippled bar corresponds to group A, the shaded bar corresponds to group B and the open bar corresponds to group C; and Figure 38D shows baseline body weight, the stippled bar corresponds to group A, the shaded bar corresponds to group B and the open bar corresponds to group C.

Figure 39 is a plot showing the percent change in body weight relative to baseline of vehicle, FGF21 (SEQ ID NO:4) and Fc-(L15)-FGF21(L98R, P171G) (SEQ ID NO:43) in *Rhesus* monkeys; shaded bars 1 and 2 correspond to weeks 1 and 2 at the low dose, open bars 3 and 4 correspond to weeks 3 and 4 at the mid dose, solid bars 5 and 6 correspond to weeks 5 and 6 at the high dose and stippled bars 7, 8 and 9 correspond to weeks 7-9 during the washout period.

Figure 40 is a plot showing the percent change in fasted insulin relative to baseline of vehicle, FGF21 (SEQ ID NO:4) and Fc-(L15)-FGF21 (L98R, P171G) (SEQ ID NO:43) on fasted insulin levels in *Rhesus* monkeys; shaded bars 1 and 2 correspond to weeks 1 and 2 at the low dose, open bars 3 and 4 correspond to weeks 3 and 4 at the mid dose, solid bars 5 and 6 correspond to weeks 5 and 6 at the high dose and stippled bars 7 and 8 correspond to weeks 7 and 8 during the washout period.

Figure 41 is a plot showing the effects of vehicle, FGF21 (SEQ ID NO:4) and Fc-(L15)-FGF21 (L98R, P171G) (SEQ ID NO:43), given at the high dose, on fed insulin levels of *Rhesus* monkeys acquired during weeks 5 and 6 of the study; solid bars correspond to week 5 and shaded bars correspond to week 6.

Figure 42 is a plot showing the glucose profiles of OGTT5 performed at the end of the two week high-dose treatment with Fc-(L15)-FGF21 (L98R, P171G) (SEQ ID NO:43); solid circle, solid line corresponds to vehicle, open square, dotted line corresponds to FGF21 and solid triangle, solid line corresponds to Fc-(L15)-FGF21 (L98R, P171G) (SEQ ID NO:43).

Figure 43 is a plot showing the insulin profiles of OGTT5 performed at the end of the two week high-dose treatment with Fc-(L15)-FGF21 (L98R, P171G) (SEQ ID NO:43); solid circle, solid line corresponds to vehicle, open square, dotted line corresponds to FGF21 and solid triangle, solid line corresponds to Fc-(L15)-FGF21 (L98R, P171G) (SEQ ID NO:43).

Figure 44 is a plot showing the percent change from baseline of glucose OGTT AUC3-5 determined at the end of each dose period (low, mid and high dose) of the *Rhesus* monkeys; open bars correspond to AUC3 calculated from glucose measurements during OGTT3, solid bars correspond to AUC4 calculated from glucose measurements during OGTT4 and shaded bars correspond to AUC5 calculated from glucose measurements during OGTT5.

Figure 45 is a graph showing the effects of vehicle, FGF21 and Fc-(L15)-FGF21 (L98R, P171G) (SEQ ID NO:43) on percent change from baseline of the fasted plasma triglyceride levels from each group of *Rhesus* monkeys; shaded bars 1 and 2 correspond to weeks 1 and 2 at the low dose, open bars 3 and 4 correspond to weeks 3 and 4 at the mid dose, solid bars 5 and 6 correspond to weeks 5 and 6 at the high dose and stippled bars 7, 8 and 9 correspond to weeks 7-9 during the washout period..

Figure 46 is a graph showing fed plasma triglyceride levels from each group of the *Rhesus* monkeys; as measured during the fifth and sixth weeks of treatment with vehicle, FGF21 or Fc-(L15)-FGF21 (L98R, P171G) (SEQ ID NO:43) at the high dose; shaded bars correspond to week 5 and solid bars correspond to week 6.

Figure 47 is a plot showing human FGF21 levels in individual monkeys measured at pre-dose, and 5, 12, 19, and 26 days, with samples acquired at approximately 21 hours after each injection.

Figure 48 is a plot showing individual monkey Fc-(L15)-FGF21 (L98R, P171G) (SEQ ID NO:43) levels measured at pre-dose, and 5, 12, 19, and 26 days, with samples acquired approximately 5 days after each injection.

Figure 49 is a plot showing mean concentrations of FGF21 and Fc-(L15)-FGF21 (L98R, P171G) (SEQ ID NO:43) levels measured from the three OGTTs performed following each of the low, mid and high doses; shaded bars correspond to OGTT3 at the low dose, solid bars correspond to OGTT4 at the mid dose and open bars correspond to OGTT5 at the high dose.

Figure 50 is the amino acid sequence of the Fc-(G4S)3-FGF21 (L98R, P171G, A180E) fusion protein (SEQ ID NO:47); IgG1 Fc residues (SEQ ID NO:11) are in bold, the (G4S)3 linker (SEQ ID NO:31) is in italics and the point mutations in the FGF21 sequence (SEQ ID NO:39) are in bold and underlined.

Figure 51 is a plot showing the dose-response of the tested compounds in Erkluciferase assays; Fc-(G4S)3-FGF21 (L98R, P171G, A180E) (SEQ ID NO:47), Fc-(L15)-FGF21 (L98R, P171G, A180E) (SEQ ID NO:57), wild-type FGF21, and an Fc fusion with wild-type FGF21 were tested.

Figure 52 is a plot showing the results from a Biacore solution equilibrium binding assay of Fc-(G4S)3-FGF21 (L98R, P171G, A180E) (SEQ ID NO:47) and Fc-(L15)-FGF21 (L98R, P171G) (SEQ ID NO:43) to human (right) and cyno β-Klotho (left).

Figure 53 is a pair of plots showing the dose response of Fc-(G4S)3-FGF21 (L98R, P171G, A180E) (SEQ ID NO:47) in db/db mice after a single injection; Figure 53A shows the blood glucose levels in db/db mice at various time points following vehicle or Fc-(G4S)3-FGF21 (L98R, P171G, A180E) injection, while Figure 53B shows the effect of Fc-(G4S)3-FGF21 (L98R, P171G, A180E) on body weight after a single injection into db/db mice.

Figure 54 is a schematic graphically presenting a dose frequency study of Fc-(G4S)3-FGF21 (L98R, P171G, A180E) (SEQ ID NO:47) and Fc-(L15)-FGF21 (L98R, P171G) (SEQ ID NO:43) in DIO mice.

Figure 55 is a plot showing the GTT profiles of mice treated with vehicle, Fc-(G4S)3-FGF21 (L98R, P171G, A180E) (SEQ ID NO:47) or Fc-(L15)-FGF21 (L98R, P171G) (SEQ ID NO:43) at different dosing frequencies.

Figure 56 is a plot showing change of body weight from baseline (day 0) in mice treated vehicle, Fc-(G4S)3-FGF21 (L98R, P171G, A180E) (SEQ ID NO:47) or Fc-(L15)-FGF21 (L98R, P171G) (SEQ ID NO:43) at different dosing frequencies.

Figure 57 is a plot showing the results of an in vitro study of hydrogels comprising the FGF21 (L98R, P171G)) (SEQ ID NO:37) FGF21 mutant.

Figure 58 is a plot showing the effect on blood glucose level of 8 week old db/db mice dosed with various hydrogel formulations.

Figure 59 is a plot showing the effect on blood glucose level of 8 week old db/db mice dosed with various hydrogel formulations.

Figure 60 is a plot showing the effect on the blood glucose level of 8 week old db/B6 mice dosed with various hydrogel formulations; solid circles represent a mice dosed with a hydrogel control, solid squares represent mice dosed with FGF21 (L98R, P171G) (SEQ ID NO:37) in a hydrogel at 10 mg/kg, solid triangles represent mice dosed with FGF21 (L98R, P171G) in a hydrogel at 30 mg/kg, and inverted triangles represent mice dosed with Fc-(L15)-FGF21 (L98R, P171G, A180E) (SEQ ID NO:57) alone.

Figure 61 is a plot showing the percent change in blood glucose level of 8 week old db/B6 mice dosed with various hydrogel formulations; solid circles represent a mice dosed with a hydrogel control, solid squares represent mice dosed with FGF21 (L98R, P171G) (SEQ ID NO:37) in a hydrogel at 10 mg/kg, solid triangles represent mice dosed with FGF21 (L98R, P171G) in a hydrogel at 30 mg/kg, and inverted triangles represent mice dosed with Fc-(L15)-FGF21 (L98R, P171G, A180E) (SEQ ID NO:57) alone.

Figure 62 is a plot showing the effect on body weight of 8 week old db/B6 mice dosed with various hydrogel formulations; solid circles represent a mice dosed with a hydrogel control, solid squares represent mice dosed with FGF21 (L98R, P171G) (SEQ ID NO:37) in a hydrogel at 10 mg/kg, solid triangles represent mice dosed with FGF21 (L98R, P171G) in a hydrogel at 30 mg/kg, and inverted triangles represent mice dosed with Fc-(L15)-FGF21 (L98R, P171G, A180E) (SEQ ID NO:57) alone.

Figure 63 is a plot showing the percent change in weight of 8 week old db/B6 mice dosed with various hydrogel formulations; solid circles represent a mice dosed with a hydrogel control, solid squares represent mice dosed with FGF21 (L98R, P171G) (SEQ ID NO:37) in a hydrogel at 10 mg/kg, solid triangles represent mice dosed with FGF21 (L98R, P171G) in a hydrogel at 30 mg/kg, and inverted triangles represent mice dosed with Fc-(L15)-FGF21 (L98R, P171G, A180E) (SEQ ID NO:57) alone.

Figure 64 is a diagram graphically depicting the study design for a nine-week dose escalation study performed in *cynomolgus* monkeys with impaired glucose tolerance (IGT).

Figure 65 is a plot depicting the effects of vehicle, Fc-(L15)-FGF21 (L98R, P171G) (SEQ ID NO:43) and Fc-(G4S)3-FGF21 (L98R, P171G, A180E) (SEQ ID NO:47) on AM meal food intake of the IGT *cynomolgus* monkeys studied.

Figure 66 is a plot depicting the effects of vehicle, Fc-(L15)-FGF21 (L98R, P171G) (SEQ ID NO:43) and Fc-(G4S)3-FGF21 (L98R, P171G, A180E) (SEQ ID NO:47) on fruit intake of the IGT *cynomolgus* monkeys studied.

Figure 67 is a plot depicting the effects of vehicle, Fc-(L15)-FGF21 (L98R, P171G) (SEQ ID NO:43) and Fc-(G4S)3-FGF21 (L98R, P171G, A180E) (SEQ ID NO:47) on PM meal food intake of the IGT *cynomolgus* monkeys studied.

Figure 68 is a plot depicting the effects of vehicle, Fc-(L15)-FGF21 (L98R, P171G) (SEQ ID NO:43) and Fc-(G4S)3-FGF21 (L98R, P171G, A180E) (SEQ ID NO:47) on body weight of the IGT *cynomolgus* monkeys studied.

Figure 69 is a plot showing the effects of vehicle, Fc-(L15)-FGF21 (L98R, P171G) (SEQ ID NO:43) and Fc-(G4S)3-FGF21 (L98R, P171G, A180E) (SEQ ID NO:47) on body mass index of the IGT *cynomolgus* monkeys studied.

Figure 70 is a plot showing the effects of vehicle, Fc-(L15)-FGF21 (L98R, P171G) (SEQ ID NO:43) and Fc-(G4S)3-FGF21 (L98R, P171G, A180E) (SEQ ID NO:47) on skin fold thickness of the IGT *cynomolgus* monkeys studied.

Figure 71 is a plot showing the effects of vehicle, Fc-(L15)-FGF21 (L98R, P171G) (SEQ ID NO:43) and Fc-(G4S)3-FGF21 (L98R, P171G, A180E) (SEQ ID NO:47) on abdominal circumference of the IGT *cynomolgus* monkeys studied.

Figure 72 is a plot showing the effects of vehicle, Fc-(L15)-FGF21 (L98R, P171G) (SEQ ID NO:43) and Fc-(G4S)3-FGF21 (L98R, P171G, A180E) (SEQ ID NO:47) on plasma glucose levels of the IGT *cynomolgus* monkeys studied.

Figure 73 is a plot showing the effects of vehicle, Fc-(L15)-FGF21 (L98R, P171G) (SEQ ID NO:43) and Fc-(G4S)3-FGF21 (L98R, P171G, A180E) (SEQ ID NO:47) on glucose tolerance of the IGT *cynomolgus* monkeys studied.

Figure 74 is a plot showing the effects of vehicle, Fc-(L15)-FGF21 (L98R, P171G) (SEQ ID NO:43) and Fc-(G4S)3-FGF21 (L98R, P171G, A180E) (SEQ ID NO:47) on plasma triglyceride levels of the IGT *cynomolgus* monkeys studied.

Figure 75 is a plot showing the effects of vehicle, Fc-(L15)-FGF21 (L98R, P171G) (SEQ ID NO:43) and Fc-(G4S)3-FGF21 (L98R, P171G, A180E) (SEQ ID NO:47) on plasma total cholesterol levels of the IGT *cynomolgus* monkeys studied.

Figure 76 is a plot showing the effects of vehicle, Fc-(L15)-FGF21 (L98R, P171G) (SEQ ID NO:43) and Fc-(G4S)3-FGF21 (L98R, P171G, A180E) (SEQ ID NO:47) on plasma HDL-cholesterol levels of the IGT *cynomolgus* monkeys studied.

Figure 77 is a series of MALDI mass spectrometry traces showing observed changes in Fc-(L15)-FGF21 (L98R, P171G) (left panel, SEQ ID NO:43) and Fc-(L15)-FGF21 (L98R, P171G, A180E) (right panel, SEQ ID NO:57) at various points over a 168 hour time period.

Figure 78 is a plot showing the relative abundance (%) of full-length C-terminal peptide over the total C-terminal peptide fragments derived from both Fc-(L15)-FGF21 (L98R, P171G) and Fc-(L15)-FGF21 (L98R, P171G, A180E) as analyzed by MRM LC/MS/MS following Asp-N digestion.

Figure 79 is a plot showing the results of an ELISA assay for the plasma concentration of intact full-length Fc-(L15)-FGF21 (L98R, P171G) (SEQ ID NO:43) and Fc-(L15)-FGF21 (L98R, P171G, A180E) (SEQ ID NO:57) over a period of 240 hours following intravenous injection in mice.

Figure 80 is a plot showing the results of an ELK-luciferase activity assay performed on a negative control, human FGF21 (SEQ ID NO:4) and the FGF21 glycosylation mutants FGF21 (Y179N, S181T) (SEQ ID NO:161), FGF21 Y179N (SEQ ID NO: 163) and FGF21 P124S (SEQ ID NO: 165).

DETAILED DESCRIPTION OF THE INVENTION

[0011] A human FGF21 protein having enhanced properties such as an increased half-life and/or decreased aggregation can be prepared using the methods disclosed herein and standard molecular biology methods. Optionally, the half-life can be further extended by fusing an antibody, or portion thereof, to the N-terminal or C-terminal end of the wild-type FGF21 sequence. It is also possible to further extend the half-life or decrease aggregation of the wild-type FGF21 protein by introducing amino acid substitutions into the protein. Such modified proteins are referred to herein as mutants, or FGF21 mutants, and form embodiments of the present invention.

[0012] Recombinant nucleic acid methods used herein, including in the Examples, are generally those set forth in Sambrook et al., Molecular Cloning: A Laboratory Manual (Cold Spring Harbor Laboratory Press, 1989) or Current Protocols in Molecular Biology (Ausubel et al., eds., Green Publishers Inc. and Wiley and Sons 1994),

1. General Definitions

[0013] The term "isolated nucleic acid molecule" refers to a nucleic acid molecule provided herein that (1) has been separated from at least about 50 percent of proteins, lipids, carbohydrates, or other materials with which it is naturally found when total nucleic acid is isolated from the source cells, (2) is not linked to all or a portion of a polynucleotide to which the "isolated nucleic acid molecule" is linked in nature, (3) is operably linked to a polynucleotide which it is not linked to in nature, or (4) does not occur in nature as part of a larger polynucleotide sequence. Preferably, an isolated nucleic acid molecule is substantially free from any other contaminating nucleic acid molecules or other contaminants that are found in its natural environment that would interfere with its use in polypeptide production or its therapeutic, diagnostic, prophylactic or research use.

[0014] The term "vector" is used to refer to any molecule (*e.g.*, nucleic acid, plasmid, or virus) used to transfer coding information to a host cell.

[0015] The term "expression vector" refers to a vector that is suitable for transformation of a host cell and contains nucleic acid sequences that direct and/or control the expression of inserted heterologous nucleic acid sequences. Expression includes, but is not limited to, processes such as transcription, translation, and RNA splicing, if introns are present.

[0016] The term "operably linked" is used herein to refer to an arrangement of flanking sequences wherein the flanking sequences so described are configured or assembled so as to perform their usual function. Thus, a flanking sequence operably linked to a coding sequence may be capable of effecting the replication, transcription and/or translation of the coding sequence. For example, a coding sequence is operably linked to a promoter when the promoter is capable of directing transcription of that coding sequence. A flanking sequence need not be contiguous with the coding sequence, so long as it functions correctly. Thus, for example, intervening untranslated yet transcribed sequences can be present between a promoter sequence and the coding sequence and the promoter sequence can still be considered "operably linked" to the coding sequence.

[0017] The term "host cell" is used to refer to a cell which has been transformed, or is capable of being transformed with a nucleic acid sequence, such as a nucleic acid provided herein, and then of expressing a selected gene of interest. The term includes the progeny of the parent cell, whether or not the progeny is identical in morphology or in genetic make-up to the original parent, so long as the selected gene is present.

[0018] The term "isolated polypeptide" refers to a polypeptide provided herein that (1) has been separated from at least about 50 percent of polynucleotides, lipids, carbohydrates, or other materials with which it is naturally found when isolated from the source cell, (2) is not linked (by covalent or noncovalent interaction) to all or a portion of a polypeptide to which the "isolated polypeptide" is linked in nature, (3) is operably linked (by covalent or noncovalent interaction) to a polypeptide with which it is not linked in nature, or (4) does not occur in nature. Preferably, the isolated polypeptide is substantially free from any other contaminating polypeptides or other contaminants that are found in its natural environment that would interfere with its therapeutic, diagnostic, prophylactic or research use.

[0019] The term "naturally occurring" when used in connection with biological materials such as nucleic acid molecules, polypeptides, host cells, and the like, refers to materials which are found in nature and are not manipulated by man. Similarly, "non-naturally occurring" as used herein refers to a material that is not found in nature or that has been structurally modified or synthesized by man. When used in connection with nucleotides, the term "naturally occurring" refers to the bases adenine (A), cytosine (C), guanine (G), thymine (T), and uracil (U). When used in connection with amino acids, the term "naturally occurring" refers to the 20 amino acids alanine (A), cysteine (C), aspartic acid (D), glutamic acid (E), phenylalanine (F), glycine (G), histidine (H), isoleucine (I), lysine (K), leucine (L), methionine (M), asparagine (N), proline (P), glutamine (Q), arginine (R), serine (S), threonine (T), valine (V), tryptophan (W), and tyrosine (Y).

[0020] The term "FGF21 polypeptide" refers to a naturally-occurring wild-type polypeptide expressed in humans. For purposes of this disclosure, the term "FGF21 polypeptide" can be used interchangeably to refer to any full-length FGF21 polypeptide, *e.g.*, SEQ ID NOs:2 and 6, which consist of 209 amino acid residues and which are encoded by the nucleotide sequences of SEQ ID NOs: 1 and 5, respectively; any mature form of the polypeptide, *e.g.*, SEQ ID NOs:4 and 8, which consist of 181 amino acid residues and which are encoded by the nucleotide sequences of SEQ ID NOs:3 and 7, respectively, and in which the 28 amino acid residues at the amino-terminal end of the full-length FGF21 polypeptide (*i.e.*, which constitute the signal peptide) have been removed. Full-length and mature FGF21 polypeptides can but need not comprise an amino-terminal methionine, which may be introduced by engineering or as a result of a bacterial expression process.

[0021] The terms "FGF21 polypeptide mutant" and "FGF21 mutant" can be used interchangeably and refer to an FGF21 polypeptide in which a naturally occurring FGF21 amino acid sequence (e.g., SEQ ID NOs:2, 4, 6, or 8) has been modified. Such modifications include, but are not limited to, one or more amino acid substitutions, including substitutions with non-naturally occurring amino acids and non-naturally-occurring amino acid analogs, and truncations. Thus, FGF21 polypeptide mutants include, but are not limited to, site-directed FGF21 mutants, truncated FGF21 polypeptides, proteolysis-resistant FGF21 mutants, aggregation-reducing FGF21 mutants, FGF21 combination mutants, and FGF21 fusion proteins, as described herein. For the purpose of identifying the specific truncations and amino acid substitutions of the FGF21 mutants of the present invention, the numbering of the amino acid residues truncated or mutated corresponds to that of the mature 181-residue FGF21 polypeptide. FGF21 mutants can but need not comprise an amino-terminal methionine, which may be introduced by engineering or as a result of a bacterial expression process. In other embodiments of the present invention, an FGF21 polypeptide mutant comprises an amino acid sequence that is at least about 85 percent identical to the mutant FGF21's amino acid sequence, but wherein specific residues conferring a desirable property to the FGF21 polypeptide mutant, e.g., proteolysis-resistance, increased half life or aggregation-reducing properties and combinations thereof, have not been further modified. In other words, with the exception of residues in the FGF21 mutant sequence that have been modified in order to confer proteolysis-resistance, aggregation-reducing, or other properties, about 15 percent of all other amino acid residues in the FGF21 mutant sequence can be modified. For example, in the FGF21 mutant Q173E, up to 15 percent of all amino acid residues other than the glutamic acid residue, which was substituted for glutamine at position 173, could be modified. In still other embodiments, an FGF21 polypeptide mutant comprises an amino acid sequence that is at least about 90 percent, or about 95, 96, 97, 98, or 99 percent identical to the mutant FGF21's amino acid sequence, but wherein the specific residues conferring the FGF21 polypeptide mutant's proteolysis-resistance or aggregation-reducing properties have not been further modified. Such FGF21 polypeptide mutants possess at least one activity of the wild-type FGF21 polypeptide.

[0022] The present invention also encompasses a nucleic acid molecule encoding an FGF21 polypeptide mutant comprising an amino acid sequence that is at least about 85 percent identical to the mutant FGF21's amino acid sequence but wherein specific residues conferring a desirable property to the FGF21 polypeptide mutant, *e.g.*, proteolysis-resistance, increased half life or aggregation-reducing properties and combinations thereof have not been further modified.

[0023] In other words, with the exception of residues in the FGF21 mutant sequence that have been modified in order to confer proteolysis-resistance, aggregation-reducing, or other properties, about 15 percent of all other amino acid residues in the FGF21 mutant sequence can be modified. For example, in the FGF21 mutant Q173E, up to 15 percent of all amino acid residues other than the glutamic acid residue, which was substituted for glutamine at position 173, could be modified. The present invention further encompasses a nucleic acid molecule comprising a nucleotide sequence that is at least about 90 percent, or about 95, 96, 97, 98, or 99 percent identical to the nucleotide sequence encoding an FGF21 mutant, but wherein the nucleotides encoding amino acid residues conferring the encoded FGF21 polypeptide mutant's proteolysis-resistance or aggregation-reducing properties have not been further modified. Such nucleic acid molecules encode FGF21 mutant polypeptides possessing at least one activity of the wild-type FGF21 polypeptide.

[0024] The term "biologically active FGF21 polypeptide mutant" refers to any FGF21 polypeptide mutant described herein that possesses an activity of the wild-type FGF21 polypeptide, such as the ability to lower blood glucose, insulin, triglyceride, or cholesterol; reduce body weight; and improve glucose tolerance, energy expenditure, or insulin sensitivity, regardless of the type or number of modifications that have been introduced into the FGF21 polypeptide mutant. FGF21 polypeptide mutants possessing a somewhat decreased level of FGF21 activity relative to the wild-type FGF21 polypeptide can nonetheless be considered to be biologically active FGF21 polypeptide mutants.

[0025] The terms "effective amount" and "therapeutically effective amount" each refer to the amount of an FGF21 polypeptide mutant used to support an observable level of one or more biological activities of the wild-type FGF21 polypeptide, such as the ability to lower blood glucose, insulin, triglyceride, or cholesterol levels; reduce body weight; or improve glucose tolerance, energy expenditure, or insulin sensitivity.

[0026] The term "pharmaceutically acceptable carrier" or "physiologically acceptable carrier" as used herein refers to one or more formulation agents suitable for accomplishing or enhancing the delivery of an FGF21 polypeptide mutant into the body of a human or non-human subject. The term includes any and all solvents, dispersion media, coatings, antibacterial and antifungal agents, isotonic and absorption delaying agents, and the like that are physiologically compatible. Examples of pharmaceutically acceptable carriers include one or more of water, saline, phosphate buffered saline, dextrose, glycerol, ethanol and the like, as well as combinations thereof. In some cases, it will be preferable to include isotonic agents, for example, sugars, polyalcohols such as mannitol, sorbitol, or sodium chloride in a pharmaceutical composition. Pharmaceutically acceptable substances such as wetting or minor amounts of auxiliary substances such as wetting or emulsifying agents, preservatives or buffers, which enhance the shelf life or effectiveness of the FGF21 polypeptide mutant can also act as, or form a component of, a carrier.

[0027] The term "antigen" refers to a molecule or a portion of a molecule that is capable of being bound by an antibody, and additionally that is capable of being used in an animal to produce antibodies that are capable of binding to an epitope of that antigen. An antigen may have one or more epitopes.

[0028] The term "native Fc" refers to molecule or sequence comprising the sequence of a non-antigen-binding fragment resulting from digestion of whole antibody or produced by other means, whether in monomeric or multimeric form, and can contain the hinge region. The original immunoglobulin source of the native Fc is preferably, but not necessarily, of human origin and can be any of the immunoglobulins, although IgG1 and IgG2 are preferred. IgG4 can also be employed. Native Fc molecules are made up of monomeric polypeptides that can be linked into dimeric or multimeric forms by covalent (*i.e.*, disulfide bonds) and non-covalent association. The number of intermolecular disulfide bonds between monomeric subunits of native Fc molecules ranges from 1 to 4 depending on class *(e.g.,* IgG, IgA, and IgE) or subclass (*e.g.,* IgG1, IgG2, IgG3, IgG4, IgA1, and IgGA2). One example of a native Fc is a disulfide-bonded dimer resulting from papain digestion of an IgG (*see* Ellison et al., 1982, Nucleic Acids Res. 10: 4071-9). The term "native Fc" as used herein is generic to the monomeric, dimeric, and multimeric forms. An example of an Fc polypeptide sequence is presented in SEQ ID NO:11, which is derived from a human IgG1 molecule. A native Fc can, but need not, comprise an amino-terminal methionine, which may be introduced by engineering or as a result of a bacterial expression process; such Fc molecules are still considered to be "native Fc" molecules.

[0029] The term "Fc variant" refers to a molecule or sequence that is modified from a native Fc but still comprises a binding site for the salvage receptor, FcRn (neonatal Fc receptor). International Publication Nos. WO 97/34631 and WO 96/32478 describe exemplary Fc variants, as well as interaction with the salvage receptor, Thus, the term "Fc variant" can comprise a molecule or sequence that is humanized from a non-human native Fc. Furthermore, a native Fc comprises regions that can be removed because they provide structural features or biological activity that are not required for the fusion molecules of the

FGF21 mutants of the present invention. Thus, the term "Fc variant" comprises a molecule or sequence that lacks one or more native Fc sites or residues, or in which one or more Fc sites or residues has be modified, that affect or are involved in: (1) disulfide bond formation, (2) incompatibility with a selected host cell, (3) N-terminal heterogeneity upon expression in a selected host cell, (4) glycosylation, (5) interaction with complement, (6) binding to an Fc receptor other than a salvage receptor, or (7) antibody-dependent cellular cytotoxicity (ADCC). Fc variants are described in further detail hereinafter. An Fc variant can, but need not, comprise an amino-terminal methionine, which may be introduced by engineering or as a result of a bacterial expression process; such Fc molecules are still considered to be "Fc variants."

[0030] The term "Fc domain" encompasses native Fc and Fc variants and sequences as defined above. As with Fc variants and native Fc molecules, the term "Fc domain" includes molecules in monomeric or multimeric form, whether digested from whole antibody or produced by other means. In some embodiments of the present invention, an Fc domain can be fused to FGF21 or a FGF21 mutant (including a truncated form of FGF21 or a FGF21 mutant) via, for example, a covalent bond between the Fc domain and the FGF21 sequence. Such fusion proteins can form multimers via the association of the Fc domains and both these fusion proteins and their multimers are an aspect of the present invention. An Fc domain can, but need not, comprise an amino-terminal methionine, which may be introduced by engineering or as a result of a bacterial expression process.

2. FGF21 Mutants

[0031] The term "FGF21 mutant" refers to an FGF21 mutant polypeptide having an amino acid sequence that differs from the amino acid sequence of a naturally occurring FGF21 polypeptide sequence, *e.g.*, SEQ ID NOs:2, 4, 6 or 8,by one or more amino acids. FGF21 mutants can be generated by introducing one or more amino acid substitutions, either conservative or non-conservative and using naturally or non-naturally occurring amino acids, at particular positions of the FGF21 polypeptide.

[0032] A "Conservative amino acid substitution" can involve a substitution of a native amino acid residue (*i.e.,* a residue found in a given position of the wild-type FGF21 polypeptide sequence) with a nonnative residue (*i.e.,* a residue that is not found in a given position of the wild-type FGF21 polypeptide sequence) such that there is little or no effect on the polarity or charge of the amino acid residue at that position. Conservative amino acid substitutions also encompass non-naturally occurring amino acid residues that are typically incorporated by chemical peptide synthesis rather than by synthesis in biological systems. These include peptidomimetics, and other reversed or inverted forms of amino acid moieties.

[0033] Naturally occurring residues can be divided into classes based on common side chain properties:

1. (1) hydrophobic: norleucine, Met, Ala, Val, Leu, Ile;
2. (2) neutral hydrophilic: Cys, Ser, Thr;
3. (3) acidic: Asp, Glu;
4. (4) basic: Asn, Gln, His, Lys, Arg;
5. (5) residues that influence chain orientation: Gly, Pro; and
6. (6) aromatic: Trp, Tyr, Phe.

[0034] Conservative substitutions can involve the exchange of a member of one of these classes for another member of the same class. Non-conservative substitutions can involve the exchange of a member of one of these classes for a member from another class.

[0035] Desired amino acid substitutions (whether conservative or non-conservative) can be determined by those skilled in the art at the time such substitutions are desired. An exemplary (but not limiting) list of amino acid substitutions is set forth in Table 1.

Table 1

Amino Acid Substitutions	
Original Residue	**Exemplary Substitutions**
Ala	Val, Leu, Ile
Arg	Lys, Gln, Asn
Asn	Gln
Asp	Glu
Cys	Ser, Ala
Gln	Asn
Glu	Asp
Gly	Pro, Ala
His	Asn, Gln, Lys, Arg
Ile	Leu, Val, Met, Ala, Phe
Leu	Ile, Val, Met, Ala, Phe
Lys	Arg, Gln, Asn
Met	Leu, Phe, Ile
Phe	Leu, Val, Ile, Ala, Tyr
Pro	Ala
Ser	Thr, Ala, Cys
Thr	Ser
Trp	Tyr, Phe
Tyr	Trp, Phe, Thr, Ser
Val	Ile, Met, Leu, Phe, Ala

3. Truncated FGF21 Polypeptides

[0036] One embodiment of the present invention is directed to truncated forms of a mature FGF21 polypeptide or FGF21 mutant. This embodiment of the present invention arose from an effort to identify truncated FGF21 polypeptides that are capable of providing an activity that is similar, and in some instances superior, to untruncated forms of the mature FGF21 polypeptide.

[0037] As used herein, the term "truncated FGF21 polypeptide" refers to an FGF21 polypeptide in which amino acid residues have been removed from the amino-terminal (or N-terminal) end of the FGF21 polypeptide, amino acid residues have been removed from the carboxyl-terminal (or C-terminal) end of the FGF21 polypeptide, or amino acid residues have been removed from both the amino-terminal and carboxyl-terminal ends of the FGF21 polypeptide. The various truncations disclosed herein were prepared as described herein Examples 3 and 6.

[0038] The activity of N-terminally truncated FGF21 polypeptides and C-terminally truncated FGF21 polypeptides can be assayed using an *in vitro* ELK-luciferase assay as described in Example 4. Specific details of the *in vitro* assays that can be used to examine the activity of truncated FGF21 polypeptides can be found in Example 4.

[0039] The activity of the truncated FGF21 polypeptides of the present invention can also be assessed in an *in vivo* assay, such as db/db mice, or ob/ob mice as shown in Examples 5 and 7. Generally, to assess the *in vivo* activity of a truncated FGF21 polypeptide, the truncated FGF21 polypeptide can be administered to a test animal intraperitoneally. After a desired incubation period (e.g., one hour or more), a blood sample can be drawn, and blood glucose levels can be measured. Specific details of the *in vivo* assays that can be used to examine the activity of truncated FGF21 polypeptides can be found in Examples 5 and 7.

a. N-terminal Truncations

[0040] In some embodiments of the present invention, N-terminal truncations comprise 1, 2, 3, 4, 5, 6, 7, or 8 amino acid residues from the N-terminal end of the mature FGF21 polypeptide or FGF21 mutant. As demonstrated in, for example, Example 5 and Figure 3, truncated FGF21 polypeptides having N-terminal truncations of fewer than 9 amino acid residues retain the ability of the mature FGF21 polypeptide to lower blood glucose in an individual. Accordingly, in particular embodiments, the present invention encompasses truncated forms of the mature FGF21 polypeptide or FGF21 polypeptide mutants having N-terminal truncations of 1, 2, 3, 4, 5, 6, 7, or 8 amino acid residues.

b. C-terminal Truncations

[0041] In some embodiments of the present invention, C-terminal truncations comprise 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, or 12 amino acid residues from the C-terminal end of the mature FGF21 polypeptide. As demonstrated in, for example, Example 4 and Figure 1B, truncated FGF21 polypeptides having C-terminal truncations of fewer than 13 amino acid residues exhibited an efficacy of at least 50% of the efficacy of wild-type FGF21 in an *in vitro* ELK-luciferase assay, indicating that these FGF21 mutants retain the ability of the mature FGF21 polypeptide to lower blood glucose in an individual. Accordingly, in particular embodiments, the present invention encompasses truncated forms of the mature FGF21 polypeptide or FGF21 polypeptide mutants having C-terminal truncations of 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, or 12 amino acid residues.

c. N-terminal and C-terminal Truncations

[0042] In some embodiments of the present invention, truncated FGF21 polypeptides can have a combination of N-terminal and C-terminal truncations. Truncated FGF21 polypeptides having a combination of N-terminal and C-terminal truncations share the activity of corresponding truncated FGF21 polypeptides having either the N-terminal or C-terminal truncations alone. In other words, truncated FGF21 polypeptides having both N-terminal truncations of fewer than 9 amino acid residues and C-terminal truncations of fewer than 13 amino acid residues possess similar or greater biological activity, e.g, blood glucose-lowering activity, as truncated FGF21 polypeptides having N-terminal truncations of fewer than 9 amino acid residues or truncated FGF21 polypeptides having C-terminal truncations of fewer than 13 amino acid residues. Accordingly, in particular embodiments, the present invention encompasses truncated forms of the mature FGF21 polypeptide or FGF21 polypeptide mutants having both N-terminal truncations of 1, 2, 3, 4, 5, 6, 7, or 8 amino acid residues and C-terminal truncations of 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, or 12 amino acid residues.

[0043] As with all FGF21 mutants of the present invention, truncated FGF21 polypeptides and FGF21 mutants can optionally comprise an amino-terminal methionine residue, which can be introduced by directed mutation or as a result of a bacterial expression process.

[0044] The truncated FGF21 polypeptides of the present invention can be prepared as described in Examples 3 and 6. Those of ordinary skill in the art, familiar with standard molecular biology techniques, can employ that knowledge, coupled with the instant disclosure, to make and use the truncated FGF21 polypeptides of the present invention. Standard techniques can be used for recombinant DNA, oligonucleotide synthesis, tissue culture, and transformation *(e.g.,* electroporation, lipofection). *See, e.g.,* Sambrook *et al., Molecular Cloning: A Laboratory Manual, supra,* Enzymatic reactions and purification techniques can be performed according to manufacturer's specifications, as commonly accomplished in the art, or as described herein. Unless specific definitions are provided, the nomenclatures utilized in connection with, and the laboratory procedures and techniques of, analytical chemistry, synthetic organic chemistry, and medicinal and pharmaceutical chemistry described herein are those well known and commonly used in the art. Standard techniques can be used for chemical syntheses; chemical analyses; pharmaceutical preparation, formulation, and delivery; and treatment of patients.

[0045] The truncated FGF21 polypeptides of the present invention can also be fused to another entity, which can impart additional properties to the truncated FGF21 polypeptide. In one embodiment of the present invention, a truncated FGF21 polypeptide can be fused to an Fc sequence. Such fusion can be accomplished using known molecular biological methods and/or the guidance provided herein. The benefits of such fusion polypeptides, as well as methods for making such fusion polypeptides, are discussed in more detail herein.

4. Proteolysis-resistant FGF21 Mutants

[0046] As described in Example 8, mature FGF21 was found to be undergoing *in vivo* degradation, which was ultimately determined to arise from proteolytic attack. The *in vivo* degradation of mature FGF21 was found to lead to shorter effective half-life, which can adversely affect the therapeutic potential of a molecule. Accordingly, a directed study was performed to identify FGF21 mutants that exhibit a resistance to proteolysis. As a result of this investigation, the sites in the mature FGF21 polypeptide that were determined to be particularly susceptible to proteolysis include the peptide bond between the amino acid residues at positions 4-5, 20-21, 151-152, 171-172 and 178-181.

[0047] A broad but focused and directed study was performed to identify particular substitutions that eliminate the observed proteolytic effect while not affecting the activity of the protein to an unacceptable degree. Tables 8 and 11 highlight some of the mutants that were prepared and tested. As described in, for example, Examples 13 and 14, not all FGF21 mutants exhibited an ideal profile; some mutants conferred proteolysis resistance but at the cost of compromised FGF21 activity. Other mutations retained FGF21 activity but did not confer proteolysis resistance. Several mutants, including, for example, FGF21 P171G, retained a similar level of activity as wild-type FGF21 while also exhibiting resistance to proteolytic degradation.

[0048] One selection criteria for identifying desirable proteolysis-resistant FGF21 mutants was that the activity of the FGF21 mutant be essentially the same as, or greater than, the activity of wild-type FGF21. Therefore, another embodiment of the present invention is directed to FGF21 mutants that are resistant to proteolysis and still retain activity that is essentially the same as, or greater than, wild-type FGF21. Although less desirable in some cases, FGF21 mutants that are resistant to proteolysis but exhibit somewhat decreased activity form another embodiment of the present invention. In some cases it can be desirable to maintain a degree of proteolysis, and consequently, FGF21 mutants that allow some degree of proteolysis to occur also form another embodiment of the present invention.

[0049] As with all FGF21 mutants provided herein, the proteolysis-resistant FGF21 mutants of the present invention can be prepared as described herein. Those of ordinary skill in the art, for example, those familiar with standard molecular biology techniques, can employ that knowledge, coupled with the instant disclosure, to make and use the proteolysis-resistant FGF21 mutants disclosed herein. Standard techniques can be used for recombinant DNA, oligonucleotide synthesis, tissue culture, and transformation *(e.g.,* electroporation, lipofection). See, *e.g.,* Sambrook *et al., Molecular Cloning: A Laboratory Manual, supra,* . Enzymatic reactions and purification techniques can be performed according to manufacturer's specifications, as commonly accomplished in the art, or as described herein. Unless specific definitions are provided, the nomenclatures utilized in connection with, and the laboratory procedures and techniques of, analytical chemistry, synthetic organic chemistry, and medicinal and pharmaceutical chemistry described herein are those well known and commonly used in the art. Standard techniques can be used for chemical syntheses; chemical analyses; pharmaceutical preparation, formulation, and delivery; and treatment of patients.

[0050] The proteolysis-resistant FGF21 mutants of the present invention can be fused to another entity, which can impart additional properties to the proteolysis-resistant FGF21 mutant. In one embodiment of the present invention, a proteolysis-resistant FGF21 mutant can be fused to an IgG Fc sequence, *e.g.*, SEQ ID NO:11. Such fusion can be accomplished using known molecular biological methods and/or the guidance provided herein. The benefits of such fusion polypeptides, as well as methods for making such fusion polypeptides, are known and are discussed in more detail herein.

5. Aggregation-reducing FGF21 Mutants

[0051] As described in Example 15, one property of the wild-type FGF21 polypeptide is its propensity to aggregate. At concentrations over about 5 mg/mL, the aggregation rate is high at room temperature. As shown and described herein, the aggregation rate for the wild-type FGF21 polypeptide is both concentration and temperature dependent.

[0052] Aggregation can prove to be a challenge when working with wild-type FGF21 at these concentrations, such as in the context of a therapeutic formulation. Accordingly, a directed study was performed to identify FGF21 mutants that exhibit reduced FGF21 aggregation. The resulting FGF21 mutants were then tested for the propensity to aggregate at various concentrations.

[0053] A broad but focused and directed study was performed to identify particular substitutions that eliminate or reduce the observed aggregation effect of wild-type FGF21 while not affecting the activity of the protein to an unacceptable degree. The approach for identifying suitable aggregation-reducing mutants is described in Example 15. Table 16 highlights some of the mutants that were prepared and tested. As described in, for example, Example 17, not all

FGF21 mutants exhibited an ideal profile. Some mutants, such as FGF21 L58E had compromised FGF21 activity and were not studied further. Other mutations, such as FGF21 A134E, retained FGF21 activity but did not confer reduced aggregation properties. Several mutants, such as FGF21 L98R, retained FGF21 activity and also exhibited reduced aggregation. One mutant, FGF21 A45K, surprisingly exhibited increased FGF21 activity while also exhibiting reduced aggregation properties.

[0054] One selection criteria for identifying desirable aggregation-reducing FGF21 mutants was that the activity of the FGF21 mutant be essentially similar to, or greater than, the activity of wild-type FGF21. Therefore, another embodiment of the present invention is directed to FGF21 mutants having reduced aggregation properties while still retaining an FGF21 activity that is similar to, or greater than, wild-type FGF21. Although less desirable in some cases, FGF21 mutants having reduced aggregation properties but exhibiting somewhat decreased FGF21 activity form another embodiment of the present invention. In some cases it may be desirable to maintain a degree of aggregation, and consequently, FGF21 mutants that allow some degree of aggregation to occur also form another embodiment of the present invention.

[0055] As with all FGF21 mutants provided herein, the aggregation-reducing FGF21 mutants provided herein can be prepared as described herein. Those of ordinary skill in the art, familiar with standard molecular biology techniques, can employ that knowledge, coupled with the instant disclosure, to make and use the aggregation-reducing FGF21 mutants of the present invention. Standard techniques can be used for recombinant DNA, oligonucleotide synthesis, tissue culture, and transformation *(e.g.,* electroporation, lipofection). See, *e.g.,* Sambrook *et al., Molecular Cloning: A Laboratory Manual, supra,* Enzymatic reactions and purification techniques can be performed according to manufacturer's specifications, as commonly accomplished in the art, or as described herein. Unless specific definitions are provided, the nomenclatures utilized in connection with, and the laboratory procedures and techniques of, analytical chemistry, synthetic organic chemistry, and medicinal and pharmaceutical chemistry described herein are those well known and commonly used in the art. Standard techniques can be used for chemical syntheses; chemical analyses; pharmaceutical preparation, formulation, and delivery; and treatment of patients.

[0056] The aggregation-reducing FGF21 mutants of the present invention can be fused to another entity, which can impart additional properties to the aggregation-reducing FGF21 mutant. In one embodiment of the present invention, an aggregation-reducing FGF21 mutant can be fused to an IgG Fc sequence, e.g., SEQ ID NO: 11. Such fusion can be accomplished using known molecular biological methods and/or the guidance provided herein. The benefits of such fusion polypeptides, as well as methods for making such fusion polypeptides, are discussed in more detail herein.

6. FGF21 Combination Mutants

[0057] As described herein, the wild-type FGF21 sequence possesses several properties that can pose significant challenges when FGF21 is used as a therapeutic molecule. Among these challenges are the protein's susceptibility to degradation and its propensity for aggregation at high concentration. After an exhaustive effort to identify FGF21 polypeptides that overcome each of these challenges, a directed study was performed to determine whether the amino acid substitutions conferring proteolysis-resistance and those conferring aggregation-reducing properties could be combined in an additive or synergistic fashion in a single polypeptide sequence while maintaining activity levels that are equal to or greater than the activity of wild-type FGF21. This represented a significant challenge, as it is known in the art that the introduction of multiple mutations in a given polypeptide can sometimes adversely affect the expression, activity, and subsequent manufacturing of the protein.

[0058] Surprisingly, as demonstrated in, for example, Examples 19 and 20, it was found that the desirable properties of several FGF21 mutants could indeed be combined in an additive or synergistic fashion to generate an FGF21 mutant having enhanced pharmaceutical properties. FGF21 mutants that are resistant to proteolysis, have a reduced rate of aggregation, and which still retain activity that is the same as, or greater than, wild-type FGF21, are disclosed herein.

[0059] One selection criteria for identifying desirable FGF21 combination mutants was that the activity of the FGF21 mutant be similar to, or greater than, the activity of wild-type FGF21. Therefore, another embodiment of the present invention is directed to FGF21 mutants that are proteolysis-resistant and have reduced aggregation properties while still retaining an FGF21 activity that is similar to, or greater than, wild-type FGF21. Although less desirable in some cases, FGF21 mutants that are proteolysis-resistant and have reduced aggregation properties but exhibit somewhat decreased FGF21 activity form another embodiment of the present invention. In some cases it may be desirable to maintain a degree of proteolysis and/or aggregation, and consequently, FGF21 mutants that allow some degree of proteolysis and/or aggregation also form another embodiment of the present invention.

[0060] As with all FGF21 mutants of the present invention, the FGF21 combination mutants of the present invention can be prepared as described herein. Those of ordinary skill in the art, familiar with standard molecular biology techniques, can employ that knowledge, coupled with the instant disclosure, to make and use the FGF21 combination mutants of the present invention. Standard techniques can be used for recombinant DNA, oligonucleotide synthesis, tissue culture, and transformation *(e.g.,* electroporation, lipofection). See, *e.g.,* Sambrook *et al., Molecular Cloning: A Laboratory Manual, supra,* Enzymatic reactions and purification techniques can be performed according to manufacturer's specifications, as commonly accomplished in the art, or as described herein. Unless specific definitions are provided, the nomenclatures utilized in connection with, and the laboratory procedures and techniques of, analytical chemistry, synthetic organic chemistry, and medicinal and pharmaceutical chemistry described herein are those well known and commonly used in the art. Standard techniques can be used for chemical syntheses; chemical analyses; pharmaceutical preparation, formulation, and delivery; and treatment of patients.

[0061] The FGF21 combination mutants of the present invention can be fused to another entity, which can impart additional properties to the FGF21 combination mutant. In one embodiment of the present invention, an FGF21 combination mutant can be fused to an IgG Fc sequence, e.g., SEQ ID NO:11. Such fusion can be accomplished using known molecular biological methods and/or the guidance provided herein. The benefits of such fusion polypeptides, as well as methods for making such fusion polypeptides, are discussed in more detail herein.

7. FGF21 Fusion Proteins

[0062] As used herein, the term "FGF21 fusion polypeptide" or "FGF21 fusion protein" refers to a fusion of one or more amino acid residues (such as a heterologous protein or peptide) at the N-terminus or C-terminus of any FGF21 polypeptide mutant described herein.

[0063] Heterologous peptides and polypeptides include, but are not limited to, an epitope to allow for the detection and/or isolation of an FGF21 polypeptide mutant; a transmembrane receptor protein or a portion thereof, such as an extracellular domain or a transmembrane and intracellular domain; a ligand or a portion thereof which binds to a transmembrane receptor protein; an enzyme or portion thereof which is catalytically active; a polypeptide or peptide which promotes oligomerization, such as a leucine zipper domain; a polypeptide or peptide which increases stability, such as an immunoglobulin constant region (e.g., an Fc domain); a half life-extending sequence comprising a combination of two or more (e.g., 2, 5, 10, 15, 20, 25, etc) naturally occurring or non-naturally occurring charged and/or uncharged amino acids (e.g., Serine, Glycine, Glutamic or Aspartic Acid) designed to form a predominantly hydrophilic or predominantly hydrophobic fusion partner for an FGF21 mutant; a functional or non-functional antibody, or a heavy or light chain thereof; and a polypeptide which has an activity, such as a therapeutic activity, different from the FGF21 polypeptide mutants of the present invention. Also encompassed by the present invention are FGF21 mutants fused to human serum albumin (HSA).

[0064] FGF21 fusion proteins can be made by fusing heterologous sequences at either the N-terminus or at the C-terminus of an FGF21 polypeptide mutant. As described herein, a heterologous sequence can be an amino acid sequence or a non-amino acidcontaining polymer. Heterologous sequences can be fused either directly to the FGF21 polypeptide mutant or via a linker or adapter molecule. A linker or adapter molecule can be one or more amino acid residues (or -mers), *e.g.*, 1, 2, 3, 4, 5, 6, 7, 8, or 9 residues (or -mers), preferably from 10 to 50 amino acid residues (or -mers), *e.g.*, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 25, 30, 35, 40, 45, or 50 residues (or -mers), and more preferably from 15 to 35 amino acid residues (or -mers). A linker or adapter molecule can also be designed with a cleavage site for a DNA restriction endonuclease or for a protease to allow for the separation of the fused moieties.

a. Fc Fusions

[0065] In one embodiment of the present invention, an FGF21 polypeptide mutant is fused to an Fc domain, e.g., one or more domains of an Fc region of a human IgG. Antibodies comprise two functionally independent parts, a variable domain known as "Fab," that binds an antigen, and a constant domain known as "Fc," that is involved in effector functions such as complement activation and attack by phagocytic cells. An Fc has a long serum half-life, whereas a Fab is short-lived (Capon et al., 1989, Nature 337: 525-31). When joined together with a therapeutic protein, an Fc domain can provide longer half-life or incorporate such functions as Fc receptor binding, protein A binding, complement fixation, and perhaps even placental transfer (Capon *et al.,* 1989).

[0066] *In vivo* pharmacokinetic analysis indicated that human FGF21 has a short half-life of about 1 hour in mice due to rapid clearance and *in vivo* degradation. Therefore, to extend the half-life of FGF21 a native Fc sequence was fused to the N- or C-terminal end of the FGF21 polypeptide. The fusion of the Fc sequence to wild type FGF21, in particularly Fc fused to the N-terminus of wild type FGF21, did not extend the half-life as expected, however this observationled to an investigation of the proteolytic degradation of FGF21 *in vivo* and the identification of FGF21 mutants that were resistant to such degradation. Such mutants are described in, for example, Examples 9 and 11, and exhibit longer half-lives than wild-type FGF21. These and other FGF21 fusion proteins form embodiments of the present invention.

[0067] Throughout the instant disclosure, Fc-FGF21 refers to a fusion protein in which the Fc sequence is fused to the N-terminus of FGF21. Similarly, throughout the disclosure, FGF21-Fc refers to a fusion protein in which the Fc sequence is fused to the C-terminus of FGF21.

[0068] The resulting FGF21 fusion protein can be purified, for example, by the use of a Protein A affinity column. Peptides and proteins fused to an Fc region have been found to exhibit a substantially greater half-life *in vivo* than the unfused counterpart. Also, a fusion to an Fc region allows for dimerization/multimerization of the fusion polypeptide. The Fc region can be a naturally occurring Fc region, or can be altered to improve certain qualities, such as therapeutic qualities, circulation time, or reduced aggregation.

[0069] Useful modifications of protein therapeutic agents by fusion with the "Fc" domain of an antibody are discussed in detail in International Publication No. WO 00/024782,

b. Fusion Protein Linkers

[0070] When forming the fusion proteins of the present invention, a linker can, but need not, be employed. When present, the linker's chemical structure may not be critical, since it serves primarily as a spacer. The linker can be made up of amino acids linked together by peptide bonds. In some embodiments of the present invention, the linker is made up of from 1 to 20 amino acids linked by peptide bonds, wherein the amino acids are selected from the 20 naturally occurring amino acids. In various embodiments, the 1 to 20 amino acids are selected from the amino acids glycine, serine, alanine, proline, asparagine, glutamine, and lysine. In some embodiments, a linker is made up of a majority of amino acids that are sterically unhindered, such as glycine and alanine. In some embodiments, linkers are polyglycines (such as $(Gly)_4$ (SEQ ID NO:29) and $(Gly)_5$ (SEQ ID NO:30)), polyalanines, combinations of glycine and alanine (such as poly(Gly-Ala)), or combinations of glycine and serine (such as poly(Gly-Ser)). Other suitable linkers include: $(Gly)_5$-Ser-$(Gly)_3$-Ser-$(Gly)_4$-Ser (SEQ ID NO:28), $(Gly)_4$-Ser-$(Gly)_4$-Ser-$(Gly)_4$-Ser (SEQ ID NO:31), $(Gly)_3$-Lys-$(Gly)_4$ (SEQ ID NO:32), $(Gly)_3$-Asn-Gly-Ser-$(Gly)_2$ (SEQ ID NO:33), $(Gly)_3$-Cys-$(Gly)_4$ (SEQ ID NO:34), and Gly-Pro-Asn-Gly-Gly (SEQ ID NO:35). While a linker of 15 amino acid residues has been found to work particularly well for FGF21 fusion proteins, the present invention contemplates linkers of any length or composition. When a linker was employed to join a heterologous sequence, such as an Fc domain, and an FGF21 polypeptide or FGF21 mutant, the linker is expressed in parentheses.

[0071] The linkers described herein are exemplary, and linkers that are much longer and which include other residues are contemplated by the present invention. Non-peptide linkers are also contemplated by the present invention. For example, alkyl linkers such as -NH-$(CH_2)_s$-C(O)-, wherein s = 2 to 20, could be used. These alkyl linkers can further be substituted by any non-sterically hindering group, including, but not limited to, a lower alkyl *(e.g.,* C1-C6), lower acyl, halogen *(e.g.,* Cl, Br), CN, NH_2, or phenyl. An exemplary non-peptide linker is a polyethylene glycol linker, wherein the linker has a molecular weight of 100 to 5000 kD, for example, 100 to 500 kD.

8. Chemically-modified FGF21 Mutants

[0072] Chemically modified forms of the FGF21 polypeptide mutants described herein, including the truncated forms of FGF21 described herein, can be prepared by one skilled in the art, given the disclosures described herein. Such chemically modified FGF21 mutants are altered such that the chemically modified FGF21 mutant is different from the unmodified FGF21 mutant, either in the type or location of the molecules naturally attached to the FGF21 mutant. Chemically modified FGF21 mutants can include molecules formed by the deletion of one or more naturallyattached chemical groups.

[0073] In one embodiment, FGF21 polypeptide mutants of the present invention can be modified by the covalent attachment of one or more polymers. For example, the polymer selected is typically water-soluble so that the protein to which it is attached does not precipitate in an aqueous environment, such as a physiological environment. Included within the scope of suitable polymers is a mixture of polymers. Preferably, for therapeutic use of the end-product preparation, the polymer will be pharmaceutically acceptable. Non-water soluble polymers conjugated to FGF21 polypeptide mutants of the present invention also form an aspect of the invention.

[0074] Exemplary polymers each can be of any molecular weight and can be branched or unbranched. The polymers each typically have an average molecular weight of between about 2 kDa to about 100 kDa (the term "about" indicating that in preparations of a water-soluble polymer, some molecules will weigh more and some less than the stated molecular weight). The average molecular weight of each polymer is preferably between about 5 kDa and about 50 kDa, more preferably between about 12 kDa and about 40 kDa, and most preferably between about 20 kDa and about 35 kDa.

[0075] Suitable water-soluble polymers or mixtures thereof include, but are not limited to, N-linked or O-linked carbohydrates, sugars, phosphates, polyethylene glycol (PEG) (including the forms of PEG that have been used to derivatize proteins, including mono-(C_1-C_{10}), alkoxy-, or aryloxy-polyethylene glycol), monomethoxy-polyethylene glycol, dextran (such as low molecular weight dextran of, for example, about 6 kD), cellulose, or other carbohydrate based polymers, poly-(N-vinyl pyrrolidone) polyethylene glycol, propylene glycol homopolymers, polypropylene oxide/ethylene oxide co-polymers, polyoxyethylated polyols (*e.g.*, glycerol), and polyvinyl alcohol. Also encompassed by the present invention are bifunctional crosslinking molecules that can be used to prepare covalently attached FGF21 polypeptide mutant multimers. Also encompassed by the present invention are FGF21 mutants covalently attached to polysialic acid.

[0076] In some embodiments of the present invention, an FGF21 mutant is covalently, or chemically, modified to include one or more water-soluble polymers, including, but not limited to, polyethylene glycol (PEG), polyoxyethylene glycol, or polypropylene glycol. *See, e.g.,* U.S. Patent Nos. 4,640,835; 4,496,689; 4,301,144; 4,670,417; 4,791,192; and 4,179,337. In some embodiments of the present invention, an FGF21 mutant comprises one or more polymers, including, but not limited to, monomethoxy-polyethylene glycol, dextran, cellulose, another carbohydrate-based polymer, poly-(N-vinyl pyrrolidone)-polyethylene glycol, propylene glycol homopolymers, a polypropylene oxide/ethylene oxide co-polymer, polyoxyethylated polyols (e.g., glycerol), polyvinyl alcohol, or mixtures of such polymers.

[0077] In some embodiments of the present invention, an FGF21 mutant is covalently-modified with PEG subunits. In some embodiments, one or more water-soluble polymers are bonded at one or more specific positions (for example, at the N-terminus) of the FGF21 mutant. In some embodiments, one or more water-soluble polymers are randomly attached to one or more side chains of an FGF21 mutant. In some embodiments, PEG is used to improve the therapeutic capacity of an FGF21 mutant. Certain such methods are discussed, for example, in U.S. Patent No. 6,133,426,

[0078] In embodiments of the present invention wherein the polymer is PEG, the PEG group can be of any convenient molecular weight, and can be linear or branched. The average molecular weight of the PEG group will preferably range from about 2 kD to about 100 kDa, and more preferably from about 5 kDa to about 50 kDa, *e.g.,* 10, 20, 30, 40, or 50 kDa. The PEG groups will generally be attached to the FGF21 mutant via acylation or reductive alkylation through a reactive group on the PEG moiety (*e.g.*, an aldehyde, amino, thiol, or ester group) to a reactive group on the FGF21 mutant (*e.g.*, an aldehyde, amino, or ester group).

[0079] The PEGylation of a polypeptide, including the FGF21 mutants of the present invention, can be specifically carried out using any of the PEGylation reactions known in the art. Such reactions are described, for example, in the following references: Francis et al., 1992, Focus on Growth Factors 3: 4-10; European Patent Nos. 0 154 316 and 0 401 384; and U.S. Patent No. 4,179,337. For example, PEGylation can be carried out via an acylation reaction or an alkylation reaction with a reactive polyethylene glycol molecule (or an analogous reactive water-soluble polymer) as described herein. For the acylation reactions, a selected polymer should have a single reactive ester group. For reductive alkylation, a selected polymer should have a single reactive aldehyde group. A reactive aldehyde is, for example, polyethylene glycol propionaldehyde, which is water stable, or mono C_1-C_{10} alkoxy or aryloxy derivatives thereof *(see, e.g.,* U.S. Patent No. 5,252,714).

[0080] In some embodiments of the present invention, a useful strategy for the attachment of the PEG group to a polypeptide involves combining, through the formation of a conjugate linkage in solution, a peptide and a PEG moiety, each bearing a special functionality that is mutually reactive toward the other. The peptides can be easily prepared with conventional solid phase synthesis. The peptides are "preactivated" with an appropriate functional group at a specific site. The precursors are purified and fully characterized prior to reacting with the PEG moiety. Ligation of the peptide with PEG usually takes place in aqueous phase and can be easily monitored by reverse phase analytical HPLC. The PEGylated peptides can be easily purified by preparative HPLC and characterized by analytical HPLC, amino acid analysis and laser desorption mass spectrometry.

[0081] Polysaccharide polymers are another type of water-soluble polymer that can be used for protein modification. Therefore, the FGF21 mutants of the present invention fused to a polysaccharide polymer form embodiments of the present invention. Dextrans are polysaccharide polymers comprised of individual subunits of glucose predominantly linked by alpha 1-6 linkages. The dextran itself is available in many molecular weight ranges, and is readily available in molecular weights from about 1 kD to about 70 kD. Dextran is a suitable water-soluble polymer for use as a vehicle by itself or in combination with another vehicle *(e.g.,* Fc). *See, e.g.,* International Publication No. WO 96/11953. The use of dextran conjugated to therapeutic or diagnostic immunoglobulins has been reported. *See, e.g.,* European Patent Publication No. 0 315 456, The present invention also encompasses the use of dextran of about 1 kD to about 20 kD.

[0082] In general, chemical modification can be performed under any suitable condition used to react a protein with an activated polymer molecule. Methods for preparing chemically modified polypeptides will generally comprise the steps of: (a) reacting the polypeptide with the activated polymer molecule (such as a reactive ester or aldehyde derivative of the polymer molecule) under conditions whereby an FGF21 polypeptide mutant becomes attached to one or more polymer molecules, and (b) obtaining the reaction products. The optimal reaction conditions will be determined based on known parameters and the desired result. An example of this is, the larger the ratio of polymer molecules to protein, the greater the percentage of attached polymer molecule. In one embodiment of the present invention, chemically modified FGF21 mutants can have a single polymer molecule moiety at the amino-terminus *(see, e.g.,* U.S. Patent No. 5,234,784)

[0083] In another embodiment of the present invention, FGF21 polypeptide mutants can be chemically coupled to biotin. The biotin/FGF21 polypeptide mutants are then allowed to bind to avidin, resulting in tetravalent avidin/biotin/FGF21 polypeptide mutants. FGF21 polypeptide mutants can also be covalently coupled to dinitrophenol (DNP) or trinitrophenol (TNP) and the resulting conjugates precipitated with anti-DNP or anti-TNP-IgM to form decameric conjugates with a valency of 10.

[0084] Generally, conditions that can be alleviated or modulated by the administration of the disclosed chemically modified FGF21 mutants include those conditions described herein for FGF21 polypeptide mutants. However, the chemically modified FGF21 mutants disclosed herein can have additional activities, enhanced or reduced biological activity, or other characteristics, such as increased or decreased half-life, as compared to unmodified FGF21 mutants.

9. Pharmaceutical Compositions of FGF21 Mutants and Administration Thereof

[0085] Pharmaceutical compositions comprising FGF21 mutants are within the scope of the present invention, and are specifically contemplated in light of the identification of several mutant FGF21 sequences exhibiting enhanced properties. Such FGF21 mutant pharmaceutical compositions can comprise a therapeutically effective amount of an FGF21 polypeptide mutant in admixture with a pharmaceutically or physiologically acceptable formulation agent selected for suitability with the mode of administration.

[0086] Acceptable formulation agents preferably are nontoxic to recipients at the dosages and concentrations employed.

[0087] The pharmaceutical composition can contain formulation agent(s) for modifying, maintaining, or preserving, for example, the pH, osmolarity, viscosity, clarity, color, isotonicity, odor, sterility, stability, rate of dissolution or release, adsorption, or penetration of the composition. Suitable formulation agents include, but are not limited to, amino acids (such as glycine, glutamine, asparagine, arginine, or lysine), antimicrobials, antioxidants (such as ascorbic acid, sodium sulfite, or sodium hydrogen-sulfite), buffers (such as borate, bicarbonate, Tris-HCl, citrates, phosphates, or other organic acids), bulking agents (such as mannitol or glycine), chelating agents (such as ethylenediamine tetraacetic acid (EDTA)), complexing agents (such as caffeine, polyvinylpyrrolidone, beta-cyclodextrin, or hydroxypropylbeta-cyclodextrin), fillers, monosaccharides, disaccharides, and other carbohydrates (such as glucose, mannose, or dextrins), proteins (such as serum albumin, gelatin, or immunoglobulins), coloring, flavoring and diluting agents, emulsifying agents, hydrophilic polymers (such as polyvinylpyrrolidone), low molecular weight polypeptides, salt-forming counterions (such as sodium), preservatives (such as benzalkonium chloride, benzoic acid, salicylic acid, thimerosal, phenethyl alcohol, methylparaben, propylparaben, chlorhexidine, sorbic acid, or hydrogen peroxide), solvents (such as glycerin, propylene glycol, or polyethylene glycol), sugar alcohols (such as mannitol or sorbitol), suspending agents, surfactants or wetting agents (such as pluronics; PEG; sorbitan esters; polysorbates such as polysorbate 20 or polysorbate 80; triton; tromethamine; lecithin; cholesterol or tyloxapal), stability enhancing agents (such as sucrose or sorbitol), tonicity enhancing agents (such as alkali metal halides - preferably sodium or potassium chloride - or mannitol sorbitol), delivery vehicles, diluents, excipients and/or pharmaceutical adjuvants (*see, e.g.,* Remington's Pharmaceutical Sciences (18th Ed., A.R. Gennaro, ed., Mack Publishing Company 1990), and subsequent editions of the same,

[0088] The optimal pharmaceutical composition will be determined by a skilled artisan depending upon, for example, the intended route of administration, delivery format, and desired dosage (*see, e.g., Remington's Pharmaceutical Sciences, supra).* Such compositions can influence the physical state, stability, rate of *in vivo* release, and rate of *in vivo* clearance of the FGF21 polypeptide mutant.

[0089] The primary vehicle or carrier in a pharmaceutical composition can be either aqueous or non-aqueous in nature. For example, a suitable vehicle or carrier for injection can be water, physiological saline solution, or artificial cerebrospinal fluid, possibly supplemented with other materials common in compositions for parenteral administration. Neutral buffered saline or saline mixed with serum albumin are further exemplary vehicles. Other exemplary pharmaceutical compositions comprise Tris buffer of about pH 7.0-8.5, or acetate buffer of about pH 4.0-5.5, which can further include sorbitol or a suitable substitute. In one embodiment of the present invention, FGF21 polypeptide mutant compositions can be prepared for storage by mixing the selected composition having the desired degree of purity with optional formulation agents (*Remington's Pharmaceutical Sciences, supra)* in the form of a lyophilized cake or an aqueous solution. Furthermore, the FGF21 polypeptide mutant product can be formulated as a lyophilizate using appropriate excipients such as sucrose.

[0090] The FGF21 polypeptide mutant pharmaceutical compositions can be selected for parenteral delivery. Alternatively, the compositions can be selected for inhalation or for delivery through the digestive tract, such as orally. The preparation of such pharmaceutically acceptable compositions is within the skill of the art.

[0091] The formulation components are present in concentrations that are acceptable to the site of administration. For example, buffers are used to maintain the composition at physiological pH or at a slightly lower pH, typically within a pH range of from about 5 to about 8.

[0092] When parenteral administration is contemplated, the therapeutic compositions for use in this invention can be in the form of a pyrogen-free, parenterally acceptable, aqueous solution comprising the desired FGF21 polypeptide mutant in a pharmaceutically acceptable vehicle. A particularly suitable vehicle for parenteral injection is sterile distilled water in which an FGF21 polypeptide mutant is formulated as a sterile, isotonic solution, properly preserved. Yet another preparation can involve the formulation of the desired molecule with an agent, such as injectable microspheres, bio-erodible particles, polymeric compounds (such as polylactic acid or polyglycolic acid), beads, or liposomes, that provides for the controlled or sustained release of the product which can then be delivered via a depot injection. Hyaluronic acid can also be used, and this can have the effect of promoting sustained duration in the circulation. Other suitable means for the introduction of the desired molecule include implantable drug delivery devices.

[0093] In one embodiment, a pharmaceutical composition can be formulated for inhalation. For example, an FGF21 polypeptide mutant can be formulated as a dry powder for inhalation. FGF21 polypeptide mutant inhalation solutions can also be formulated with a propellant for aerosol delivery. In yet another embodiment, solutions can be nebulized. Pulmonary administration is further described in International Publication No. WO 94/20069, which describes the pulmonary delivery of chemically modified proteins.

[0094] It is also contemplated that certain formulations can be administered orally. In one embodiment of the present invention, FGF21 polypeptide mutants that are administered in this fashion can be formulated with or without those carriers customarily used in the compounding of solid dosage forms such as tablets and capsules. For example, a capsule can be designed to release the active portion of the formulation at the point in the gastrointestinal tract when bioavailability is maximized and pre-systemic degradation is minimized. Additional agents can be included to facilitate absorption of the FGF21 polypeptide mutant. Diluents, flavorings, low melting point waxes, vegetable oils, lubricants, suspending agents, tablet disintegrating agents, and binders can also be employed.

[0095] Another pharmaceutical composition can involve an effective quantity of FGF21 polypeptide mutants in a mixture with non-toxic excipients that are suitable for the manufacture of tablets. By dissolving the tablets in sterile water, or another appropriate vehicle, solutions can be prepared in unit-dose form. Suitable excipients include, but are not limited to, inert diluents, such as calcium carbonate, sodium carbonate or bicarbonate, lactose, or calcium phosphate; or binding agents, such as starch, gelatin, or acacia; or lubricating agents such as magnesium stearate, stearic acid, or talc.

[0096] Additional FGF21 polypeptide mutant pharmaceutical compositions will be evident to those skilled in the art, including formulations involving FGF21 polypeptide mutants in sustained- or controlled-delivery formulations. Techniques for formulating a variety of other sustained- or controlled-delivery means, such as liposome carriers, bio-erodible microparticles or porous beads and depot injections, are also known to those skilled in the art *(see, e.g.,* International Publication No. WO 93/15722, which describes the controlled release of porous polymeric microparticles for the delivery of pharmaceutical compositions, and Wischke & Scliwendeman, 2008, Int. J. Pharm. 364: 298-327, and Freiberg & Zhu, 2004, Int. J. Pharm.

282: 1-18, which discuss microsphere/microparticle preparation and use). As described herein, a hydrogel is an example of a sustained- or controlled-delivery formulation.

[0097] Additional examples of sustained-release preparations include semipermeable polymer matrices in the form of shaped articles, e.g. films, or microcapsules. Sustained release matrices can include polyesters, hydrogels, polylactides (U.S. Patent No. 3,773,919 and European Patent No. 0 058 481), copolymers of L-glutamic acid and gamma ethyl-L-glutamate (Sidman et al., 1983, Biopolymers 22: 547-56), poly(2-hydroxyethyl-methacrylate) (Langer et al., 1981, J. Biomed. Mater. Res. 15: 167-277 and Langer, 1982, Chem. Tech. 12: 98-105), ethylene vinyl acetate (Langer *et al., supra*) or poly-D(-)-3-hydroxybutyric acid (European Patent No. 0 133 988). Sustained-release compositions can also include liposomes, which can be prepared by any of several methods known in the art. *See, e.g.,* Epstein et al., 1985, Proc. Natl. Acad. Sci. U.S.A. 82: 3688-92; and European Patent Nos. 0 036 676, 0 088 046, and 0 143 949.

[0098] The FGF21 polypeptide mutant pharmaceutical composition to be used for *in vivo* administration typically should be sterile. This can be accomplished by filtration through sterile filtration membranes. Where the composition is lyophilized, sterilization using this method can be conducted either prior to, or following, lyophilization and reconstitution. The composition for parenteral administration can be stored in lyophilized form or in a solution. In addition, parenteral compositions generally are placed into a container having a sterile access port, for example, an intravenous solution bag or vial having a stopper pierceable by a hypodermic injection needle.

[0099] Once the pharmaceutical composition has been formulated, it can be stored in sterile vials as a solution, suspension, gel, emulsion, solid, or as a dehydrated or lyophilized powder. Such formulations can be stored either in a ready-to-use form or in a form (*e.g.*, lyophilized) requiring reconstitution prior to administration.

[0100] In a specific embodiment, the present invention is directed to kits for producing a single-dose administration unit. The kits can each contain both a first container having a dried protein and a second container having an aqueous formulation. Also included within the scope of this invention are kits containing single and multi-chambered pre-filled syringes (*e.g.*, liquid syringes and lyosyringes).

[0101] The effective amount of an FGF21 polypeptide mutant pharmaceutical composition to be employed therapeutically will depend, for example, upon the therapeutic context and objectives. One skilled in the art will appreciate that the appropriate dosage levels for treatment will thus vary depending, in part, upon the molecule delivered, the indication for which the FGF21 polypeptide mutant is being used, the route of administration, and the size (body weight, body surface, or organ size) and condition (the age and general health) of the patient. Accordingly, the clinician can titer the dosage and modify the route of administration to obtain the optimal therapeutic effect. A typical dosage can range from about 0.1 μg/kg to up to about 100 mg/kg or more, depending on the factors mentioned above. In other embodiments, the dosage can range from 0.1 µg/kg up to about 100 mg/kg; or 1 µg/kg up to about 100 mg/kg; or 5 µg/kg, 10 µg/kg, 15 µg/kg, 20 µg/kg, 25 µg/kg, 30 µg/kg, 35 µg/kg, 40 µg/kg, 45 µg/kg, 50 µg/kg, 55 µg/kg, 60 µg/kg, 65 µg/kg, 70 µg/kg, 75 µg/kg, up to about 100 mg/kg. In yet other embodiments, the dosage can be 50 µg/kg, 100 µg/kg, 150 µg/kg, 200 µg/kg, 250 µg/kg, 300 µg/kg, 350 µg/kg, 400 µg/kg, 450 µg/kg, 500 µg/kg, 550 µg/kg, 600 µg/kg, 650 µg/kg, 700 µg/kg, 750 µg/kg, 800 µg/kg, 850 µg/kg, 900 µg/kg, 950 µg/kg, 100 µg/kg, 200 µg/kg, 300 µg/kg, 400 µg/kg, 500 µg/kg, 600 µg/kg, 700 µg/kg, 800 µg/kg, 900 µg/kg, 1000 µg/kg, 2000 µg/kg, 3000 µg/kg, 4000 µg/kg, 5000 µg/kg, 6000 µg/kg, 7000 µg/kg, 8000 µg/kg, 9000 µg/kg or 10 mg/kg.

[0102] The frequency of dosing will depend upon the pharmacokinetic parameters of the FGF21 polypeptide mutant in the formulation being used. Typically, a clinician will administer the composition until a dosage is reached that achieves the desired effect. The composition can therefore be administered as a single dose, as two or more doses (which may or may not contain the same amount of the desired molecule) over time, or as a continuous infusion via an implantation device or catheter. Further refinement of the appropriate dosage is routinely made by those of ordinary skill in the art and is within the ambit of tasks routinely performed by them. Appropriate dosages can be ascertained through use of appropriate dose-response data.

[0103] The route of administration of the pharmaceutical composition is in accord with known methods, *e.g.*, orally; through injection by intravenous, intraperitoneal, intracerebral (intraparenchymal), intracerebroventricular, intramuscular, intraocular, intraarterial, intraportal, or intralesional routes; by sustained release systems (which may also be injected); or by implantation devices. Where desired, the compositions can be administered by bolus injection or continuously by infusion, or by implantation device.

[0104] Alternatively or additionally, the composition can be administered locally via implantation of a membrane, sponge, or other appropriate material onto which the desired molecule has been absorbed or encapsulated. Where an implantation device is used, the device can be implanted into any suitable tissue or organ, and delivery of the desired molecule can be via diffusion, timed-release bolus, or continuous administration.

[0105] In order to deliver drug, *e.g.*, an FGF21 mutant disclosed herein, at a predetermined rate such that the drug concentration can be maintained at a desired therapeutically effective level over an extended period, a variety of different approaches can be employed. In one example, a hydrogel comprising a polymer such as a gelatin (*e.g.*, bovine gelatin, human gelatin, or gelatin from another source) or a naturally-occurring or a synthetically generated polymer can be employed. Any percentage of polymer (*e.g.*, gelatin) can be employed in a hydrogel, such as 5, 10, 15 or 20%. The selection of an appropriate concentration can depend on a variety of factors, such as the therapeutic profile desired and the pharmacokinetic profile of the therapeutic molecule.

[0106] Examples of polymers that can be incorporated into a hydrogel include polyethylene glycol ("PEG"), polyethylene oxide, polyethylene oxide-co-polypropylene oxide, co-polyethylene oxide block or random copolymers, polyvinyl alcohol, poly(vinyl pyrrolidinone), poly(amino acids), dextran, heparin, polysaccharides, polyethers and the like.

[0107] Another factor that can be considered when generating a hydrogel formulation is the degree of crosslinking in the hydrogel and the crosslinking agent. In one embodiment, cross-linking can be achieved via a methacrylation reaction involving methacrylic anhydride. In some situations, a high degree of cross-linking may be desirable while in other situations a lower degree of crosslinking is preferred. In some cases a higher degree of crosslinking provides a longer sustained release. A higher degree of crosslinking may provide a firmer hydrogel and a longer period over which drug is delivered.

[0108] Any ratio of polymer to crosslinking agent (e.g., methacrylic anhydride) can be employed to generate a hydrogel with desired properties. For example, the ratio of polymer to crosslinker can be, *e.g.,* 8:1, 16:1, 24:1, or 32:1. For example, when the hydrogel polymer is gelatin and the crosslinker is methacrylate, ratios of 8:1, 16:1, 24:1, or 32:1 methyacrylic anhydride: gelatin can be employed.

10. Therapeutic Uses of FGF21 Polypeptide Mutants

[0109] FGF21 polypeptide mutants can be used to treat, diagnose, ameliorate, or prevent a number of diseases, disorders, or conditions, including, but not limited to metabolic disorders. In one embodiment, the metabolic disorder to be treated is diabetes, *e.g.*, type 2 diabetes. In another embodiment, the metabolic disorder is obesity. Other embodiments include metabolic conditions or disorders such as dyslipidimia; hypertension; hepatosteaotosis, such as non-alcoholic steatohepatitis (NASH); cardiovascular disease, such as atherosclerosis; and aging.

[0110] In application, a disorder or condition such as diabetes or obesity can be treated by administering an FGF21 polypeptide mutant as described herein to a patient in need thereof in the amount of a therapeutically effective dose. The administration can be performed as described herein, such as by IV injection, intraperitoneal injection, intramuscular injection, or orally in the form of a tablet or liquid formation. In most situations, a desired dosage can be determined by a clinician, as described herein, and can represent a therapeutically effective dose of the FGF21 mutant polypeptide. It will be apparent to those of skill in the art that a therapeutically effective dose of FGF21 mutant polypeptide will depend, *inter alia,* upon the administration schedule, the unit dose of agent administered, whether the nucleic acid molecule or polypeptide is administered in combination with other therapeutic agents, the immune status and the health of the recipient. The term "therapeutically effective dose," as used herein, means that amount of FGF21 mutant polypeptide that elicits the biological or medicinal response in a tissue system, animal, or human being sought by a researcher, medical doctor, or other clinician, which includes alleviation of the symptoms of the disease or disorder being treated.

EXAMPLES

[0111] The Examples that follow are illustrative of specific embodiments of the invention, and various uses thereof.

EXAMPLE 1

Preparation of FGF21 Expression Constructs

[0112] A nucleic acid sequence encoding the mature FGF21 polypeptide was obtained by polymerase chain reaction (PCR) amplification using primers having nucleotide sequences corresponding to the 5' and 3' ends of the mature FGF21 sequence. Table 2 lists the primers that were used to amplify the mature FGF21 sequence.

Table 2

PCR Primers for Preparing FGF21 Construct		
Primer	**Sequence**	**SEQ ID NO:**
Sense	5'-AGGAGGAATAACATATGCATCCAATTCCAGATTCTTCTCC-3'	12
Antisense	5' -TAGTGAGCTCGAATTCTTAGGAAGCGTAGCTGG-3 '	13

[0113] The primers used to prepare the mature FGF21 expression construct incorporated restriction endonuclease sites (the NdeI site also comprises an N-terminal methionine for bacterial expression) for directional cloning of the sequence into a suitable expression vector (*e.g.*, pET30 (Novagen/EMD Biosciences; San Diego, CA) or pAMG33 (Amgen; Thousand Oaks, CA)). The expression vector pAMG33 contains a low-copy number R-100 origin of replication, a modified *lac* promoter, and a kanamycin-resistance gene. The expression vector pET30 contains a pBR322-derived origin of replication, an inducible T7 promoter, and a kanamycin-resistance gene. While expression from pAMG33 was found to be higher, pET30 was found to be a more reliable cloning vector. Thus, the majority of the constructs described in the instant disclosure were first generated in pET30 and then screened for efficacy. Selected sequences were then transferred to pAMG33 for further amplification.

[0114] The FGF21 sequence was amplified in a reaction mixture containing 40.65 µL dH_2O, 5µL PfuUltra II Reaction Buffer (10x), 1.25 µL dNTP Mix (40 mM - 4 x 10mM), 0.1 µL Template (100 ng/mL), 1 µL Primer1 (10 µM), 1 µL Primer2 (10 µM), and 1 µL PfuUltra II fusion HS DNA Polymerase (Stratagene; La Jolla, CA). Amplification reactions were performed by heating for 2 minutes at 95°C; followed by ten cycles at 95°C for 20 seconds, 60°C for 20 seconds (with an additional 1°C subtracted per cycle), and 72°C for 15 seconds/kilobase of desired product; followed by 20 cycles at 94°C for 20 seconds, 55°C for 20 seconds, and 72°C for 15 seconds/kilobase of desired product; followed by 72°C for 3 minutes. Amplification products were digested with the restriction endonucleases NdeI, DpnI, and EcoRI; ligated into a suitable vector; and then transformed into competent cells.

EXAMPLE 2

Purification of FGF21 Proteins from Bacteria

[0115] In the Examples that follow, various FGF21 proteins, including the wild-type FGF21 polypeptide, truncated FGF21 polypeptides, FGF21 mutants, and FGF21 fusion proteins, were expressed in a bacterial expression system. After expression, which is described below, the FGF21 proteins were purified as described in this Example, unless otherwise indicated.

[0116] To purify the wild-type FGF21 polypeptide, truncated FGF21 polypeptides, and FGF21 mutants from bacterial inclusion bodies, double-washed inclusion bodies (DWIBs) were solubilized in a solubilization buffer containing guanidine hydrochloride and DTT in Tris buffer at pH 8.5. They were then mixed for one hour at room temperature, and the solubilization mixture was added to a refold buffer containing urea, arginine, cysteine, and cystamine hydrochloride at pH 9.5 and then mixed for 24 hours at 5°C *(see, e.g.,* Clarke, 1998, Curr. Opin. Biotechnol. 9: 157-63; Mannall et al., 2007, Biotechnol. Bioeng. 97: 1523-34; Rudolph et al., 1997, "Folding proteins," Protein Function: A Practical Approach (Creighton, ed., New York, IRL Press) 57-99; and Ishibashi et al., 2005, Protein Expr. Purif. 42: 1-6).

[0117] Following solubilization and refolding, the mixture was filtered through a 0.45 micron filter. The refold pool was then concentrated approximately 10-fold with a 10 kD molecular weight cut-off Pall Omega cassette at a transmembrane pressure (TMP) of 20 psi, and dialfiltered with 3 column volumes of 20 mM Tris, pH 8.0 at a TMP of 20 psi.

[0118] The clarified sample was then subjected to anion exchange (AEX) chromatography using a Q Sepharose HP resin. A linear salt gradient of 0 to 250 mM NaCl in 20 mM Tris was run at pH 8.0 at 5°C. Peak fractions were analyzed by SDS-PAGE and pooled.

[0119] The AEX eluate pool was then subjected to hydrophobic interaction chromatography (HIC) using a Phenyl Sepharose HP resin. Protein was eluted using a decreasing linear gradient of 0.7 M to 0 M ammonium sulfate at pH 8.0 and ambient temperature. Peak fractions were analyzed by SDS-PAGE (Laemmli, 1970, Nature 227: 680-85) and pooled.

[0120] The HIC pool was concentrated with a 10 kD molecular weight cut-off Pall Omega 0.2

m^2 cassette to 7 mg/mL at a TMP of 20 psi. The concentrate was dialfiltered with 5 column volumes of formulation buffer at a TMP of 20 psi, and the recovered concentrate was diluted to 5 mg/mL. Finally, the solution was filtered through a Pall mini-Kleenpac 0.2 μM Posidyne membrane.

[0121] To purify FGF21 fusion proteins and FGF21 fusion mutant proteins from bacterial inclusion bodies, double-washed inclusion bodies (DWIBs) were solubilized in a solubilization buffer containing guanidine hydrochloride and DTT in Tris buffer at pH 8.5 and then mixed for one hour at room temperature. Then the solubilization mixture was added to a refold buffer containing urea, arginine, cysteine, and cystamine hydrochloride at pH 9.5 and then mixed for 24 hours at 5°C (*see, e.g.,* Clarke, 1998, Curr. Opin. Biotechnol. 9: 157-63; Mannall et al., 2007, Biotechnol. Bioeng. 97: 1523-34; Rudolph et al., 1997, "Folding proteins," Protein Function: A Practical Approach (Creighton, ed., New York, IRL Press) 57-99 ; and Ishibashi et al., 2005, Protein Expr. Purif. 42: 1-6).

[0122] Following solubilization and refolding, the mixture was dialyzed against 5 volumes of 20 mM Tris, pH 8.0 using 10 kD dialysis tubing. The pH of the dialyzed refold was adjusted to 5.0 with 50% acetic acid, and then clarified by centrifugation for 30 minutes at 4K.

[0123] The clarified sample was then subjected to anion exchange (AEX) chromatography using a Q Sepharose HP resin. A linear salt gradient of 0 to 250 mM NaCl in 20 mM Tris was run at pH 8.0 at 5°C. Peak fractions were analyzed by SDS-PAGE (Laemmli, 1970, Nature 227: 680-85) and pooled.

[0124] The AEX eluate pool was then subjected to hydrophobic interaction chromatography (HIC) using a Phenyl Sepharose HP resin. Protein was eluted using a decreasing linear gradient of 0.6 M to 0 M ammonium sulfate at pH 8.0 at ambient temperature. Peak fractions were analyzed by SDS-PAGE and pooled.

[0125] Following the HIC step, the pool was then dialyzed 60 volumes of formulation buffer. The dialyzed pool was concentrated to 5 mg/mL using a Pall Jumbosep. Finally, the solution was filtered through a Pall mini-Kleenpac 0.2 μM Posidyne membrane.

EXAMPLE 3

Preparation and Expression of Truncated FGF21 Proteins

[0126] Constructs encoding the truncated FGF21 proteins listed in Table 3 were prepared by PCR amplification of the wild-type FGF21 expression vector as described below (the construction of the wild-type FGF21 expression vector is described in Example 1).

Table 3

FGF21 Truncations	
Amino Acid Residues	**Number of Residues Truncated***
C-terminus Truncations	
1 - 180	1
1 - 179	2
1 - 178	3
1 - 177	4
1 - 176	5
1 - 175	6
1 - 174	7
1 - 173	8
1 - 172	9
1 - 171	10
1 - 169	12
1 - 168	13
1 - 167	14
1 - 166	15
1 - 165	16
1 - 164	17
1 - 160	21
1 - 156	25
1 - 152	29
1 - 149	32
1 - 113	68
N-terminus Truncations	
2 - 181	1
3 - 181	2
4 - 181	3
5 - 181	4
6 - 181	5
7 - 181	6
8 - 181	7
9 - 181	8
C- and N-terminus Truncations	
5 - 174	11

C- and N-terminus Truncations	
7 - 172	17
9 - 169	20
9 - 149	40
15 - 169	26
15 - 149	46
15 - 113	82
* relative to mature FGF21 polypeptide	

[0127] Truncated FGF21 protein constructs were prepared using primers having sequences that are homologous to regions upstream and downstream of a codon (or codons) to be deleted (resulting in the truncation). The primers used in such amplification reactions also provided approximately 15 nucleotides of overlapping sequence to allow for recircularization of the amplified product, namely the entire vector now having the desired mutant or truncation.

[0128] An exemplary truncated FGF21 construct, encoding an FGF21 protein lacking the histidine residue at position 1 of the mature FGF21 sequence (*i.e.*, the 2-181 truncation mutant), was prepared using the primers shown in Table 4.

Table 4

PCR Primers for Preparing Exemplary Truncation FGF21 Mutant		
Primer	**Sequence**	**SEQ ID NO:**
Sense	5'-GGAGATATACATATGCCAATTCCAGATTCTTCTCCATTATT-3'	14
Antisense	5'-CATATGTATATCTCCTTCTTAAAGTTAAACAAAA-3'	15

[0129] The primers shown in Table 4 allow for the deletion of the histidine residue as shown below, wherein the upper sequence (SEQ ID NO:9) is a portion of a mature FGF21 polypeptide comprising a N-terminal methionine, the second sequence is the sense primer (SEQ ID NO:14), the third and fourth sequences (SEQ ID NOs:17 and 18) are portions of an FGF21 expression construct, and the fifth sequence is the antisense primer (SEQ ID NO:16):

```
                       MetHisProIleProAspSerSerProLeu
           5'-GGAGATATACATATG---
CCAATTCCAGATTCTTCTCCATTATT
TTTTGTTTAACTTTAAGAAGGAGATATACATATGCATCCAATTCCAGATTCTTCTCCATTAT
T
AAAACAAATTGAAATTCTTCCTCTATATGTATACGTAGGTTAAGGTCTAAGAAGAGGTAATA
A
AAAACAAATTGAAATTCTTCCTCTATATGTATAC-5'
```

[0130] Truncated FGF21 protein constructs were prepared using essentially the PCR conditions described in Example 1. Amplification products were digested with the restriction endonuclease DpnI, and then transformed into competent cells. The resulting clones were sequenced to confirm the absence of polymerase-generated errors.

[0131] Truncated FGF21 proteins were expressed by transforming competent BL21 (DE3) or BL21 Star (Invitrogen; Carlsbad, CA) cells with the construct encoding a particular truncated FGF21 protein. Transformants were grown overnight with limited aeration in TB media supplemented with 40 µg/mL kanamycin, were aerated the next morning, and after a short recovery period, were induced in 0.4 mM IPTG. FGF21 mutants were harvested by centrifugation 18-20 hours after induction.

EXAMPLE 4

***In vitro* Activity of Truncated FGF21 Proteins**

[0132] Experiments were performed to identify truncated FGF21 proteins that retain wild-type FGF21 activity in an ELK-luciferase *in vitro* assay. Table 5 summarizes the results obtained for FGF21 proteins having truncations at the N-terminus, the C-terminus, or at both the N-terminus and C-terminus. ELK-luciferase assays were performed using a recombinant human 293T kidney cell system, in which the 293T cells overexpress β-Klotho and luciferase reporter constructs. These constructs also contain sequences encoding GAL4-ELK1 and 5xUAS-Luc, a luciferase reporter driven by a promoter containing five tandem copies of the Gal4 binding site. β-Klotho is a co-receptor that is required by FGF21 for activation of its FGF receptors and induction of intracellular signal transduction, which in turn leads to Erk and ELK phosphorylation. Luciferase activity is regulated by the level of phosphorylated Erk/ELK1, and is used to indirectly monitor and quantify FGF21 activity.

[0133] ELK-luciferase assays were performed by culturing the 293T cells in the presence of different concentrations of wild-type FGF21 or FGF21 mutant polypeptide for 6 hours, and then assaying the cell lysates for luciferase activity. Figures 1A-1B show the results of an ELK-luciferase activity assay performed on the FGF21 truncation mutants 7-181 and 8-181 (Figure 1A) and the FGF21 truncation mutants 1-172, 1-171, 1-169, and 1-164 (Figure 1B). The luminescence obtained in ELK-luciferase assays for each of the FGF21 truncation mutants 3-181, 4-181, 5-181, 7-181, 8-181, 1-180, 1-178, 1-177, 1-176, 1-175, 1-174, 1-173, 1-172, 9-181, and 1-149 is shown in Figure 2.

[0134] FGF21 mutant polypeptides were compared with a wild-type FGF21 standard and mutants showing an efficacy of at least 50% of the efficacy of wild-type FGF21 were considered as having not lost FGF21 activity and were assigned a "+" in Table 5.

Table 5

Truncated FGF21 Proteins: *in vitro* Assay		
C-terminus Truncations		
Amino Acid Residues	**Efficacy**	**Activity (+/-)**
1 - 180	93.2%	+
1 - 178	95.0%	+
1 - 177	112.0%	+
1 - 176	104.8%	+
1 - 174	104.6%	+
1 - 173	96.1%	+
1 - 172	97.5%	+
1 - 171	113.0%	+
1 - 169	84.9%	+
1 - 167	20%	-
1 - 166	20%	-
1 - 165	10%	-
N-terminus Truncations		
Amino Acid Residues	**Efficacy**	**Activity** (+/-)
2- 181	112.5%	+
3 - 181	130.3%	+
4 - 181	117.0%	+
5 - 181	119.6%	+
7 - 181	74.2%	+
8 - 181	24.9%	-
9 - 181	12.5%	-

[0135] Collectively, the results presented in Table 5 indicate that C-terminal deletions of 14 or more amino acid residues (*i.e.,* a C-terminally truncated FGF21 protein consisting of amino acid residues 1-167 and shorter proteins) eliminate the activity of FGF21. In addition, Table 5 indicates that N-terminal deletions of 7 or more amino acid residues (i.e., an N-terminally truncated FGF21 protein consisting of amino acid residues 8-181 and shorter proteins) eliminate the activity of FGF21. Not surprisingly, truncated FGF21 proteins possessing both an N-terminal truncation of 8 to 14 residues and a C-terminal truncation of 12 or 32 residues were found to lack activity in ELK-luciferase assays.

[0136] Consistent with the data presented in Table 5, truncated FGF21 polypeptides having N-terminal truncations of fewer than 7 amino acid residues constitute embodiments of the present invention. Similarly, truncated FGF21 polypeptides having C-terminal truncations of fewer than 13 amino acid residues constitute embodiments of the present invention.

EXAMPLE 5

***In vivo* Activity of Truncated FGF21 Proteins**

[0137] FGF21 possesses a number of biological activities, including the ability to lower blood glucose, insulin, triglyceride, or cholesterol levels; reduce body weight; or improve glucose tolerance, energy expenditure, or insulin sensitivity. Truncated FGF21 polypeptides were further analyzed for *in vivo* FGF21 activity, by introducing the truncated FGF21 polypeptides into insulin resistant ob/ob mice, and measuring the ability of a particular truncated FGF21 polypeptide to lower blood glucose. The truncated FGF21 polypeptide to be tested was injected intraperitoneally into an 8 week old ob/ob mouse (Jackson Laboratory), and blood samples were obtained at various time points following a single injection, e.g., 0, 6, 24, 72, 120, and 168 hours after injection. Blood glucose levels were measured with a OneTouch Glucometer (LifeScan, Inc. Milpitas, CA), and the results expressed as a percent change of blood glucose relative to the baseline level of blood glucose (*i.e.*, at time 0).

[0138] The results of one experiment are provided in Figure 3, which shows the amount of blood glucose detected in mice injected with the FGF21 truncation mutants 8-181 and 9-181. This experiment demonstrated that truncated FGF21 fusion proteins comprising amino acid residues 8-181 exhibit blood glucose lowering activity *in vivo* however the activity is slightly less than the activity of wild-type FGF21 at 3 and 6 hours after injection, but that truncated FGF21 fusion proteins comprising amino acid residues 9-181 do not exhibit such activity. Thus, the *in vivo* analysis of truncated FGF21 polypeptides indicated that the deletion of up to 7 amino acids from the N-terminus of mature FGF21 does not abolish the molecule's biological activity (in contrast with the *in vitro* analysis, which suggested that the deletion of 7 amino acids from the N-terminus of mature FGF21 would abolish activity).

[0139] The differing results obtained with particular N-terminally truncated FGF21 polypeptides *(e.g.,* FGF21 8-181) in *in vitro* and *in vivo* assays can be explained by the interaction of FGF21 with β-Klotho and FGF receptor in effecting signal transduction. In particular, FGF21 activates a dual receptor complex comprising the co-receptor β-Klotho and FGF receptor (FGFR), which initiates a signaling cascade involving tyrosine kinase. The N-terminus of FGF21 has been shown to be involved in binding and activation of FGFR while the C-terminus of FGF21 is required for β-Klotho interaction (Yie et al., 2009 FEBS Lett. 583:19-24). The ELK-luciferase *in vitro* assay is performed in 293 kidney cells in which the co-receptor β-Klotho is overexpressed and FGFR is expressed at normal levels. The amount of FGFR is low relative to that of β-Klotho and the ratio of β-Klotho to FGFR in 293 cells is therefore non-physiological, which may affect receptor complex formation and ultimately ligand binding and activation of FGFR. The 293 *in vitro* system appears to be more vulnerable to N-terminally truncated FGF21 polypeptides and therefore may have produced loss of activity results for a few of the N-terminally truncated mutants tested, such as FGF21 8-181. Thus, in determining whether a particular N-terminally truncated FGF21 mutant retained wild-type FGF21 activity, the activity of that FGF21 mutant in the *in vivo* assay was considered to be dispositive. Accordingly, truncated FGF21 polypeptides having N-terminal truncations of fewer than 8 amino acid residues are encompassed by the invention.

EXAMPLE 6

Preparation and Expression of Truncated FGF21 Fusion Proteins

[0140] Because the half-life of a protein can be increased by fusing the protein to an Fc sequence, fusion proteins comprising truncated FGF21 polypeptides were prepared and analyzed. The truncated FGF21 fusion proteins listed in Table 6 were prepared from amplified FGF21 sequences by SOEing (gene splicing by overlap extension) PCR. FGF21 fusion proteins were prepared such that the Fc portion of the human immunoglobulin IgG1 gene (SEQ ID NO:11) was fused to either the N-terminus or the C-terminus of the FGF21 protein.

Table 6

Truncated FGF21 Fusion Proteins		
Amino Acid Residues	**Fc Position**	**Linker**
C-terminus Truncations		
1 - 178	$-NH_2$	15
1 - 175	$-NH_2$	14
1 - 175	-COOH	15
1 - 171	$-NH_2$	15
1 - 171	-COOH	15
1 - 170	-COOH	15
N-terminus Truncations		
5 - 181	$-NH_2$	15
5 - 181	-COOH	15
7 - 181	$-NH_2$	15
7 - 181	-COOH	15
C- and N-terminus Truncations		
5 - 175	$-NH_2$	15

C- and N-terminus Truncations		
5 - 175	-COOH	15
5 - 171	$-NH_2$	15
5 - 171	-COOH	15
6 - 170	-COOH	15
7 - 178	-COOH	35
7 - 175	$-NH_2$	15
7 - 175	-COOH	15
7 - 174	-COOH	35
7 - 172	-COOH	35
7 - 171	$-NH_2$	15
7 - 171	-COOH	35
7 - 171	-COOH	15

[0141] In particular, FGF21 fusion protein constructs (including those encoding truncated FGF21 fusion proteins) were prepared in a series of three amplification reactions using essentially the reaction conditions described in Example 1. In the first reaction, a pair of primers was designed to produce a sequence containing an NdeI cloning site (including an N-teriminal methionine for bacterial expression), Fc region, and linker sequence. In the second reaction, a pair of primers was designed to produce a sequence containing an overlapping portion of the linker, a portion of the FGF21 coding sequence, and an EcoRI cloning site. Finally, in the third reaction, a pair of primers was designed for the purpose of linking the products of the first two reactions. An exemplary set of primers for the construction of Fc-FGF21 1-181 is listed in Table 7.

Table 7

PCR Primers for Preparing Exemplary FGF21 Fusion Protein Construct		
Primer	**Sequence**	**SEQ ID NO:**
Reaction 1		
Sense	5' -AGGAGGAATAACATATGGACAAAACTCACACATG-3'	19
Antisense	5' -GGATCCACCACCACCGCTACCAC-3'	20
Reaction 2		
Sense	5'-GGTGGTGGTGGATCCCATCCAATTCCAGATTCTTCTCCA-3'	21
Antisense	5'-TAGTGAGCTCGAATTCTTAGGAAGCGTAGCTGG-3'	22

Reaction 3		
Sense	5'-AGGAGGAATAACATATGGACAAAACTCACACATG-3'	19
Antisense	5'-TAGTGAGCTCGAATTCTTAGGAAGCGTAGCTGG-3'	22

[0142] The product of the final reaction was digested with the restriction endonucleases NdeI and EcoRI, ligated into the pET30 vector, and then transformed into competent cells. The resulting clones were sequenced to confirm the absence of polymerase-generated errors.

EXAMPLE 7

***In vivo* Activity of Truncated FGF21 Fusion Proteins**

[0143] Fusion proteins comprising a truncated FGF21 sequence fused to an Fc sequence were generated and assayed for *in vivo* activity. Truncated FGF21 fusion proteins were prepared by fusing an IgG1 Fc molecule to either the N-terminal or C-terminal end of a truncated FGF21 protein to form a single contiguous sequence. To distinguish between N-terminal and C-terminal fusions, FGF21 fusion proteins in which the Fc molecule was fused to the N-terminal end of the FGF21 protein are designated as Fc-FGF21, and fusion proteins in which the Fc molecule was fused to the C-terminal end of the FGF21 protein are designated as FGF21-Fc.

[0144] FGF21 possesses a number of biological activities, including the ability to lower blood glucose, insulin, triglyceride, or cholesterol levels; reduce body weight; or improve glucose tolerance, energy expenditure, or insulin sensitivity. To assess *in vivo* FGF21 activity, FGF21 polypeptides, FGF21 mutant polypeptides, and FGF21 fusion polypeptides were introduced into insulin resistant ob/ob mice, and the ability of a particular FGF21 protein to lower blood glucose levels was measured. The FGF21 polypeptide, FGF21 mutant polypeptide, or FGF21 fusion polypeptide to be tested was injected intraperitoneally into 8 week old ob/ob mice (Jackson Laboratory), and blood samples were obtained at various time points following a single injection, *e.g.,* 0, 6, 24, 72, 120, and 168 hours after injection. Blood glucose levels were measured with a OneTouch Glucometer (LifeScan, Inc. Milpitas, CA), and the results expressed as a percent change of blood glucose relative to the baseline level of blood glucose (i.e., at time 0).

[0145] The results of one experiment are provided in Figure 4, which shows the percent change in blood glucose levels observed in mice injected with a PBS control, a wild-type Fc-FGF21 control comprising amino acid residues 1-181, or truncated Fc-FGF21 fusion proteins comprising amino acid residues 5-181 or 7-181. This experiment demonstrated that truncated Fc-FGF21 fusion proteins comprising amino acid residues 5-181 or 7-181 exhibit blood glucose lowering activity that is similar to the activity of wild-type Fc-FGF21 at 6 hours after injection. Thus, the *in vivo* analysis of truncated FGF21 polypeptides indicated that the deletion of up to 6 amino acids from the N-terminus of mature FGF21 does not affect the molecule's biological activity. *In vivo* analysis also indicated, however, that the ability of truncated FGF21 polypeptides to lower blood glucose was reduced and that blood glucose levels returned to baseline at 24 hours after injection (similar results were obtained with wild-type FGF21). The short *in vivo* activity was found to be a result of the proteolytic degradation of FGF21, as described in Example 8.

[0146] The results of another experiment are provided in Figure 5, which shows the percent change in blood glucose levels observed in mice injected with a PBS control, a wild-type FGF21-Fc control comprising amino acid residues 1-181, a truncated FGF21-Fc fusion protein comprising residues 1-175, or a truncated Fc-FGF21 protein comprising amino acid residues 1-171. This experiment demonstrates that the wild-type FGF21-Fc comprising amino acid residues 1-181 has a sustained glucose-lowering activity resulting in a reduction of blood glucose levels of approximately 30% over the time period of 24 hours to 120 hours following injection. The truncated Fc-FGF21 protein comprising amino acid residues 1-171 exhibits delayed blood glucose lowering activity evident only at 72 hours after injection. However, the activity observed is the same as the activity of wild-type FGF21-Fc. The truncated FGF21-Fc fusion protein comprising residues 1-175 is not active *in vivo* in lowering blood glucose.

[0147] Collectively, the truncation experiments described herein demonstrate that truncated FGF21 fusion proteins having an N-terminal truncation exhibit blood glucose lowering activity that is similar to that of the wild-type FGF21 fusion protein, and further, that truncated FGF21 fusion proteins in which the Fc molecule has been fused to the N-terminal end of the truncated FGF21 protein exhibit more activity than fusion proteins in which the Fc molecule has been fused to the C-terminal end of the truncated FGF21 protein.

EXAMPLE 8

Observed *in vivo* Degradation of FGF21

[0148] FGF21 degradation was first observed with FGF21 Fc fusion protein constructs as described in Example 7. *In vivo* pharmacokinetic analysis indicated that human FGF21 has a short half-life of about 1 hour in mice due to rapid clearance and *in vivo* degradation. Therefore, to extend the half-life of FGF21 an Fc sequence was fused to the N- or C-terminal end of the FGF21 polypeptide. However, the fusion of an Fc region did not completely resolve the half-life issue since fusion proteins in which an Fc sequence was fused to the N- or C-terminal end of the FGF21 polypeptide (and in particular Fc-FGF21 fusions, *i.e.,* in which the Fc sequence is fused to the N-terminus of mature FGF21), did not exhibit the expected *in vivo* efficacy, and instead were found to maintain blood glucose lowering activity for no more than

24 hours in ob/ob mice. As described in Figure 4, Fc-FGF21 fusion proteins reduced blood glucose levels by about 30-40% at 6 hours after injection, while the blood glucose levels returned to baseline levels at 24 hours.

[0149] The proteolytic degradation of wild-type FGF21 was subsequently investigated, and the rapid loss of *in vivo* activity with Fc-FGF21 fusion proteins was found to be the result of *in vivo* degradation of FGF21. Proteolytic degradation leads to decreased biological activity of the molecule *in vivo* and thus a shorter effective half-life, and such degradation adversely impacts the therapeutic use of that molecule. Accordingly, the observed degradation of FGF21 Fc fusion proteins led to the investigation of the proteolytic degradation of FGF21 *in vivo* and to identify FGF21 mutants that were resistant to such degradation.

[0150] To determine the sites of degradation, LC-MS analysis and Edman sequencing was performed on wild-type human FGF21 and FGF21 Fc fusion proteins obtained at various time points after injection into male C57B6 mice. The Edman sequencing helped confirm whether the N-terminal or C-terminal end of the protein was undergoing degradation. When an Fc sequence was fused to the N-terminus of human FGF21, degradation was found to occur at the peptide bond between amino acid residues 151 and 152 and between amino acid residues 171 and 172 of the human FGF21 portion of the fusion molecule (the residue numbering above is based on the mature FGF21 sequence and does not include the Fc portion of the fusion protein). The degradation at 171-172 was found to occur first, and was followed by degradation at 151-152. Degradation at 171-172 appears to be the rate-limiting step and plays a role in the half-life of the molecule. When an Fc sequence was fused to the C-terminus of FGF21, degradation was found to occur at the peptide bond between amino acid residues 4 and 5 and between amino acid residues 20 and 21. As a result of these experiments, it was determined that the Fc sequence appears to protect the portion of the FGF21 sequence that is adjacent to the Fc sequence from degradation. An analysis of the *in vivo* degradation of wild-type FGF21 and Fc-FGF21 fusion proteins was further conducted in *cynomolgus* monkeys. These studies confirmed that the cleavage site of FGF21 at amino acid residues 171-172 is the major site of degradation in monkeys and that this site of degradation is conserved between murine and primate.

EXAMPLE 9

<u>Identification of FGF21 Proteolysis-Resistant Mutants</u>

[0151] Suitable FGF21 mutants were identified by experimentally determining the positions of the wild-type FGF21 sequence that are sites of major proteolytic activity, and specific amino acid substitutions were introduced at these sites. Amino acid substitutions were based on FGF21 sequence conservation with other species (as described in Example 8) and biochemical conservation with other amino acid residues. A list of amino acid substitutions that were or can be introduced into the wild-type FGF21 protein is provided in Table 8, although Table 8 is only exemplary and other substitutions can be made. The numbers of the positions given in Table 8 correspond to the residue position in the mature FGF21 protein, which consists of 181 amino acid residues.

Table 8

FGF21 Residues Mutated		
Amino Acid Position	**Native Residue**	**Mutations**
19	Arg	Gln, Ile, Lys
20	Tyr	His, Leu, Phe
21	Leu	Ile, Phe, Tyr, Val
22	Tyr	Ile, Phe, Val
150	Pro	Ala, Arg
151	Gly	Ala, Val
152	Ile	His, Leu, Phe, Val
170	Gly	Ala, Asn, Asp, Cys, Gln, Glu, Pro, Ser
171	Pro	Ala, Arg, Asn, Asp, Cys, Glu, Gln, Gly, His, Lys, Ser, Thr, Trp, Tyr
172	Ser	Leu, Thr
173	Gln	Arg, Glu

EXAMPLE 10

In vivo Analysis of Fc-FGF21 and FGF21-Fc Degradation

[0152] The stability of FGF21 Fc fusion proteins *in vivo* was determined by injecting mice with a fusion protein, drawing blood from the mice at various time points, and analyzing the serum by liquid chromatography-mass spectrometry (LC-MS). In particular, mice were intraperitoneally injected with 10 mg/kg of Fc-(G5)-FGF21 (SEQ ID NO:107) (expressed in *E. coli* and purified as described in Example 2) or FGF21-(G3)-Fc (SEQ ID NO:105) (expressed in mammalian cells and purified according to standard procedures). Blood was drawn from the mice at 6, 24, and 48 hours after injection (Table 9) and collected into EDTA tubes pretreated with protease inhibitor cocktails (Roche Diagnostics). Plasma was separated by centrifuging the samples at 12,000xg for 10 minutes. FGF21 proteins were affinity purified from blood using an anti-human-Fc agarose resin.

Table 9

FGF21 Samples		
Sample	**Protein Administered**	**Blood Withdrawn**
D6	Fc-(G5)-FGF21	6 hours
D24	Fc-(G5)-FGF21	24 hours
D48	Fc-(G5)-FGF21	48 hours
E6	FGF21-(G3)-Fc	6 hours
E24	FGF21-(G3)-Fc	24 hours
E48	FGF21-(G3)-Fc	48 hours

[0153] Prior to analyzing the affinity purified samples by LC-MS, Fc-(G5)-FGF21 and FGF21-(G3)-Fc protein standards were analyzed as a reference. Protein standards were either reduced with tris[2-carboxyεthyl] phosphine (TCEP) or not reduced. Reduced and non-reduced standards were analyzed by LC-MS using an ACE cyano 0.3 mm x 30 cm column with the column effluent spraying into an LCQ Classic ion-trap mass spectrometer. Since the deconvoluted spectra of the reduced samples were cleaner, the affinity purified samples were reduced prior to LC-MS analysis.

[0154] The observed masses for the reduced Fc-(G5)-FGF21 standard and samples D6, D24, and D48 are shown in Figures 6A-6D. The observed masses for the reduced FGF21-(G3)-Fc standard and samples E6, E24, and E48 are shown in Figures 7A-7D. Some of the standard and sample eluates were subjected to Edman sequencing in order to confirm the N-terminus of the proteins and the fragments as determined by LC-MS. Results of the LC-MS analysis of the standards and samples are provided in Table 10.

<u>**Table 10**</u>

Results of LC-MS Analysis and Predicted Fragments			
FGF21 Sample	**Major Observed Masses**	**Fragment**	**Intact N-terminus?**
Fc-(G5)-FGF21 standard	45,339 Da	1-414	Yes
D6	45,338 Da	1-414	Yes
	44,317 Da	1-404	
D24	44,321 Da	1-404	Yes
D48	44,327 Da	1-404	Yes
	42,356 Da	?	
FGF21-(G3)-Fc standard	46,408 Da (glycosylated, G0F)	1-410	Yes
		1-410	
	44,964 Da (non-glycosylated)		
E6	45,963 Da (glycosylated,	5-410	No

Results of LC-MS Analysis and Predicted Fragments			
FGF21 Sample	**Major Observed Masses**	**Fragment**	**Intact N-terminus?**
	G0F)	5-410	
	44,516 Da (non-glycoylated)		
E24	45,963 Da (glycosylated, G0F)	5-410	No
		5-410	
	44,526 Da (non-glycosylated)	21-410	
	44,130 Da (glycosylated, G0F)		
E48	45,984 Da	5-410?	No
	44,130 Da	21-410	
	44,022 Da	?	

[0155] As indicated in Table 10, all of the affinity purified samples showed some degree of degradation after only 6 hours of circulation. After 24 hours of circulation, the major product of Fc-(G5)-FGF21 was a fragment consisting of amino acid residues 1-404, which was seen in both the D and E samples. In the E samples, however, the major product of FGF21-(G3)-Fc was a fragment consisting of amino acid residues 5-410. For both of the fusion proteins tested, the FGF21 portion of the fusion protein was more susceptible to degradation than the Fc portion of the protein.

EXAMPLE 11

Preparation and Expression of Proteolysis-Resistant FGF21 Mutants and Fusion Proteins

[0156] Constructs encoding the FGF21 mutants listed in Table 11 were prepared by PCR amplification of the wild-type FGF21 expression vector as described below (the construction of the wild-type FGF21 expression vector is described in Example 1). When a linker was included in the construct, the linker used was GGGGGSGGGSGGGGS ("L15," SEQ ID NO: 28), The goal of these experiments was to generate FGF21 mutants that are resistant to proteolysis and exhibit longer half-lives.

Table 11

Proteolysis-Resistant FGF21 Mutants		
Mutation(s)	**Fc**	**Linker**
R19I		
R19I	-COOH	L15
R19K		
R19K	-COOH	L15
R19Q		
R19Q	-COOH	L15
R19K, Y20H		
R19K, Y20H	-COOH	L15
R19K, L21I		
R19K, L21I	-COOH	L15
R19K, Y20H, L21I		
R19K, Y20H, L21I	-COOH	L15
Y20F		
Y20F	-COOH	L15
Y20H		
Y20H	-COOH	L15
Y20L		
Y20L	-COOH	L15
Y20H, L21I		
Y20H, L21I	-COOH	L15
L21I		
L21I	-COOH	L15
L21F		
L21F	-COOH	L15
L21V		
L21V	-COOH	L15
L21Y		
L21Y	-COOH	L15
Y22F		
Y22F	-COOH	L15
Y22I		
Y22I	-COOH	L15
Y22V		

Proteolysis-Resistant FGF21 Mutants		
Mutation(s)	**Fc**	**Linker**
Y22V	-COOH	L15
P150A		
P150A	$-NH_2$	L15
P150R	$-NH_2$	L15
P150A, G151A		
P150A, G151A	$-NH_2$	L15
P150A, I152V		
P150A, I152V	$-NH_2$	L15
P150A, G151A, I152V		
P150A, G151A, I152V	$-NH_2$	L15
G151A		
G151A	$-NH_2$	L15
G151V		
G151V	$-NH_2$	L15
G151A, I152V		
G151A, I152V	$-NH_2$	L15
I152F		
I152F	$-NH_2$	L15
I152H		
I152H	$-NH_2$	L15
I152L		
I152L	$-NH_2$	L15
I152V		
G170A		
G170A	$-NH_2$	L15
G170C		
G170C	$-NH_2$	L15
G170D		
G170D	$-NH_2$	L15
G170E		
G170E	$-NH_2$	L15
G170N		

Proteolysis-Resistant FGF21 Mutants		
Mutation(s)	**Fc**	**Linker**
G170N	$-NH_2$	L15
G170P		
G170P	$-NH_2$	L15
G170Q		
G170Q	$-NH_2$	L15
G170S		
G170S	$-NH_2$	L15
G170E, P171A		
G170E, P171A	$-NH_2$	L15
G170E, S172L		
G170E, S172L	$-NH_2$	L15
G170E, P171A, S172L		
G170E, P171A, S172L	$-NH_2$	L15
P171A		
P171A	$-NH_2$	L15
P171C	$-NH_2$	L15
P171D	$-NH_2$	L15
P171E	$-NH_2$	L15
P171G	$-NH_2$	L15
P171H	$-NH_2$	L15
P171K	$-NH_2$	L15
P171N	$-NH_2$	L15
P171Q	$-NH_2$	L15
P171S	$-NH_2$	L15
P171T	$-NH_2$	L15
P171W	$-NH_2$	L15
P171Y	$-NH_2$	L15
P171A, S172L		
P171A, S172L	$-NH_2$	L15
S172L	$-NH_2$	L15
S172T		

Proteolysis-Resistant FGF21 Mutants		
Mutation(s)	**Fc**	**Linker**
S172T	$-NH_2$	L15
Q173E		
Q173E	$-NH_2$	L15
Q173R		
Q173R	$-NH_2$	L15

[0157] FGF21 mutant constructs were prepared using primers having sequences that are homologous to regions upstream and downstream of a codon (or codons) to be mutated. The primers used in such amplification reactions also provided approximately 15 nucleotides of overlapping sequence to allow for recircularization of the amplified product, namely the entire vector now having the desired mutant.

[0158] An exemplary FGF21 mutant construct, encoding an FGF21 mutant having a glutamic acid residue at position 170 instead of the native glycine residue *(i.e.,* the G170E mutant), was prepared using the primers shown in Table 12.

Table 12

PCR Primers for Preparing Exemplary FGF21 Mutant		
Primer	**Sequence**	**SEQ ID NO:**
Sense	5'-ATGGTGGAACCTTCCCAGGGCCGAAGC-3'	23
Antisense	5'-GGAAGGTTCCACCATGCTCAGAGGGTCCGA-3'	24

[0159] The primers shown in Table 12 allow for the substitution of the glycine residue with a glutamic acid residue as shown below, wherein the upper sequence is the sense primer (SEQ ID NO:23), the second and third sequences (SEQ ID NOs: 25 and 27) are portions of an FGF21 expression construct, and the fourth sequence is the antisense primer (SEQ ID NO:26):

5'-ATGGTGG**A**ACCTTCCCAGGGCCGAAGC

CTCCTCGGACCCTCTGAGCATGGTG**GGA**CCTTCCCAGGGCCGAAGCCCCA

GAGGAGCCTGGGAGACTCGTACCAC**CCT**GGAAGGGTCCCGGCTTCGGGGT

AGCCTGGGAGACTCGTACCACC**T**TGGAAGG-5'

[0160] FGF21 mutant constructs were prepared using essentially the PCR conditions described in Example 1. Amplification products were digested with the restriction endonuclease DpnI, and then transformed into competent cells. The resulting clones were sequenced to confirm the absence of polymerase-generated errors. Fc-(L15)-FGF21 and FGF21-(L15)-Fc fusion proteins were generated as described herein, e.g., in Example 6.

[0161] FGF21 mutants were expressed by transforming competent BL21 (DE3) or BL21 Star (Invitrogen; Carlsbad, CA) cells with the construct encoding a particular mutant. Transformants were grown overnight with limited aeration in TB media supplemented with 40 µg/mL kanamycin, were aerated the next morning, and after a short recovery period, were induced in 0.4 mM IPTG. FGF21 mutant polypeptides were harvested by centrifugation 18-20 hours after induction.

[0162] FGF21 mutants were also analyzed for predicted immunogenicity. Immune responses against proteins are enhanced by antigen processing and presentation in the major histocompatability complex (MHC) class II binding site. This interaction is required for T cell help in maturation of antibodies that recognize the protein. Since the binding sites of MHC class II molecules have been characterized, it is possible to predict whether proteins have specific sequences that can bind to a series of common human alleles. Computer algorithms have been created based on literature references and MHC class II crystal structures to determine whether linear amino acid peptide sequences have the potential to break immune tolerance. The TEPITOPE computer program was used to determine if point mutations in particular FGF21 mutants would increase antigen specific T cells in a majority of humans. Based on an analysis of the linear protein sequence of each FGF21 mutant, none of the mutants was predicted to enhance immunogenicity.

EXAMPLE 12

<u>Impact of Linker Sequence on FGF21 Degradation</u>

[0163] To determine whether the presence of a longer amino acid linker between the Fc sequence and the FGF21 sequence affects FGF21 degradation, mice were injected with FGF21 fusion proteins in which the Fc region was separated from the FGF21 sequence by a 15 amino acid linker having the sequence GGGGGSGGGSGGGGS (designated "L15," SEQ ID NO:28), blood was withdrawn from the mice at various time points, and the serum was analyzed by LC-MS. In particular, mice were injected with Fc-(L15)-FGF21 or FGF21-(L15)-Fc (obtained from *E. coli)* at 23 mg/kg, blood was drawn at 6, 24, and 48 hours, and drawn blood was affinity purified using an anti-human-Fc agarose resin.

[0164] Prior to analyzing the purified samples by LC-MS, Fc-(L15)-FGF21 and FGF21-(L15)-Fc protein standards were analyzed as a reference. Protein standards were either reduced with TCEP or not reduced. Both reduced and non-reduced standards were analyzed by LC-MS using an ACE cyano 0.3 mm x 30 cm column with the column effluent spraying into an LCQ Classic ion-trap mass spectrometer. Since the deconvoluted spectra of the reduced samples were cleaner, the affinity purified samples were reduced prior to LC-MS analysis.

[0165] The observed masses for the reduced Fc-(L15)-FGF21 standard and corresponding affinity purified samples withdrawn at various time points are shown in Figures 8A-8D. The observed masses for the reduced FGF21-(L15)-Fc standard and corresponding affinity purified samples withdrawn at various time points are shown in Figures 9A-9D. Some of the standard and sample eluates were subjected to Edman sequencing in order to confirm the N-terminus of the proteins and assist in predicting the identity of the fragments observed by LC-MS. Results of the LC-MS analysis of the standards and samples and an indication of predicted fragments are provided in Table 13.

Table 13

Results of LC-MS Analysis and Predicted Fragments				
FGF21 Sample	**Major Observed Masses**	**Percent of Total**	**Fragment**	**Intact N-terminus?**
Fc-(L15)-FGF21	46,002 Da	100%	1-424	Yes
Standard				
Fc-(L15)-FGF21	46,000 Da	65%	1-424	Yes
6 hours	44,978 Da	35%	1-414	
Fc-(L15)-FGF21	44,978 Da	85%	1-414	Yes
24 hours	43,022 Da	15%	1-394	
Fc-(L15)-FGF21	44,976 Da	60%	1-414	Yes
48 hours	43,019 Da	40%	1-394	
FGF21-(L15)-Fc	45,999 Da	100%	1-424	Yes
Standard				
FGF21-(L15)-Fc	45,870 Da	100%	1-423	Yes
6 hours				
FGF21-(L15)-Fc	45,869 Da	40%	1-423	Some
24 hours	45,301 Da	35%	6-423	
	43,460 Da	25%	22-423	
FGF21-(L15)-Fc	45,870 Da	15%	1-423	Some
48 hours	45,297 Da	20%	6-423	
	43,461 Da	65%	22-423	

[0166] As indicated in Table 13, all of the affinity purified samples showed some degree of degradation after only 6 hours of circulation. After 24 hours of circulation, the major products of Fc-(L15)-FGF21 were fragments consisting of amino acid residues 1-414 (85% of sample) and 1-394 (15% of sample), and the major products of FGF21(15)Fc were fragments consisting of amino acid residues 1-423 (40% of sample), 6-423 (35% of sample), and 22-423 (25% of sample). Identified cleavage points for the Fc-(L15)-FGF21 and FGF21-(L15)-Fc proteins are shown in Figures 10A and 10B, respectively.

EXAMPLE 13

***In vivo* Activity of Proteolysis-resistant Fc-(L15)-FGF21 Mutants at 1-7 Days after injection**

[0167] As described herein, proteolytic cleavage of FGF21 Fc fusion proteins depends upon the orientation of the Fc sequence, with the Fc end of the fusion protein being more stable than the FGF21 end of the fusion protein *(i.e.,* the N-terminal portion of Fc-(L15)-FGF21 fusion proteins and the C-terminal portion of FGF21-(L15)-Fc fusion proteins were found to be more stable). For example, cleavage was identified at positions 5 and 21 of FGF21-(L15)Fc and positions 151 and 171 of Fc-(L15)-FGF21.

[0168] As a result of these observations, an investigation was performed to identify proteolysis-resistant FGF21 mutants. LC-MS analysis of Fc-(L15)-FGF21 demonstrates that *in vivo* proteolytic degradation first occurs between amino acid residues 171-172, followed by degradation between amino acid residues 151-152. By blocking proteolytic degradation at position 171, the cleavage at position 151 can be prevented, effectively extending the half-life of the molecule. However, proteolysis-resistant mutants in which cleavage is prevented at position 151 can still possess residues at position 171 that are susceptible to protease attack, thereby resulting in a molecule missing the last 10 amino acids, which are known to be involved in the binding of the co-receptor β-Klotho, which is a determinant of ligand receptor affinity and *in vitro* and *in vivo* potency. Therefore, the mutagenesis of amino acid residues surrounding position 171 in mature FGF21 appear to be more critical for improving the *in vivo* stability, potency, and efficacy of the molecule.

[0169] The *in vivo* activity of particular proteolysis-resistant Fc-(L15)-FGF21 mutants was assayed by intraperitoneally injecting ob/ob mice with an FGF21 mutant, drawing blood samples from injected mice at 0, 0.25, 1, 3, 5, and 7 days after injection, and then measuring blood glucose levels in the samples. The results of one experiment are provided in Figure 11, which shows the blood glucose levels measured in mice injected with a PBS control, an Fc-(L15)-FGF21 (SEQ ID NO:49) control, or the Fc-(L15)-FGF21 mutants Fc-(L15)-FGF21 G170E (SEQ ID NO:51), Fc-(L15)-FGF21 P171A (SEQ ID NO:53), Fc-(L15)-FGF21 S172L (SEQ ID NO:55), Fc-(L15)-FGF21 (G170E, P171A, S172L) (SEQ ID NO:59), or Fc-(L15)-FGF21 G151A (SEQ ID NO:61). Figure 12 shows the percent change in blood glucose levels as determined in this experiment. This experiment demonstrates that the Fc-(L15)-FGF21 G170E, Fc-(L15)-FGF21 P171A, Fc-(L15)-FGF21 S172L, and Fc-(L15)-FGF21 (G170E, P171A, S172L) mutants exhibit sustained blood glucose lowering activity for up to 5 days, which is superior to the activity of wild-type Fc-(L15)-FGF21. The Fc-(L15)-FGF21 G151A mutant only partially improved the duration of blood glucose lowering activity as compared with wild-type Fc-(L15)-FGF21 fusion protein. Surprisingly, although the Fc-(L15)-FGF21 S172L mutant is not a proteolysis-resistant mutant, and therefore has similar degradation profile as the wild-type Fc-(L15)-FGF21 polypeptide, this mutant was found to exhibit improved *in vivo* efficacy as compared with the wild-type Fc-(L15)-FGF21 polypeptide.

[0170] The results of another experiment are provided in Figure 13, which shows the blood glucose levels measured in mice injected with a PBS control, an Fc-(L15)-FGF21 control, or the Fc-(L15)-FGF21 mutants Fc-(L15)-FGF21 (P150A, G151A, I152V) (SEQ ID NO:65), Fc-(L15)-FGF21 G170E (SEQ ID NO:51), Fc-(L15)-FGF21 (G170E, P171A) (SEQ ID NO:63), or Fc-(L15)-FGF21 (G170E, S172L) (SEQ ID NO:67). Figure 14 shows the percent change in blood glucose levels as determined in this experiment. As in the experiment described above, the wild-type Fc-FGF21 fusion protein and the Fc-(L15)-FGF21 (P150A, G151A, I152V) mutant do not exhibit sustained blood glucose lowering activity, possibly because the degradation at 171 site could still occur, and blood glucose levels in animals injected with these proteins returned to baseline at 24 hours after injection. However, the Fc-(L15)-FGF21 G170E, Fc-(L15)-FGF21 (G170E, P171A), or Fc-(L15)-FGF21 (G170E, S172L) exhibit maximal blood glucose lowering activity up to 5 days after injection, which is superior to the wild-type Fc-(L15)-FGF21 fusion protein and the Fc-(L15)-FGF21 (P150A, G151A, I152V) mutant.

[0171] The results of another experiment are provided in Figure 15, which shows the blood glucose levels measured in mice injected with a PBS control or the Fc-(L15)-FGF21 mutants Fc-(L15)-FGF21 G170E (SEQ ID NO:51), Fc-(L15)-FGF21 G170A (SEQ ID NO:69), Fc-(L15)-FGF21 G170C (SEQ ID NO:71), Fc-(L15)-FGF21 G170D (SEQ ID NO:73), Fc-(L15)-FGF21 G170N (SEQ ID NO:75), or Fc-(L15)-FGF21 G170S (SEQ ID NO:77). Figure 16 shows the percent change in blood glucose levels as determined in this experiment. All of the FGF21 mutants tested in this experiment exhibited sustained blood glucose lowering activity for up to 5 days after injection.

[0172] The results of another experiment are provided in Figure 17, which shows the blood glucose levels measured in mice injected with PBS or the Fc-(L15)-FGF21 mutants Fc-(L15)-FGF21 G170E (SEQ ID NO:51), Fc-(L15)-FGF21 P171E (SEQ ID NO:79), Fc-(L15)-FGF21 P171H (SEQ ID NO:81), Fc-(L15)-FGF21 P171Q (SEQ ID NO:83), Fc-(L15)-FGF21 P171T (SEQ ID NO:85), or Fc-(L15)-FGF21 P171Y (SEQ ID NO:87). Figure 18 shows the percent change in blood glucose levels as determined in this experiment. All of the FGF21 mutants tested in this experiment exhibited improved blood glucose lowering activity when compared with wild-type Fc-FGF21.

EXAMPLE 14

***In vivo* Degradation of Proteolysis-resistant Fc-(L15)-FGF21 Mutants at 6 to 120 Hours after Injection**

[0173] The *in vivo* stability of selected FGF21 mutants was analyzed by injecting mice with an FGF21 mutant, drawing blood from the mice at various time points, and analyzing the serum by LC-MS. In particular, mice were injected with either the Fc-(L15)-FGF21 G170E, Fc-(L15)-FGF21 P171A, or Fc-(L15)-FGF21 S172L mutants (obtained from *E. coli* as described in Example 2), each of which were diluted in approximately 180 µL of 10 mM HCl prior to injection, and blood was drawn at 6, 24, 48, 72, and 120 hours. FGF21 proteins were affinity purified from the drawn blood using an anti-human-Fc agarose resin column. Samples were eluted from the column using 10 mM HCl. All of the FGF21 constructs comprise an Fc region and 15 amino acid linker at the amino-terminal end of the FGF21 protein. Mice were also injected with a wild-type FGF21 control.

[0174] Prior to analyzing the affinity purified samples by LC-MS, unprocessed wild-type FGF21 and unprocessed FGF21 mutants were analyzed as a reference. All standards and time point samples were reduced with TCEP, and then analyzed by LC-MS using an ACE cyano 0.3 mm x 30 cm column with the column effluent spraying into an LCQ Classic ion-trap mass spectrometer. Affinity purified samples were diluted with ammonium acetate, reduced with TCEP, and then analyzed by LC-MS as described above.

[0175] The observed masses for wild-type Fc-(L15)-FGF21 at 0, 6, 24, and 48 hours after injection are shown in Figures 19A-19D, respectively. The observed masses for Fc-(L15)-FGF21 G170E at 0, 6, 24, and 48 hours after injection are shown in Figures 20A-20D, respectively. The observed masses for Fc-(L15)-FGF21 P171A at 0, 6, 24, and 48 hours after injection are shown in Figures 21A-21D, respectively. The observed masses for Fc-(L15)-FGF21 S172L at 0, 6, 24, and 48 hours after injection are shown in Figures 22A-22D, respectively.

[0176] All of the samples drawn at 72 and 120 hours were found to contain a high molecular weight (>200 kDa by non-reducing SDS-PAGE) component of fibrinogen that is much more abundant than the remaining Fc-(L15)-FGF21 fusion protein. Results of the LC-MS analysis of the other standards and samples are provided in Table 14.

Table 14

Results of LC-MS Analysis and Predicted Fragments				
FGF21 Sample	**Major Observed Masses**	**Percent of Total**	**Fragment**	**Edman**
Fc-(L15)-FGF21 WT	45,994 Da	100%	1-424	-
Standard				
Fc-(L15)-FGF21 WT	46,001 Da	80%	1-424	No

Results of LC-MS Analysis and Predicted Fragments				
FGF21 Sample	**Major Observed Masses**	**Percent of Total**	**Fragment**	**Edman**
6 hours	44,987 Da	20%	1-414	
Fc-(L15)-FGF21 WT	44,979 Da	-100%	1-414	No
24 hours				
Fc-(L15)-FGF21 WT	44,980 Da	-100%	1-414	-
48 hours				
Fc-(L15)-FGF21 G170E	46,068 Da	100%	1-424	-
Standard				
Fc-(L15)-FGF21 G170E	46,078 Da	100%	1-424	No
6 hours				
Fc-(L15)-FGF21 G170E	46,074 Da	80%	1-424	No
24 hours	45,761 Da	20%	1-421	
Fc-(L15)-FGF21 G170E	46,072 Da	-60%	1-424	No
48 hours	45,760 Da	~40%	1-421	
Fc-(L15)-FGF21 P171A	45,970 Da	100%	1-424	-
Standard				
Fc-(L15)-FGF21 P171A	45,980 Da	100%	1-424	No
6 hours				
Fc-(L15)-FGF21 P171A	45,973 Da	-70%	1-424	No
24 hours	45,657 Da	-30%	1-421	
Fc-(L15)-FGF21 P171A	45,992 Da	~50%	1-424	No
48 hours	45,673 Da	~50%	1-421	
Fc-(L15)-FGF21 S172L	46,022 Da	100%	1-424	-
Standard				
Fc-(L15)-FGF21 S172L	46,027 Da	100%	1-424	No
6 hours				
Fc-(L15)-FGF21	44,984 Da	100%	1-414	No

Results of LC-MS Analysis and Predicted Fragments				
FGF21 Sample	**Major Observed Masses**	**Percent of Total**	**Fragment**	**Edman**
S172L				
24 hours				
Fc-(L15)-FGF21 S172L	44,985 Da	100%	1-414	No
48 hours				

[0177] As indicated in Table 14, the degradation of wild-type Fc-(L15)-FGF21 and the S172L mutant look similar, in that after 24 hours of circulation, the major product of the fusion protein was a fragment consisting of amino acid residues 1-414. The degradation products of the Fc-(L15)-FGF21 G170E and Fc-(L15)-FGF21 P171A mutants also look similar in that the samples drawn after 24 hours of circulation contain 70-80% intact protein (amino acids 1-424) and 20-30% of a fragment consisting of amino acid residues 1-421. Even after 48 hours, the Fc-(L15)-FGF21 G170E and Fc-(L15)-FGF21 P171A mutants still retain intact protein while showing an increase in the amount of the fragment consisting of amino acid residues 1-421. As observed in prior analyses of Fc-FGF21 constructs, degradation of the FGF21 portion of the fusion protein was detected and the Fc portion was found to remain stable. The cleavage sites identified for wild-type, Fc-(L15)-FGF21 G170E, Fc-(L15)-FGF21 P171A, and Fc-(L15)-FGF21 S172L are shown in Figures 23A-23D, respectively.

EXAMPLE 15

Identification of Aggregation-reducing FGF21 Mutants

[0178] One property of wild-type FGF21 is its propensity to aggregate. In view of this property, it was desired to generate aggregation-reducing FGF21 mutants. Aggregation-reducing FGF21 mutants were identified on the basis of two hypotheses. The first hypothesis is that, with respect to FGF21, aggregation (or dimerization) is triggered by hydrophobic interactions and van der Waals interactions between FGF21 molecules caused by hydrophobic residues that are exposed to hydrophilic water-based solvent environment. The second hypothesis is that these exposed hydrophobic residues can be substituted to create aggregation-reducing point-mutations in the FGF21 amino acid sequence without compromising FGF21 activity.

[0179] A systematic rational protein engineering approach was used to identify exposed hydrophobic residues in FGF21. As there were no known X-ray or NMR structures of FGF21 that could be used to identify exposed hydrophobic residues, a high resolution (1.3 Å) X-ray crystal structure of FGF19 (1PWA) obtained from the Protein Databank (PDB) was used to create a 3D homology model of FGF21 using MOE (Molecular Operating Environment; Chemical Computing Group; Montreal, Quebec, Canada) modeling software. FGF19 was chosen as a template, since among the proteins deposited in the PDB, FGF19 is the most closely related protein to FGF21 in terms of the amino acid sequence homology.

[0180] Solvent accessibility was calculated by the following method using MOE. A first measure of surface area (SA1) is defined as the area of the residue's accessible surface in $Å^2$. While a particular amino acid residue appears in a protein's primary sequence multiple times, each occurrence of the residue can have a different surface area due to differences in, *inter alia,* the residue's proximity to the protein surface, the orientation of the residue's side-chain, and the spatial position of adjacent amino acid residues. Therefore, a second measure of surface area (SA2) is made wherein the residue of interest is extracted from the protein structure along with that residue's neighboring, or adjacent, residues. These spatially adjacent residues are mutated *in silica* to glycines to remove their side-chains, and then the SA2 for the residue of interest is calculated, giving a measure of the total possible surface area for that residue in its particular conformation. A ratio of SA1 to SA2 (SA1/SA2) can then give a measure of the percentage of the possible surface area for that residue that is actually exposed.

[0181] Several hydrophobic residues that are highly exposed to the solvent were selected for further analysis, and *in silica* point mutations were made to these residues to replace the selected residue with the other naturally occurring amino acid residues. The changes in protein thermal stability resulting from different substitutions were calculated using the FGF21 model and the interactive web-based program CUPSAT (Cologne University Protein Stability Analysis Tools) according to instructions provided at the CUPSAT website. *See* Parthiban et al., 2006, Nucleic Acids Res. 34: W239-42; Parthiban et al., 2007, BMC Struct. Biol. 7:54. Significantly destabilizing or hydrophobic mutations were excluded in the design of aggregation-reducing point-mutation FGF21 mutants. Stabilizing (or, in rare cases, slightly destabilizing) substitutions that introduce improved hydrophilic and/or ionic characteristics were considered as candidates for aggregation-reducing FGF21 mutants.

[0182] A summary of the data generated through this rational protein engineering approach is provided in Table 15, which also lists exemplary FGF21 mutants expected to have reduced protein aggregation and improved stability.

Table 15

Calculated Effect of FGF21 Mutants on Stability			
Residue #	**WT Residue**	**Mutation**	**Stabilization (Kcal/mol)**
26	A	K	1.25
		E	1.54
		R	2.016
45	A	T	0.66
		Q	0.71
		K	1.8

Calculated Effect of FGF21 Mutants on Stability			
Residue #	**WT Residue**	**Mutation**	**Stabilization (Kcal/mol)**
		E	2.34
		R	1.59
52	L	T	-0.33
58	L	G	0.16
		S	-0.15
		C	1.0
		E	0.08
60	P	A	1.3
		K	1.51
		E	0.66
		R	1.31
78	P	A	0.14
		C	2.48
		R	0.08
		H	0.13
86	L	T	0.18
		C	4.1
88	F	A	2.52
		S	3.08
		K	2.88
		E	1.48
98	L	T	0.49
		Q	0.17
		K	-0.19
		C	3.08
		E	0.84
		R	3.4
99	L	C	7.34
		E	2.0
		D	1.01
		R	1.61
111	A	T	0.47
		K	-0.12
129	A	Q	3.93

Calculated Effect of FGF21 Mutants on Stability			
Residue #	WT Residue	Mutation	Stabilization (Kcal/mol)
		K	1.02
		N	3.76
		E	3.01
		D	3.76
		R	1.68
		H	2.9
134	A	K	5.37
		Y	4.32
		E	5.13
		R	6.18
		H	2.86

EXAMPLE 16

Preparation and Expression of Aggregation-reducing FGF21 Mutants and Fusion Proteins

[0183] Constructs encoding the FGF21 mutants listed in Table 16 were prepared by PCR amplification of the wild-type FGF21 expression vector as described in Example 11 (the construction of the wild-type FGF21 expression vector is described in Example 1). Fusion proteins were generated as described herein, e.g., in Example 6. When a linker was employed it was GGGGGSGGGSGGGGS ("L15," SEQ ID NO:28)

Table 16

Aggregation-reducing FGF21 Mutants		
Mutation(s)	Fc	Linker
A26E		
A26K		
A26R		
A45E		
A45K		
A45K	$-NH_2$	L15
A45R	$-NH_2$	L15

Aggregation-reducing FGF21 Mutants		
Mutation(s)	**Fc**	**Linker**
A45Q	$-NH_2$	L15
A45T	$-NH_2$	L15
A45K, L98R	$-NH_2$	L15
L52T		
L58C		
L58E		
L58G		
L58S		
P60A		
P60E		
P60K		
P60R		
P78A		
P78C		
P78H		
P78R		
L86C		
L86T		
F88A		
F88E		
F88K		
F88R		
F88S		
L98C		
L98E	$-NH_2$	L15
L98K	$-NH_2$	L15
L98Q	$-NH_2$	L15
L98R		
L98R	$-NH_2$	L15
L99C		
L99D		
L99E		
L99R		

Aggregation-reducing FGF21 Mutants		
Mutation(s)	**Fc**	**Linker**
A111K	$-NH_2$	L15
A111T		
A129D		
A129E	$-NH_2$	L15
A129H	$-NH_2$	L15
A129K		
A129N	$-NH_2$	L15
A129R	$-NH_2$	L15
A129Q		
A134E		
A134H	$-NH_2$	L15
A134K		
A134Y		

[0184] The aggregation of various FGF21 proteins, including wild-type FGF21, truncated FGF21 polypeptides, FGF21 mutants, and FGF21 fusion proteins was assayed by Size Exclusion Chromatography (SEC). Samples to be analyzed were incubated at 4°C, room temperature, or 37°C for various time points, and then subjected to SEC analysis. Experiments were performed on a Beckman HPLC system equipped with a SEC column. For wild-type FGF21, a TOSOHAAS TSK-Gel G2000 SEC column was used with 2x PBS containing 2% isopropyl alcohol as the mobile phase. For FGF21 Fc fusion proteins and FGF21 mutant polypeptides, a TOSOHAAS TSK-Gel G3000 SEC column was used with 2x PBS as the mobile phase.

EXAMPLE 17

***In vitro* Activity of Aggregation-reducing FGF21 Mutants**

[0185] Experiments were performed to identify aggregation-reducing mutants that retain wild-type FGF21 activity in an ELK-luciferase *in vitro* assay. ELK-luciferase assays were performed as described in Example 4. Figures 24A-24C show the results of an ELK-luciferase activity assay performed on the FGF21 mutants FGF21 L99R (SEQ ID NO:109), FGF21 L99D (SEQ ID NO:111), and FGF21 A111T (SEQ ID NO:113) (Figure 24A); the FGF21 mutants FGF21 A129D (SEQ ID NO:115), FGF21 A129Q (SEQ ID NO:117), and FGF21 A134K (SEQ ID

NO:119) (Figure 24B); and the FGF21 mutants FGF21 A134Y (SEQ ID NO:121), FGF21 A134E (SEQ ID NO:123), and FGF21 A129K (SEQ ID NO:125) (Figure 24C). The results of these experiments demonstrate that some of the aggregation-reducing mutations did not adversely impact FGF21 activity as assayed in ELK-luciferase assays.

EXAMPLE 18

Preparation and Expression of Fc-(L15)-FGF21 Combination Mutants Showing Longer Half life and Lower Levels of Aggregation

[0186] A number of FGF21 combination mutants, containing mutations shown to reduce aggregation as well as to increase half-life by disrupting proteolytic degradation, were prepared and conjugated to IgG1 Fc molecules (SEQ ID NO:11). These FGF21 mutants were prepared essentially as described in Example 11.

EXAMPLE 19

***In vitro* Studies of Fc-(L15)-FGF21 Mutants**

Showing Longer Half life and Lower Levels of Aggregation

[0187] Experiments were performed to identify FGF21 combination mutants that retain wild-type FGF21 activity in an ELK-luciferase *in vitro* assay. ELK-luciferase assays were performed as described in Example 4.

[0188] Figures 25A-25D show the results of an ELK-luciferase activity assay performed on the Fc-(L15)-FGF21 mutants Fc-(L15)-FGF21 P171G, Fc-(L15)-FGF21 P171S, and Fc-(L15)-FGF21 P171T (Figure 25A); the Fc-(L15)-FGF21 mutants Fc-(L15)-FGF21 P171Y, Fc-(L15)-FGF21 P171W, and Fc-(L15)-FGF21 P171C (Figure 25B); Fc-(L15)-FGF21, Fc-(L15)-FGF21 (A45K, G170E), and FGF21 A45K (Figure 25C); and Fc-(L15)-FGF21, Fc-(L15)-FGF21 P171E, and Fc-(L15)-FGF21 (A45K, G170E) (Figure 25D). The results of these experiments demonstrate that mutations aimed at improving stability, or both stability and solubility, did not compromise the *in vitro* activity as compared with wild-type Fc-(L15)-FGF21. Interestingly, the FGF21 A45K mutant showed improved potency relative to wild-type Fc-(L15)-FGF21.

[0189] Figure 26A shows the change in percent aggregation for an FGF21 control (WT) and FGF21 A45K following incubation of 65 mg/mL protein at 4°C for 1, 2, and 4 days. The data indicated that the A45K mutation leads to a decrease in aggregation of the protein, compared to the wild-type protein.

[0190] Figure 26B shows the change in percent aggregation for an FGF21 control (WT) and FGF21 P78C, FGF21 P78R, FGF21 L86T, FGF21 L86C, FGF21 L98C, FGF21 L98R, FGF21 A111T, FGF21 A129D, FGF21 A129Q, FGF21 A129K, FGF21 A134K, FGF21 A134Y, and FGF21 A134E following incubation of 65 mg/mL protein at 4°C for 1, 6, and 10 days. The data indicated that the FGF21 L86C, FGF21 L98C, FGF21 L98R, FGF21 A111T, FGF21 A129Q, and FGF21 A129K lead to a decrease in aggregation of the protein, compared to the wild-type protein.

[0191] Figure 27 shows the results of an ELK-luciferase activity assay performed on a human FGF21 control and the FGF21 mutants FGF21 A45K, FGF21 L52T, and FGF21 L58E. This experiment demonstrates that the FGF21 A45K mutant retains the full efficacy of wild-type FGF21 and exhibits a potency that is even greater than wild-type FGF21. However, the FGF21 L52T, and FGF21 L58E mutants show reduced potency and efficacy as compared with wild-type FGF21

[0192] Figures 28A-28B show the change in aggregation levels for the Fc-(L15)-FGF21 mutants Fc-(L15)-FGF21 (6-181, G170E), Fc-(L15)-FGF21 (A45K, G170E), Fc-(L15)-FGF21 P171E, Fc-(L15)-FGF21 P171A, Fc-(L15)-FGF21 G170E, and an FGF21 control following incubation at 4°C for 1, 4, and 8 days. This experiment demonstrates that over the 8 day period, the Fc-(L15)-FGF21 (A45K, G170E) mutant showed less aggregation than did the Fc-(L15)-FGF21 G170E or Fc-(L15)-FGF21 P171E mutants, but all three mutants showed less aggregation than did the Fc-(L15)-FGF21 control. Table 17 shows the percent aggregation obtained for an Fc-(L15)-FGF21 control and the Fc-(L15)-FGF21 (A45K, G170E) mutant following incubation at 4°C or room temperature for 0, 2, 3, 4, or 7 days.

Table 17

Percent Aggregation for Fc-FGF21 and Fc-FGF21 Mutant						
Sample		Day 0	Day 2	Day 3	Day 4	Day 7
Fc-(L15)-FGF21 WT	4°C	1.12	1.71	1.89	2.14	2.32
32 mg/mL	RT	1.12	6.09	7.94	9.57	12.59
Fc-(L15)-FGF21 (A45K, G170E)	4°C	0.45	0.77	0.88	1.03	1.24
33 mg/mL	RT	0.45	3.86	5.22	6.62	8.60

EXAMPLE 20

Preparation and Expression of Fc-FGF21 Fusion Combination Mutants

[0193] As described above, the stability and solubility of FGF21 can be modulated through the introduction of specific truncations and amino acid substitutions. In addition, FGF21 stability can be further enhanced by fusing such modified FGF21 proteins with the Fc portion of the human immunoglobulin IgG1 gene. Moreover, by introducing combinations of the above modifications, FGF21 molecules having both enhanced stability and solubility can be generated. Nucleic acid sequences encoding the FGF21 combination mutants listed in Table 18 were prepared using the techniques described above. The linker employed was the L15 linker, GGGGGSGGGSGGGGS (SEQ ID NO:28).

Table 18

FGF21 Combination Mutants				
Amino Acid Residues	**Proteolysis Mutation**	**Aggregation Mutation**	**Fc**	**Linker**
1-181	G170E	A45K	$-NH_2$	L15
1-181	G170E	L98R	$-NH_2$	L15
1-181	G170E	A45K, L98R	$-NH_2$	L15
1-181	P171G	A45K	$-NH_2$	L15
1-181	P171S	A45K	$-NH_2$	L15
1-181	P171G	L98R	$-NH_2$	L15
1-181	P171S	L98R	$-NH_2$	L15
1-181	P171G	A45K, L98R	$-NH_2$	L15
1-178	G170E		$-NH_2$	L15
6-181	G170E		$-NH_2$	L15
6-181	G170E	A45K	$-NH_2$	L15
6-181	G170E	L98R	$-NH_2$	L15
6-181	P171G		$-NH_2$	L15
6-181	P171G	L98R	$-NH_2$	L15
7-181	G170E		$-NH_2$	L15

[0194] Figure 29 shows the blood glucose levels measured in mice injected with the Fc-(L15)-FGF21 combination mutants Fc-(L15)-FGF21 (A45K, G170E), Fc-(L15)-FGF21 (A45K, P171G), or Fc-(L15)-FGF21 (L98R, P171G).

[0195] In another experiment the FGF21 mutant Fc-(L15)-FGF21 (L98R, P171G) was studied side-by-side with wild-type mature FGF21 and Fc-FGF21. In one experiment, a recombinant 293T cell line was cultured in the presence of different concentrations of FGF21, Fc-(L15)-FGF21, or Fc-(L15) FGF21 (L98R, P171G) for 6 hours. Cell lysates were then assayed for luciferase activity. As shown in Figure 30, Fc-(L15)-FGF21 (L98R, P171G) had similar activity to Fc-(L15)-FGF21, indicating that the introduction of the two point mutations didn't alter the molecule's *in vitro* activity.

[0196] In yet another experiment, the stability of the Fc-(L15)-FGF21 (L98R, P171G) at 65 mg/mL was evaluated for nine days at two different temperatures, namely room temperature and 4°C, side-by-side with FGF21 and Fc-(L15)-FGF21. After the incubation period cell lysates were then analyzed with SEC-HPLC to determine an aggregation versus time profile at various temperatures. The data shown in Figure 31A and 31B indicate that the rate of aggregation formation was significantly reduced in the Fc-(L15)-FGF21 (L98R, P171G) at room temperature (solid triangles, dotted line in Figure 31A) and at 4°C (solid triangles, dotted line in Figure 31B).

EXAMPLE 21

Proteolysis-resistant FGF21 Mutants Comprising C-terminal Mutations

[0197] The *in vivo* stability of combination mutants was also studied. Specifically, the *in vivo* stability of Fc-(L15)-FGF21 (L98R, P171G) was compared with the stability of Fc-(L15)-FGF21 in murine and *cynomolgus* models. The results were found to be similar in both species. In the *cynomolgus* study, Fc-(L15)-FGF21 (L98R, P171G) and Fc-(L15)-FGF21 were injected IV at 23.5 mg/kg and aliquots of serum and plasma were collected at time points out to 840 hours post dose. Time points out to 168 hours were analyzed. Time point samples were affinity-purified using anti-Fc reagents, then analyzed using MALDI mass spectrometry. The results correlated well between the two analyses.

[0198] Analyzing data generated using immunoaffinity-MALDI, clipping at the P171 site was seen to be eliminated in the Fc-(L15)-FGF21 (L98R, P171G) molecule as a result of the mutation of P171 to P171G. However, a minor and slow degradation resulting in a loss of up to 3 C-terminal residues was observed for Fc-(L15)-FGF21 (L98R, P171G) (Figure 32). The minor cleavages at the three C-terminal residues were also observed with other FGF21 mutants after the more susceptible cleavage site between amino acid residues 171 and 172 was blocked as shown in Figures 20 and 21. The 3 C-terminal residue cleavage may represent the cessation of cleavage from the C-terminal end of the molecule by a carboxypeptidase in a sequential, residue-by-residue fashion or a specific protease attack at amino acid residues 178 and 179 with non-specific clipping at amino acid residues 179-180 and 180-181. The loss of 2-3 amino acids at the C-terminus could cause reduced β-Klotho binding and ultimately decreased potency and in vivo activity of the molecule *See, e.g.,* Yie et al., 2009, FEBS Lett. 583:19-24. To address the apparent carboxypeptidase degradation of the C-terminus, the impact of adding an amino acid residue "cap" to various FGF21 mutant polypeptides were studied. A variety of constructs, including those presented in Table 19, were made and assayed using the techniques described herein. Table 19 summarizes the results of the *in vitro* ELK luciferase assay.

[0199] Suitable amino acid caps can be between 1 and 15 amino acids in length, for example 1, 2, 3, 4, 5, 10 or 15 amino acids in length. Any number and type of amino acid(s) can be employed as a cap, for example, a single proline residue, and single glycine residue, two glycine residues, five glycine residues, as well as other combinations. Additional examples of caps are provided in the instant Example and in Table 19.

[0200] Additionally, to address the apparent protease attack at amino acid residues 178 and 179, mutation of amino acid residues at positions 179, 180 and 181 was studied. Again, a variety of constructs, including those presented in Table 19, were made and assayed using the techniques described herein. The impact of combinations of cap and mutations at these sites was also explored. Table 19 summarizes exemplary constructs that were made and studied in the *in vitro* ELK-luciferase assay, which was performed as described herein. Consistent with the terminology used herein, hFc means a human Fc sequence (*i.e.,* SEQ ID NO:11), L15 refers to the L15 linker (*i.e.,* GGGGGSGGGSGGGGS, SEQ ID NO:28).

Table 19

Efficacy and EC50 Values for FGF21 Polypeptides Comprising C-terminal Modifications		
Constructs	**EC50(nM)**	**Efficacy**
huF GF21	0.4	100.0%
hFc-(L15)-hFGF21(L98R, P171G)	2.5	76.1%
hFc-(L15)-hFGF21(L98R, P171G, Y179F)	2.6	78.3%
hFc-(L15)-hFGF21(L98R, P171G, 1-180)		
hFc-(L15)-hFGF21(L98R, P171G, 1-179)	7.8	77.4%
hFc-(L15)-hFGF21(L98R, P171G, A180E)	1.9	79.6%
hFc-(L15)-hFGF21(L98R, P171G, S181K)	130	87.9%
GSGSGSGSGS-hFGF21 -(L15)-hFc		
MKEDD-hFGF21-(L15)-hFc	834	83.1%
hFc-(L15)-hFGF21(L98R, P171G, S181P, P182)	272	69.9%
hFc-(L15)-hFGF21(L98R, P1 71G, A180G)	3.25	76.9%
hFc-(L15)-hFGF21(L98R, P171G, S181G)	3.43	77.3%
hFc-(L15)-hFGF21(L98R, P171G,		

Efficacy and EC50 Values for FGF21 Polypeptides Comprising C-terminal Modifications		
Constructs	**EC50(nM)**	**Efficacy**
L182)		
hFGF21(L98R, P171G, G182)		
hFc-(L15)-hFGF21(L98R, P171G, Y179P)	428	44.4%
hFc-(L15)-hFGF21(L98R, P171G, Y179G)	61	82.6%
hFc-(L15)-hFGF21(L98R, P171G, Y179S)	25.3	74.8%
hFc-(L15)-hFGF21(L98R, P171G, Y179A)	43.2	79.6%
hFc-(L15)-hFGF21(L98R, P171G, S181T)	3.07	77.6%
hFc-(L15)-hFGF21(L98R, P171G, S181A)	2.66	73.5%
hFc-(L15)-hFGF21(L98R, P171G, S181L)	3.46	72.6%
hFc-(L15)-hFGF21(L98R, P171G, S181P)	33.8	79.5%
hFc-(L15)-hFGF21(L98R, P171G, A180P)	617	77.1%
hFc-(L15)-hFGF21(L98R, P171G, A180S)	2.18	84.7%
hFGF21(L98R, P171G, GGGGG182-6)		
hFc-(L15)-hFGF21(L98R, P171G, P182)	6.1	85.9%
hFc-(L15)-hFGF21(L98R, P171G, G182)	6.5	71.1%
hFc-(L15)-hFGF21(1-178, L98R, P171G)	167	63.9%
hFc-(L15)-hFGF21(L98R, P171G, GG182-3)	1941	84.2%
hFc-(L15)-hFGF21(L98R, P171G, GGGGG182-6)	4307	99.7%

[0201] Figure 33 shows the percent change in blood glucose levels observed in diabetic db/db mice (C57B6 background) injected with a PBS control, wild type native FGF21, Fc-(L15)-FGF21 (L98R, P171G) and two capped molecules to which either a proline or glycine residue was added at the C-terminal end, *i.e.,* Fc-(L15)-FGF21 (L98R, P171G, 182P) and Fc-(L15)-

FGF21 (L98R, P171G, 182G). When a residue was added to the C-terminus of a wild-type or mutant FGF21 polypeptide, the residue is referred to by its position in the resultant protein. Thus, "182G" indicates that a glycine residue was added to the C-terminus of the mature 181 residue wild-type or mutant protein. Figure 33 shows that native FGF21 lowered blood glucose levels for 6 hours while all three Fc-FGF21 mutants studied showed sustained blood glucose-lowering activity for at least 120 hours. Fc-(L15)-FGF21 (L98R, P171G, 182P), a molecule comprising the addition of a proline residue at the C-terminus of the FGF21 component of the fusion molecule, appeared most potent and resulted in lowest blood glucose levels compared with Fc-(L15)-FGF21 (L98R, P171G) and Fc-(L15)-FGF21 (L98R, P171G, 182G).

[0202] In a subsequent experiment, the *in vivo* activity of Fc-(L15)-FGF21 (L98R, P171G, 182G) and Fc-(L15)-FGF21 (L98R, P171G, 182P) was studied and compared to the *in vivo* activity of a capped molecule comprising a two glycine addition at the C-terminus, namely Fc-(L15)-FGF21 (L98R, P171G, 182G, 183G). Figure 34 shows the percent change in blood glucose levels observed in ob/ob mice injected with PBS control, Fc-(L15)-FGF21 (L98R, P171G), Fc-(L15)-FGF21 (L98R, P171G, 182G, 183G), Fc-(L15)-FGF21 (L98R, P171G, 182G) and Fc-(L15)-FGF21 (L98R, P171G, 182P).

[0203] As shown in Figure 34, all of the molecules studied showed sustained glucose-lowering activity compared with the PBS control. This experiment confirmed the previous results (Figure 33) that Fc-(L15)-FGF21 (L98R, P171G, 182P) with a proline addition at the C-terminus showed slightly enhanced glucose-lowering efficacy compared with the molecule without a proline cap, e.g. Fc-(L15)-FGF21 (L98R, P171G). However, the addition of two glycine residues at the C-terminus, e.g. Fc-(L15)-FGF21 (L98R, P171G, 182G 183G), appeared to reduce the molecule's *in vivo* potency and shortened the duration of *in vivo* glucose-lowering effect.

[0204] Figure 35 shows the percent change in blood glucose levels observed in diabetic db/db mice (C57B6 background) injected with PBS control or the FGF21 mutant polypeptides Fc-(L15)-FGF21 (L98R, P171G), Fc-(L15)-FGF21 (L98R, P171G, Y179S), Fc-(L15)-FGF21 (L98R, P171G, Y179A), Fc-(L15)-FGF21 (L98R, P171G, A180S), and Fc-(L15)-FGF21 (L98R, P171G, A180G). All mutants showed similar glucose-lowering activity with similar duration of action.

[0205] Figure 36 shows the percent change in blood glucose levels observed in diabetic db/db mice (C57B6 background) injected with vehicle control, Fc-(L15)-FGF21 (L98R, P171G), Fc-(L15)-FGF21 (L98R, P171G, Y179F), and Fc-(L15)-FGF21 (L98R, P171G, A180E). Compared with Fc-(L15)-FGF21 (L98R, P171G), Fc-(L15)-FGF21 (L98R, P171G, Y179F) was less efficacious in lowering blood glucose. However, Fc-(L15)-FGF21 (L98R, P171G, A180E), in which alanine at amino acid position of 180 was mutated to glutamic acid, was more efficacious than Fc-(L15)-FGF21 (L98R, P171G) and caused additional 20% reduction of blood glucose levels compared with Fc-(L15)-FGF21 (L98R, P171G). These data suggest that A180E mutation may have reduced the C-terminal degradation *in vivo* and thereby improved *in vivo* potency and efficacy of the molecule.

EXAMPLE 22

***Rhesus* Monkey Study**

[0206] An Fc-Linker-FGF21 construct was generated using methodology described herein. The construct comprised an IgG1 Fc sequence (SEQ ID NO:11) fused at the C-terminus to the L15 $(Gly)_5$-Ser-$(Gly)_3$-Ser-$(Gly)_4$-Ser linker sequence (SEQ ID NO:28) which was then fused at the C-terminus to the N terminus of a mature FGF21 sequence (SEQ ID NO:4), into which two mutations, L98R and P171G, had been introduced. This construct was then expressed and purified as described herein. A dimeric form of the protein was isolated, which was linked via intermolecular disulfide bonds between the Fc region of each monomer. This molecule is referred to in the instant Example 22 as "Fc-(L15)-FGF21 (L98R, P171G)" and has the amino acid sequence of SEQ ID NO:43 and is encoded by SEQ ID NO:42. In this Example, FGF21 refers to the mature form of FGF21, namely SEQ ID NO:4.

22.1 Study Design

[0207] The Fc-(L15)-FGF21 (L98R, P171G) construct was administered chronically and subcutaneously ("SC") into non-diabetic male *Rhesus* monkeys with a BMI > 35. Two other groups of monkeys (n=10 per group) were treated with either mature FGF21 (i.e., SEQ ID NO:4) or a vehicle control.

[0208] Animals were acclimated for 42 days prior to administration of any test compound and were then divided into groups of 10 and administered multiple SC injections of test compounds or control article in a blinded fashion, as depicted graphically in Figure 37. In brief, each animal was injected once a day with compound or vehicle. FGF21 was administered daily, whereas Fc-(L15)-FGF21 (L98R, P171G) was administered weekly. Fc-(L15)-FGF21 (L98R, P171G) and FGF21 doses were escalated every 2 weeks, as shown in Figure 37. Body weight and food intake were monitored throughout the study. The CRO was blinded to the treatment.

[0209] Two oral glucose tolerance tests (OGTTs) were performed prior to the start of the treatment. OGTT1 was used to sort the animals into three equivalent groups having a similar distribution of animals based on area under the curve (AUC) and body weight. The results of the second OGTT (OGTT2) were used to confirm the sorting of the first OGTT (OGTT1). Monkeys with OGTT profiles that were inconsistent from one test (OGTT1) to the next (OGTT2) were excluded. The results of OGTTs 1 and 2 are shown in Figures 38A and 38B, with AUC measurements shown in Figure 38C. Baseline body weight is shown in Figure 38D and Table 20.

[0210] OGTTs 3, 4, and 5 were performed every 2 weeks at the end of each dose treatment of low, mid and high doses. Blood samples were collected from fasted animals weekly and were used to measure glucose, insulin, triglyceride levels, as well as the levels of test compound. Blood samples were also collected weekly during the 3-week washout period.

[0211] Baseline OGTT1 and OGTT2 showed an expected glucose profile as seen in normal animals, with a maximum plasma glucose obtained at 30 minutes, and demonstrated stable AUCs for the 3 different groups.

[0212] Fasting baselines values for plasma chemistry are shown in Table 20. Plasma chemistry measurements were performed on blood samples collected prior to the start of the treatment.

Table 20

Baseline Values for Body Weight, Fasting Plasma Glucose, Insulin, and Triglyceride Levels of the Three Groups of *Rhesus* Monkeys			
	Vehicle	FGF21	Fc-(L15)-FGF21 (L98R, P171G)
N	10	10	10
Body weight (kg)	8.5 ± 0.5	8.7 ± 0.4	8.5 ± 0.4
Plasma glucose (mg/dL)	91.9 ± 4.8	94.8 ± 5.3	82.2 ± 3.7
Insulin (pg/mL)	942.6 ± 121.4	976.1 ±107.7	1023.4 ± 205.1
Triglycerides (mg/dL)	44.4 ± 4.8	58.6 ± 5.2	71.7 ± 9.8

[0213] Three different dose levels were selected, the low dose was 0.1 and 0.3 mg/kg, the mid dose was 0.3 and 1 mg/kg and the high dose was 1 and 5 mg/kg for FGF21 and Fc-(L15)-FGF21(L98R, P171G), respectively. Dose levels were chosen based on the observed dose-response in mice, with a dosing regimen based on the anticipated frequency of injection in humans. Equimolar doses of FGF21 were used for the low and mid doses, and the Fc-(L15)-FGF21(L98R, P171G) high dose was raised to 5 mg/kg (i.e., instead of 3 mg/kg, which would have been equimolar to the 1 mg/kg FGF21 dose).

22.2 Effect of Test Compounds on Body Weight

[0214] In this experiment, in order to measure effect of the test compounds on body weight measured weekly, the percent body weight change from baseline was calculated weekly in the three different groups of *Rhesus* monkeys. Body weight was also measured during the three week of wash out period. Baseline body weight values for each group are included in Table 20.

[0215] Body weight was followed throughout the study, both pre- and post-administration of test compounds. Body weight percent change from baseline of the vehicle animals increased with time, whereas body weight of animals treated with Fc-(L15)-FGF21 (L98R, P171G) and FGF21 decreased in a dose-dependent fashion over the course of the 6 week treatment period, as shown in Figure 39. As observed previously in rodents (Xu et al., Diabetes 58(1):250-9 (2009)), treatment with FGF21 statistically significantly decreased body weight. Fc-(L15)-FGF21 (L98R, P171G) had a greater exposure than did FGF21 (Figure 48 and Figure 47, respectively), offering a possible explanation for the observation that Fc-(L15)-FGF21 (L98R, P171G) showed a more pronounced body weight decrease than FGF21.

22.3. Effect of Test Compounds on Insulin Levels

[0216] Insulin levels were measured in blood samples that had been collected after an overnight fast or after an afternoon meal.

[0217] Fasting plasma insulin levels were measured in *Rhesus* monkeys every week in animals treated with either vehicle, FGF21 or Fc-(L15)-FGF21 (L98R, P171G) and during the 3-week washout period. Fasted blood samples were drawn approximately five days after the last Fc-(L15)-FGF21 (L98R, P171G) injection and approximately 21 hours after the last FGF21 injection.

[0218] Fed plasma insulin levels were measured in *Rhesus* monkeys during the fifth and sixth week of treatment with either vehicle or FGF21 during the high dose treatment. Fed blood samples were drawn approximately three days after Fc-(L15)-FGF21 (L98R, P171G) injection and approximately 2 hours after last FGF21 injection. Figure 40 shows the effect of vehicle, FGF21 and Fc-(L15)-FGF21 (L98R, P171G) on fasted insulin levels over the full nine week study, while Figure 41 depicts fed insulin levels determined from samples taken during weeks 5 and 6.

[0219] Summarily, at the two highest doses, both FGF21 and Fc-(L15)-FGF21(L98R, P171G) statistically significantly decreased fasted and fed plasma insulin levels. The observation that insulin levels of animals treated with FGF21 and Fc-(L15)-FGF21 (L98R, P171G) were decreased without observing increased glucose levels is indicative of increased insulin sensitivity.

22.4 Effect of Test Compounds on OGTT (Glucose and Insulin)

[0220] Three OGTTs (OGTTs 3, 4 and 5) were performed after treatment was initiated. OGTT5 glucose and insulin level profiles were measured in animals treated for 6 weeks with vehicle, FGF21 or Fc-FGF21 (L98R, P171G), corresponding to the last two weeks of the high dose escalation regimen. OGTT5 was conducted approximately 7 days after the last Fc-(L15)-FGF21 (L98R, P171G) injection, and approximately 21 hours after the last FGF21 injection.

The OGTT5 glucose and insulin profiles are shown in Figure 42 and Figure 43, respectively. Animals treated with Fc-(L15)-FGF21(L98R, P171G) showed an improved glucose clearance compared to vehicle-treated animals only at the highest dose and at the last time point measured, as shown in Figure 42. At the end of the last dose, Fc-(L15)-FGF21(L98R, P171G) showed the strongest improvement in glucose clearance. FGF21 showed no improvement in glucose clearance. Fc-(L15)-FGF21 (L98R, P171G) had a greater exposure than did FGF21 (Figure 48 and Figure 47, respectively), offering a possible explanation for the observation that Fc-(L15)-FGF21 (L98R, P171G) showed a more pronounced effect in glucose clearance than FGF21 Insulin levels during OGTT5 were statistically significantly lowered at the last time point measured in animals treated with Fc-(L15)-FGF21 (L98R, P171G) compared to animals treated with vehicle.

[0221] Glucose AUC percent change from baseline was calculated for the three OGTT (OGTTs 3, 4 and 5) performed at the end of each of the low, mid and high doses in the three groups different groups of *Rhesus* monkeys as shown in Figure 44. OGTT5 was conducted approximately seven days after the last Fc-(L15)-FGF21 (L98R, P171G) injection and 21 hours after last FGF21 injection and showed that Fc-(L15)-FGF21 (L98R, P171G) statistically significantly reduced AUC5. Baseline OGTT values for each group are shown on Figure 38C.

[0222] Fasted plasma glucose levels were measured on days when no OGTTs were performed. There were no meaningful statistical differences observed in fasted plasma glucose levels measured among the three groups of animals.

22.5 Effect of Test Compounds on Triglyceride Levels

[0223] Percent change of fasting plasma triglyceride levels was calculated in *Rhesus* monkeys every week in animals treated with either vehicle, FGF21 or Fc-(L15)-FGF21 (L98R, P171G) and during the 3-week washout period. Fasted blood samples were drawn approximately five days after last Fc-(L15)-FGF21 (L98R, P171G) injection and approximately 21 hours after last FGF21 injection. Triglyceride levels were measured every week after the treatment was initiated and percent changes from baseline are shown in Figure 45, fasting baseline values are shown in Table 20.

[0224] As depicted in Figure 45, animals treated with either Fc-(L15)-FGF21 (L98R, P171G) or FGF21 showed a dose-dependent decrease in triglyceride levels, with Fc-(L15)-FGF21 (L98R, P171G) having the greatest lowering effect compared to FGF21.

[0225] Figure 46 shows the plasma triglyceride levels in samples acquire from *Rhesus* monkeys in a fed state, during the fifth and sixth week of treatment with vehicle or Fc-(L15)-FGF21 (L98R, P171G) or FGF21. Fed blood samples were drawn approximately 3 days after Fc-(L15)-FGF21 (L98R, P171G) injection and approximately 2 hours after last FGF21 injection. Fed plasma triglyceride levels of animals treated with FGF21 and Fc-(L15)-FGF21 (L98R, P171G) were statistically significantly reduced, compared to the triglyceride levels of animals treated with vehicle (Figure 46).

22.6 Concentration of Test Compounds

[0226] The exposure of the tested compounds administered at approximately equivalent molar dose levels was assessed throughout the study period. The concentration of Fc-(L15)-FGF21 (L98R, P171G) was measured at pre-dose, and approximately 5 days after the last injection. FGF21 levels were measured at pre-dose, and at 5, 12, 19, and 26 days. Blood samples were drawn at approximately 21 hours after the last injection.

[0227] The individual concentration of the tested compounds in each monkeys are shown in Figures 47 and 48. As shown in Figure 47, the majority of the animals in the FGF21-treated group had concentrations below the quantitation limit. Figure 48 shows that animals in the Fc-(L15)-FGF21 (L98R, P171G)-treated group had detectable levels of Fc-(L15)-FGF21 (L98R, P171G) during each dosing phase (two weekly doses at the same dose strength). The average concentration from each dosing phase increased approximately dose-proportionally from 0.3 to 5 mg/kg for Fc-(L15)-FGF21 (L98R, P171G). There is minimal accumulation as demonstrated by the steady concentrations after the first and second weekly dose within each dose escalation phase for both compounds. During the treatment-free phase (washout period) Fc-(L15)-FGF21 (L98R, P171G) levels were detectable up to approximately day 47 (12 days post last dose) and were below lower limit of quantification (LLOQ) afterwards.

[0228] Exposure of the test compounds was also monitored during each OGTT. FGF21 was not detectable during OGTTs 3 and 4, following low- and mid-dose FGF21 treatment. However, measurable levels were observed during OGTT5, following high-dose treatment. A dose proportional increase in Fc-(L15)-FGF21 (L98R, P171G) levels was observed across the third to fifth OGTT with escalating dose levels, as shown in Figure 49.

[0229] Compound levels data confirm that the animals were exposed to the expected amount of each compound, namely FGF21 and Fc-(L15)-FGF21 (L98R, P171G), in a dose escalation manner. A large variability was observed in the amount of FGF21 measured, which was an expected result considering the sampling was performed approximately 21 hours post the last dose and the half life of FGF21 is approximately 1 hour.

22.7 Conclusions

[0230] FGF21 decreased fasted and fed plasma triglyceride and insulin levels and decreased body weight at the highest doses. Fc-(L15)-FGF21 (L98R, P171G) improved OGTT and decreased insulin levels at the highest dose, and dose dependently decreased fasted and fed plasma triglyceride levels as well as body weight. Both FGF21 and Fc-(L15)-FGF21(L98R, P171G) decreased a number of metabolic parameters in the non diabetic *Rhesus* monkeys.

Insulin and triglyceride level decreases were identical between FGF21 and Fc-(L15)-FGF21 (L98R, P171G) when circulating compound levels were in a similar range, in the fed condition. Due to its improved properties, Fc-(L15)-FGF21 (L98R, P171G) was superior to FGF21 in most of the parameters measured and could be administered once-a-week to observe efficacy on metabolic parameters.

REFERENCE EXAMPLE 23

Fc-(G4S)3-FGF21(L98R, P171G, A180E) Fc fusion Molecule

[0231] An Fc fusion comprising an FGF21 mutant, which was joined to an IgG1 Fc component by a linker, was generated. The FGF21 component of the Fc fusion comprised three point mutations engineered in the polypeptide sequence of FGF21, namely L98R, P171G, A180E (numbering based on the mature form of FGF21, provided as SEQ ID NO:4). This molecule was constructed by conjugating a human Fc (SEQ ID NO:11) to the N-terminus of the L98R, P171G, A180E mutant FGF21 (SEQ ID NO:39) via a 15 amino acid linker comprising the sequence of GGGGSGGGGSGGGGS (SEQ ID NO:31). This molecule was designated as "Fc-(G4S)3-FGF21(L98R, P171G, A180E)" and its full length amino acid sequence is shown in Figure 50 and in SEQ ID NO:47; it is encoded by the nucleic acid of SEQ ID NO:46. *In vitro* testing of Fc-(G4S)3-FGF21(L98R, P171G, A180E) showed it is a potent stimulator of Erk phosphorylation in a recombinant cell line overexpressing β-Klotho. Fc-(G4S)3-FGF21 (L98R, P171G, A180E) also showed enhanced β-Klotho binding affinity compared with Fc fusion of wild type FGF21 or Fc fusion of FGF21-(G4S)3-FGF21 (L98R, P171G) (SEQ ID NO:45). When injected into diabetic animal models, Fc-(G4S)3-FGF21(L98R, P171G, A180E) reduced blood glucose levels, decreased body weight, and was suitable for biweekly injection.

23.1 *In vitro* Activity of Fc-(G4S)3-FGF21(L98R, P171G, A180E)

[0232] Experiments were performed to examine whether Fc-(G4S)3-FGF21 (L98R, P171G, A180E) retains similar activity to Fc fusion of wild type FGF21 or wild type native FGF21 in an ELK-luciferase *in vitro* assay.

[0233] ELK-luciferase assays were performed using a recombinant human 293T kidney cell system, in which the 293T cells overexpress β-Klotho and luciferase reporter constructs. β-klotho is a co-receptor required for FGF21 to activate FGF receptors and induce intracellular signal transduction, including Erk phosphorylation. The Erk- luciferase reporter constructs contain sequences encoding GAL4-ELK1 and 5xUAS-Luciferase reporter. The 5xUAS-Luciferase reporter is driven by a promoter containing five tandem copies of the Gal4 binding site. The reporter activity is regulated by the level of phosphorylated Erk, and is used to indirectly monitor and quantify FGF21 activity.

[0234] ELK-luciferase assays were performed by culturing the 293T cells in the presence of different concentrations of wild-type FGF21, Fc fusion of wild type FGF21, Fc-L15-FGF21 (L98R, P171G, A180E) and Fc-(G4S)3-FGF21 (L98R, P171G, A180E) for 6 hours, and then assaying the cell lysates for luciferase activity. The luminescences obtained in ELK-luciferase assays for each of the FGF21 constructs were expressed in y-axis and the compound concentrations were expressed in x-axis.

[0235] Figure 51 shows the dose-response of the tested compounds in Erk-luciferase assays. Fc-(G4S)3-FGF21 (L98R, P171G, A180E) retained similarly activity compared with Fc fusion of FGF21 wild type, suggesting that a combination of mutations with L98R, P171G and A180E didn't change the bioactivity of FGF21. Compared with native wild type FGF21, Fc fusion constructs showed slightly reduced potency and the maximal activity in this cell-based assay with the co-receptor β-Klotho overexpressed.

23.2 *In vitro* Activity of Fc-FGF21(L98R, P171G, A180E) Fusions Comprising Different Linker Sequences

[0236] A similar Fc fusion analog was generated by fusing the human IgG1 Fc to FGF21 (L98R, P171G, A180E) via a different linker sequence, GGGGGSGGGSGGGGS (SEQ ID NO:28). This linker was designated L15 and the resulting fusion molecule was designated Fc-L15-FGF21 (L98R, P171G, A180E) (SEQ ID NO:57). In this experiment, the effect of different linker sequences on the activity of Fc-FGF21 (L98R, P171G, A180E) fusions was studied.

[0237] ELK-luciferase assays were performed by culturing the 293T cells in the presence of different concentrations of Fc-(G4S)3-FGF21 (L98R, P171G, A180E) and Fc-L15-FGF21 (L98R, P171G, A180E) for 6 hours, and then assaying the cell lysates for luciferase activity. Fc-(G4S)3-FGF21 (L98R, P171G, A180E) showed similar activity to Fc-L15-FGF21 (L98R, P171G, A180E), indicating that different linker sequences, e.g., (G4S)3 or L15 linkers, had no significant impact on the bioactivity of Fc-FGF21 fusions.

23.3 *In vitro* Binding Affinity of Fc-(G4S)3-FGF21(L98R, P171G, A180E) for β-Klotho in Binding Assays

[0238] The binding of Fc-(G4S)3-FGF21 (L98R, P171G, A180E) to human and cyno β-Klotho was tested in a Biacore solution equilibrium binding assay. The affinity of Fc-(G4S)3-FGF21 (L98R, P171G, A180E) was also compared with an Fc- fusion FGF21 analog with only L98R and P171G mutations, namely Fc-L15-FGF21 (L98R, P171G) (SEQ ID NO:43).

[0239] Neutravidin was immobilized on a CM5 chip using amine coupling. Biotin-FGF21 was captured on the second flow cell to -1500RU. The first flow cell was used as a background control. FGF21 mutants at 5x dilutions (0.03-2000 nM) were incubated with 10nM human or

25nM cyno β-Klotho in PBS plus 0.1mg/ml BSA, 0.005% P20 at room temperature for 1 hour. Binding of the free β-Klotho in the mixed solutions was measured by injecting over the biotin-FGF21 surface. 100% β-Klotho binding signal was determined in the absence of FGF21 mutants in the solution. A decreased β-Klotho binding response with increasing concentrations of FGF21 mutants indicated that β-Klotho was binding to FGF21 mutants in solution, which blocked β-Klotho from binding to the immobilized biotin-FGF21 surface. Relative binding of the mixture versus molar concentration of FGF21 was plotted using GraphPad Prizm 5. EC_{50} was calculated using one site competition nonlinear fit in the same software.

[0240] Figure 52 showed the results from a Biacore solution equilibrium binding assay of Fc-(G4S)3-FGF21 (L98R, P171G, A180E) and Fc-L15-FGF21 (L98R, P171G) to human (right) and cyno β-Klotho (left). Fc-(G4S)3-FGF21 (L98R, P171G, A180E) showed at least 2x improved binding activity to both human and cyno β-Klotho compared to Fc-L15-FGF21 (L98R, P171G).

23.4 *In vivo* Efficacy of Fc-(G4S)3-FGF21 (L98R, P171G, A180E) in Diabetic *db/db* Mice

[0241] The question of whether Fc-(G4S)3-FGF21 (L98R, P171G, A180E) could exert metabolic beneficial effects, such as lowering blood glucose and reducing body weight, in diabetic db/db mice was studied. The study was also intended to examine the duration and dose response of Fc-(G4S)3-FGF21 (L98R, P171G, A180E) after a single injection. Fc-(G4S)3-FGF21 (L98R, P171G, A180E) at doses of 0.1, 0.3, 1 and 3 mg/kg was intraperitoneally injected into diabetic db/db mice. A vehicle (10mM Tris, 2.2% sucrose, 3.3% Sorbitol, pH8.5)-treated group was also included in the study. Blood samples were obtained from each animal (n=10 per group) at baseline (before injection), and 6, 24, 72, 120, and 168 hours after injection. Blood glucose levels were measured with a OneTouch Glucometer (LifeScan, Inc. Milpitas, CA). Body weight was measured at baseline (time 0), 24, 72, 120, and 168 hours after injection.

[0242] Figure 53A shows the blood glucose levels in db/db mice at various time points following vehicle or Fc-(G4S)3-FGF21 (L98R, P171G, A180E) injection. Fc-(G4S)3-FGF21 (L98R, P171G, A180E) resulted in a dose-dependent decrease in blood glucose levels in db/db mice. The maximum glucose reduction was about 50% from baseline or compared with the vehicle-treated group. The maximum effect was reached within 6 hours after injection and sustained for 120 hours post injection. The blood glucose levels started to return to baseline in about 168 hours. The estimated ED50, the dose required to achieve the half maximum effect, for Fc-(G4S)3-FGF21 (L98R, P171G, A180E) was approximately 1 mg/kg in db/db mice.

[0243] Figure 53B shows the effect of Fc-(G4S)3-FGF21 (L98R, P171G, A180E) on body weight after a single injection into db/db mice. Results are expressed as change of body weight from time 0 (before injection). Vehicle-treated mice showed progressive and stable body weight gain during the 7 days study period. However, the rate of body weight growth was inhibited in mice treated with Fc-(G4S)3-FGF21 (L98R, P171G, A180E) in a dose-dependent manner. The higher the dose, the longer the growth inhibition was. In one example, Fc-(G4S)3-FGF21 (L98R, P171G, A180E) blunted body weight gain for 5 days at 3 mg/kg, 3 days at 1 mg/kg, or 1 day at 0.3 mg/kg. The growth rates were recovered afterwards. The estimated ED50 of Fc-(G4S)3-FGF21 (L98R, P171G, A180E) on body weight reduction was approximately 1 mg/kg in this experiment.

23.5 Efficacy Comparison of Fc-(G4S)3-FGF21 (L98R, P171G, A180E) and Fc-(L15)-FGF21(L98R, P171G) in DIO Mice with Different Injection Frequencies

[0244] The study was to determine whether Fc-(G4S)3-FGF21 (L98R, P171G, A180E) could be injected less frequently than Fc-(L15)-FGF21 (L98R, P171G) but achieve similar efficacy. The study was conducted in DIO mice with Fc-(G4S)3-FGF21 (L98R, P171G, A180E) given once a week (Q7D) or once every two weeks (Q14D), or Fc-L15-FGF21 (L98R, P171G) administered at twice a week (BIW), Q7D or Q14D.

[0245] DIO mice were prepared by feeding 4-week old male C57BL/6 mice a high fat-diet that contained 60% of energy from fat enriched with saturated fatty acids (D12492, Research Diets, Inc., New Brunswick, NJ). After 12 weeks of high fat diet feeding, body weight and blood glucose levels were measured. DIO mice were then randomized into vehicle or treatment groups to achieve similar baseline average blood glucose levels and body weight. A total of 7 groups were included in the study: vehicle administered at Q7D; Fc-(G4S)3-FGF21 (L98R, P171G, A180E) administered at Q7D or Q14D; or Fc-(L15)-FGF21 (L98R, P171G) administered at BIW, Q7D or Q14D. The injection was intraperitoneal and the study was carried out for 31 days. Body weight was measured weekly. A GTT was performed at study day 28 and the study was terminated at day 31. The study design is shown graphically in Figure 54.

[0246] Figure 55 shows the GTT profiles in mice treated with vehicle, Fc-(G4S)3-FGF21 (L98R, P171G, A180E) or Fc-(L15)-FGF21(L98R, P171G) at different dosing frequencies. Glucose tolerance was statistically significantly improved in mice treated with Fc-(G4S)3-FGF21 (L98R, P171G, A180E) at either Q7D or Q14D dosing when compared with vehicle, suggesting that Fc-(G4S)3-FGF21(L98R, P171G, A180E) is efficacious and suitable for Q14D administration in DIO mice. Fc-(L15)-FGF21(L98R, P171G) improved glucose tolerance when administered at BIW or Q7D, but not Q14D, suggesting that Fc-(L15)-FGF21(L98R, P171G) may be less suitable for Q14D injection in mice. The efficacy of Fc-(G4S)3-FGF21 (L98R, P171G, A180E) at Q7D or Q14D was comparable to that of Fc-(L15)-FGF21(L98R, P171G) at BIW or Q7D respectively, suggesting that Fc-(G4S)3-FGF21(L98R, P171G, A180E) could be given 2 fold less frequently than Fc-(L15)-FGF21(L98R, P171G).

[0247] Figure 56 shows changes of body weight from baseline (day 0) in mice treated vehicle, Fc-(G4S)3-FGF21 (L98R, P171G, A180E) or Fc-(L15)-FGF21 (L98R, P171G) at different dosing frequencies. Mice treated Q7D with Fc-(G4S)3-FGF21 (L98R, P171G, A180E) lost significant body weight as did mice treated BIW with Fc-(L15)-FGF21 (L98R, P171G). The body weight was moderately reduced in mice treated Q14D with Fc-(G4S)3-FGF21 (L98R, P171G, A180E) or Q7D with Fc-(L15)-FGF21 (L98R, P171G). No significant body weight effect was observed in mice treated Q14D with Fc-(L15)-FGF21 (L98R, P171G). The effect on body weight was consistent with that on GTT as described above, suggesting that Fc-(G4S)4-FGF21 (L98R, P171G, A180E) was efficacious at Q14D dosing and required about 2 fold less frequent injections than Fc-(L15)-FGF21 (L98R, P171G) to achieve the same effect.

EXAMPLE 24

Hydrogel Formulations Comprising FGF21 Mutants

[0248] As a formulation agent for protein-based therapeutics, hydrogels offer a number of desired properties. For example, hydrogels preserve the native structure and function of the protein incorporated in the hydrogel. Moreover, they are well tolerated and depending on the polymer and type of crosslinking, they may be biodegradable. Additionally, hydrogels have previously been used successfully for sustained release of proteins. Accordingly, hydrogels were investigated as a possible delivery method for the FGF21 mutants disclosed herein.

[0249] For all experiments described in this example, hydrogels were prepared as follows. A 1.25% bovine gelatin (Sigma) solution in PBS was prepared. The cross-linking agent methacrylic anhydride was added to a molar ratio (MA to gelatin) of 16:1, 24:1 or 32:1. The resulting solution was dialyzed against water to remove any un-polymerized methacrylamide to create a hydrogel vehicle. Finally, the hydrogel vehicle was lyophilized and stored at 4°C until ready to make hydrogels comprising an FGF21 mutant. This prep can be used to prepare gelatin-based hydrogel vehicles that can subsequently be adapted to comprise any of the FGF21 mutants disclosed herein.

[0250] Hydrogels with specific FGF21 mutants were then prepared. Starting with a 10% lyophilized, methacrylic gelatin hydrogel vehicle, solutions were prepared. The hydrogel vehicles were warmed and then centrifuged to dissolve and liquify the lyophilized MA gelatin hydrogel vehicle. The selected FGF21 protein, (FGF21 (L98R, P171G), (SEQ ID NO:37)) in the instant Example), was then added to the liquefied gelatin solution to a pre-determined concentration. A TEMED stock solution was then added. A KPS stock solution was then added and the solution was mixed gently. 1 ml syringes were filled to 200 µl and allowed to set for 1.5 to 2 hours at room temperature. The syringes were stored at -20°C and thawed at 4°C overnight prior to use. Hydrogel vehicle comprising 10mM Tris, 9% sucrose, pH8.5 with no FGF21 mutant added was used as a control.

[0251] For the *in vivo* experiments, the syringes were put on heating pad at 37°C for approximately 10 minutes before injection into the animals.

24.1 *In vitro* Activity of FGF21 (L98R, P171G) Released from 10% Hydrogels with Various Crosslink Ratios

[0252] A goal of this experiment was to test whether FGF21 (L98R, P171G) released from hydrogel is biologically active compared with the native form of FGF21 (L98R, P171G) in an ELK-luciferase *in vitro* assay.

[0253] FGF21 (L98R, P171G) was prepared and incorporated into 10% methacrylic gelatin solutions with methacrylic gelatin crosslink ratios at 16:1, 24:1 and 32:1 as described. The hydrogels were then dispersed into an *in vitro* buffer solution to allow release of FGF21 (L98R, P171G). The medium were collected after 100 or 150 hours and subject to *in vitro* assays for FGF21 (L98R, P171G) activity. Analytical assays (e.g., SDS-PAGE, size exclusion HPLC, and reverse phase HPLC) show the FGF21 (L98R, P171G) released was intact at all time points.

[0254] ELK-luciferase assays were performed using a recombinant human 293T kidney cell system, in which the 293T cells overexpress β-Klotho and luciferase reporter constructs. β-Klotho is a co-receptor that is required by FGF21 for activation of its FGF receptors. The FGF receptors used in this assay are endogenous FGF receptors expressed in 293T kidney cell. The luciferase reporter constructs contain sequences encoding GAL4-ELK1 and a luciferase reporter driven by a promoter containing five tandem copies of the Gal4 binding site (5xUAS-Luc). Luciferase activity is regulated by the level of phosphorylated Erk/ELK1, and is used to indirectly monitor and quantify FGF21 activity.

[0255] ELK-luciferase assays were performed by culturing the 293T cells in the presence of different concentrations of the native form of FGF21 (L98R, P171G) or hydrogel-released FGF21 (L98R, P171G) for 6 hours, and then assaying the cell lysates for luciferase activity. Figure 57 shows the *in vitro* results from the ELK-luciferase assay. FGF21 (L98R, P171G) released from hydrogels with methacrylic gelatin crosslink ratios at 16:1, 24:1 and 32:1 was biologically active with equivalent activity to the native form of FGF21 (L98R, P171G). The data demonstrated that the hydrogel preserved the structure and function of the incorporated protein and the released FGF21 (L98R, P171G) is active and stable even after 10-15 hours in the medium.

24.2 *In vivo efficacy* of Hydrogel FGF21 (L98R, P171G) at Different Crosslink Ratios in ob/ob Mice

[0256] The goal of this experiment was to determine whether an FGF21 (L98R, P171G) hydrogel prepared with methacrylic gelatin crosslink ratios at 24:1 and 32:1 provided a sustained release of biologically active FGF21 (L98R, P171G) *in vivo* and ultimately resulting in longer *in vivo* efficacy as compared with native form of FGF21 (L98R, P171G). In addition, based on the assessment of *in vitro* release rates, it was determined that higher cross-linking ratios of methacrylic gelatin gives better sustained release of the incorporated FGF21 (L98R, P171G). Therefore, another goal of this experiment was to compare two FGF21 (L98R, P171G) hydrogels prepared with methacrylic gelatin crosslink ratios at 24:1 and 32:1.

[0257] FGF21 possesses a number of biological activities, including the ability to lower blood glucose, insulin, triglyceride, or cholesterol levels; reduce body weight; or improve glucose tolerance, energy expenditure, or insulin sensitivity. FGF21 (L98R, P171G) hydrogels were introduced into insulin resistant ob/ob mice, and the abilities of FGF21 (L98R, P171G) hydrogel to lower blood glucose and reduce body weight were measured. The procedure for the *in vivo* work was as follows.

[0258] Hydrogels were prepared using the procedure described above. 8 week old ob/ob mice (Jackson Laboratory) were hair-shaved at the injection site and were anesthetized with isoflurane and O_2 just before injection. Hydrogels (0.2 ml) were slowly injected under the skin and Vetbond was applied at the injection site after injection. Vehicle (10mM Tris, 9% sucrose pH8.5) or native FGF21 (L98R, P171G) were also included in the experiment and injected similarly as hydrogels. Animals were returned to their cage after awaking from anesthesia. Blood samples were obtained before injection and at various time points following injection, e.g., 0, 3, 6, 24, 72, 120, 192 and 264 hours after injection. Blood glucose levels were measured with a OneTouch Glucometer (LifeScan, Inc. Milpitas, CA). Body weight was also monitored.

[0259] Figures 58 and 59 summarize the results of the experiment. Compared with vehicle or control hydrogel, the native form of FGF21 (L98R, P171G) rapidly reduced blood glucose levels at 3 and 6 hr post injection. However, the *in vivo* activity of the native form of FGF21 (L98R, P171G) waned and the blood glucose levels returned to baseline 24 hours after injection. FGF21 (L98R, P171G) hydrogels resulted in blood glucose reduction as early as 3 hr post injection and the activity was sustained up to 8 days. There was no significant difference between the crosslink ratios at 24:1 or 32: 1. FGF21 (L98R, P171G) hydrogel groups also showed slower body weight gain than mice treated with vehicle or hydrogel alone. These results demonstrated that FGF21 (L98R, P171G) hydrogels prepared with methacrylic gelatin crosslink ratios at 24:1 and 32:1 are capable of providing a sustained release of biologically active FGF21 (L98R, P171G) *in vivo* and ultimately resulting in longer *in vivo* efficacy as compared with the native form of FGF21 (L98R, P171G).

24.3 *In vivo* Efficacy of Hydrogel FGF21 (L98R, P171G) and FGF21 (L98R, P171G, A180E) at Different Crosslink Ratios in db/B6 Mice

[0260] Hydrogel formulations were prepared using bovine gelatin (Sigma) and several FGF21 mutants and constructs, namely FGF21 (L98R, P171G) and Fc-(G4S)3-FGF21 (L98R, P171G, A180E). A hydrogel control was also prepared. The 0.2 mL of hydrogel was placed in a 1 ml syringe having a 21G needle.

[0261] Hydrogel controls and hydrogels comprising an FGF21 mutant were prepared as described above. 8 week old db/B6 mice (Jackson Laboratory) were hair-shaved at the injection site and were anesthetized with isoflurane and O_2 just before injection. Hydrogels (0.2 ml) were slowly injected under the skin and Vetbond was applied at the injection site after injection. Vehicle (10mM Tris, 9% sucrose pH8.5) or native FGF21 (L98R, P171G) were also included in the experiment and injected similarly as hydrogels. Animals were returned to their cage after awaking from anesthesia. Blood samples were obtained before injection and at various time points following injection, *e.g.,* 0, 24, 96, 168, 240, 312 hours after injection. Blood glucose levels were measured with a OneTouch Glucometer (LifeScan, Inc. Milpitas, CA). Body weight was also monitored.

[0262] The experimental design was as follows: Group of animals (n=9 per group)

A.	Control hydrogel 32:1 (10%) MA:HU4	200µl
B.	FGF21 (L98R, P171G) hydrogel 32:1 (10%) MA:HU4	0.5 mg/mouse
		(200µl, ~ 10 mg/kg)
C.	FGF21 (L98R, P171G) hydrogel 32:1 (10%) MA:HU4	1.5 mg/mouse
		(200µl ~ 30 mg/kg)
D.	Fc-(G4S)3-FGF21 (L98R, P171G, A180E)	(no hydrogel)
		3 mg/kg

[0263] Various parameters were measured and the results of the experiments are shown in Figures 60-63. Figure 60 shows the change in blood glucose over the course of the 14 day experiment, while Figure 61 shows the percent change in blood glucose over the same period. Figure 62 shows the change in body weight over the course of the 14 day experiment, while Figure 63 shows the percent change in body weight over the same period.

[0264] The results of the experiment shown graphically in Figures 60-63 can be summarized as follows:
FGF21 (L98R, P171G) 32:1(10%)MA:HU4 at 10 mg/kg was efficacious in reducing blood glucose at 24 hours post injection and the blood glucose level returned to baseline between 4-7 days.

[0265] FGF21 (L98R, P171G) 32:1(10%)MA:HU4 at 30 mg/kg was more efficacious in reducing blood glucose than the 10 mg/kg dosage, and the blood glucose level was seen to return to baseline between 7-10 days.

[0266] Fc-(G4S)3-FGF21(L98R, P171G, A180E) at 3 mg/kg itself reduced blood glucose at 24 hours post injection to a degree that was similar to FGF21 (L98R, P171G) at 30mg/kg from hydrogels.

[0267] The hydrogel control (which did not comprise an FGF21 mutant) did not have any effect in reducing blood glucose.

[0268] The FGF21 (L98R, P171G) hydrogel groups and Fc-(G4S)3-FGF21(L98R, P171G, A180E) (which was not presented in a hydrogel) showed reduced body weight gain compared to mice treated with a hydrogel control.

EXAMPLE 25

***Cynomolgus* Monkey Study**

[0269] Two Fc-Linker-FGF21 constructs were generated using methodology described herein. One construct comprised an IgG1 Fc sequence (SEQ ID NO:11) fused at the C-terminus to a $(Gly)_5$-Ser-$(Gly)_3$-Ser-$(Gly)_4$-Ser linker sequence (SEQ ID NO:28) which was then fused to the N terminus of a mature FGF21 sequence (SEQ ID NO:4), in which two mutations, L98R and P171G, were introduced. This molecule is referred to in the instant Example as "Fc-(L15)-FGF21 (L98R, P171G)" (SEQ ID NO:43). A second construct comprised an IgG1 Fc sequence (SEQ ID NO:11) fused at the C-terminus to a $(Gly)_4$-Ser-$(Gly)_4$-Ser-$(Gly)_4$-Ser linker sequence (SEQ ID NO:31) which was then fused to the N terminus of a mature FGF21 sequence (SEQ ID NO:4), in which three mutations, L98R, P171G, and A180E, were introduced. This molecule is referred to in the instant Example as "Fc-(G4S)3-FGF21 (L98R, P171G, A180E)" (SEQ ID NO:47). These constructs were then expressed and purified as described herein, and were isolated as a dimeric form of the protein, each monomer of which was linked via intermolecular disulfide bonds between the Fc region of each monomer.

25.1 Study Design

[0270] The study was conducted in *cynomolgus* monkeys with characteristics of impaired glucose tolerance (IGT). The monkeys were 8-18 years old. Their body weights ranged from 5-15 kg and BMI ranged from 32-70 kg/m2. 44 monkeys were acclimated for 6 weeks prior to the initiation of compound administration. During the acclimation period, monkeys were trained 4 times a week for 4 weeks to familiarize the procedures including chair-restrain, subcutaneous injection (PBS, 0.1 ml/kg), gavage (Water, 10 ml/kg), blood drawn for non OGTT and OGTT samples. After 4 weeks of training, baseline OGTT and plasma metabolic parameters were measured. 40 out of 44 monkeys were selected and randomized into three treatment groups to achieve similar baseline levels of body weight, OGTT AUC response, and plasma glucose and triglyceride levels.

[0271] The study was conducted in a blind fashion. Vehicle (n=14), Fc-(L15)-FGF21 (L98R, P171G) (n=13) and Fc-(G4S)3-FGF21 (L98R, P171G, A180E) (n=13) were labeled as compound A, B and C and administered once a week via subcutaneous injection. Compounds were given in a dose-escalation fashion from low (0.3 mg/kg), medium (1 mg/kg) to high (3 mg/kg) levels and the dose was escalated every three weeks. After 9 weeks of compound treatments, animals were monitored for additional 3 weeks for compound washout and recovery from treatments. Food intake, body weight, clinical chemistry and OGTT were monitored throughout the study. Food intake was measured every meal. Body weight was measured weekly. Blood samples were collected weekly 5 days post each injection to measure glucose, triglyceride, total cholesterol, HDL- and LDL-cholesterol levels. OGTTs were conducted every three weeks after the initiation of treatments (at the end of each dose level). The day starting the treatment is designated as 0 and the detailed study plan is shown in Figure 64.

[0272] The results shown in this example are data collected at the end of 9 weeks treatment.

25.2 Effect of Test Compounds on Food Intake

[0273] Animals were fed twice a day, with each animal receiving 120 g of formulated food established during the acclimation period. The remaining food was removed and weighed after each meal to calculate food intake. The feeding time were from 8:00 AM to 8:30 AM (±30 minutes) and then from 4:30PM to 5:00PM (±30 minutes). To produce treats, apple (150 g) was supplied to each animal at 11:30 to 12:30 PM (±30 minutes) every day.

[0274] Compared with vehicle, both Fc-(L15)-FGF21 (L98R, P171G) and Fc-(G4S)3-FGF21 (L98R, P171G, A180E) reduced food intake in monkeys (Figures 65, 66 and 67). Fc-(G4S)3-FGF21 (L98R, P171G, A180E) inhibited food intake on every meal including AM, fruit and PM meals at 0.3 mg/kg dose. However, the effect diminished and the food intake returned close to baseline or control levels after about 30 days of treatment when the dose was escalated to 1 mg/kg. Fc-(L15)-FGF21 (L98R, P171G) didn't have a significant effect on AM food intake and only modestly reduced food intake on PM meal when the dose was escalated to 1 and 3 mg/kg. However, Fc-(L15)-FGF21 (L98R, P171G) reduced fruit intake similarly as Fc-(G4S)3-FGF21 (L98R, P171G, A180E). Overall, Fc-(G4S)3-FGF21 (L98R, P171G, A180E) showed a stronger effect on inhibiting food intake than Fc-(L15)-FGF21 (L98R, P171G). The effect on food intake appeared to be short term and food intake was recovered after approximately 30 days of treatment.

25.3. Effect of Test Compounds on Body Weight

[0275] Body weight was monitored weekly throughout the study. Over the course of the 9 week treatments, the body weight of animals treated with vehicle remained constant while body weight of animals treated with Fc-(L15)-FGF21 (L98R, P171G) and Fc-(G4S)3-FGF21 (L98R, P171G, A180E) progressively decreased. Fc-(G4S)3-FGF21 (L98R, P171G, A180E) resulted in a more pronounced body weight decrease than Fc-(L15)-FGF21 (L98R, P171G) as shown in Figure 68.

25.4. Effect of Test Compounds on Body Mass Index (BMI), Skin Fold Thickness (SFT) and Abdominal Circumference (AC)

[0276] BMI, SFT and AC were monitored weekly throughout the study, both pre- and post-administration of test compounds when the body weight was taken. BMI is defined as the individual's body weight divided by the square of his or her height. SFT is the thickness of a double layer of skin and the fat beneath it with a special caliber that exerts a constant tension on the site. BMI, SFT and AC are relatively accurate, simple, and inexpensive measurements of body composition particularly indicative of subcutaneous fat. Animals treated with vehicle showed relatively stable BMI, SFT and AC throughout the study. Animals treated with Fc-(L15)-FGF21 (L98R, P171G) and Fc-(G4S)3-FGF21 (L98R, P171G, A180E) showed decreased levels of BMI, SFT and AC over the course of the 9 week study, suggesting both compounds resulted in reduction of fat mass. Fc-(G4S)3-FGF21 (L98R, P171G, A180E) was more effective and resulted in more pronounced reductions in BMI, SFT and AC than Fc-(L15)-FGF21 (L98R, P171G). Results are shown in Figures 69, 70 and 71, respectively.

25.5 Effect of Test Compounds on Fasting Blood Glucose Levels

[0277] Blood was collected from overnight fasted animals. The blood drawn was conducted weekly at 5 days post each injection. Both Fc-(G4S)3-FGF21 (L98R, P171G, A180E) and Fc-(L15)-FGF21 (L98R, P171G) reduced fasting blood glucose levels. Fc-(G4S)3-FGF21 (L98R, P171G, A180E) reduced fasting blood glucose levels at the dose of 0.3 mg/kg and the maximum glucose reduction was achieved when the dose was escalated to 1 mg/kg. However, Fc-(L15)-FGF21 (L98R, P171G) only resulted in a modest reduction of blood glucose levels at the highest dose tested (3 mg/kg). Therefore, Fc-(G4S)3-FGF21 (L98R, P171G, A180E) was more efficacious and produced more pronounced blood glucose reduction than Fc-(L15)-FGF21 (L98R, P171G). No hypoglycemia was observed in any of the monkeys treated with Fc-(G4S)3-FGF21 (L98R, P171G, A180E) or Fc-(L15)-FGF21 (L98R, P171G). Figure 72 shows the levels of fasting plasma glucose during the course of study.

25.6 Effect of Test Compounds on Oral Glucose Tolerance Test (OGTT)

[0278] OGTTs were conducted before and after initiation of treatments. Post-dose OGTTs were performed every three weeks to test compound effect at each dose level. Fc-(G4S)3-FGF21 (L98R, P171G, A180E) improved glucose tolerance at all tested doses from 0.3 to 3 mg/kg. Glucose levels were reduced and the glucose excursion following a bolus of glucose challenge increased in response to Fc-(G4S)3-FGF21 (L98R, P171G, A180E) treatment. There was no dose-response observed suggesting that Fc-(G4S)3-FGF21 (L98R, P171G, A180E) achieved its maximal effect at the dose of 0.3 mg/kg. Fc-(L15)-FGF21 (L98R, P171G) only resulted in an improvement of glucose tolerance at 1 mg/kg dose and it was not clear why the effect diminished when the dose was escalated to 3 mg/kg. Figure 73 shows pre- and post-OGTT curve profiles and the area under the OGTT curve.

25.7 Effect of Test Compounds on Trigylceride Levels

[0279] Blood was collected from overnight fasted animals. The blood drawn was conducted weekly at 5 days post each injection. Triglyceride levels were significantly reduced in animals treated with Fc-(G4S)3-FGF21 (L98R, P171G, A180E) or Fc-(L15)-FGF21 (L98R, P171G). However, Fc-(G4S)3-FGF21 (L98R, P171G, A180E) was more effective than Fc-(L15)-FGF21 (L98R, P171G). Fc-(G4S)3-FGF21 (L98R, P171G, A180E) resulted in a maximal reduction of plasma triglyceride levels at 0.3 mg/kg while Fc-(L15)-FGF21 (L98R, P171G) only resulted in an intermediate reduction of triglyceride levels with the highest tested dose (3 mg/kg). Figure 74 shows the levels of fasting plasma triglycerides during the course of study.

25.8 Effect of Test Compounds on Total Cholesterol and HDL-Cholesterol Levels

[0280] Blood was collected from overnight fasted animals. The blood drawn was conducted weekly at 5 days post each injection. Plasma total cholesterol and HDL-cholesterol levels tended to increase following Fc-(G4S)3-FGF21 (L98R, P171G, A180E) or Fc-(L15)-FGF21 (L98R, P171G) treatment. Figures 75 and 76 show the levels of total cholesterol and HDL-cholesterol over the course of study.

25.9 Conclusions

[0281] In a dose-escalation study conducted in male IGT *cynomolgus* monkeys, animals treated with Fc conjugated FGF21 mutants, namely Fc-(G4S)3-FGF21 (L98R, P171G, A180E) and Fc-(L15)-FGF21 (L98R, P171G), showed improved metabolic parameters. Body weight was reduced and body composition was improved. Short-term reduction of food intake was observed and and the food intake recovered to baseline or control levels mid study. Fasting blood glucose and triglyceride levels were also reduced by both compounds, Fc-(G4S)3-FGF21 (L98R, P171G, A180E) or Fc-(L15)-FGF21(L98R, P171G). OGTT was improved and HDL-cholesterol levels were slightly elevated. Compared with Fc-(L15)-FGF21 (L98R, P171G), Fc-(G4S)3-FGF21 (L98R, P171G, A180E) appeared to be superior to Fc-(L15)-FGF21 (L98R, P171G) in all parameters measured at any tested dose. Fc-(G4S)3-FGF21 (L98R, P171G, A180E) achieved its maximal effects for most of the parameters measured when administered at 0.3 mg/kg. Therefore the therapeutic effective dose of Fc-(G4S)3-FGF21 (L98R, P171G, A180E) in higher species may be lower than 0.3 mg/kg.

EXAMPLE 26

Stability Study in *Cynomolgus* Monkeys

[0282] This study was designed to determine whether Fc-(L15)-FGF21 (L98R, P171G, A180E) (SEQ ID NO:57) was more protease-resistant than Fc-(L15)-FGF21 (L98R, P171G) (SEQ ID NO:43). Carboxy terminal processing were observed following Fc-(L15)-FGF21 (L98R, P171G) injection into mice or monkeys as shown in Example 21. The degradation resulted in a successive loss of 1 to 3 amino acid residues from the C-terminus. Efforts by capping the C-terminus or introducing additional mutations into the C-terminus of Fc-(L15)-FGF21 (L98R, P171G) yielded a superior molecule Fc-(L15)-FGF21 (L98R, P171G, A180E). This study was designed to assess whether Fc-(L15)-FGF21 (L98R, P171G, A180E) had improved *in vivo* stability compared with Fc-(L15)-FGF21 (L98R, P171G).

[0283] Fc-(L15)-FGF21 (L98R, P171G, A180E) and Fc-(L15)-FGF21 (L98R, P171G) constructs were generated. These constructs comprised an IgG1 Fc sequence (SEQ ID NO:11) fused at the C-terminus to a (Gly)5-Ser-(Gly)3-Ser-(Gly)4-Ser linker sequence (SEQ ID NO:28) which was then fused to the N terminus of a mature FGF21 sequence (SEQ ID NO:4), in which either two mutations, L98R, P171G, or three mutations, L98R, P171G, and A180E, were introduced. These constructs were then expressed and purified as described herein, and were isolated as a dimeric form of the protein, each monomer of which was linked via intermolecular disulfide bonds between the Fc region of each monomer.

[0284] The *in vivo* stability of Fc-(L15)-FGF21 (L98R, P171G) and Fc-(L15)-FGF21 (L98R, P171G, A180E) was compared in male *cynomolgus* monkeys. Fc-(L15)-FGF21 (L98R, P171G) and Fc-(L15)-FGF21 (L98R, P171G, A180E) were intravenously injected into cynomolgus monkeys at 23.5 mg/kg. Blood samples were collected at various time points following a single iv injection. Immunoaffinity-MALDI-TOF mass spectrometry was used to monitor metabolites at each time point following injection. Results are shown in Figure 77.

[0285] Compared with Fc-(L15)-FGF21(L98R, P171G), Fc-(L15)-FGF21 (L98R, P171G, A180E) showed significantly reduced C-terminal degradation with fewer detectable mass peaks adjacent to the parental peak of the intact molecule, suggesting that the A180E mutation slowed down C-terminal peptidase degradation. Larger truncations with mass losses estimated at [1-376], [1-394] and [1-401] were also observed and the sites corresponded to 133-134, 153-154 and 158-159 in the FGF21 polypeptide sequence. The internal endopeptidase clipping contributed to the overall metabolism of both Fc-(L15)-FGF21 (L98R, P171G) and Fc-(L15)-FGF21 (L98R, P171G, A180E), and the A180E mutation did not appear to significantly impact the rate of internal endopeptidase degradation.

[0286] In order to increase the resolution and provide details of the degradation mixture, MRM (multiple-reaction-monitoring) LC-MS mass spectrometry was also performed to monitor various forms of the C-terminal degradation fragments. Monkey samples were affinity-purified and then subjected to Asp-N digestion. The C-terminal digested peptides were then monitored by MRM. Results for various forms of the C-terminal degradation fragments are expressed as relative amount to full length peptide species (%) shown in Figure 78. Consistent with MALDI spectra, the MRM semi-quantitative analysis of the C-terminal fragments also showed reduced relative abundance of the peptide fragments missing 1-3 amino acids from the C-terminus and the increased relative abundance of the intact molecule in monkeys administered with Fc-(L15)-FGF21 (L98R, P171G, A180E) compared with Fc-(L15)-FGF21 (L98R, P171G).

[0287] In summary, Fc-(L15)-FGF21 (L98R, P171G, A180E) showed reduced C-terminal degradation and enhanced *in vivo* stability compared with Fc-(L15)-FGF21 (L98R, P171G) in *cynomolgus* monkeys.

EXAMPLE 27

Pharmacokinetics of Fc-(L15)-FGF21 (L98R, P171G, A180E) and Fc-(L15)-FGF21 (L98R, P171G) in Mice

[0288] This study was designed to assess the pharmacokinetics of Fc-(L15)-FGF21 (L98R, P171G, A180E) (SEQ ID NO:57) and Fc-(L15)-FGF21 (L98R, P171G) (SEQ ID NO:43) following a single intravenous dose to male C57BL/6 mice.

[0289] Fc-(L15)-FGF21 (L98R, P171G, A180E) and Fc-(L15)-FGF21 (L98R, P171G) were given at 20 mg/kg through intravenous injection. Blood samples were collected at 0.083 (5 minutes), 1, 4, 8, 16, 24, 48, 72, 96, 168, and 240 hours post-dosing. In order to determine plasma concentrations of intact full-length molecule, an ELISA assay with the immunoreactivity directed to the N-terminal and C-terminal FGF21 was developed. The assay tracks the full length intact molecule with negligible contaminations from other degradation products. The plasma concentrations of intact Fc-(L15)-FGF21 (L98R, P171G, A180E) and Fc-(L15)-FGF21 (L98R, P171G) over a period of 240 hours following intravenous injection in mice are shown in Figure 79.

[0290] The plasma concentrations of Fc-(L15)-FGF21 (L98R, P171G, A180E) were significantly higher than those of Fc-(L15)-FGF21 (L98R, P171G) administered at the same dose level from 24 to 168 hours post injection. A significant amount of Fc-(L15)-FGF21 (L98R, P171G, A180E) was measurable at 168 hours post injection in mice. As a result, Fc-(L15)-FGF21 (L98R, P171G, A180E) showed increased AUC coverage and plasma circulating half-life by 2 fold compared with Fc-(L15)-FGF21 (L98R, P171G) in mice. The half-life of Fc-(L15)-FGF21 (L98R, P171G, A180E) was 16.6 hours and that of Fc-(L15)-FGF21 (L98R, P171G) was 9.4 hours. Both compounds were below detectable level at 240 hours post dose.

EXAMPLE 28

Generation of N-linked Glycosylation Mutants to Improve Solubility or Decrease C-terminal Clipping to Increase Half-life

[0291] FGF21 mutants were designed and generated to create potential N-linked glycosylation sites for mammalian expression with minimal disruption to the native amino acid sequence. The mutants constructed include FGF21 (Y179N, S181T) (SEQ ID NO:161), FGF21 Y179N (SEQ ID NO:163) and FGF21 P124S (SEQ ID NO: 165).

[0292] Expression of the mutants was performed transiently in 293-6E cells and conditioned media was tested for activity in an ELK-luciferase *in vitro* assay. ELK-luciferase assays were performed as described in Example 4, with the exception that serial dilutions of conditioned media were used rather than different concentrations of purified proteins.

[0293] Analysis of the conditioned media revealed that increased glycosylation compared to wild type was not achieved in the transient expression system. Figure 80 shows the results of an ELK-luciferase activity assay. The results shown in Figure 80 demonstrate that the FGF21 P124S mutant did not adversely impact FGF21 activity but the FGF21 Y179N and FGF21 (Y179N, S181T) mutants, in the absence of glycosylation, resulted in reduced activity as assayed in the ELK-luciferase assay.

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PATENTKRAV

1. Polypeptid, der omfatter en aminosyresekvens ifølge SEQ ID NO: 4, hvor: (a) aminosyreresten ved position 180 ifølge SEQ ID NO: 4 er substitueret med en aminosyre valgt fra gruppen bestående af glycin, prolin, serin og glutaminsyre; og (b) aminosyreresten ved position 98 ifølge SEQ ID NO: 4 er substitueret med arginin eller aminosyreresten ved position 171 ifølge SEQ ID NO: 4 er glycin, og hvor polypeptidet kan sænke blodglucoseniveauer hos et pattedyr.

2. Polypeptid ifølge krav 1, og som endvidere omfatter en linker-sekvens omfattende SEQ ID NO: 31.

3. Polypeptid ifølge krav 1 eller krav 2, og som endvidere omfatter et Fc-domæne omfattende SEQ ID NO: 11.

4. Polypeptid ifølge et hvilket som helst af kravene 1-3, hvor (i) polypeptidet ifølge SEQ ID NO: 4 omfatter: (a) en aminoterminal trunkering af ikke flere end 8 aminosyrerester, hvor polypeptidet kan sænke blodglucose hos et pattedyr; (b) en carboxylterminal trunkering af ikke flere end 12 aminosyrerester, hvor polypeptidet kan sænke blodglucose hos et pattedyr; eller (c) en aminoterminal trunkering af ikke flere end 8 aminosyrerester og en carboxylterminal trunkering af ikke flere end 12 aminosyrerester, hvor polypeptidet kan sænke blodglucose hos et pattedyr, eller (ii) polypeptidet er kovalent bundet til én eller flere polymerer, polymeren er eventuelt PEG.

5. Farmaceutisk sammensætning, der omfatter polypeptidet ifølge et hvilket som helst af kravene 1-3 og et farmaceutisk acceptabelt formuleringsmiddel.

6. Farmaceutisk sammensætning ifølge krav 5, hvor det farmaceutisk acceptable formuleringsmiddel er en hydrogel.

7. Farmaceutisk sammensætning ifølge krav 5 eller 6 til anvendelse i en fremgangsmåde til behandling af en metabolisk lidelse.

8. Farmaceutisk sammensætning til anvendelse ifølge krav 7, hvor den metaboliske lidelse er type 2 diabetes eller fedme.

9. Farmaceutisk sammensætning til anvendelse ifølge krav 7, hvor den metaboliske lidelse er ikke-alkoholisk steatohepatitis (NASH).

10. Farmaceutisk sammensætning til anvendelse ifølge krav 9, hvor polypeptidet omfatter en aminosyresekvens ifølge SEQ ID NO: 4, og som endvidere omfatter substitution af en argininrest med leucinresten ved position 98, en glycinrest med prolinresten ved position 171, og en glutaminsyre med alanin ved position 180.

11. Nukleinsyre, der koder for polypeptidet ifølge et hvilket som helst af kravene 1-3.

12. Vektor, der omfatter nukleinsyremolekylet ifølge krav 10.

13. Værtscelle, der omfatter nukleinsyremolekylet ifølge krav 10.

14. Multimer, der omfatter to eller flere af polypeptiderne ifølge krav 3.

15. Multimer ifølge krav 14, der omfatter en første o gen og en kæde, hvor den første kæde omfatter:

(a.1) polypeptidet ifølge SEQ ID NO: 4, hvor (i) leucin ved position 98 er substitueret med arginin; (ii) prolin ved position 171 er substitueret med glycin; og (iii) alanin ved position 180 er substitueret med glutaminsyre;

(b.1) en linker-sekvens, der omfatter SEQ ID NO: 31; og

(c.1) et Fc-domæne, der omfatter SEQ ID NO: 11; og

hvor den anden kæde omfatter:

(a.2) polypeptidet ifølge SEQ ID NO: 4, hvor (i) leucin ved position 98 er substitueret med arginin; (ii) prolin ved position 171 er substitueret med glycin; og (iii) alanin ved position 180 er substitueret med glutaminsyre;

(b.2) en linker-sekvens, der omfatter SEQ ID NO: 31; og

(c.2) et Fc-domæne, der omfatter SEQ ID NO: 11.

DRAWINGS

FIG. 1A

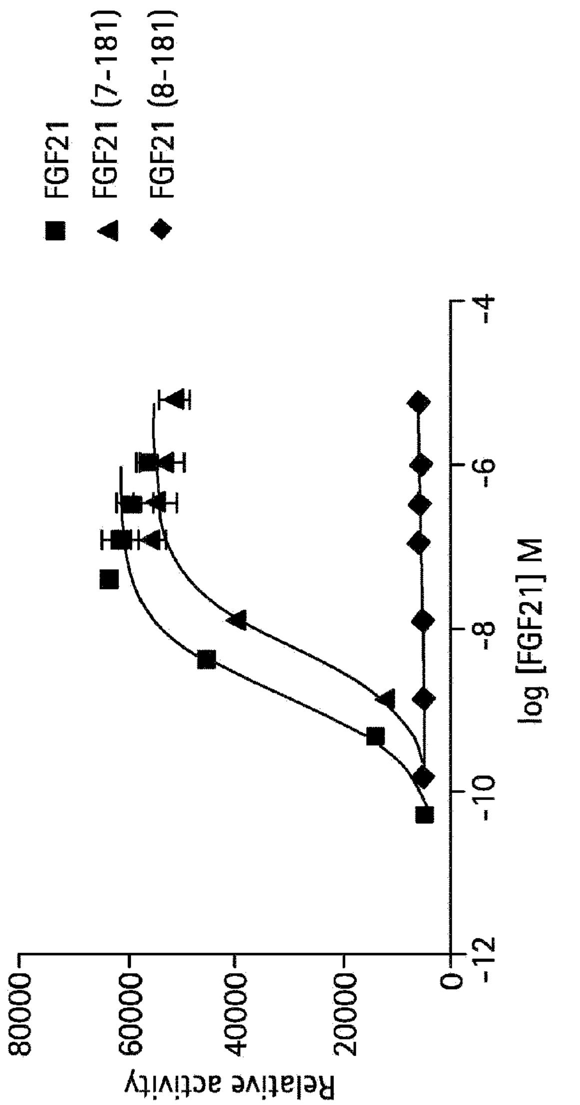


FIG. 1B

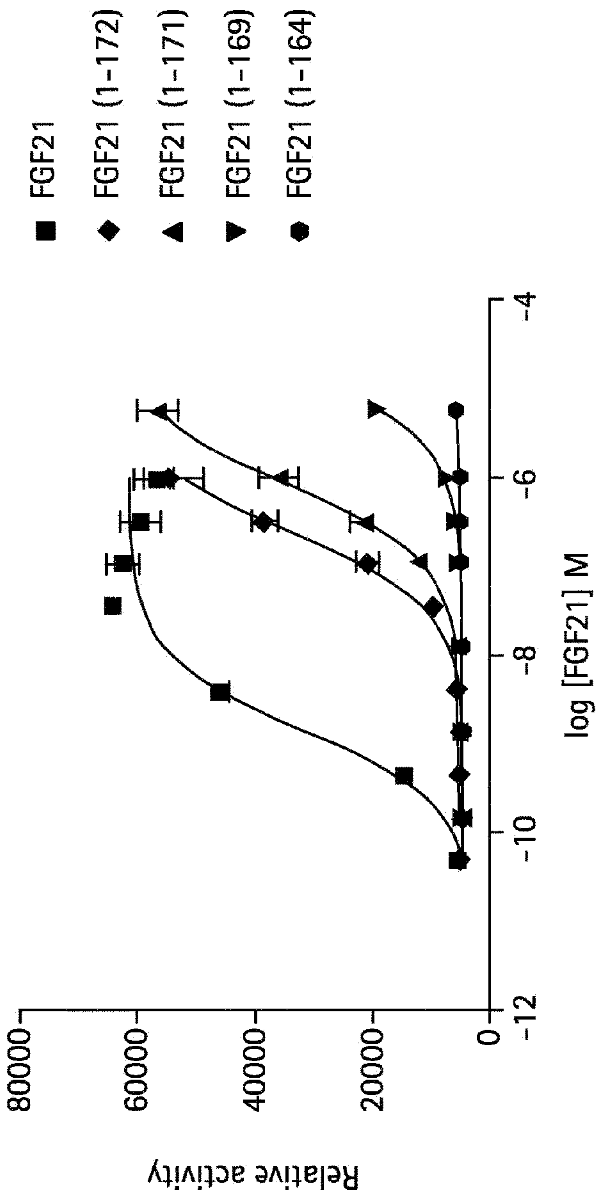

FGF21
FGF21 (1-172)
FGF21 (1-171)
FGF21 (1-169)
FGF21 (1-164)
Relative activity
80000
60000
40000
20000
0
-12
-10
-8
-6
-4
log [FGF21] M

FIG. 2

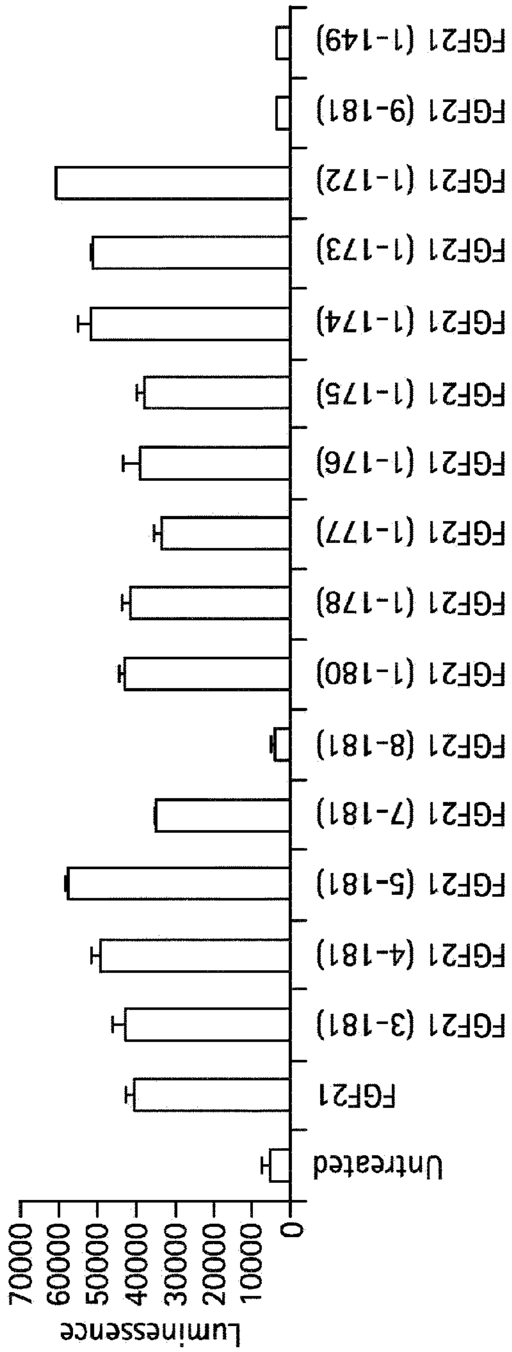

Luminescence
0
10000
20000
30000
40000
50000
60000
70000
Untreated
FGF21
FGF21 (3-181)
FGF21 (4-181)
FGF21 (5-181)
FGF21 (7-181)
FGF21 (8-181)
FGF21 (1-180)
FGF21 (1-178)
FGF21 (1-177)
FGF21 (1-176)
FGF21 (1-175)
FGF21 (1-174)
FGF21 (1-173)
FGF21 (1-172)
FGF21 (9-181)
FGF21 (1-149)

FIG. 3

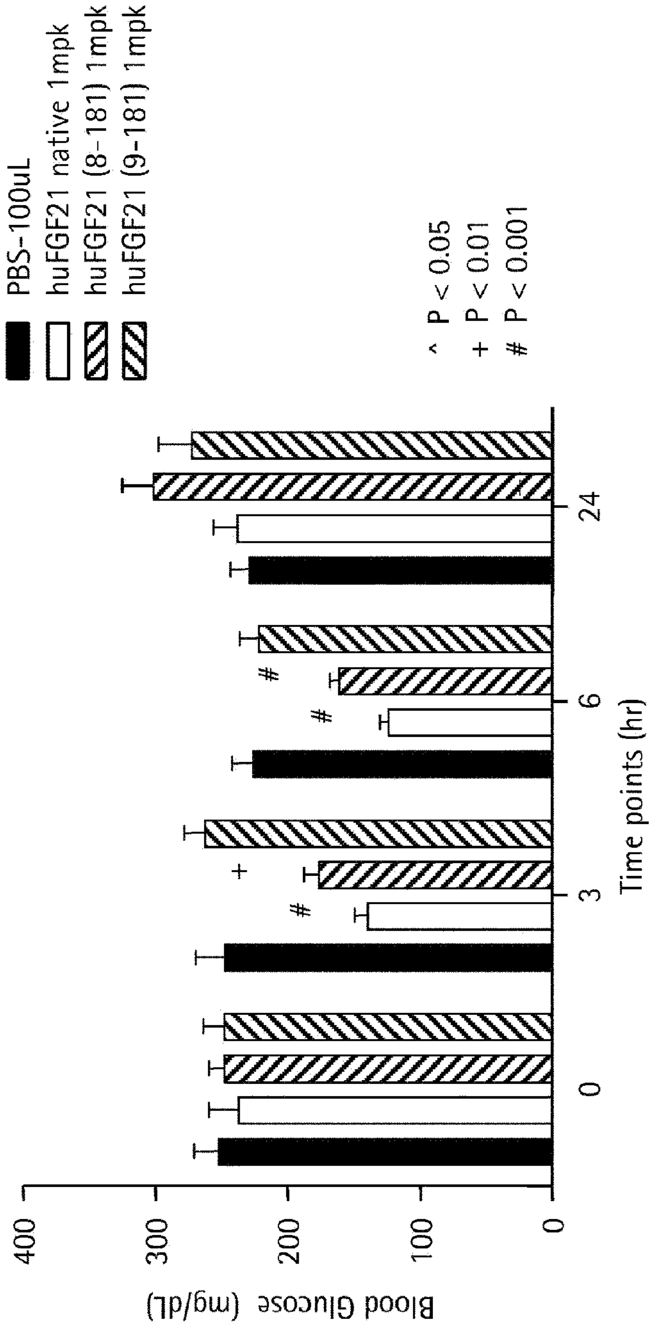

PBS-100uL
huFGF21 native 1mpk
huFGF21 (8-181) 1mpk
huFGF21 (9-181) 1mpk
^ P < 0.05
+ P < 0.01
# P < 0.001
Blood Glucose (mg/dL)
400
300
200
100
0
Time points (hr)
0
3
6
24
#
+
#
#

FIG. 4

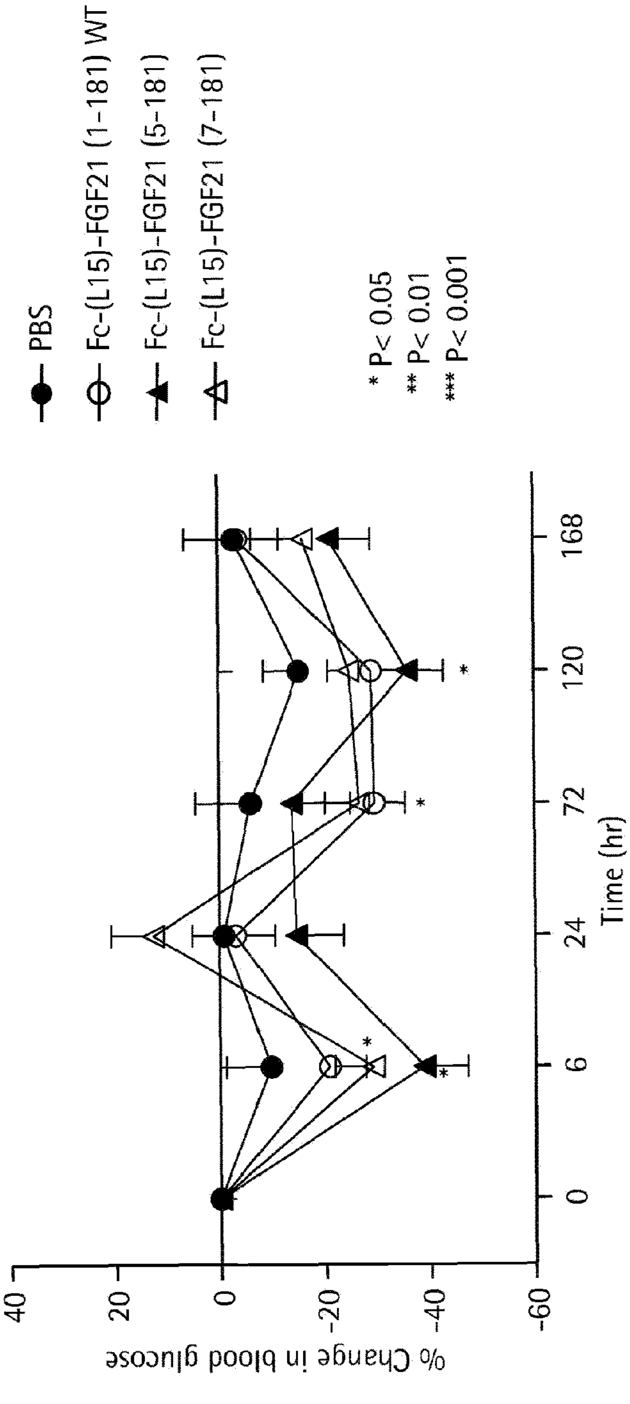

PBS
Fc-(L15)-FGF21 (1-181) WT
Fc-(L15)-FGF21 (5-181)
Fc-(L15)-FGF21 (7-181)
* P< 0.05
** P< 0.01
*** P< 0.001
% Change in blood glucose
Time (hr)
40
20
0
-20
-40
-60
0
6
24
72
120
168

FIG. 5

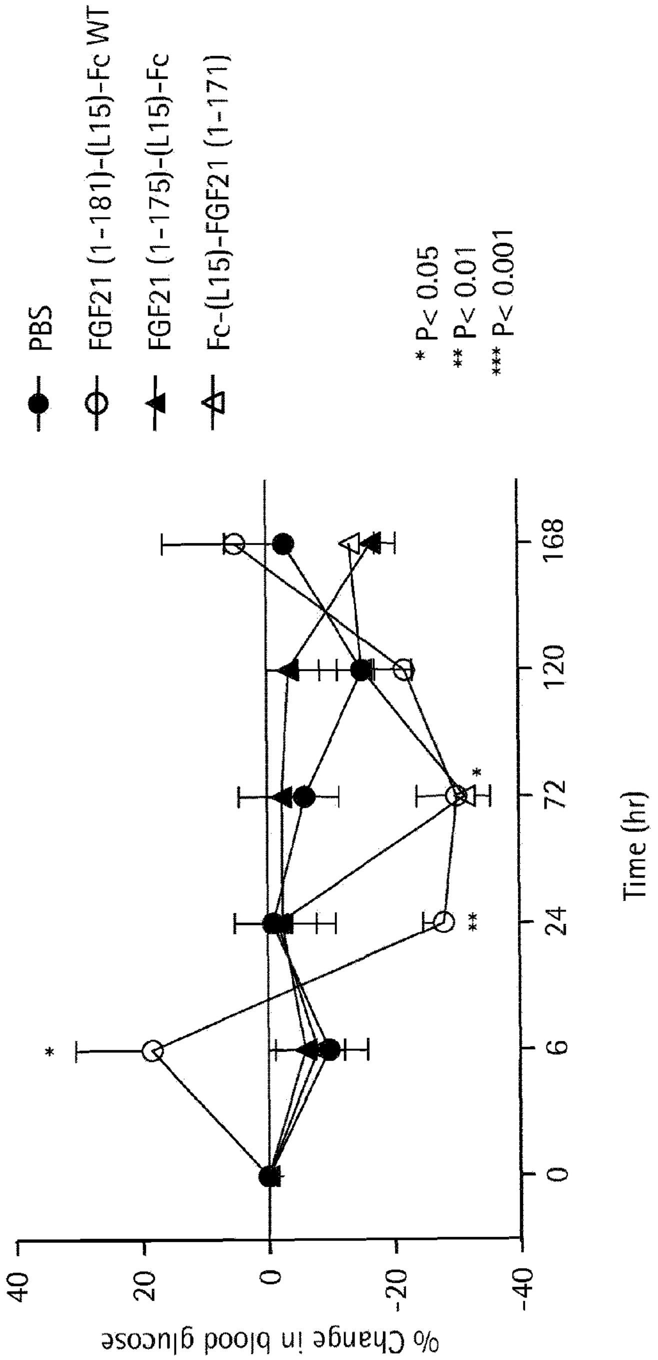

PBS
FGF21 (1-181)-(L15)-Fc WT
FGF21 (1-175)-(L15)-Fc
Fc-(L15)-FGF21 (1-171)
* P< 0.05
** P< 0.01
*** P< 0.001
% Change in blood glucose
40
20
0
-20
-40
0
6
24
72
120
168
Time (hr)

FIG. 6A

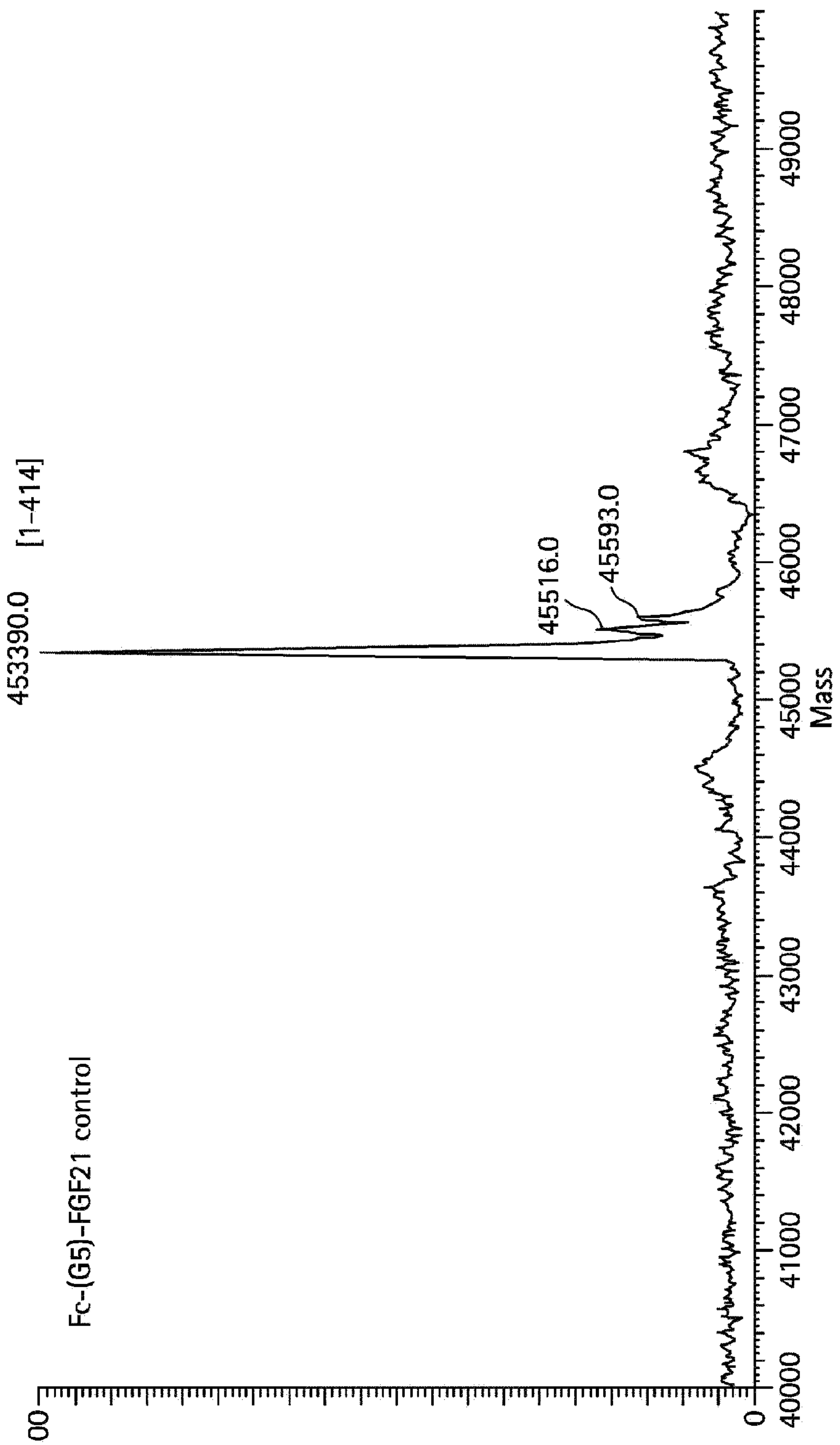
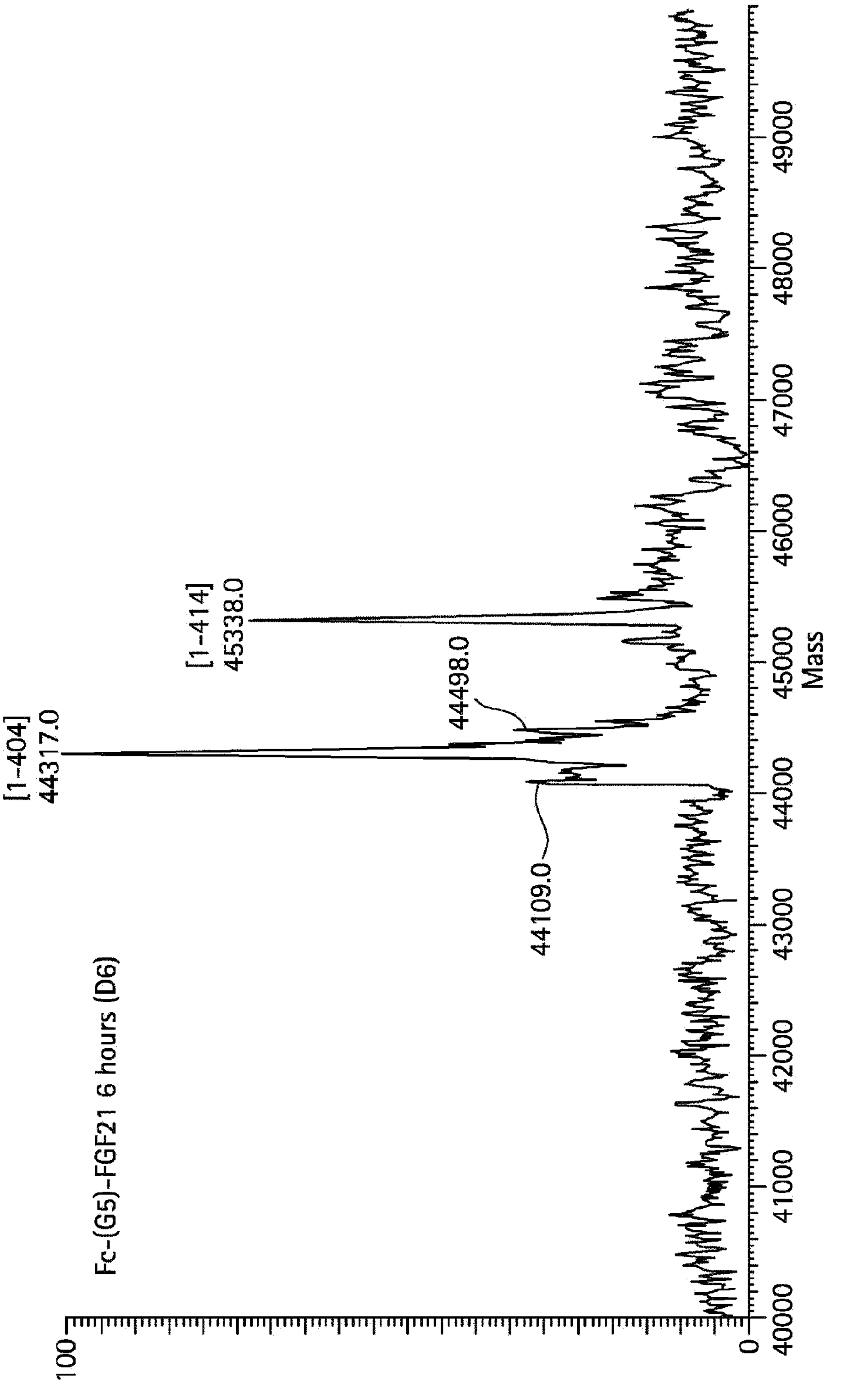

Fc-(G5)-FGF21 control
453390.0
[1-414]
45516.0
45593.0
100
0
40000
41000
42000
43000
44000
45000
46000
47000
48000
49000
Mass

FIG. 6B


Fc-(G5)-FGF21 6 hours (D6)
[1-404]
44317.0
44109.0
44498.0
[1-414]
45338.0
100
0
40000
41000
42000
43000
44000
45000
46000
47000
48000
49000
Mass

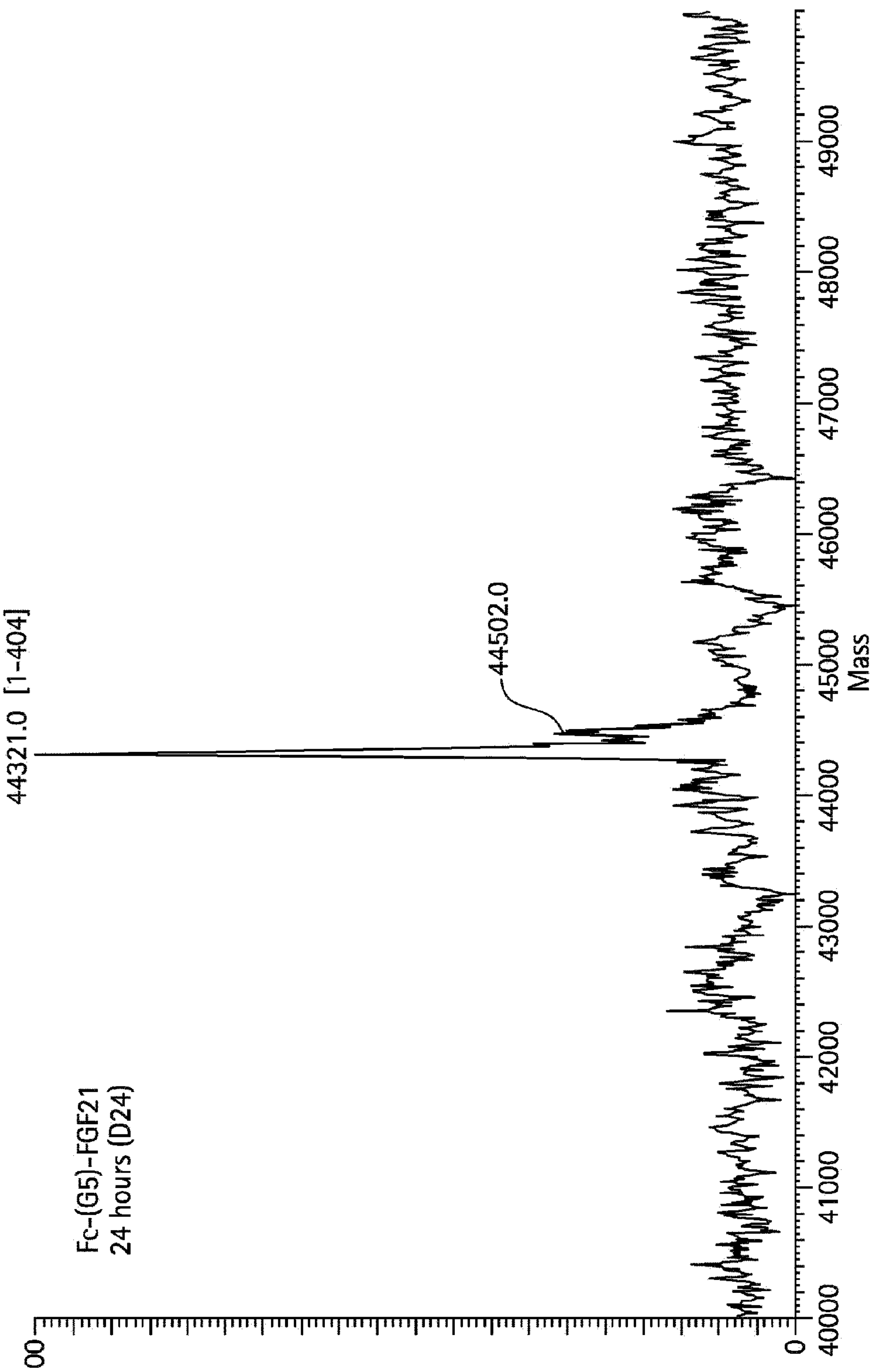

Fc-(G5)-FGF21
24 hours (D24)
44321.0 [1-404]
44502.0
100
0
40000
41000
42000
43000
44000
45000
46000
47000
48000
49000
Mass

FIG. 6C

FIG. 6D

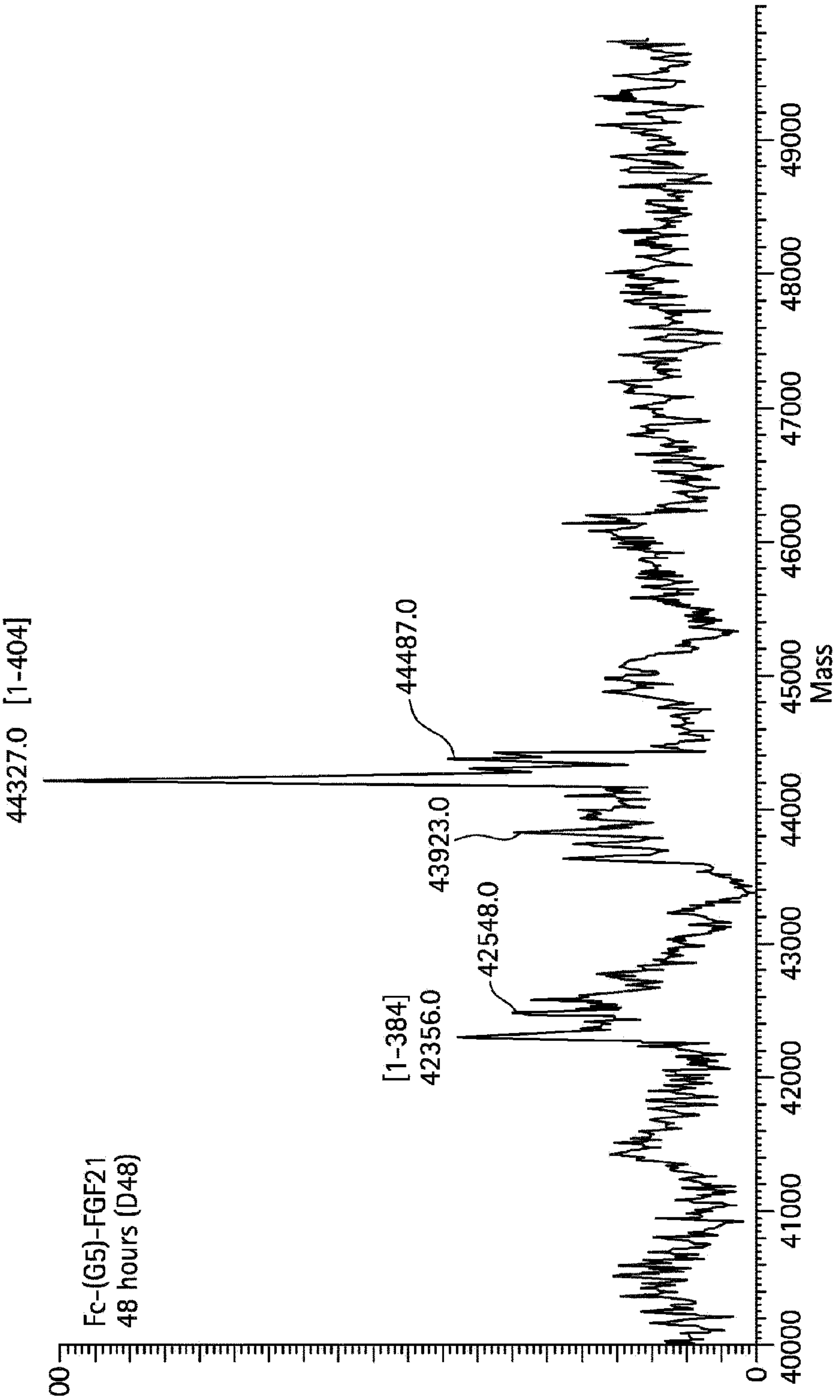

Fc-(G5)-FGF21
48 hours (D48)
44327.0 [1-404]
44487.0
43923.0
42548.0
[1-384]
42356.0
100
0
40000
41000
42000
43000
44000
45000
46000
47000
48000
49000
Mass

FIG. 7A

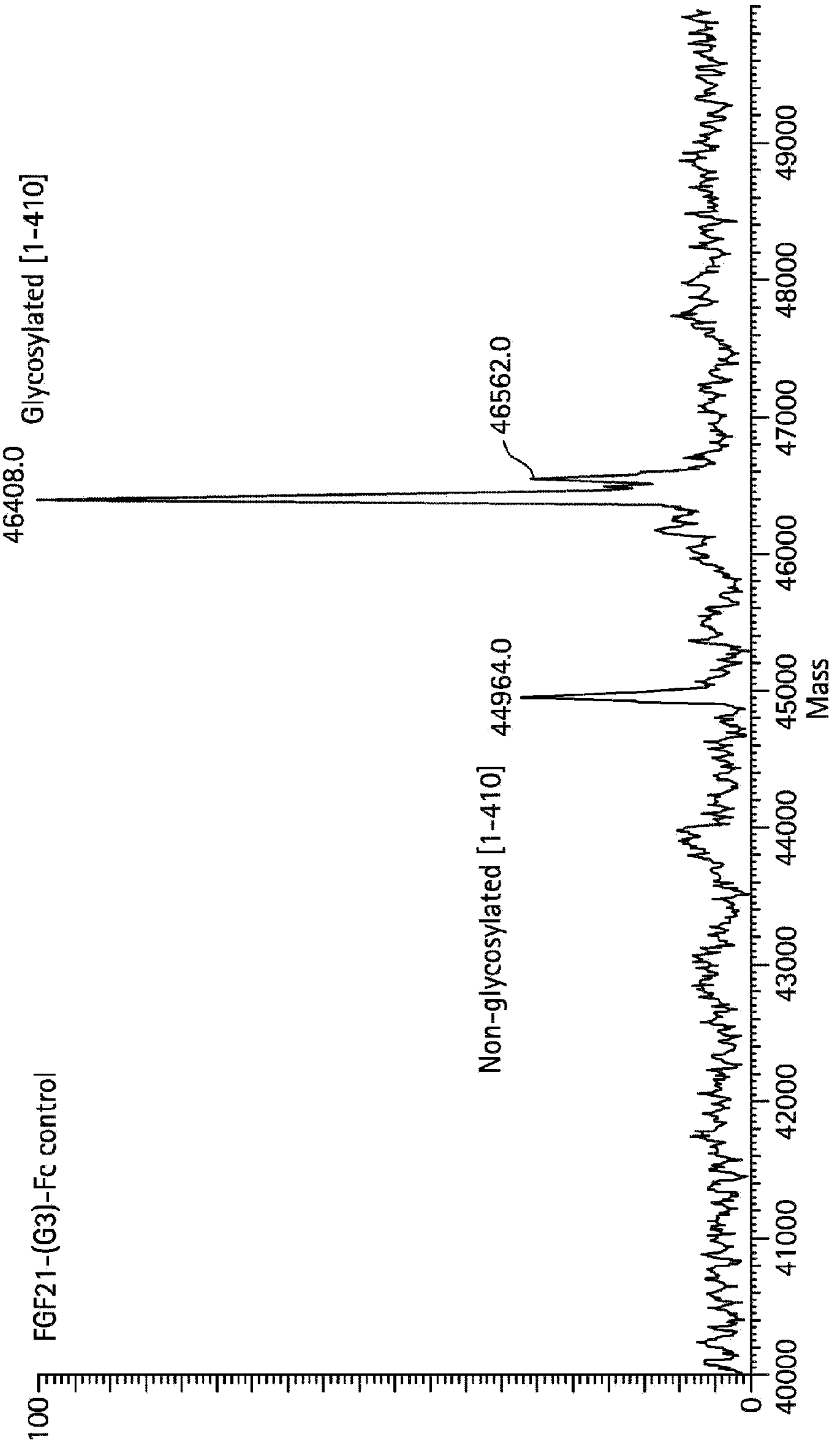

FGF21-(G3)-Fc control
Non-glycosylated [1-410]
44964.0
46408.0
Glycosylated [1-410]
46562.0
100
0
40000
41000
42000
43000
44000
45000
46000
47000
48000
49000
Mass

FIG. 7B

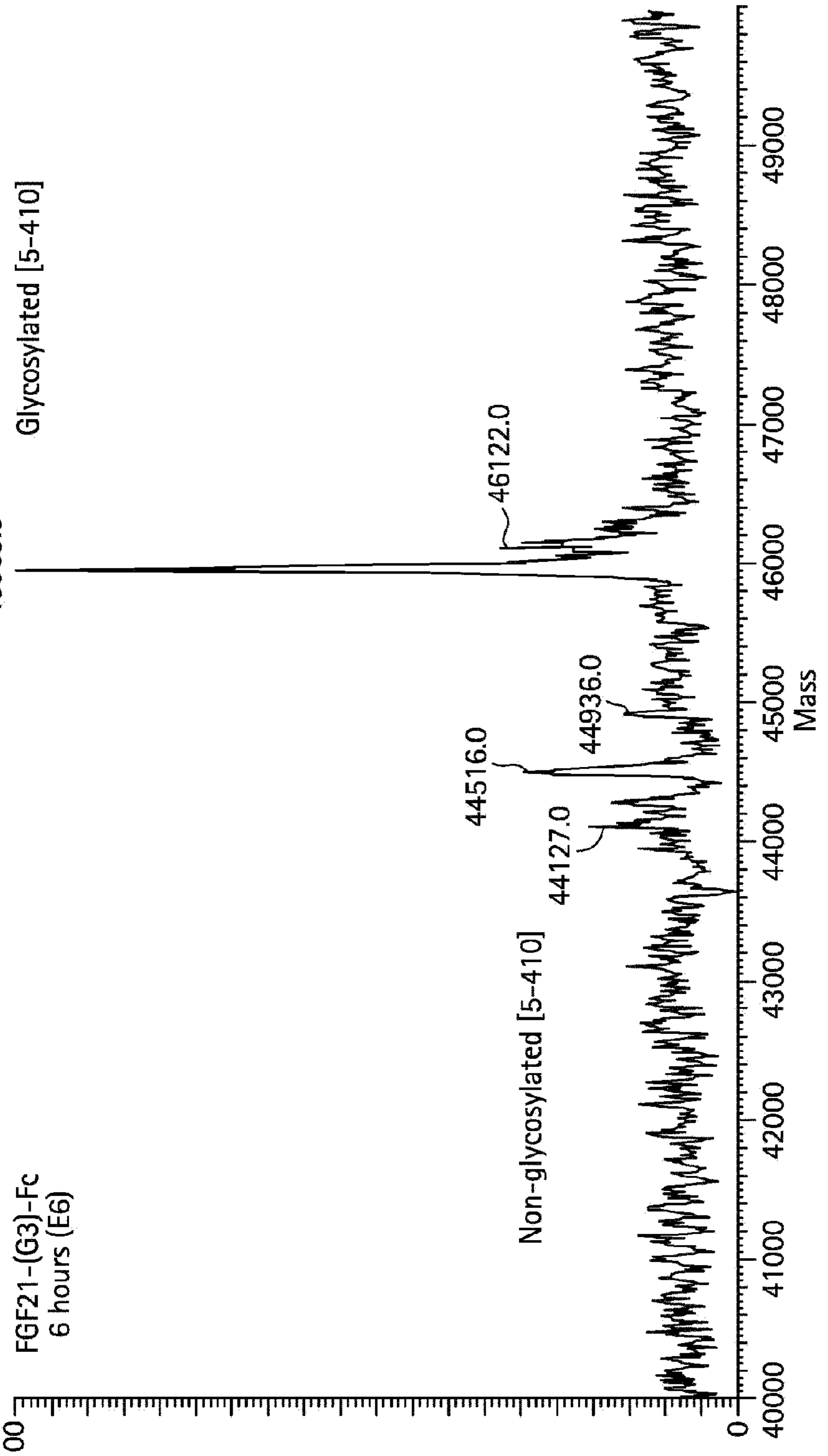

FGF21-(G3)-Fc
6 hours (E6)
Non-glycosylated [5-410]
Glycosylated [5-410]
45963.0
46122.0
44516.0
44936.0
44127.0
100
0
40000
41000
42000
43000
44000
45000
46000
47000
48000
49000
Mass

FIG. 7C

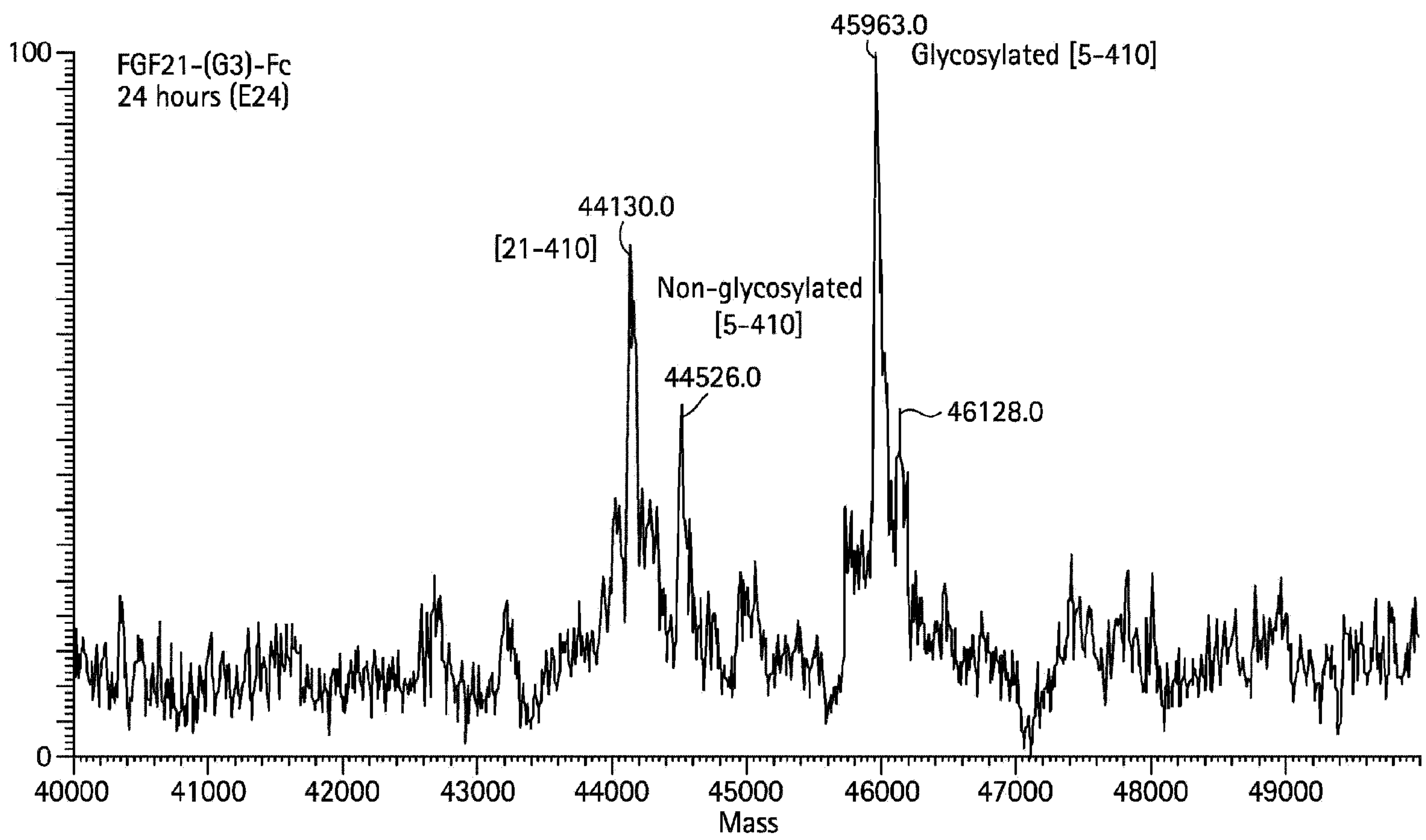

FGF21-(G3)-Fc
24 hours (E24)
100
0
45963.0
Glycosylated [5-410]
44130.0
[21-410]
Non-glycosylated
[5-410]
44526.0
46128.0
40000
41000
42000
43000
44000
45000
46000
47000
48000
49000
Mass

FIG. 7D

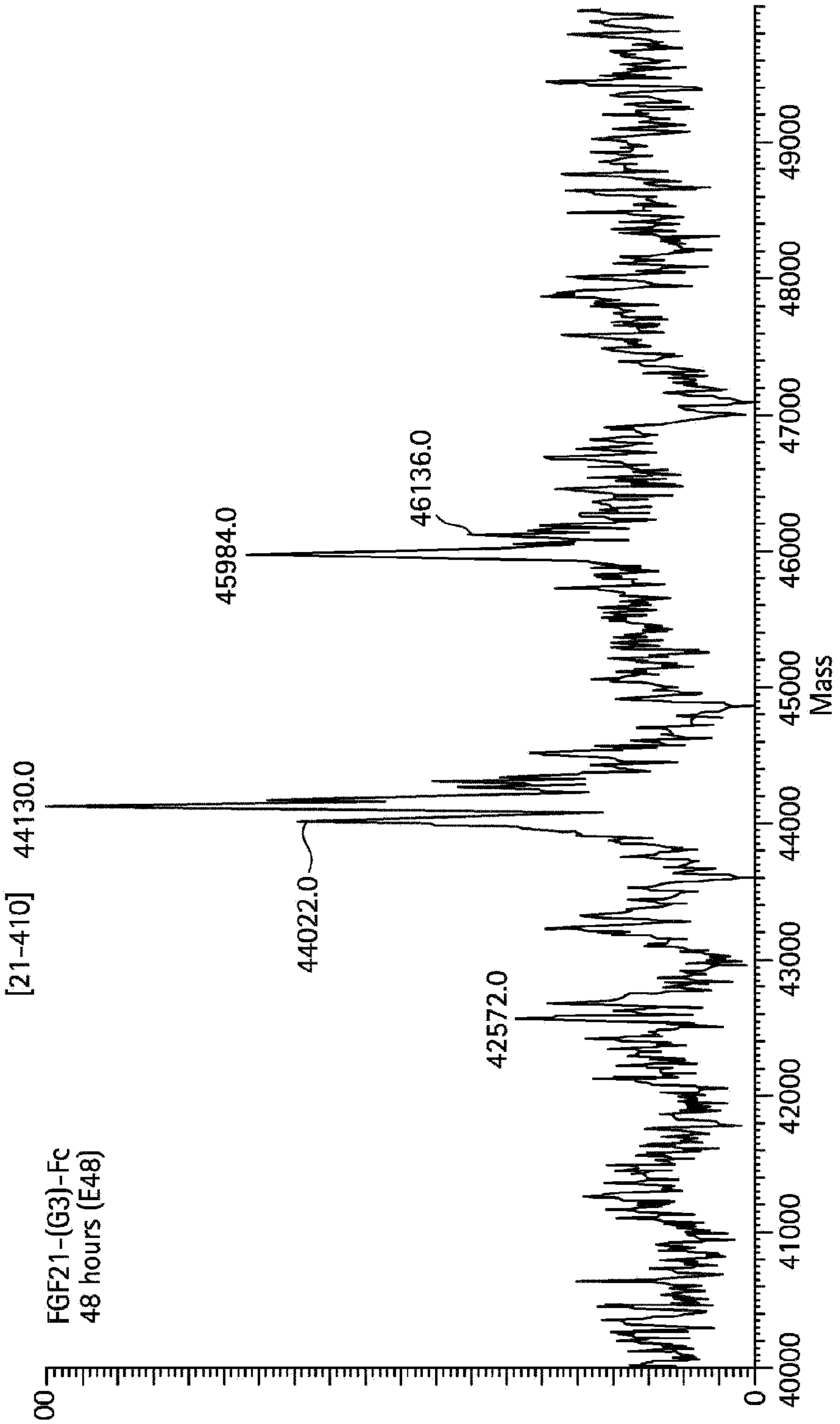

FGF21-(G3)-Fc
48 hours (E48)
[21-410]
44130.0
44022.0
42572.0
45984.0
46136.0
100
0
40000
41000
42000
43000
44000
45000
46000
47000
48000
49000
Mass

FIG. 8A

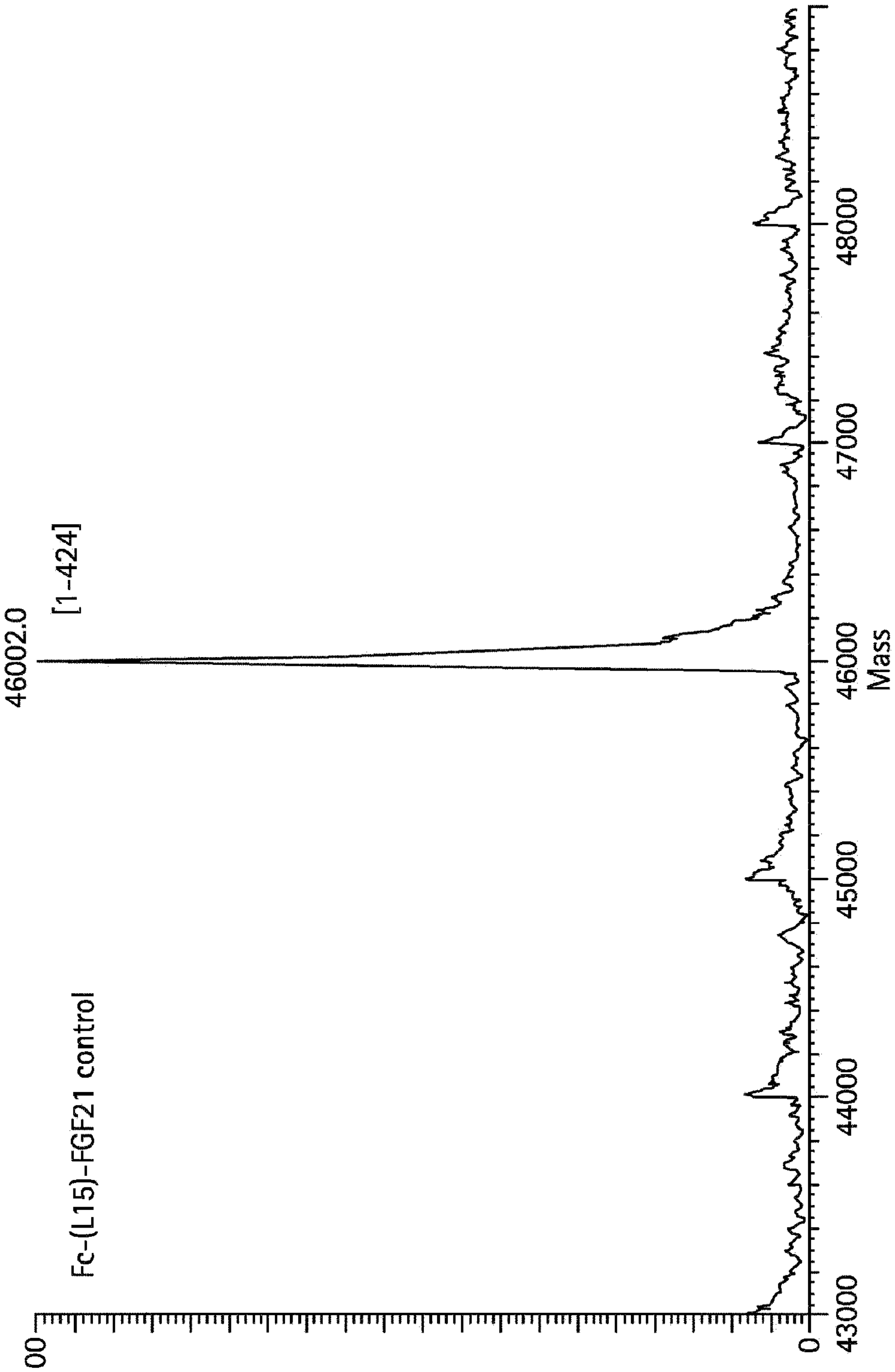

Fc-(L15)-FGF21 control
46002.0
[1-424]
100
0
43000
44000
45000
46000
47000
48000
Mass

FIG. 8B

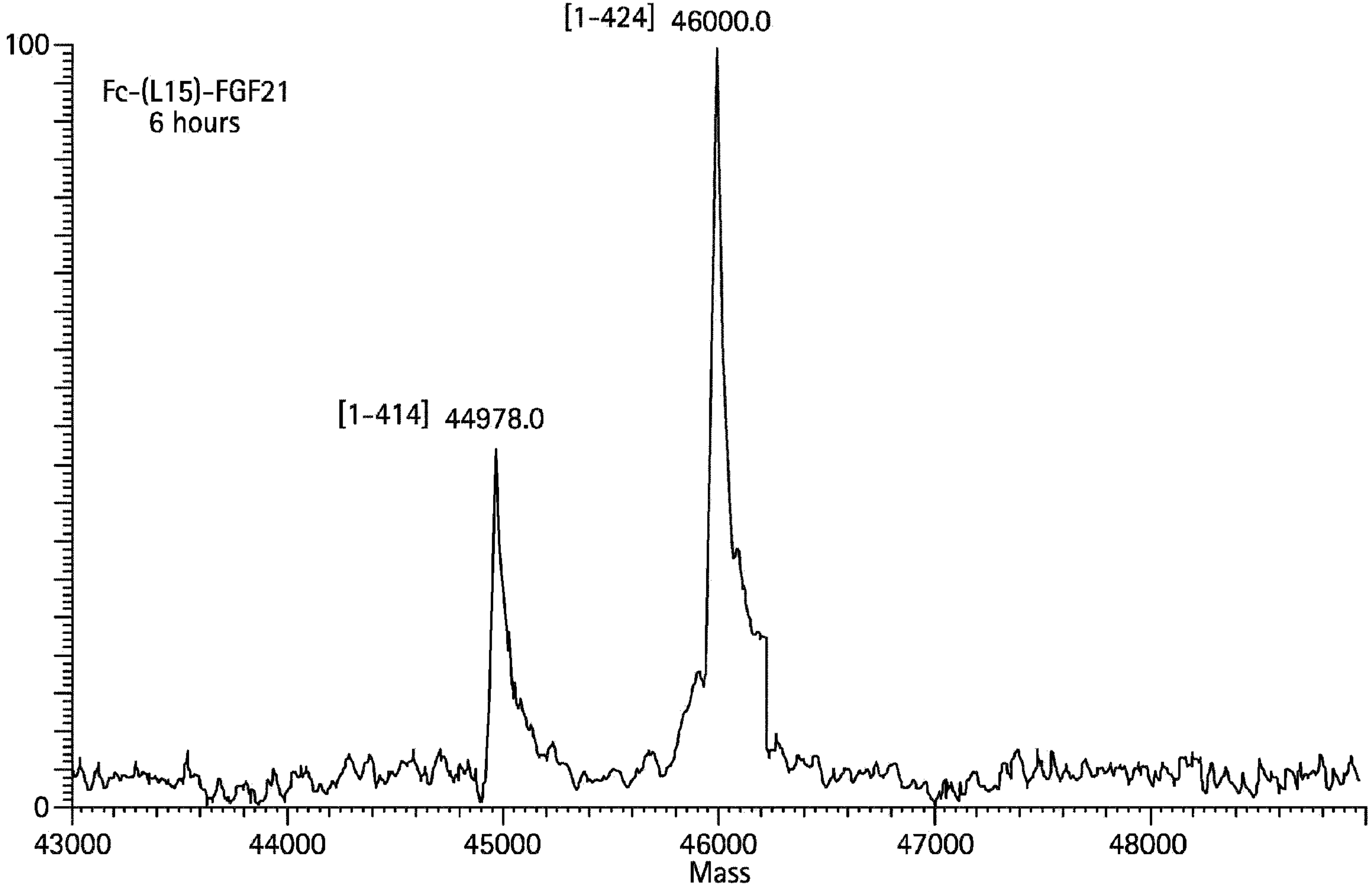

100
0
Fc-(L15)-FGF21
6 hours
[1-414] 44978.0
[1-424] 46000.0
43000
44000
45000
46000
47000
48000
Mass

FIG. 8C

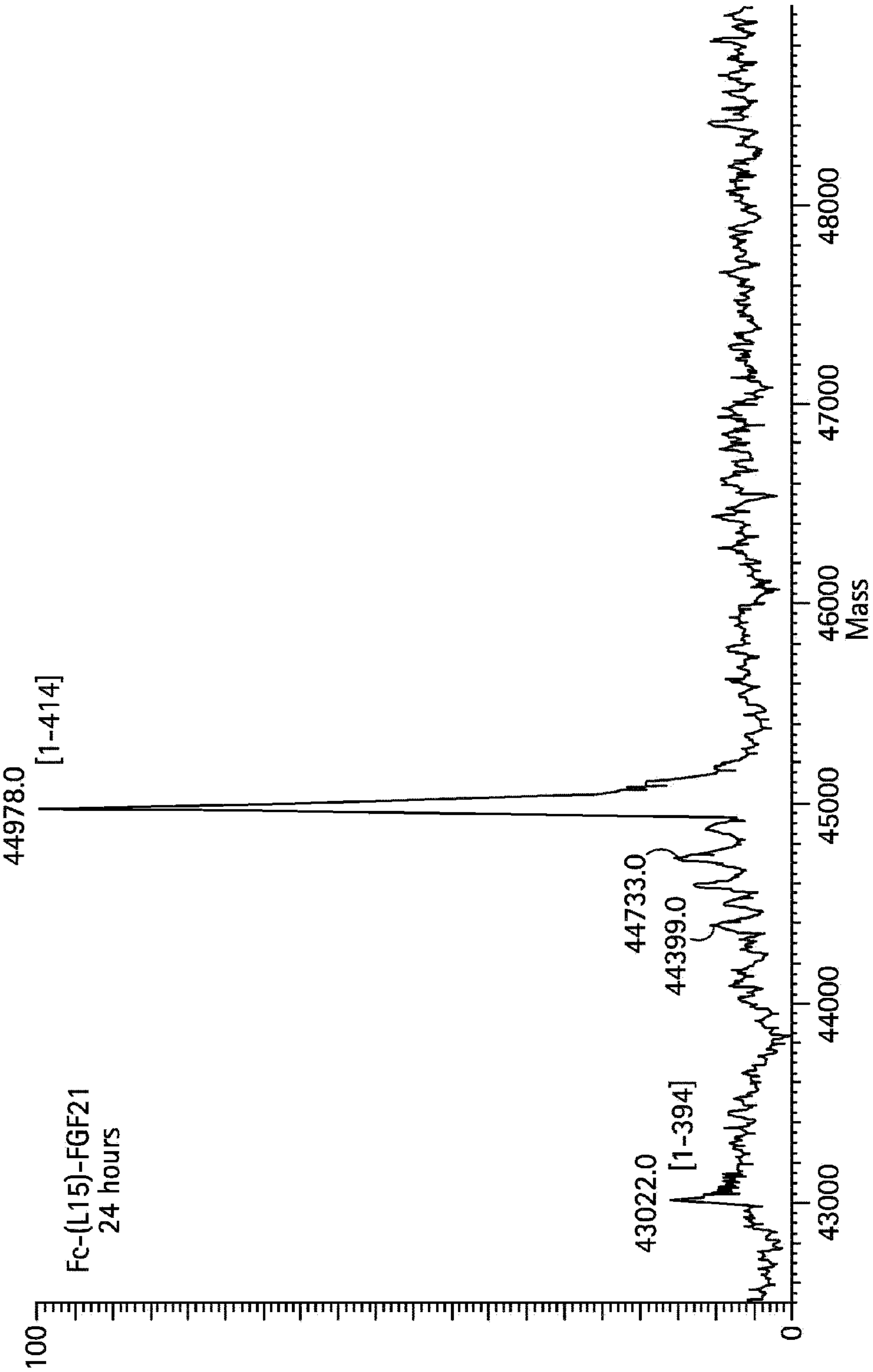

Fc-(L15)-FGF21
24 hours
43022.0
[1-394]
44399.0
44733.0
44978.0
[1-414]
100
0
43000
44000
45000
46000
47000
48000
Mass

FIG. 8D

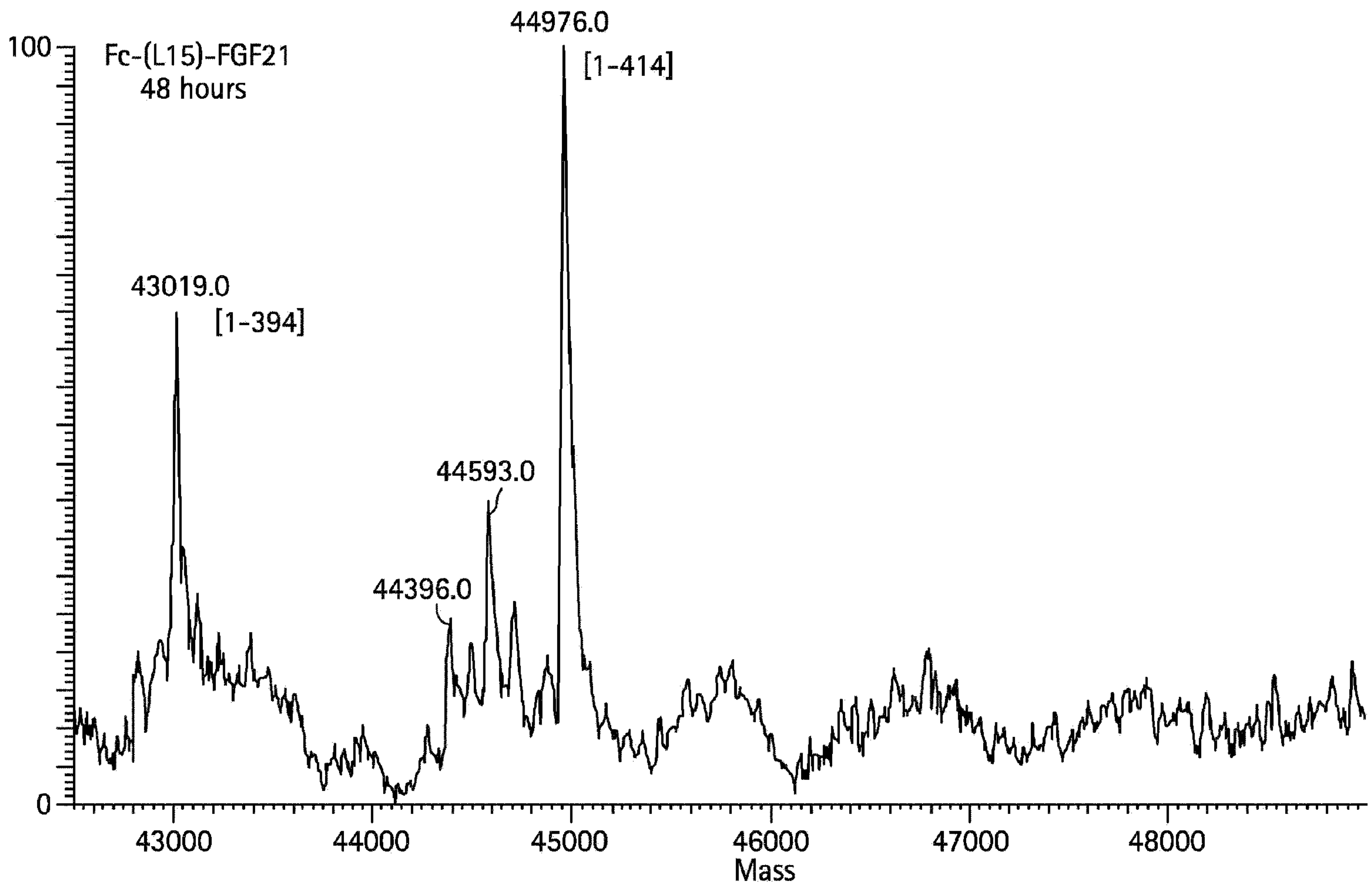

Fc-(L15)-FGF21
48 hours
100
0
43019.0
[1-394]
44396.0
44593.0
44976.0
[1-414]
43000
44000
45000
46000
47000
48000
Mass

FIG. 9A

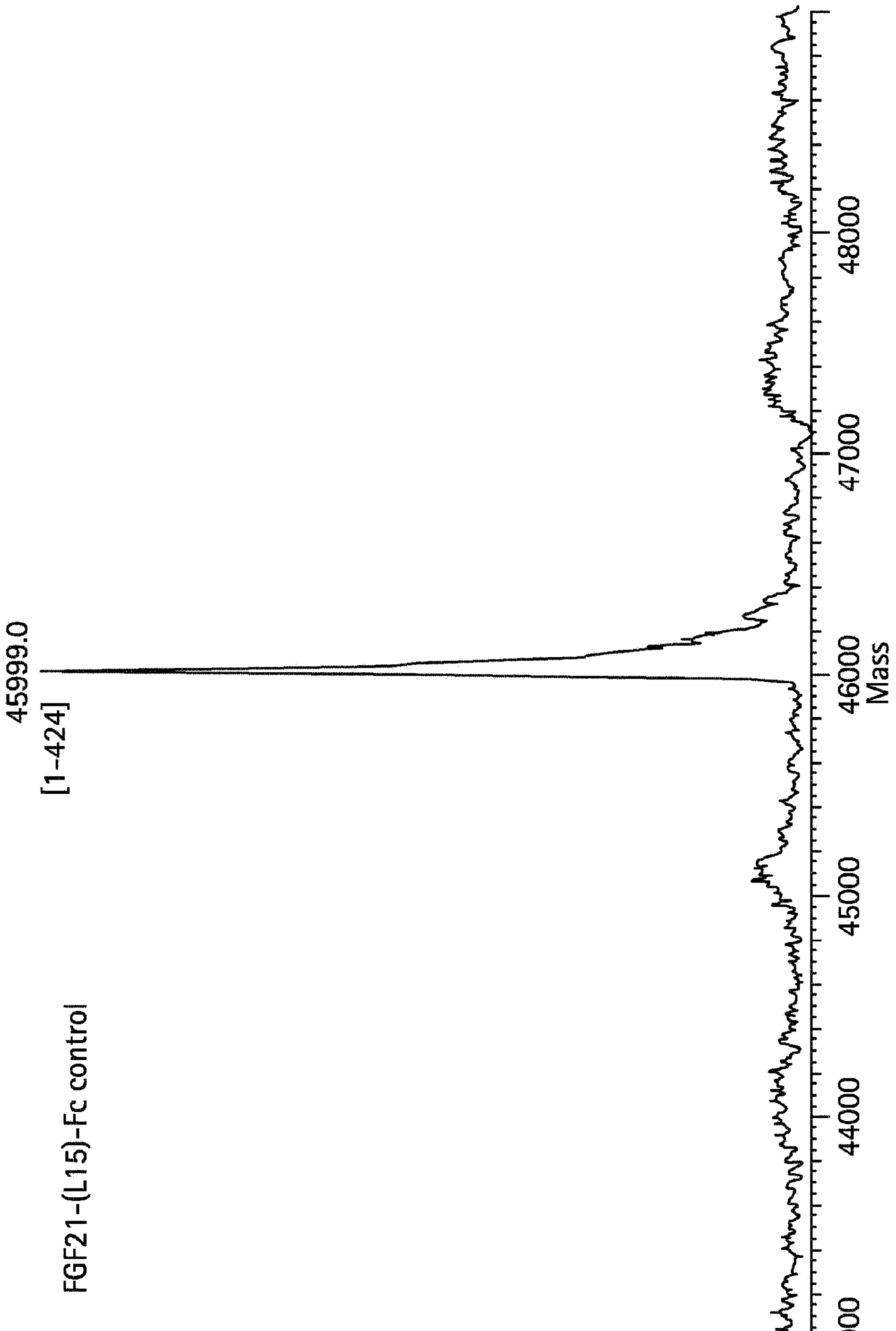

45999.0
[1-424]
FGF21-(L15)-Fc control
100
0
43000
44000
45000
46000
47000
48000
Mass

FIG. 9B

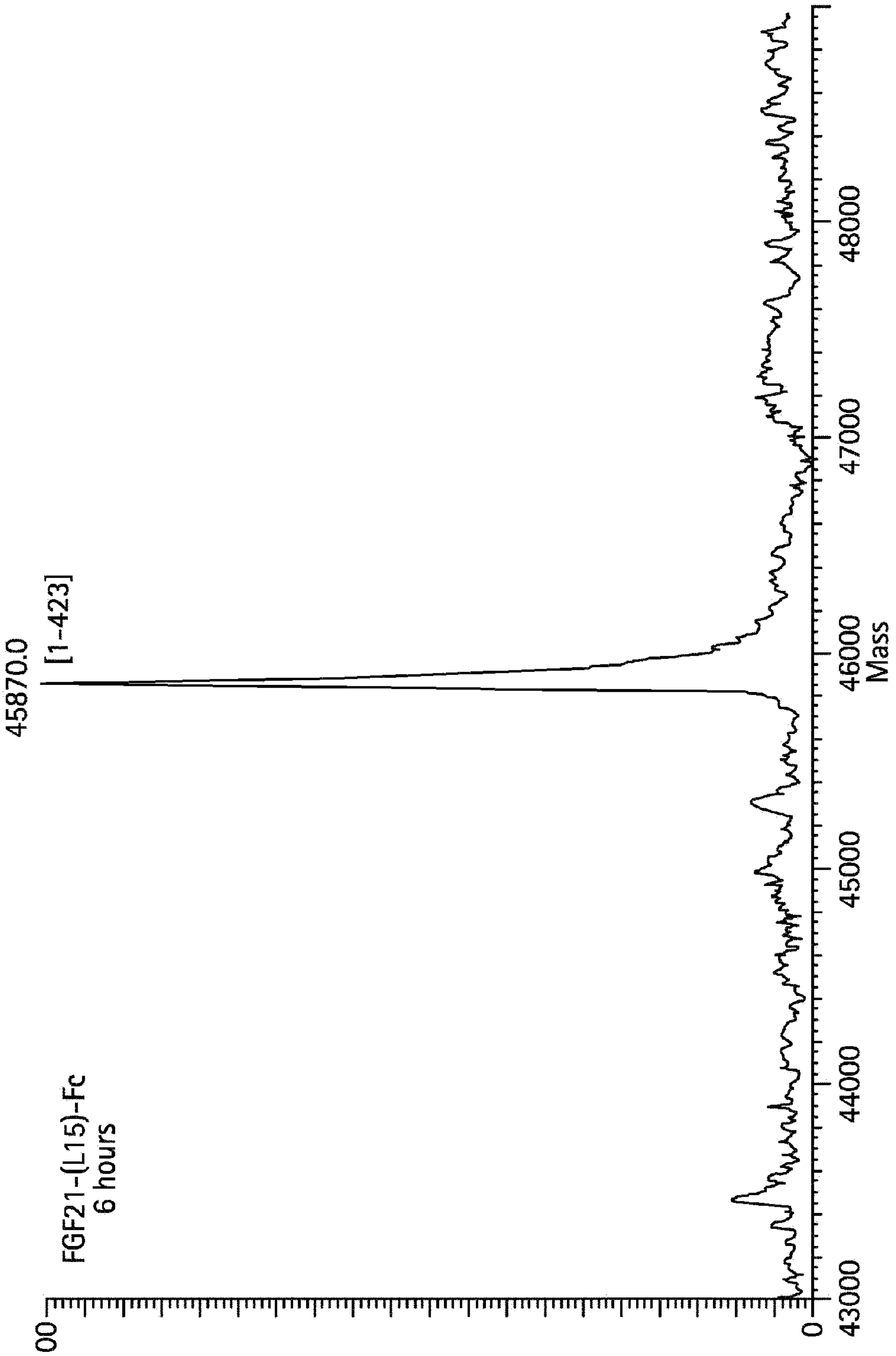

45870.0
[1-423]
FGF21-(L15)-Fc
6 hours
100
0
43000
44000
45000
46000
47000
48000
Mass

FIG. 9C

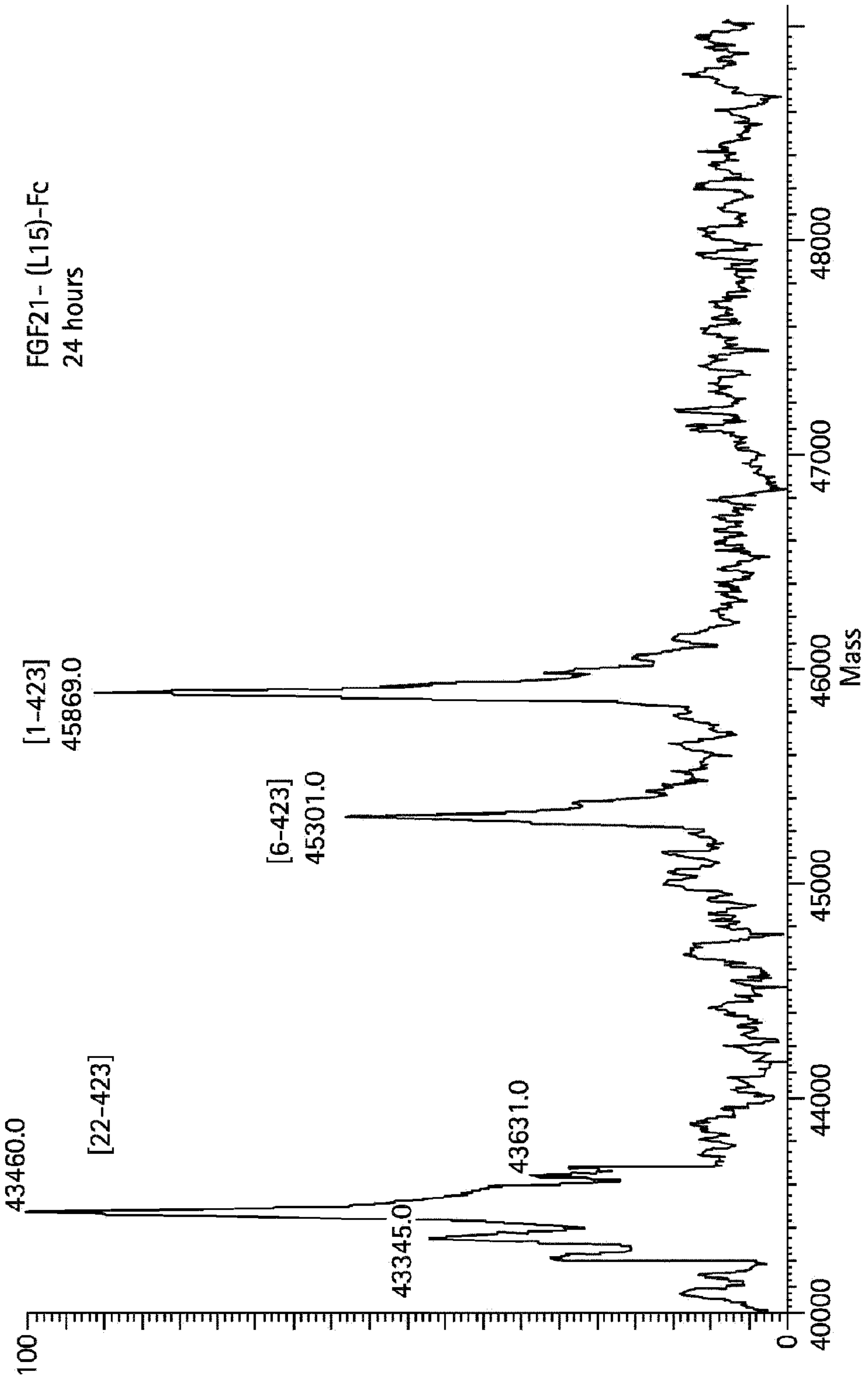
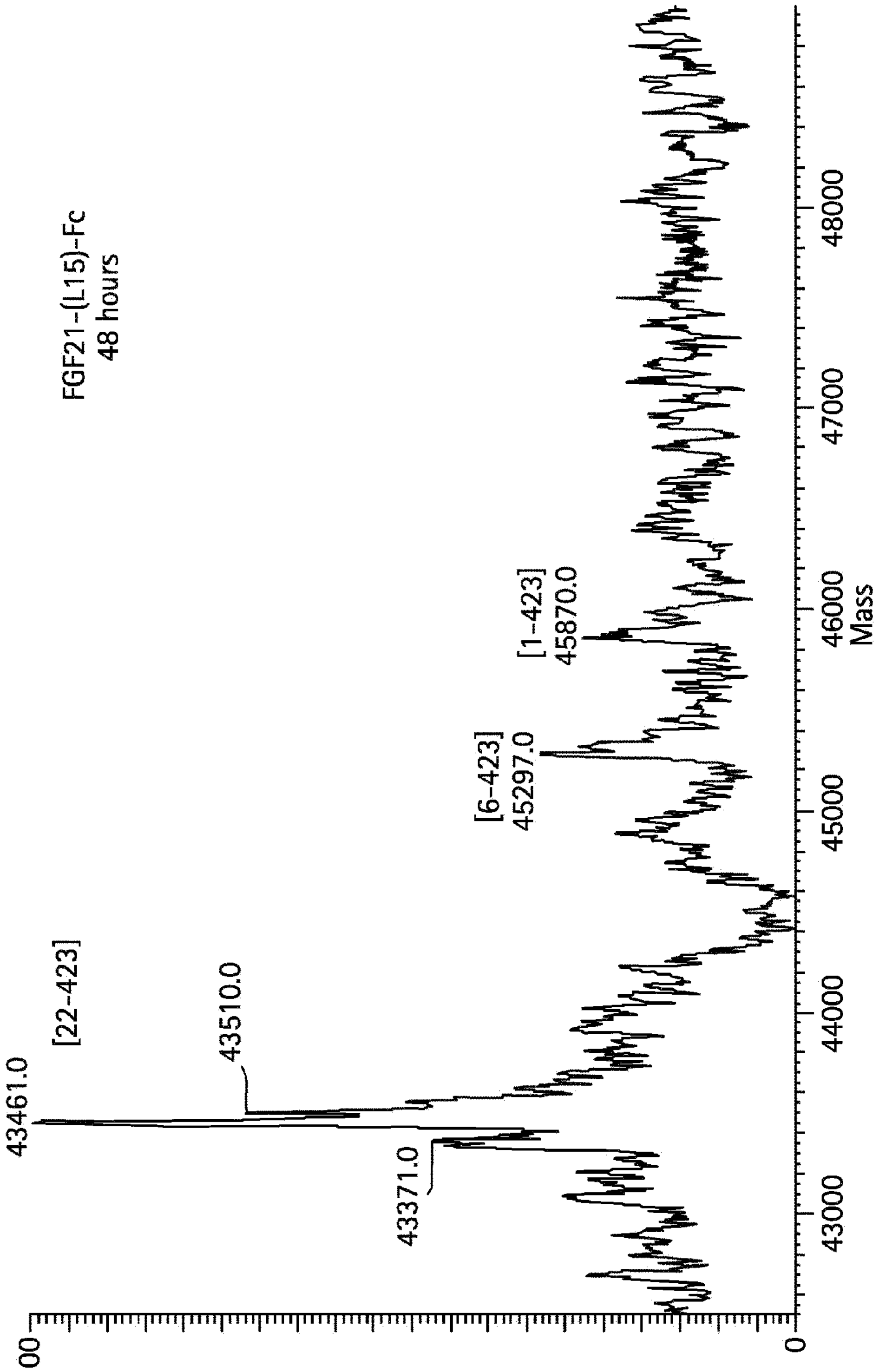

FGF21- (L15)-Fc
24 hours
[1-423]
45869.0
[6-423]
45301.0
[22-423]
43460.0
43631.0
43345.0
100
0
40000
44000
45000
46000
47000
48000
Mass

FIG. 9D



FGF21-(L15)-Fc
48 hours
43461.0
[22-423]
43510.0
43371.0
[6-423]
45297.0
[1-423]
45870.0
100
0
43000
44000
45000
46000
47000
48000
Mass

FIG. 10A

Fc-(L15)-FGF21

MDKTHTCPPCPAPELLGGPSVFLFPPKPKDTLMISRTPEVTCVVVDVSHEDPEVKFNWYVDGVEVHNAKTKPREEQYNST
YRVVSVLTVLHQDWLNGKEYKCKVSNKALPAPIEKTISKAKGQPREPQVYTLPPSRDELTKNQVSLTCLVKGFYPSDIAV
EWESNGQPENNYKTTPPVLDSDGSFFLYSKLTVDKSRWQQGNVFSCSVMHEALHNHYTQKSLSLSPGK*GGGGGSGGGSGG*
*GGS*HPIPDSSPLLQFGGQVRQRYLYTDDAQQTEAHLEIREDGTVGGAADQSPESLLQLKALKPGVIQILGVKTSRFLCQR
PDGALYGSLHFDPEACSFRELLLEDGYNVYQSEAHGLPLHLPGNKSPHRDPAPRGPARFLPLPGLPPAPPEPPGILAPQP
PDVGSSDPLSMVGPSQGRSPSYAS

6 hrs (35%)
24 hrs (85%) [1-414]
48 hrs (60%)

24 hrs (15%)
48 hrs (40%) [1-394]

FIG. 10B

Fc-(L15)-FGF21

24 hrs (35%) 48 hrs (20%) [6-423]

24 hrs (25%) 48 hrs (65%) [22-423]

MHPIPDSSPLLQFGGQVRQRYLYTDDAQQTEAHLEIREDGTVGGAADQSPESLLQLKALKPGVIQILGVKTSRFLCQRPD
GALYGSLHFDPEACSFRELLLEDGYNVYQSEAHGLPLHLPGNKSPHRDPAPRGPARFLPLPGLPPAPPEPPGILAPQPPD
VGSSDPLSMVGPSQGRSPSYAS*GGGGGSGGGSGGGGS*DKTHTCPPCPAPELLGGPSVFLFPPKPKDTLMISRTPEVTCVV
VDVSHEDPEVKFNWYVDGVEVHNAKTKPREEQYNSTYRVVSVLTVLHQDWLNGKEYKCKVSNKALPAPIEKTISKAKGQP
REPQVYTLPPSRDELTKNQVSLTCLVKGFYPSDIAVEWESNGQPENNYKTTPPVLDSDGSFFLYSKLTVDKSRWQQGNVF
SCSVMHEALHNHYTQKSLSLSPGK

6 hrs (100%) [1-423]

FIG. 11

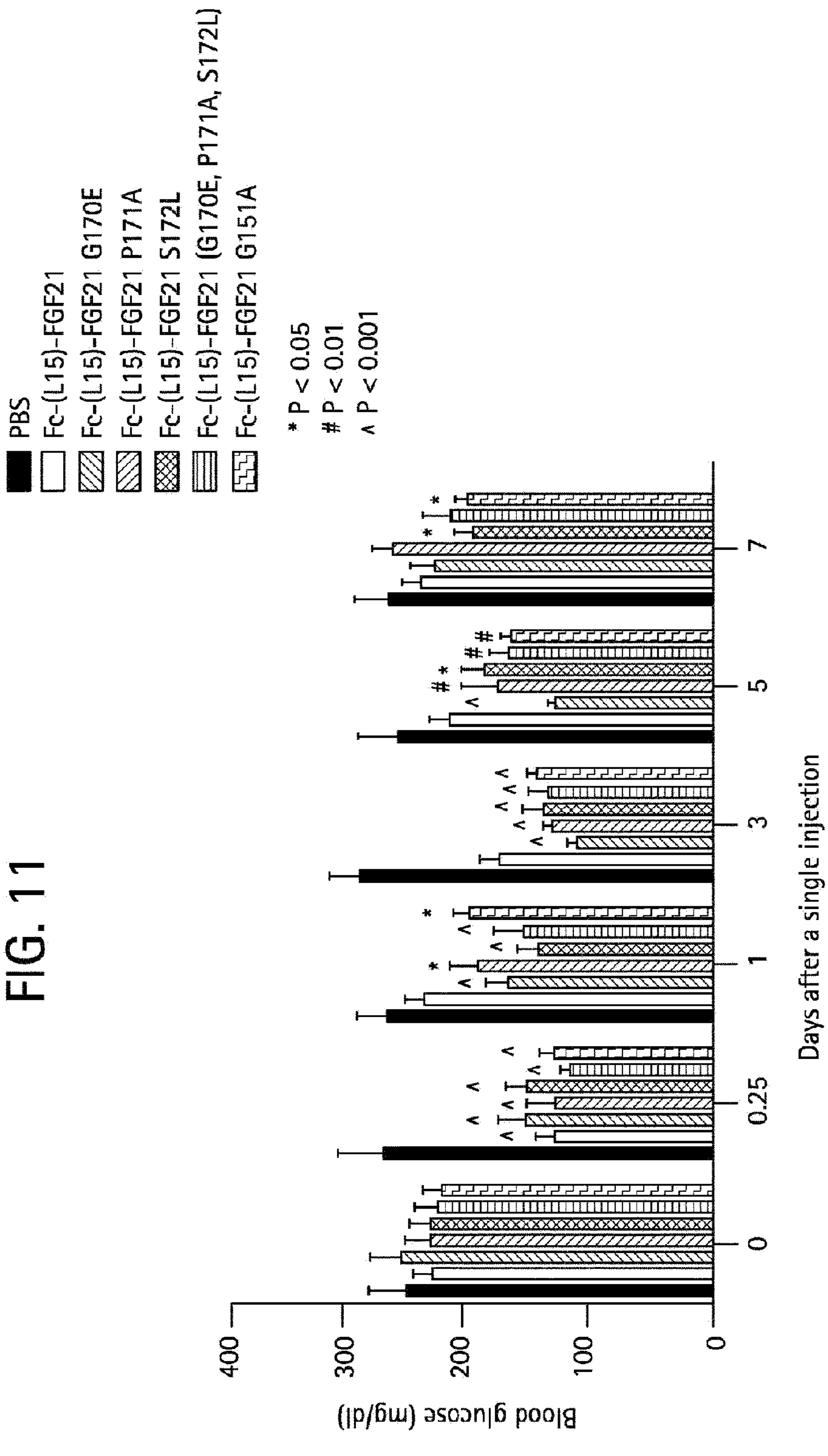

PBS
Fc-(L15)-FGF21
Fc-(L15)-FGF21 G170E
Fc-(L15)-FGF21 P171A
Fc-(L15)-FGF21 S172L
Fc-(L15)-FGF21 (G170E, P171A, S172L)
Fc-(L15)-FGF21 G151A
* P < 0.05
# P < 0.01
^ P < 0.001
Blood glucose (mg/dl)
0
100
200
300
400
0
0.25
1
3
5
7
Days after a single injection

FIG. 12

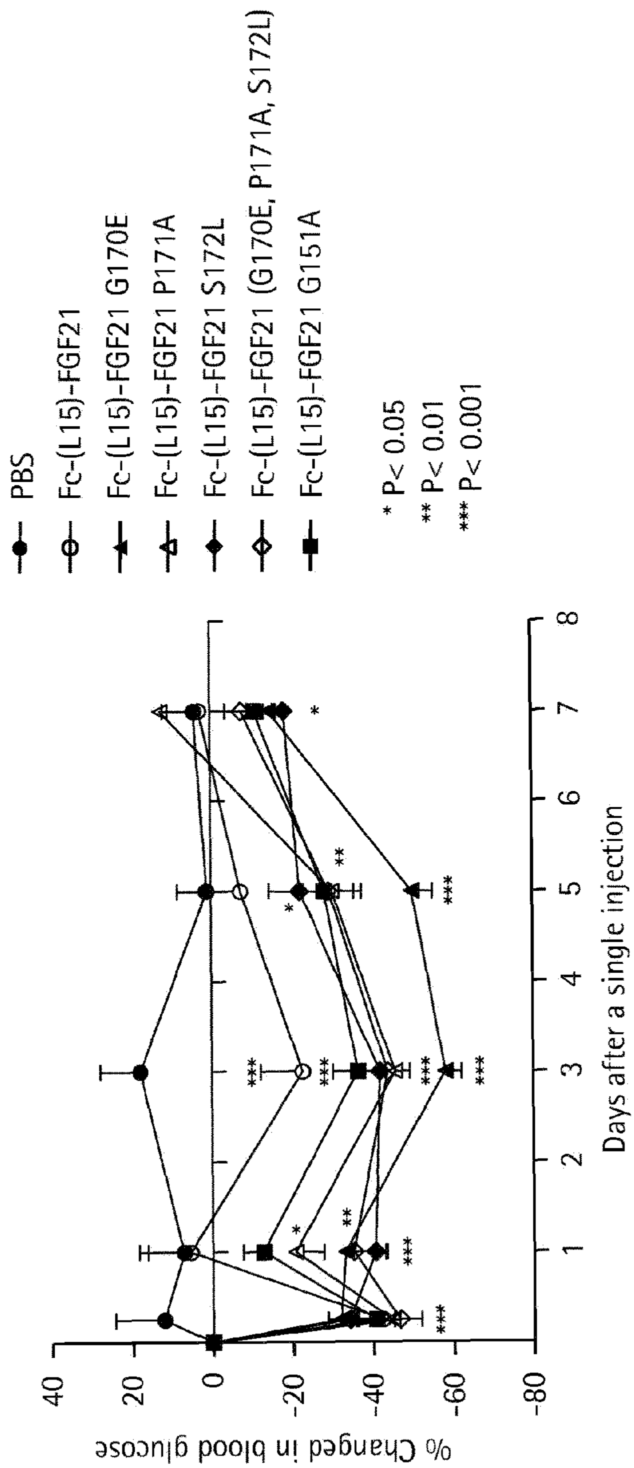
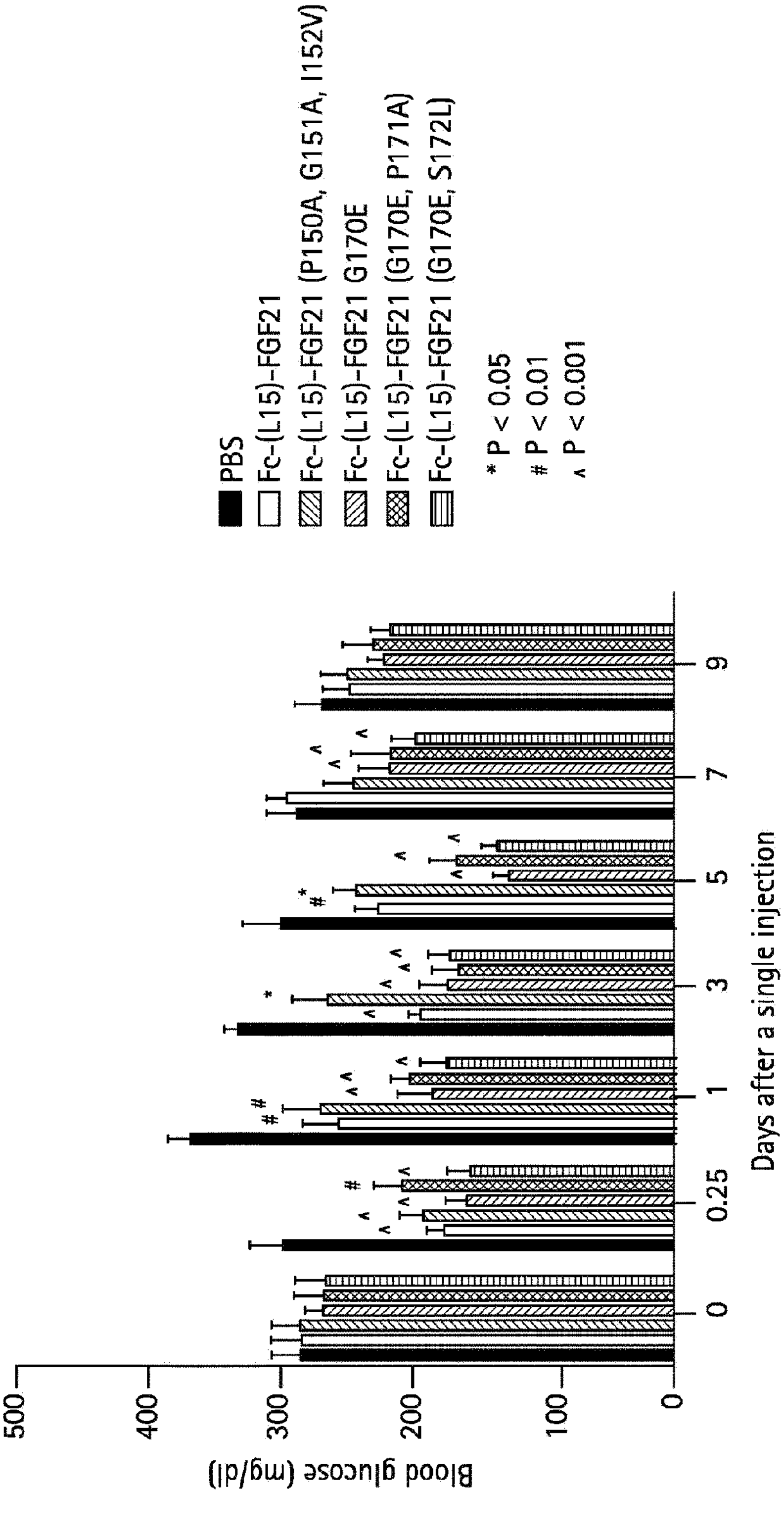

PBS
Fc-(L15)-FGF21
Fc-(L15)-FGF21 G170E
Fc-(L15)-FGF21 P171A
Fc-(L15)-FGF21 S172L
Fc-(L15)-FGF21 (G170E, P171A, S172L)
Fc-(L15)-FGF21 G151A
* P< 0.05
** P< 0.01
*** P< 0.001
% Changed in blood glucose
Days after a single injection
40
20
0
-20
-40
-60
-80
1
2
3
4
5
6
7
8

FIG. 13


Blood glucose (mg/dl)
Days after a single injection
PBS
Fc-(L15)-FGF21
Fc-(L15)-FGF21 (P150A, G151A, I152V)
Fc-(L15)-FGF21 G170E
Fc-(L15)-FGF21 (G170E, P171A)
Fc-(L15)-FGF21 (G170E, S172L)
* P < 0.05
# P < 0.01
^ P < 0.001

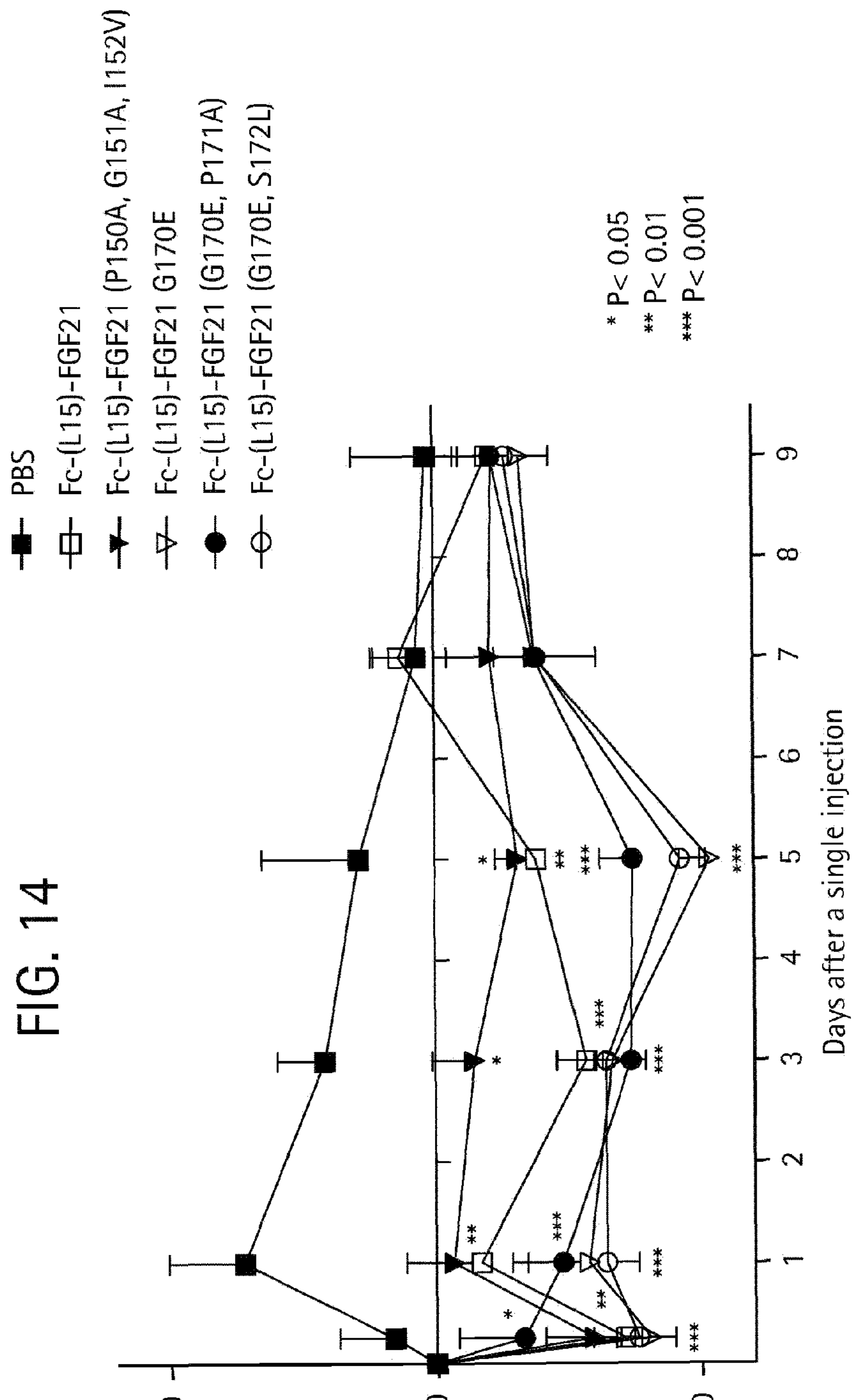

PBS
Fc-(L15)-FGF21
Fc-(L15)-FGF21 (P150A, G151A, I152V)
Fc-(L15)-FGF21 G170E
Fc-(L15)-FGF21 (G170E, P171A)
Fc-(L15)-FGF21 (G170E, S172L)
* P< 0.05
** P< 0.01
*** P< 0.001
% Change in blood glucose
50
0
-50
1
2
3
4
5
6
7
8
9
Days after a single injection

FIG. 14

FIG. 15

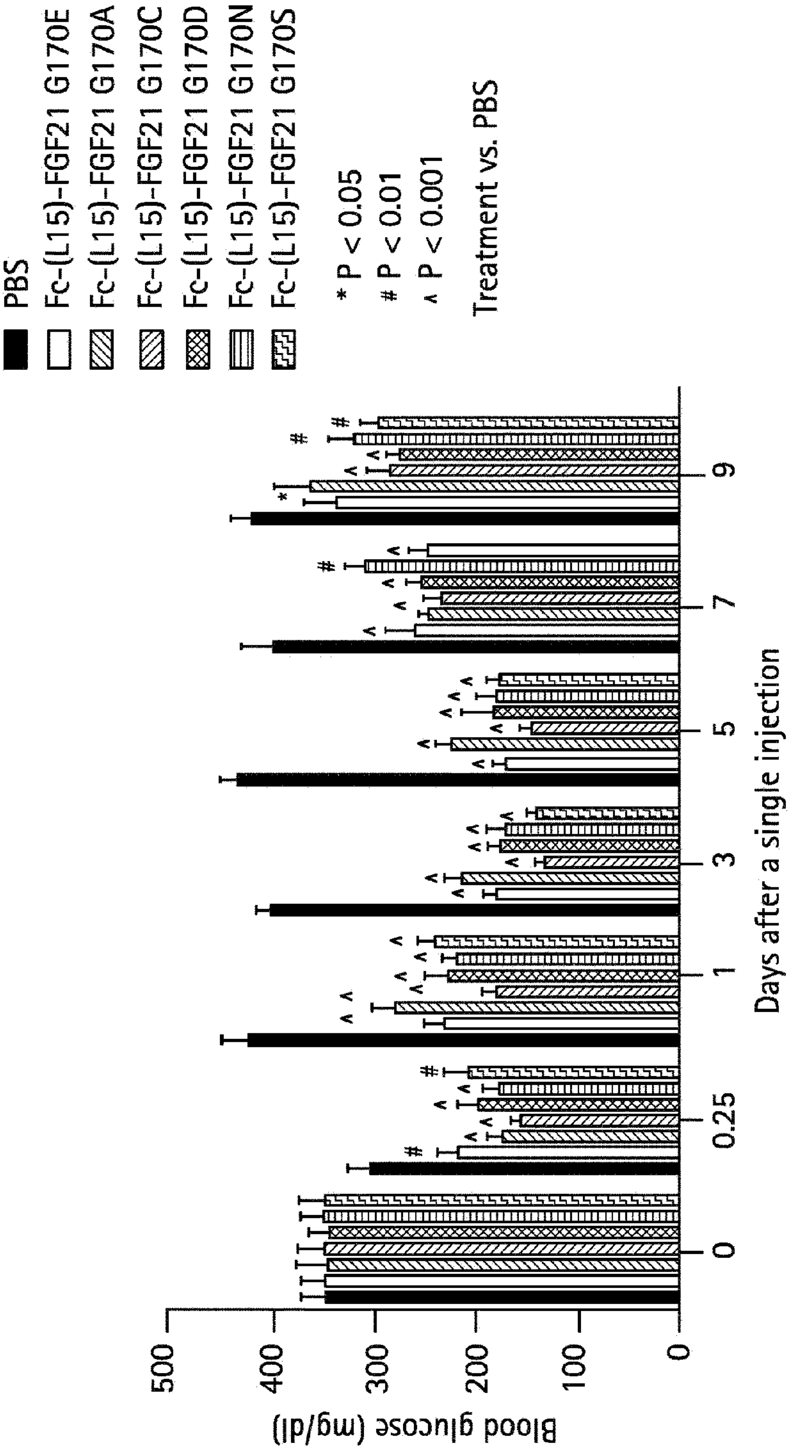

PBS
Fc-(L15)-FGF21 G170E
Fc-(L15)-FGF21 G170A
Fc-(L15)-FGF21 G170C
Fc-(L15)-FGF21 G170D
Fc-(L15)-FGF21 G170N
Fc-(L15)-FGF21 G170S
* P < 0.05
# P < 0.01
∧ P < 0.001
Treatment vs. PBS
Blood glucose (mg/dl)
0
100
200
300
400
500
0
0.25
1
3
5
7
9
Days after a single injection

FIG. 16

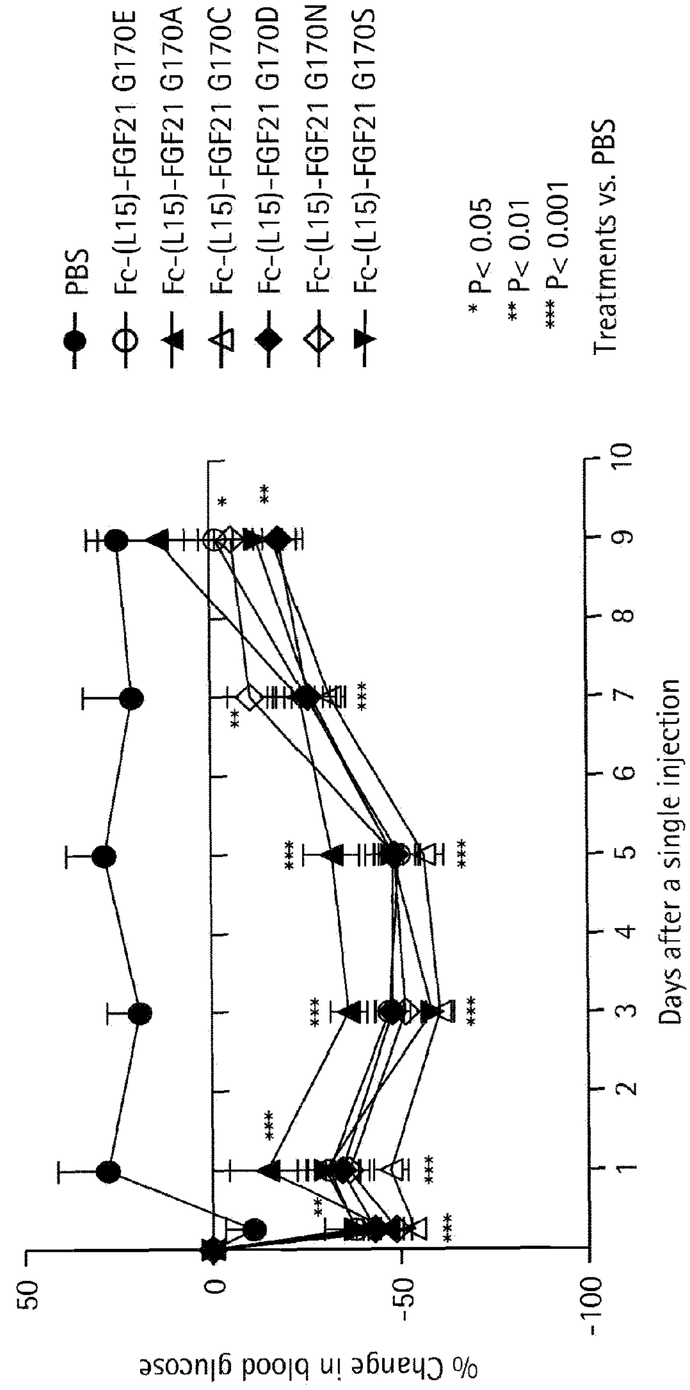

PBS
Fc-(L15)-FGF21 G170E
Fc-(L15)-FGF21 G170A
Fc-(L15)-FGF21 G170C
Fc-(L15)-FGF21 G170D
Fc-(L15)-FGF21 G170N
Fc-(L15)-FGF21 G170S
* P< 0.05
** P< 0.01
*** P< 0.001
Treatments vs. PBS
% Change in blood glucose
Days after a single injection
50
0
-50
-100
1
2
3
4
5
6
7
8
9
10

FIG. 17

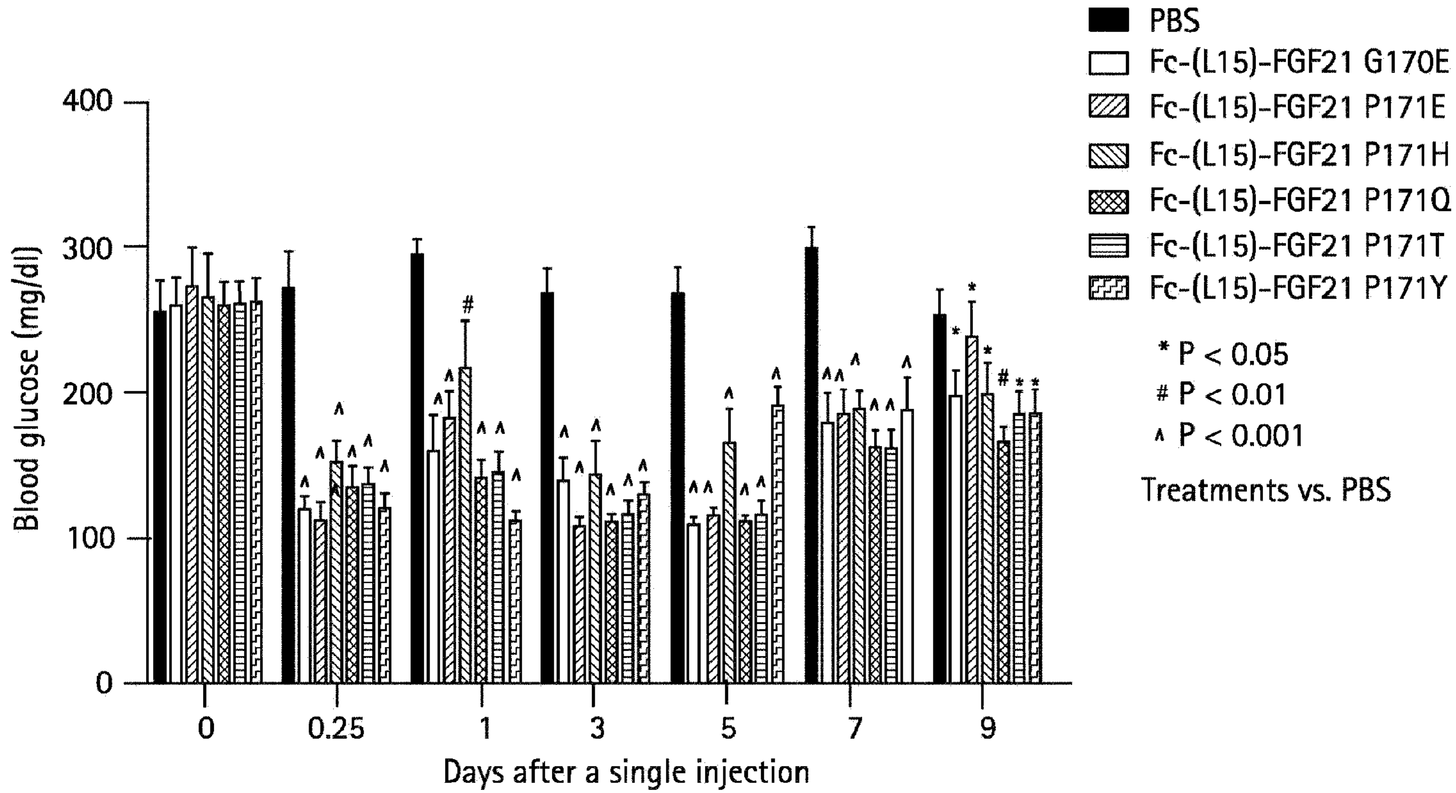

Blood glucose (mg/dl)
400
300
200
100
0
0
0.25
1
3
5
7
9
Days after a single injection
PBS
Fc-(L15)-FGF21 G170E
Fc-(L15)-FGF21 P171E
Fc-(L15)-FGF21 P171H
Fc-(L15)-FGF21 P171Q
Fc-(L15)-FGF21 P171T
Fc-(L15)-FGF21 P171Y
* P < 0.05
# P < 0.01
∧ P < 0.001
Treatments vs. PBS

FIG. 18

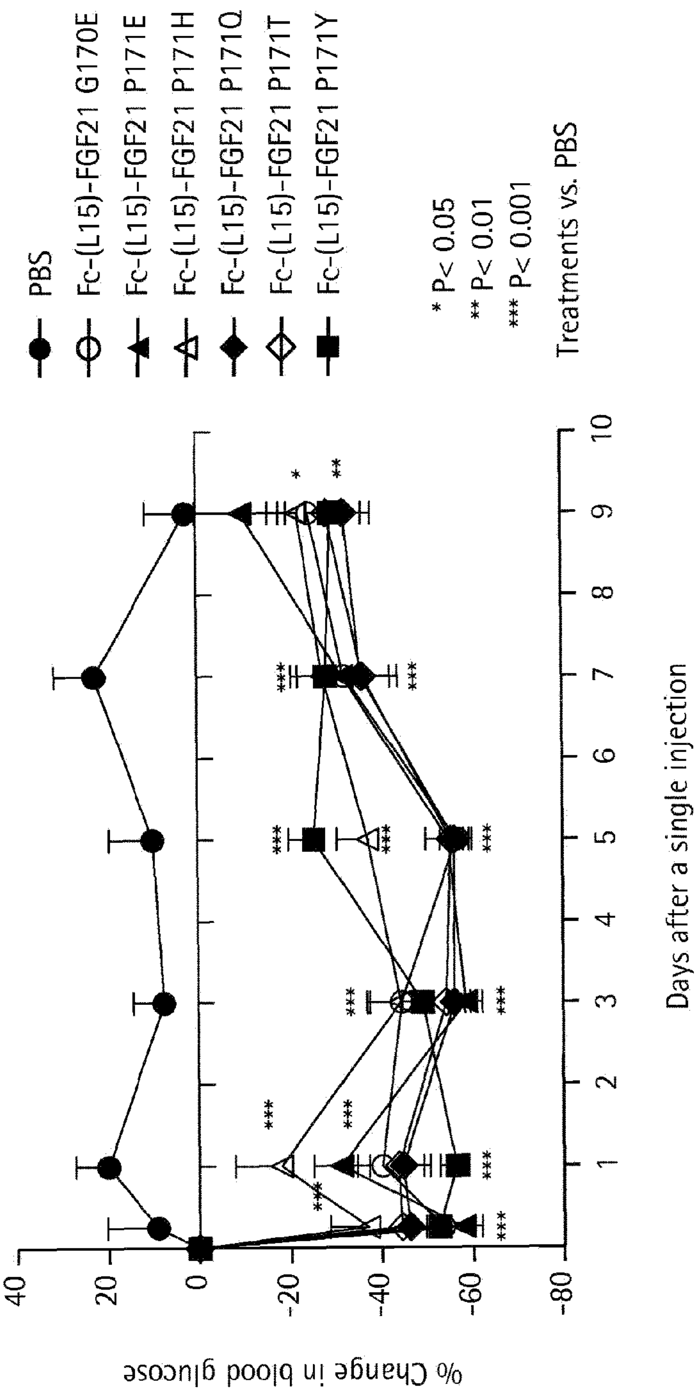

PBS
Fc-(L15)-FGF21 G170E
Fc-(L15)-FGF21 P171E
Fc-(L15)-FGF21 P171H
Fc-(L15)-FGF21 P171Q
Fc-(L15)-FGF21 P171T
Fc-(L15)-FGF21 P171Y
* P< 0.05
** P< 0.01
*** P< 0.001
Treatments vs. PBS
% Change in blood glucose
Days after a single injection
40
20
0
-20
-40
-60
-80
1
2
3
4
5
6
7
8
9
10

FIG. 19A

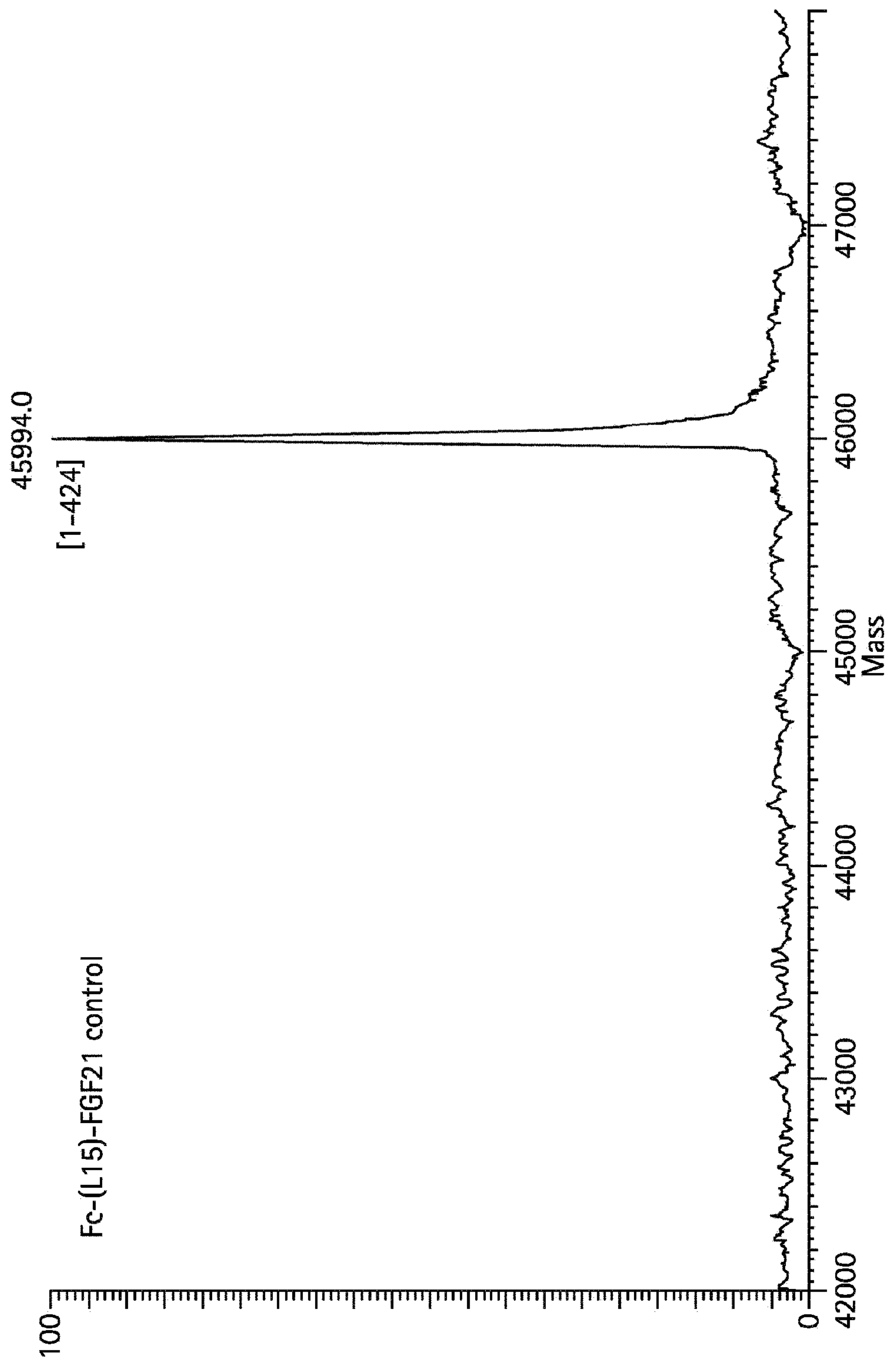

45994.0
[1-424]
Fc-(L15)-FGF21 control
100
0
42000
43000
44000
45000
46000
47000
Mass

FIG. 19B

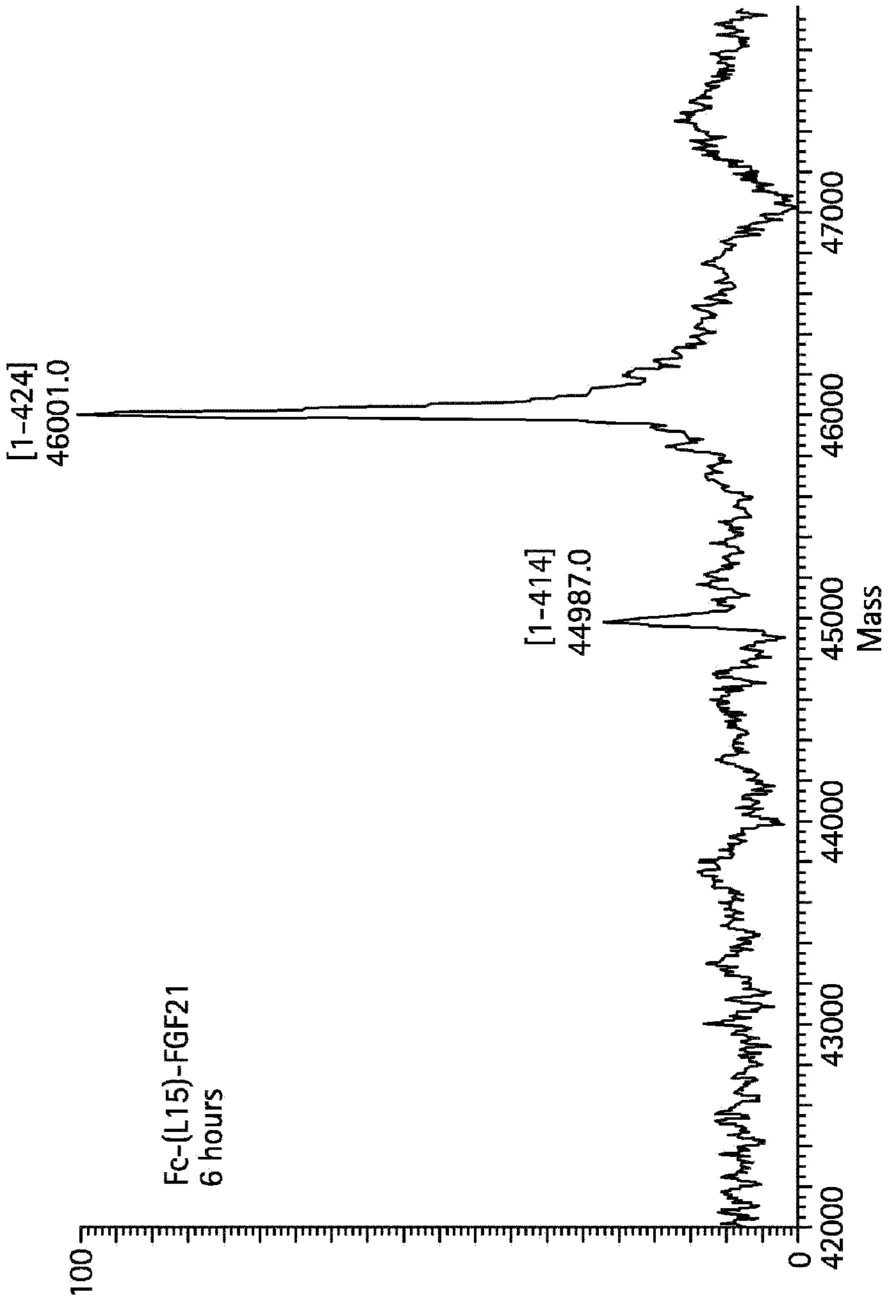

Fc-(L15)-FGF21
6 hours
[1-414]
44987.0
[1-424]
46001.0
100
0
42000
43000
44000
45000
46000
47000
Mass

FIG. 19C

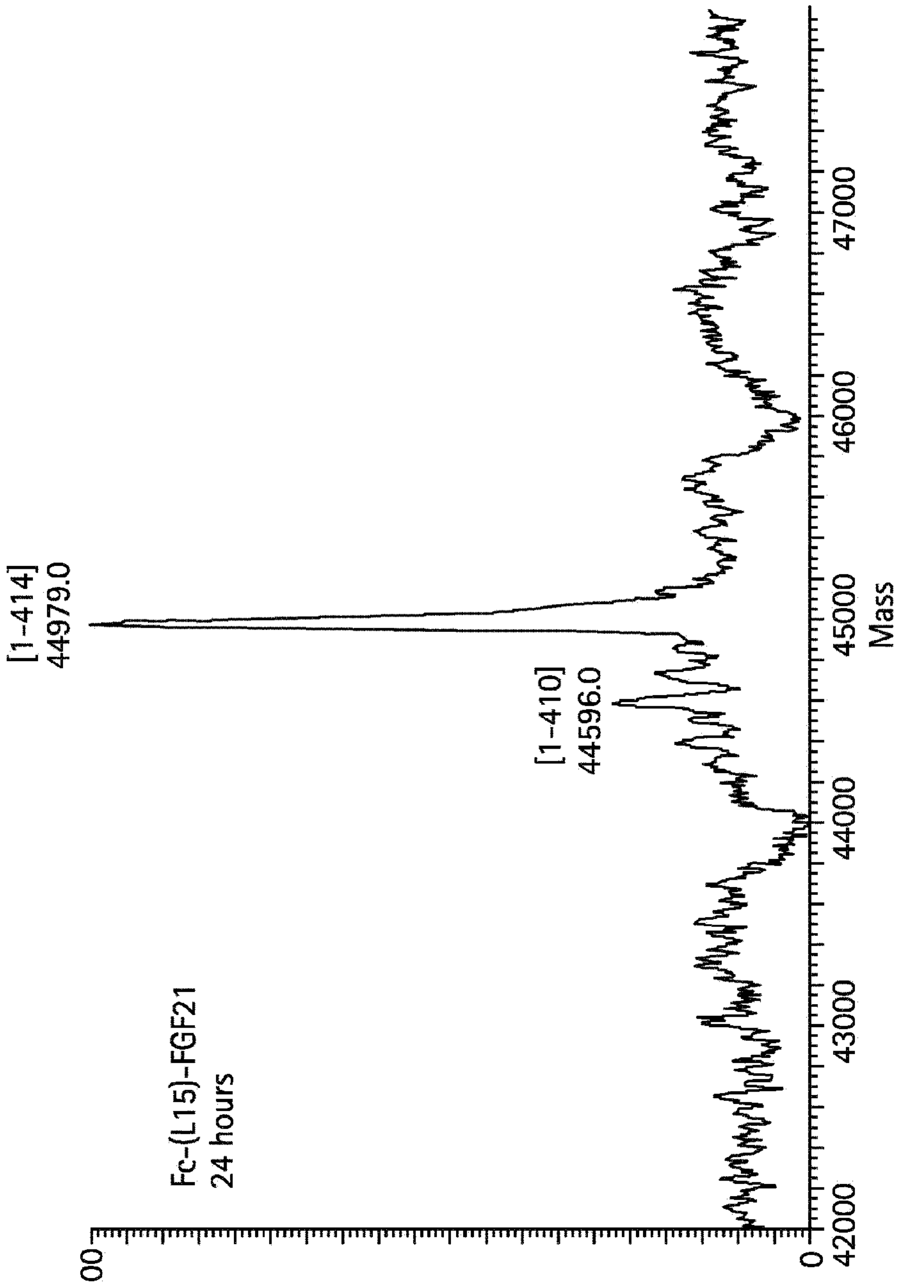

Fc-(L15)-FGF21
24 hours
[1-414]
44979.0
[1-410]
44596.0
100
0
42000
43000
44000
45000
46000
47000
Mass

FIG. 19D

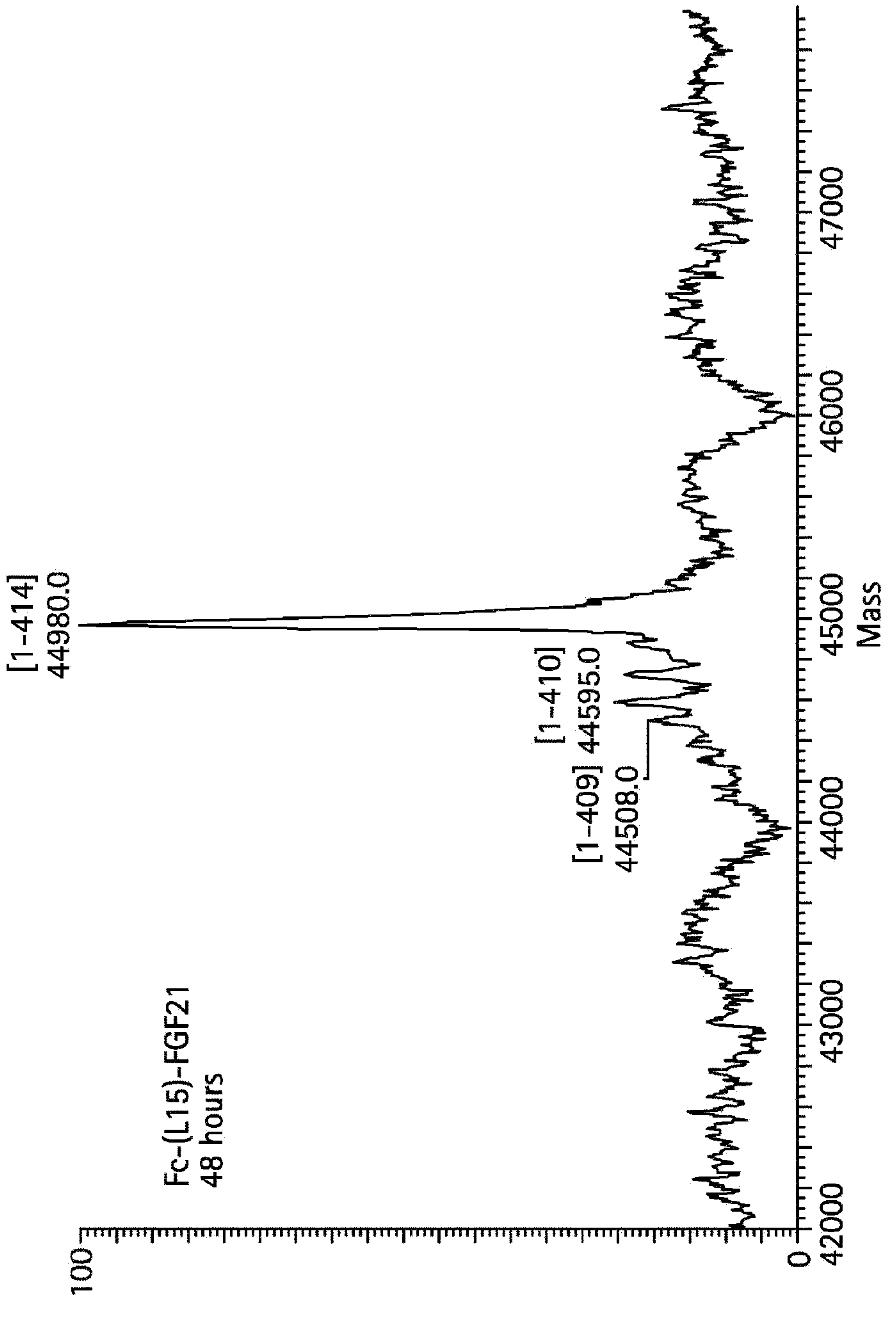

Fc-(L15)-FGF21
48 hours
[1-414]
44980.0
[1-410]
44595.0
[1-409]
44508.0
100
0
42000
43000
44000
45000
46000
47000
Mass

FIG. 20A

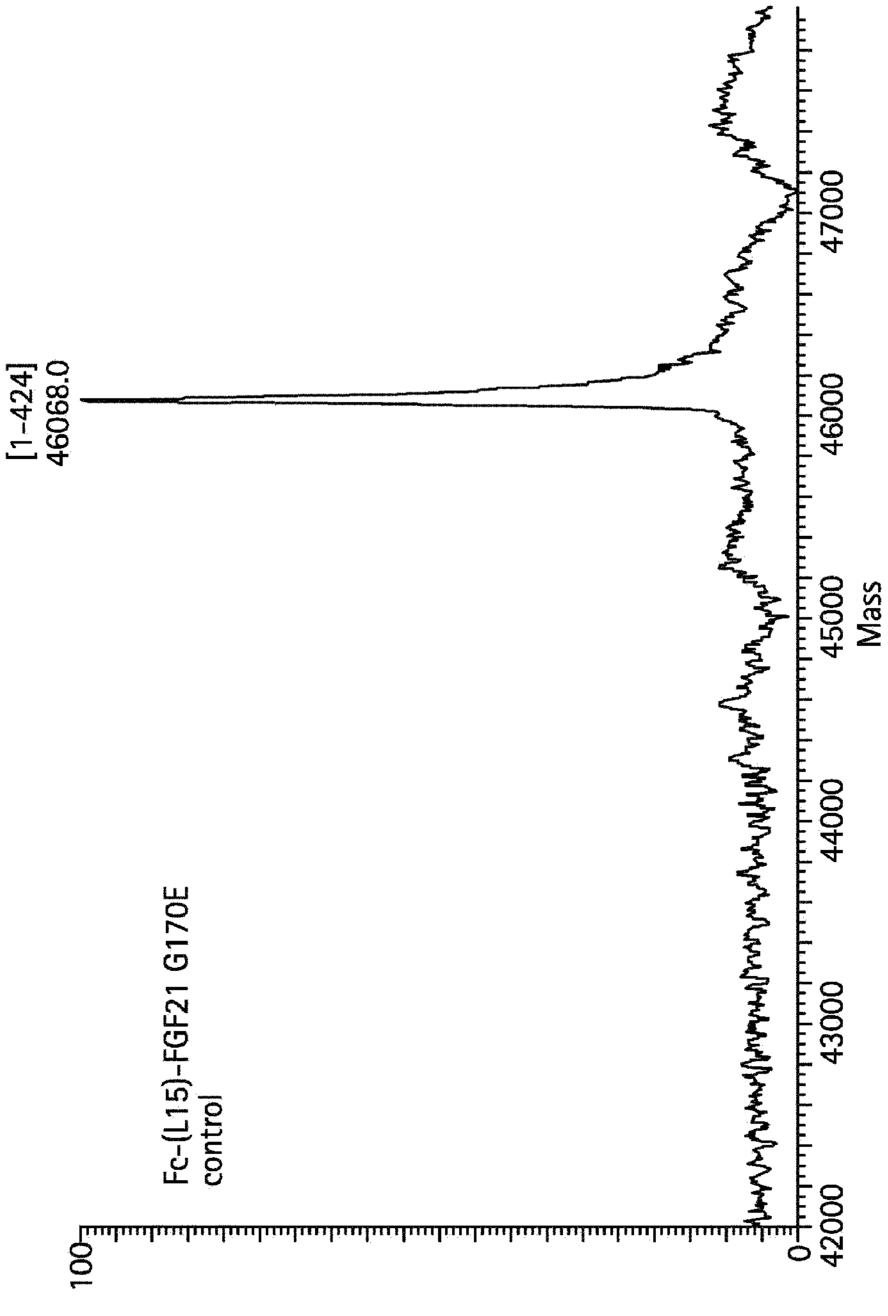

Fc-(L15)-FGF21 G170E
control
[1-424]
46068.0
100
0
42000
43000
44000
45000
46000
47000
Mass

FIG. 20B

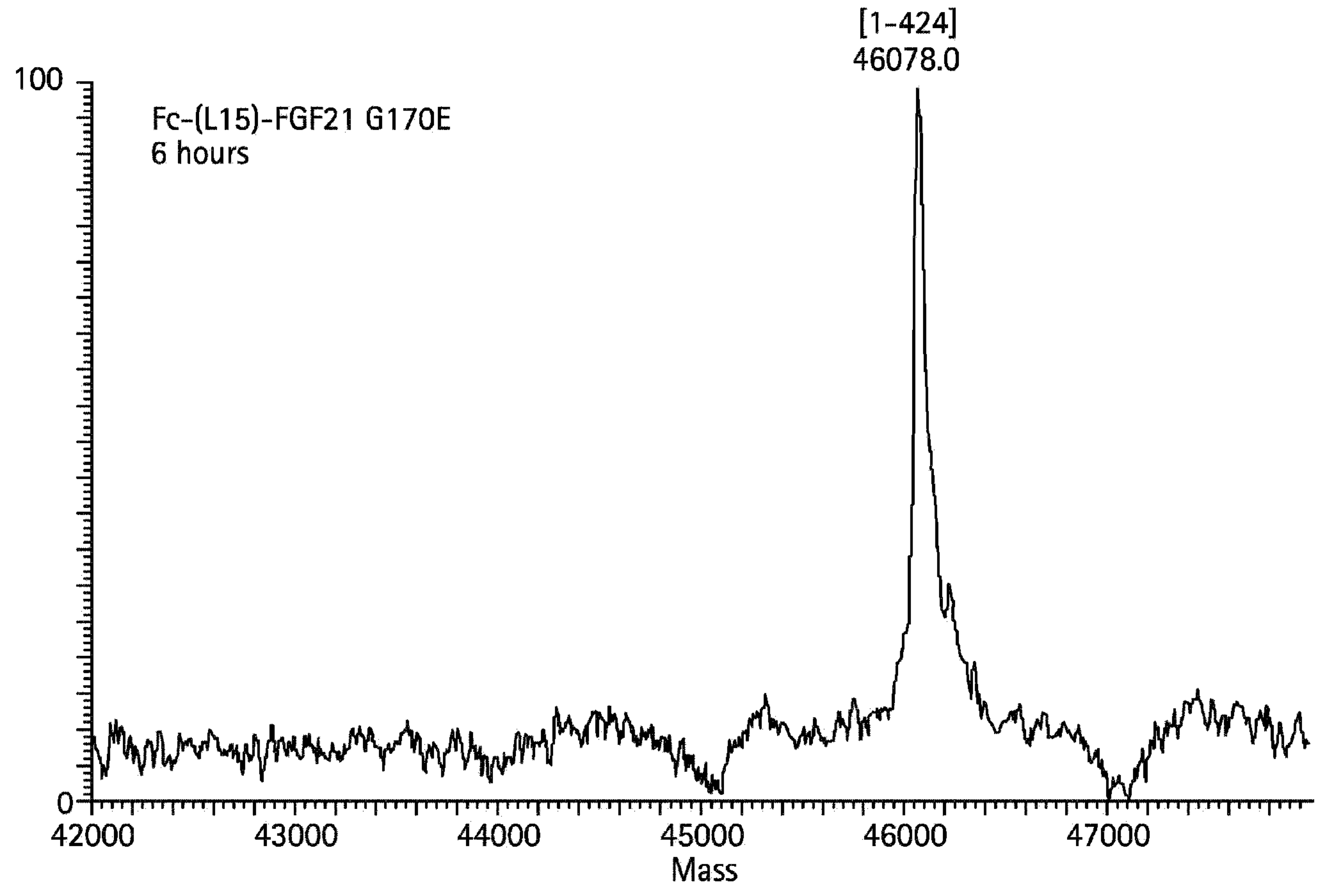

[1-424]
46078.0
100
0
Fc-(L15)-FGF21 G170E
6 hours
42000
43000
44000
45000
46000
47000
Mass

FIG. 20C

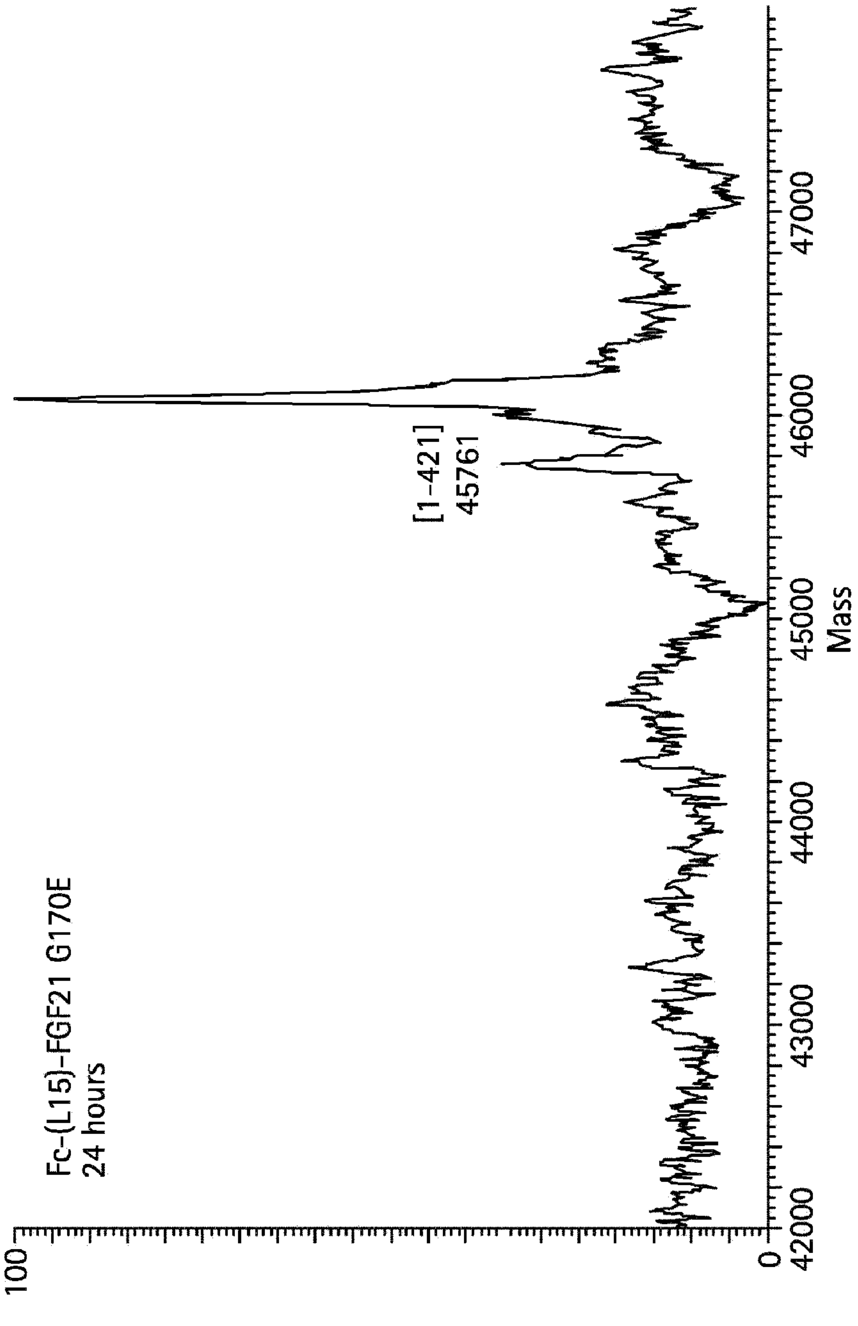

Fc-(L15)-FGF21 G170E
24 hours
[1-424]
46074.0
[1-421]
45761
100
0
42000
43000
44000
45000
46000
47000
Mass

FIG. 20D

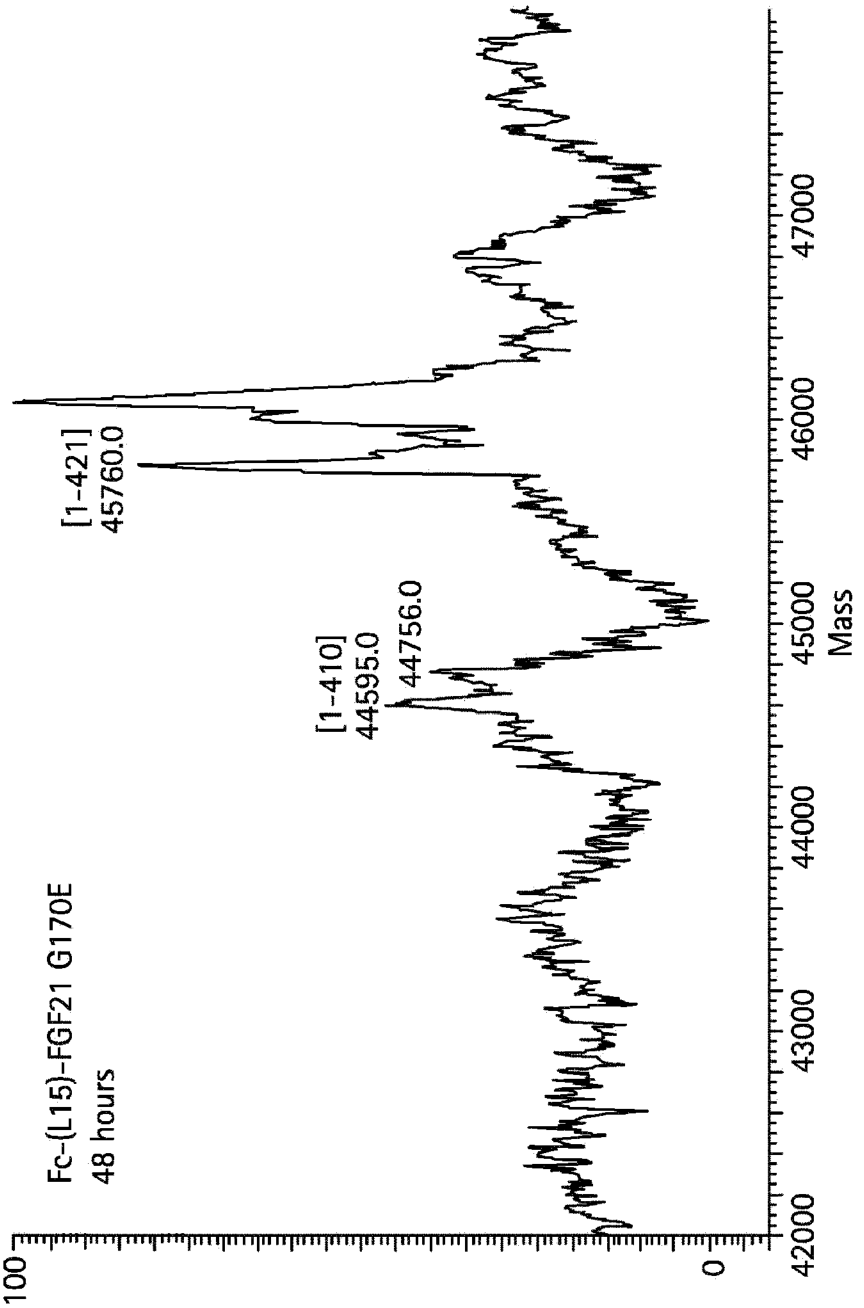

Fc-(L15)-FGF21 G170E
48 hours
[1-410]
44595.0
44756.0
[1-421]
45760.0
[1-424]
46072.0
100
0
42000
43000
44000
45000
46000
47000
Mass

FIG. 21A

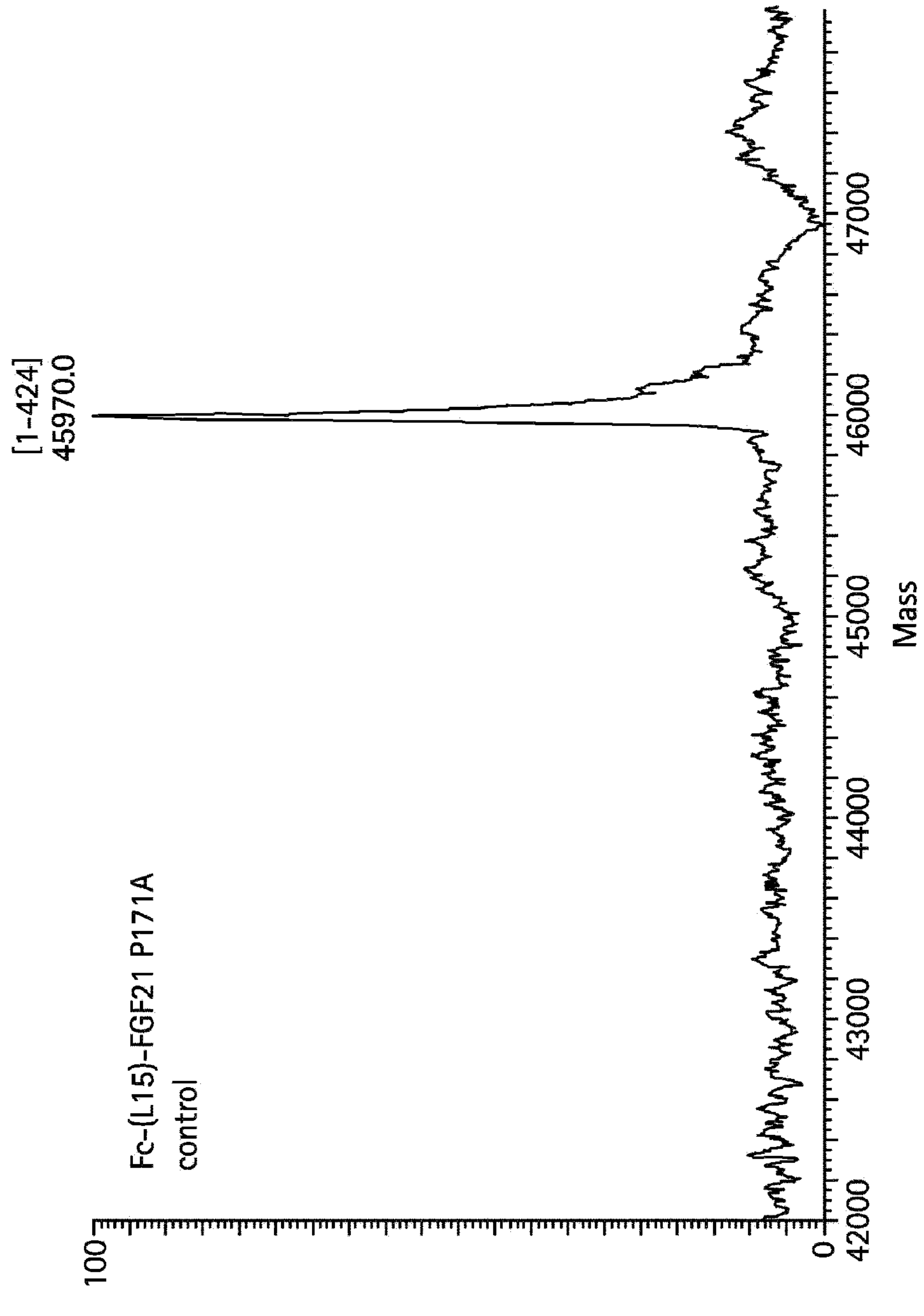

Fc-(L15)-FGF21 P171A
control
[1-424]
45970.0
100
0
42000
43000
44000
45000
46000
47000
Mass

FIG. 21B

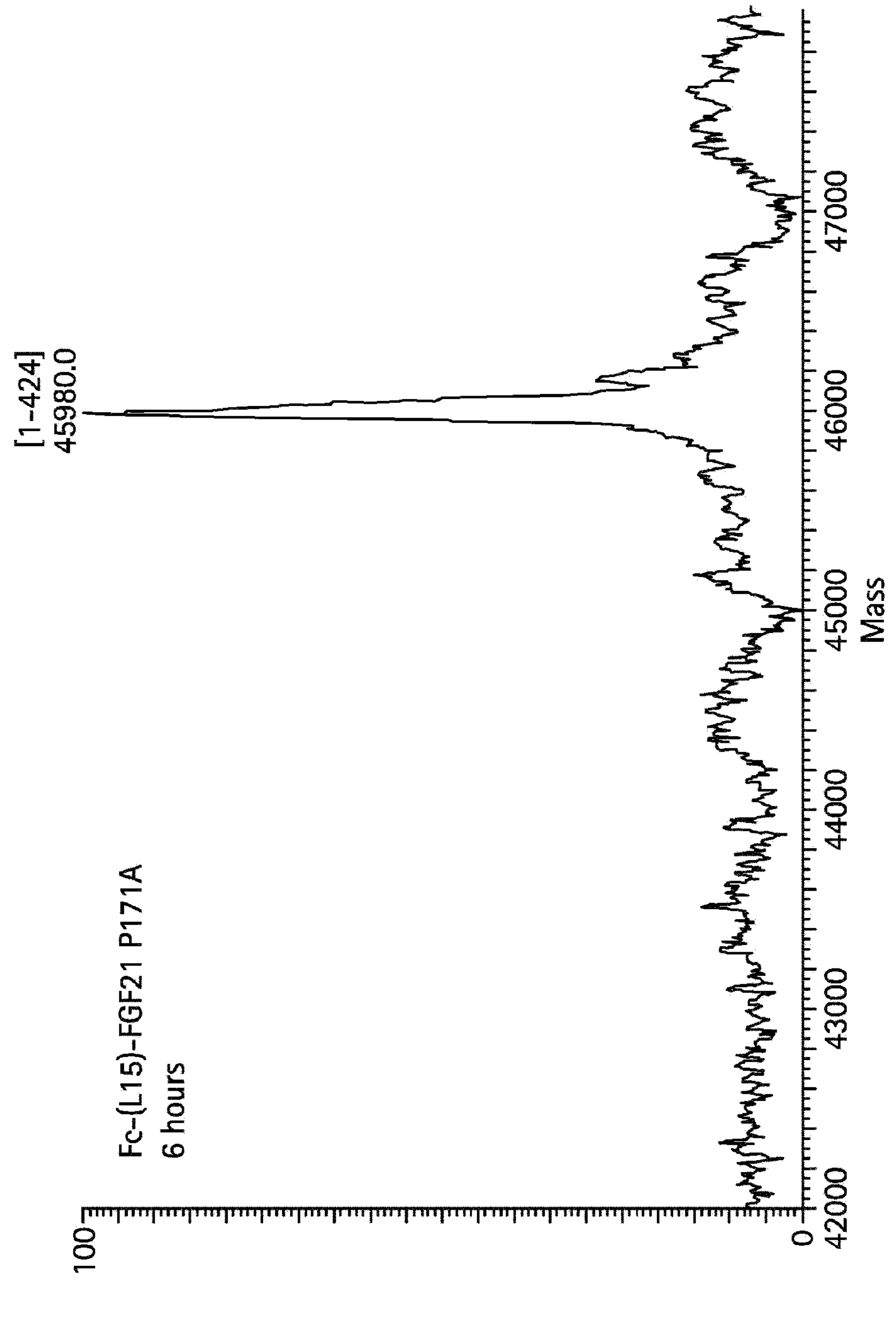

Fc-(L15)-FGF21 P171A
6 hours
[1-424]
45980.0
100
0
42000
43000
44000
45000
46000
47000
Mass

FIG. 21C

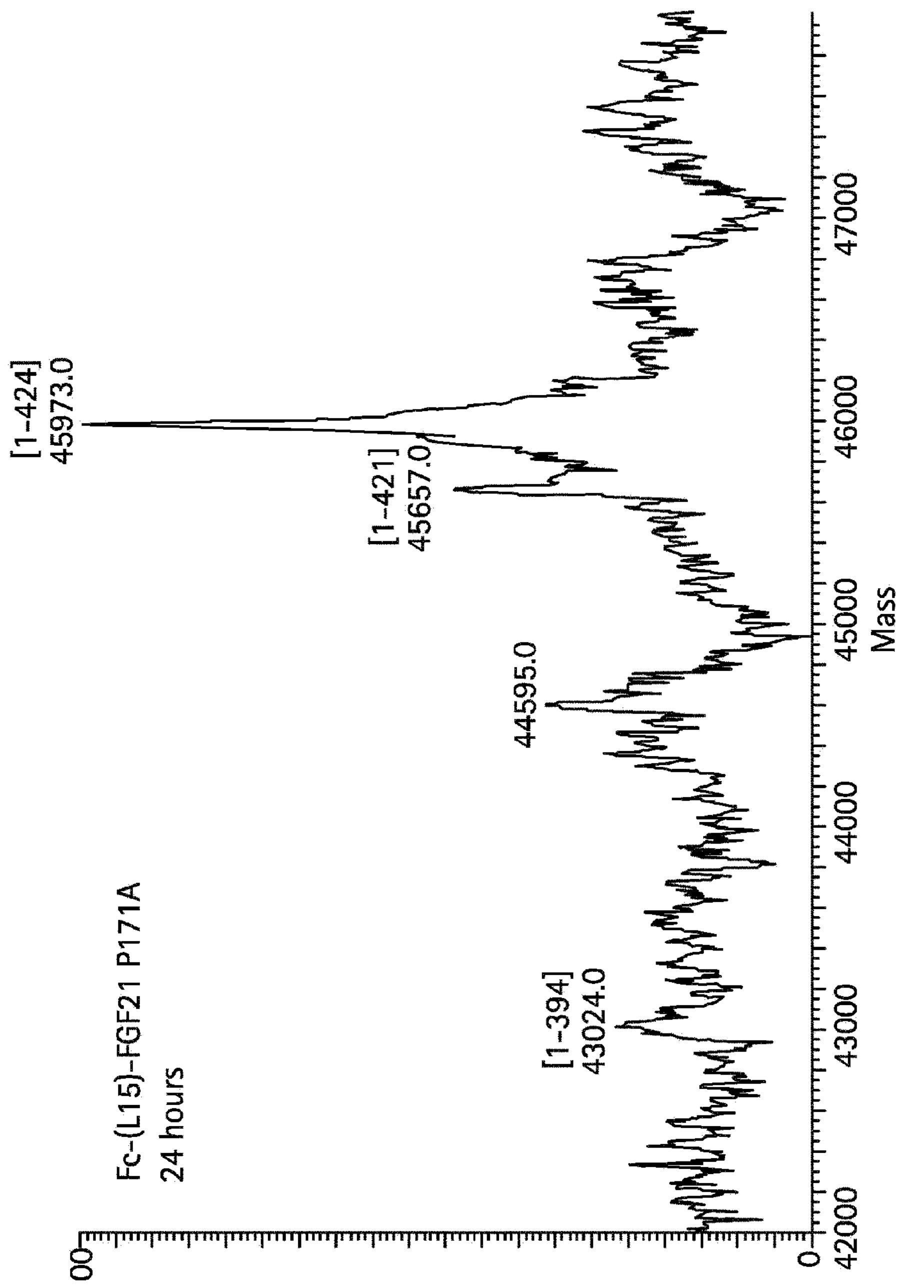

Fc-(L15)-FGF21 P171A
24 hours
[1-424]
45973.0
[1-421]
45657.0
44595.0
[1-394]
43024.0
100
0
42000
43000
44000
45000
46000
47000
Mass

FIG. 21D

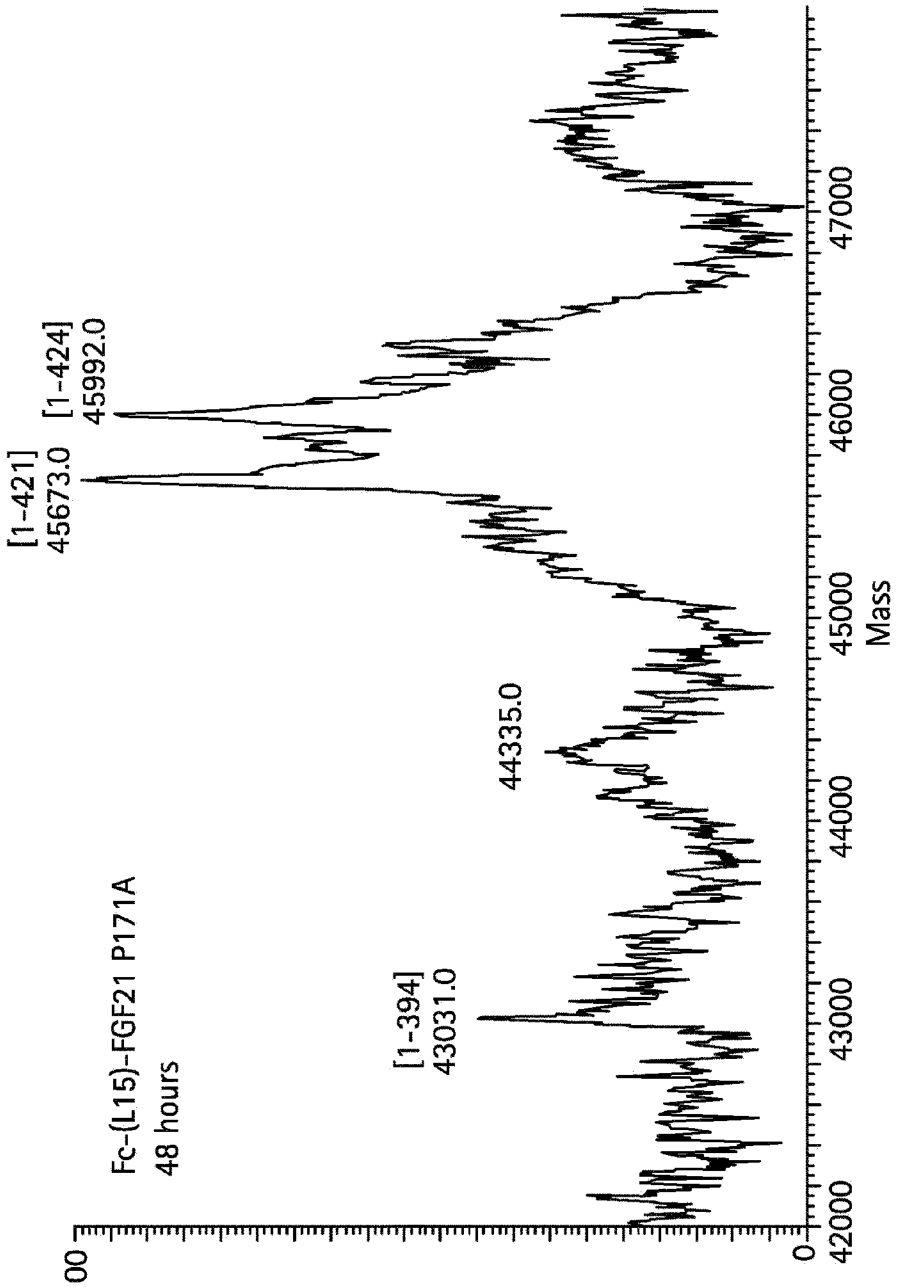

Fc-(L15)-FGF21 P171A
48 hours
[1-394]
43031.0
44335.0
[1-421]
45673.0
[1-424]
45992.0
100
0
42000
43000
44000
45000
46000
47000
Mass

FIG. 22A

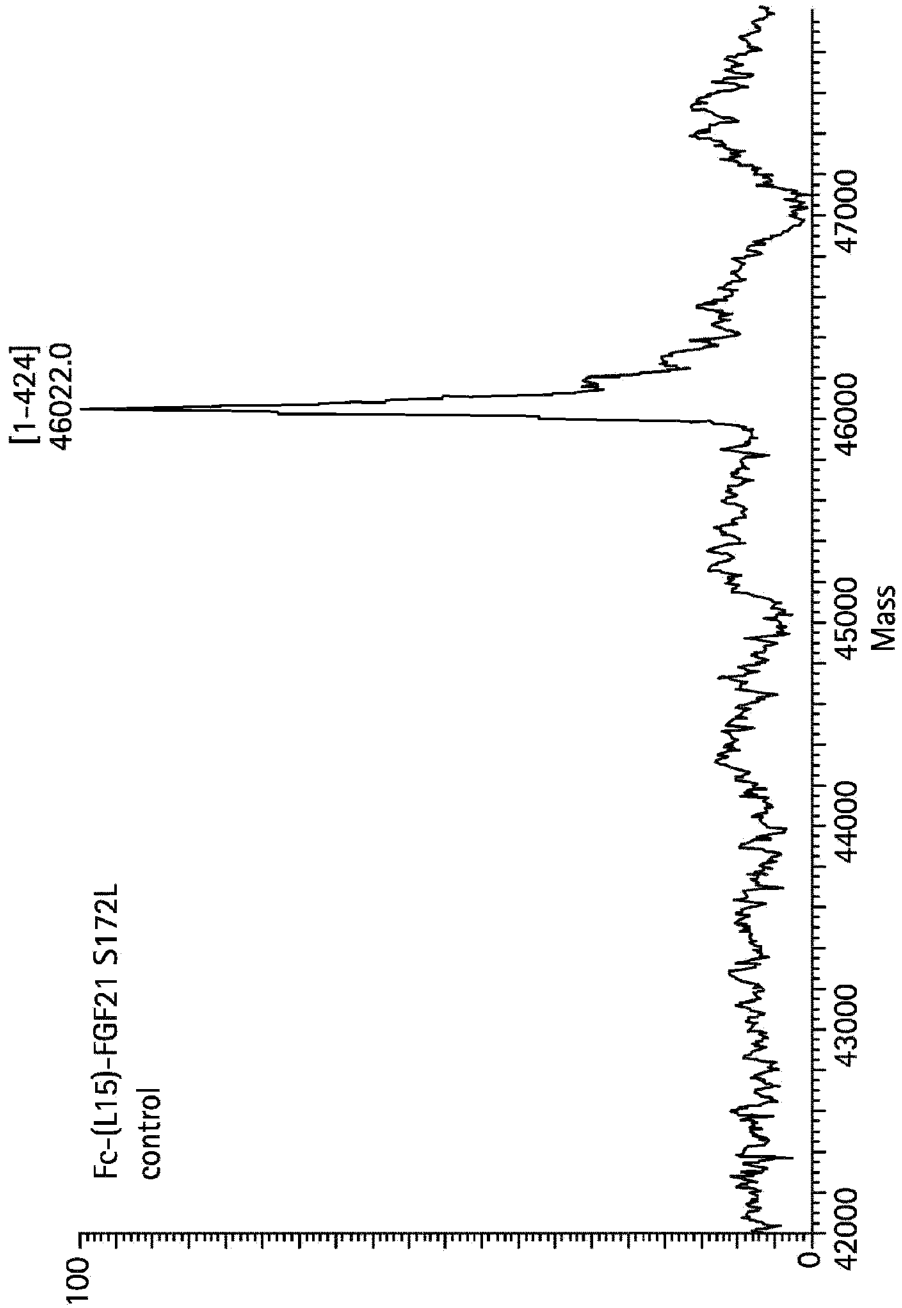

Fc-(L15)-FGF21 S172L
control
[1-424]
46022.0
100
0
42000
43000
44000
45000
46000
47000
Mass

FIG. 22B

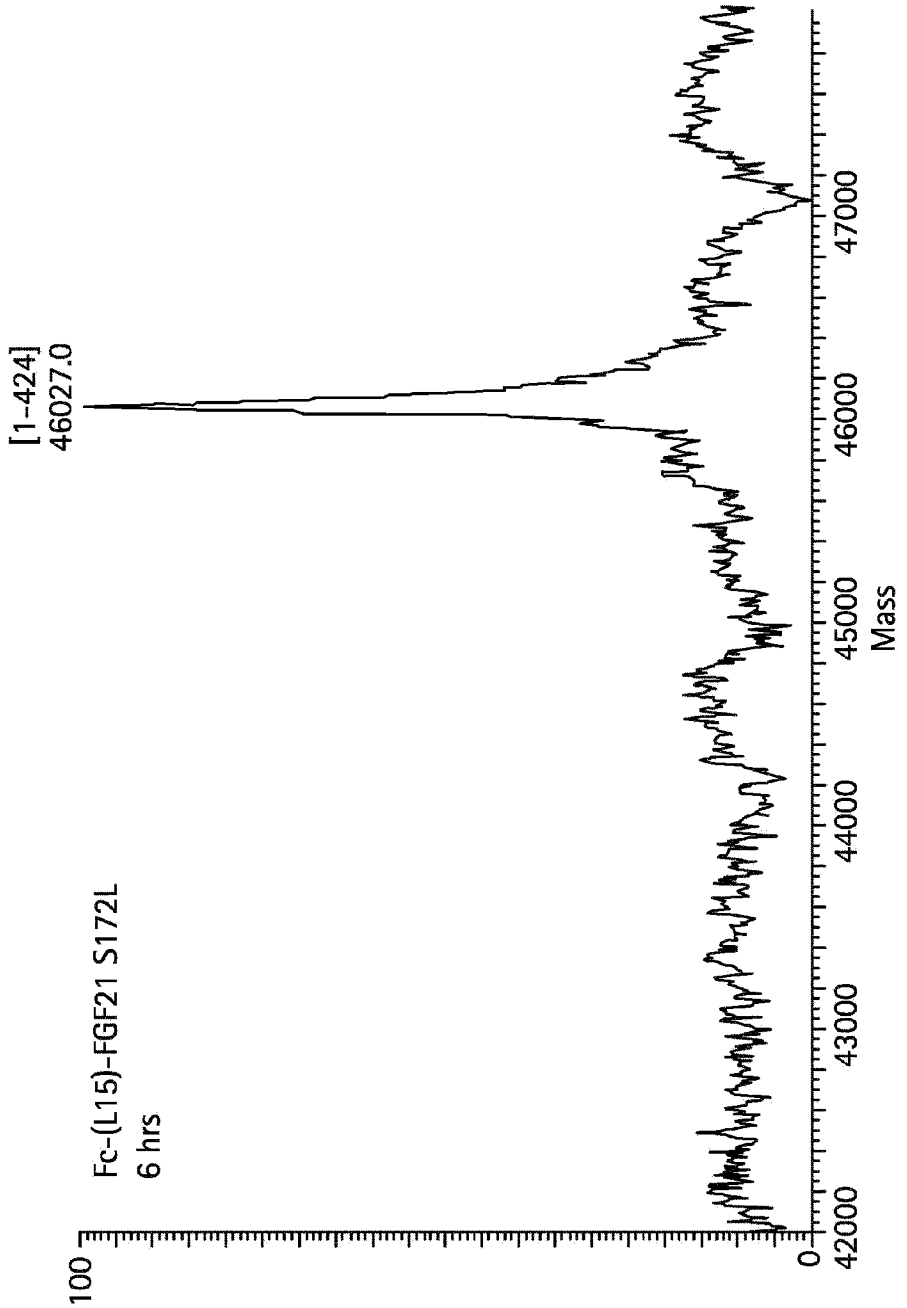
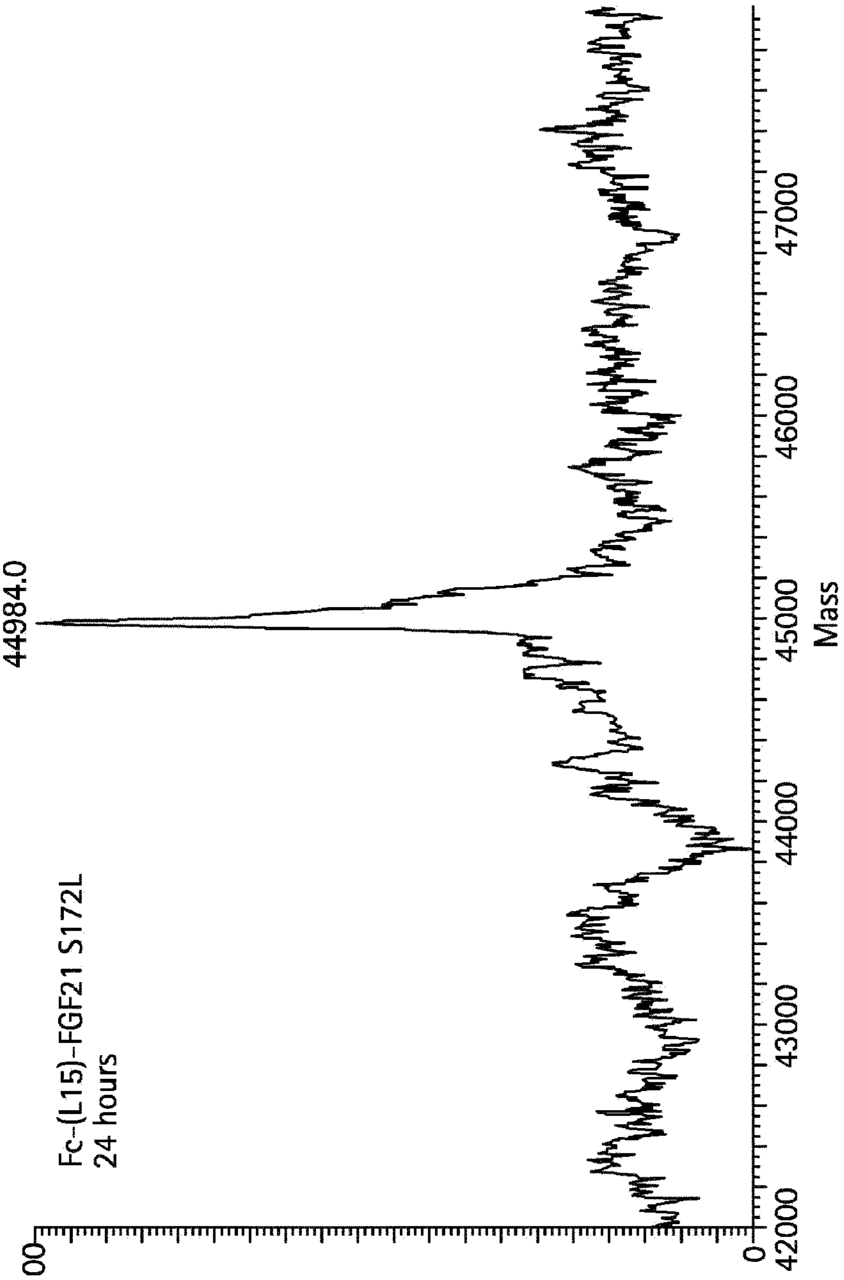

Fc-(L15)-FGF21 S172L
6 hrs
[1-424]
46027.0
100
0
42000
43000
44000
45000
46000
47000
Mass

FIG. 22C



Fc–(L15)–FGF21 S172L
24 hours
[1-414]
44984.0
100
0
42000
43000
44000
45000
46000
47000
Mass

FIG. 22D

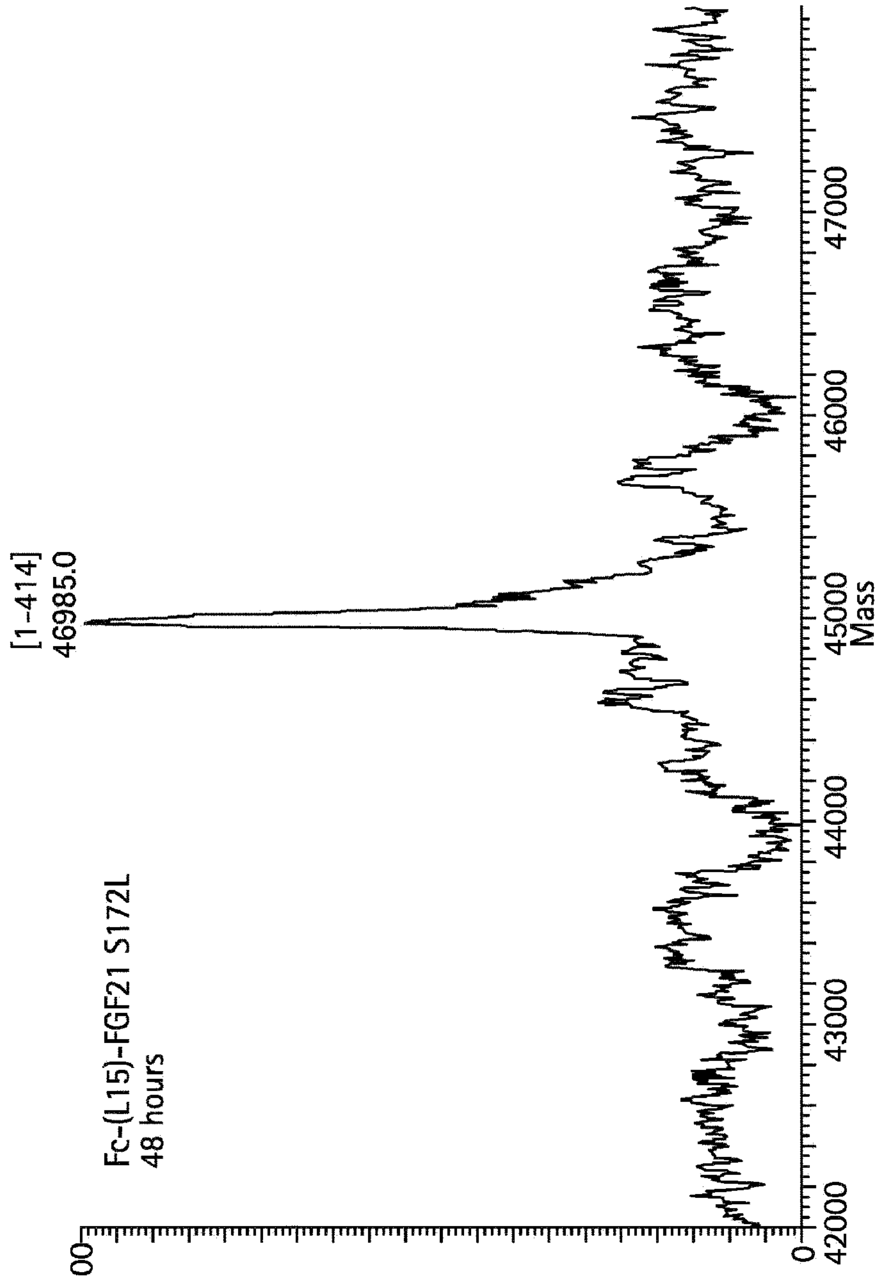

Fc-(L15)-FGF21 S172L
48 hours
[1-414]
46985.0
100
0
42000
43000
44000
45000
46000
47000
Mass

FIG. 23A

Fc-(L15)-FGF21

MDKTHTCPPCPAPELLGGPSVFLFPPKPKDTLMISRTPEVTCVVVDVSHEDPEVKFNWYVDGVEVHNAKTKPREEQYNST
YRVVSVLTVLHQDWLNGKEYKCKVSNKALPAPIEKTISKAKGQPREPQVYTLPPSRDELTKNQVSLTCLVKGFYPSDIAV
EWESNGQPENNYKTTPPVLDSDGSFFLYSKLTVDKSRWQQGNVFSCSVMHEALHNHYTQKSLSLSPGK*GGGGGSGGGSGG*
*GGS*HPIPDSSPLLQFGGQVRQRYLYTDDAQQTEAHLEIREDGTVGGAADQSPESLLQLKALKPGVIQILGVKTSRFLCQR
PDGALYGSLHFDPEACSFRELLLEDGYNVYQSEAHGLPLHLPGNKSPHRDPAPRGPARFLPLPGLPPAPPEPPGILAPQP
PDVGSSDPLSMVGPSQGRSPSYAS

↑

6 hrs (20%)
24 hrs (100%) [1-414]
48 hrs (~100%)

FIG. 23B

Fc-(L15)-FGF21 G170E

MDKTHTCPPCPAPELLGGPSVFLFPPKPKDTLMISRTPEVTCVVVDVSHEDPEVKFNWYVDGVEVHNAKTKPREEQYNST
YRVVSVLTVLHQDWLNGKEYKCKVSNKALPAPIEKTISKAKGQPREPQVYTLPPSRDELTKNQVSLTCLVKGFYPSDIAV
EWESNGQPENNYKTTPPVLDSDGSFFLYSKLTVDKSRWQQGNVFSCSVMHEALHNHYTQKSLSLSPGK*GGGGGSGGGSGG*
*GGS*HPIPDSSPLLQFGGQVRQRYLYTDDAQQTEAHLEIREDGTVGGAADQSPESLLQLKALKPGVIQILGVKTSRFLCQR
PDGALYGSLHFDPEACSFRELLLEDGYNVYQSEAHGLPLHLPGNKSPHRDPAPRGPARFLPLPGLPPAPPEPPGILAPQP
PDVGSSDPLSMVEPSQGRSPSYAS

↑

6 hrs (0%)
24 hrs (20%) [1-442]
48 hrs (~40%)

FIG. 23C

Fc-(L15)-FGF21 P171A

MDKTHTCPPCPAPELLGGPSVFLFPPKPKDTLMISRTPEVTCVVVDVSHEDPEVKFNWYVDGVEVHNAKTKPREEQYNST
YRVVSVLTVLHQDWLNGKEYKCKVSNKALPAPIEKTISKAKGQPREPQVYTLPPSRDELTKNQVSLTCLVKGFYPSDIAV
EWESNGQPENNYKTTPPVLDSDGSFFLYSKLTVDKSRWQQGNVFSCSVMHEALHNHYTQKSLSLSPGK*GGGGGSGGGSGG*
*GGS*HPIPDSSPLLQFGGQVRQRYLYTDDAQQTEAHLEIREDGTVGGAADQSPESLLQLKALKPGVIQILGVKTSRFLCQR
PDGALYGSLHFDPEACSFRELLLEDGYNVYQSEAHGLPLHLPGNKSPHRDPAPRGPARFLPLPGLPPAPPEPPGILAPQP
PDVGSSDPLSMVGASQGRSPSYAS

↑

6 hrs (0%)
24 hrs (~30%) [1-421]
48 hrs (~50%)

FIG. 23D

Fc-(L15)-FGF21 S172L

MDKTHTCPPCPAPELLGGPSVFLFPPKPKDTLMISRTPEVTCVVVDVSHEDPEVKFNWYVDGVEVHNAKTKPREEQYNST
YRVVSVLTVLHQDWLNGKEYKCKVSNKALPAPIEKTISKAKGQPREPQVYTLPPSRDELYKNQVSLTCLVKGFYPSDIAV
EWESNGQPENNYKTTPPVLDSDGSFFLYSKLTVDKSRWQQGNVFSCSVMHEALHNHYTQKSLSLSPGK*GGGGGSGGGSGG*
*GGS*HPIPDSSPLLQFGGQVRQRYLYTDDAQQTEAHLEIREDGTVGGAADQSPESLLQLKALKPGVIQILGVKTSRFLCQR
PDGALYGSLHFDPEACSFRELLLEDGYNVYQSEAHGLPLHLPGNKSPHRDPAPRGPARFLPLPGLPPAPPEPPGILAPQP
PDVGSSDPLSMVGPLQGRSPSYAS

6 hrs (0%)
24 hrs (100%) [1-414]
48 hrs (100%)

FIG. 24A

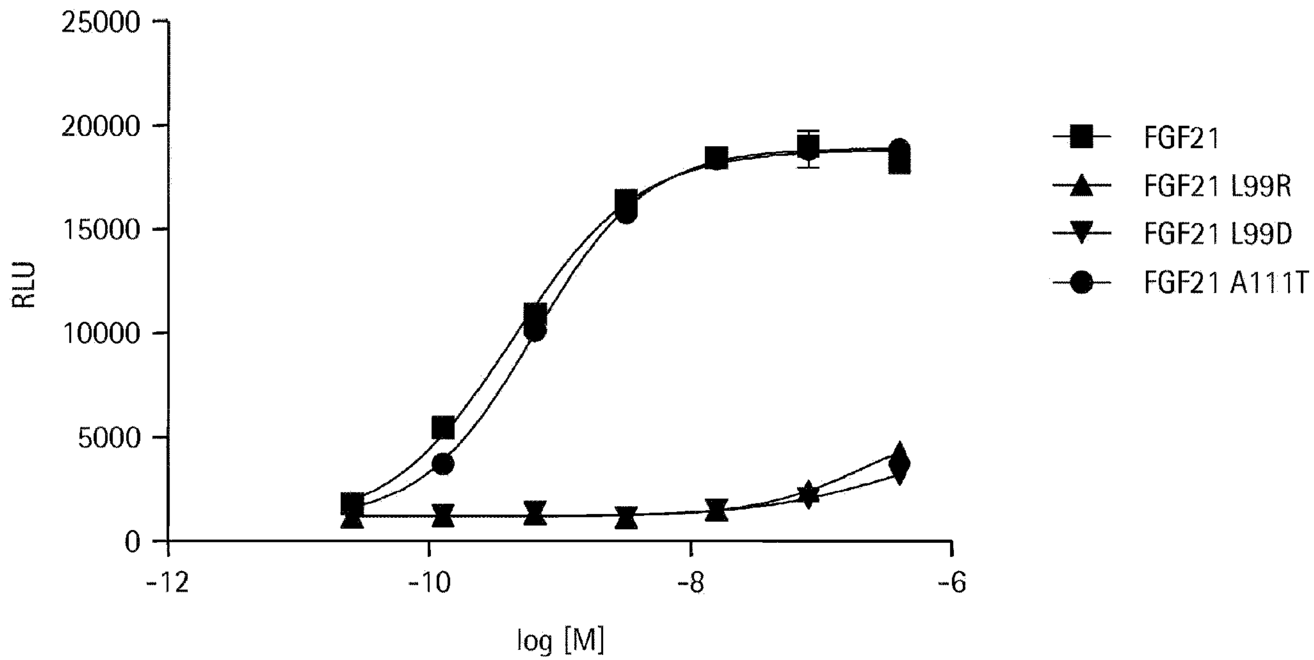

25000
20000
15000
10000
5000
0
RLU
-12
-10
-8
-6
log [M]
FGF21
FGF21 L99R
FGF21 L99D
FGF21 A111T

FIG. 24B

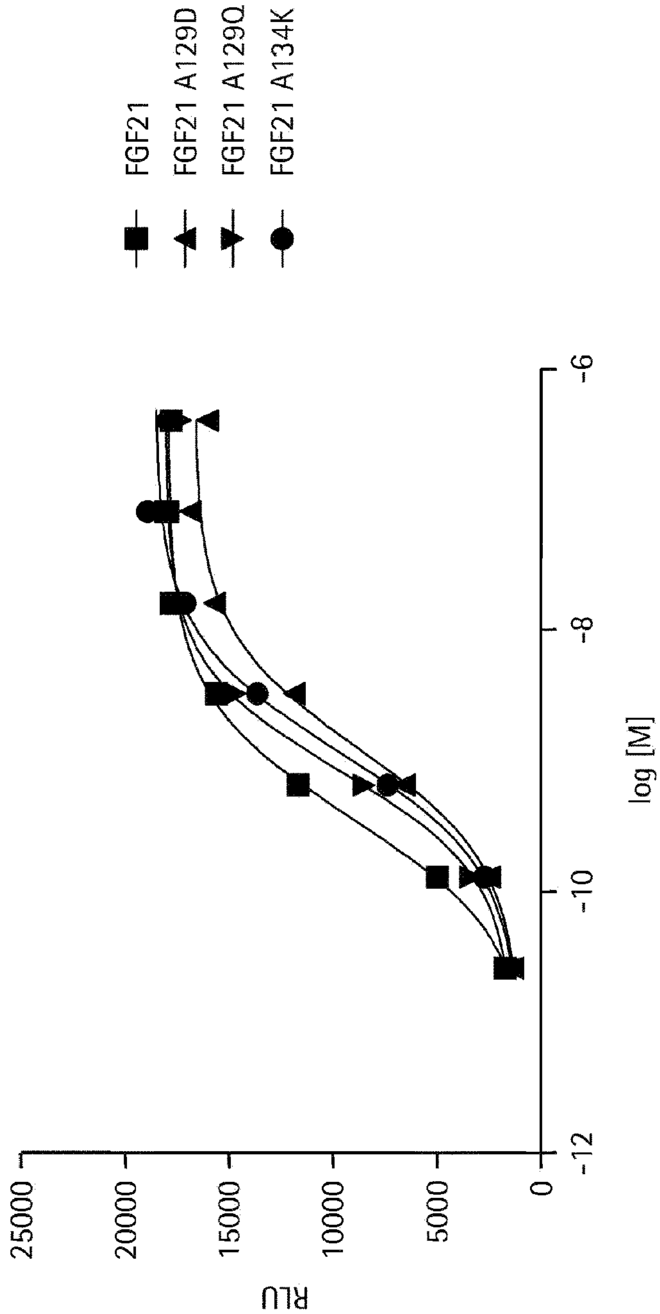
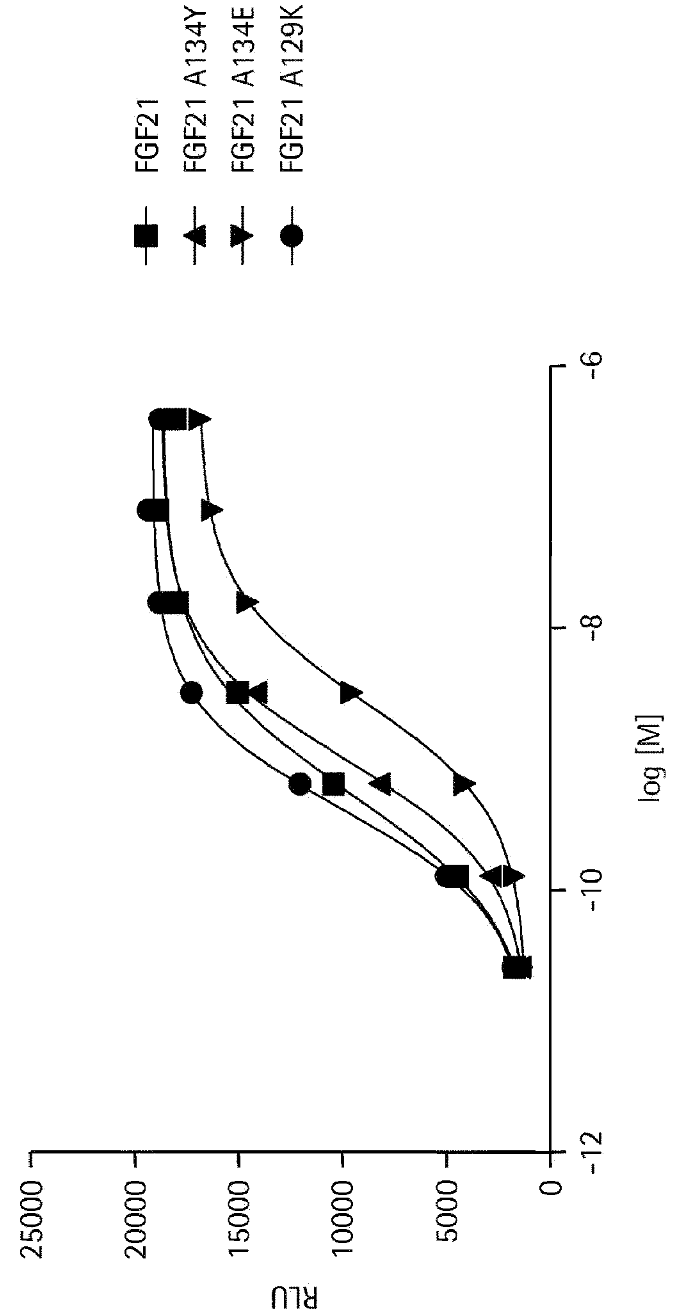

FGF21
FGF21 A129D
FGF21 A129Q
FGF21 A134K
RLU
25000
20000
15000
10000
5000
0
-12
-10
-8
-6
log [M]

FIG. 24C



FGF21
FGF21 A134Y
FGF21 A134E
FGF21 A129K
RLU
25000
20000
15000
10000
5000
0
-12
-10
-8
-6
log [M]

FIG. 25A

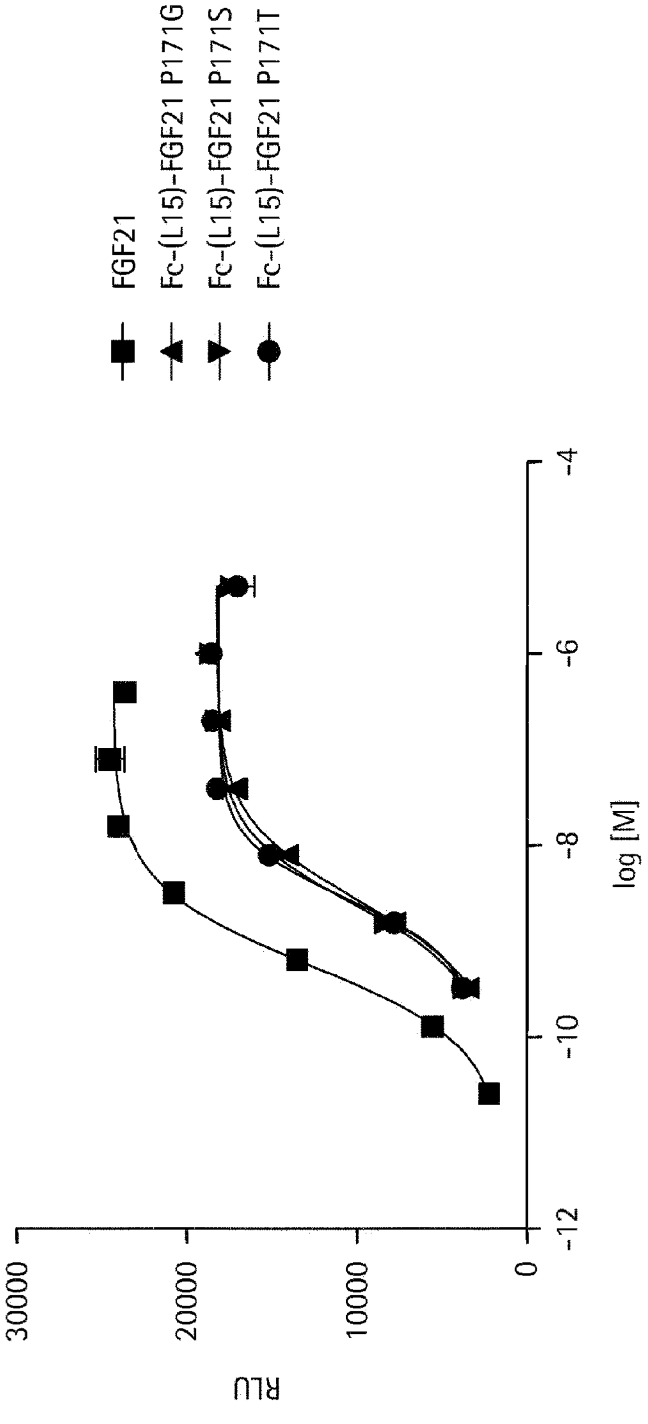

RLU
30000
20000
10000
0
-12
-10
-8
-6
-4
log [M]
FGF21
Fc-(L15)-FGF21 P171G
Fc-(L15)-FGF21 P171S
Fc-(L15)-FGF21 P171T

FIG. 25B

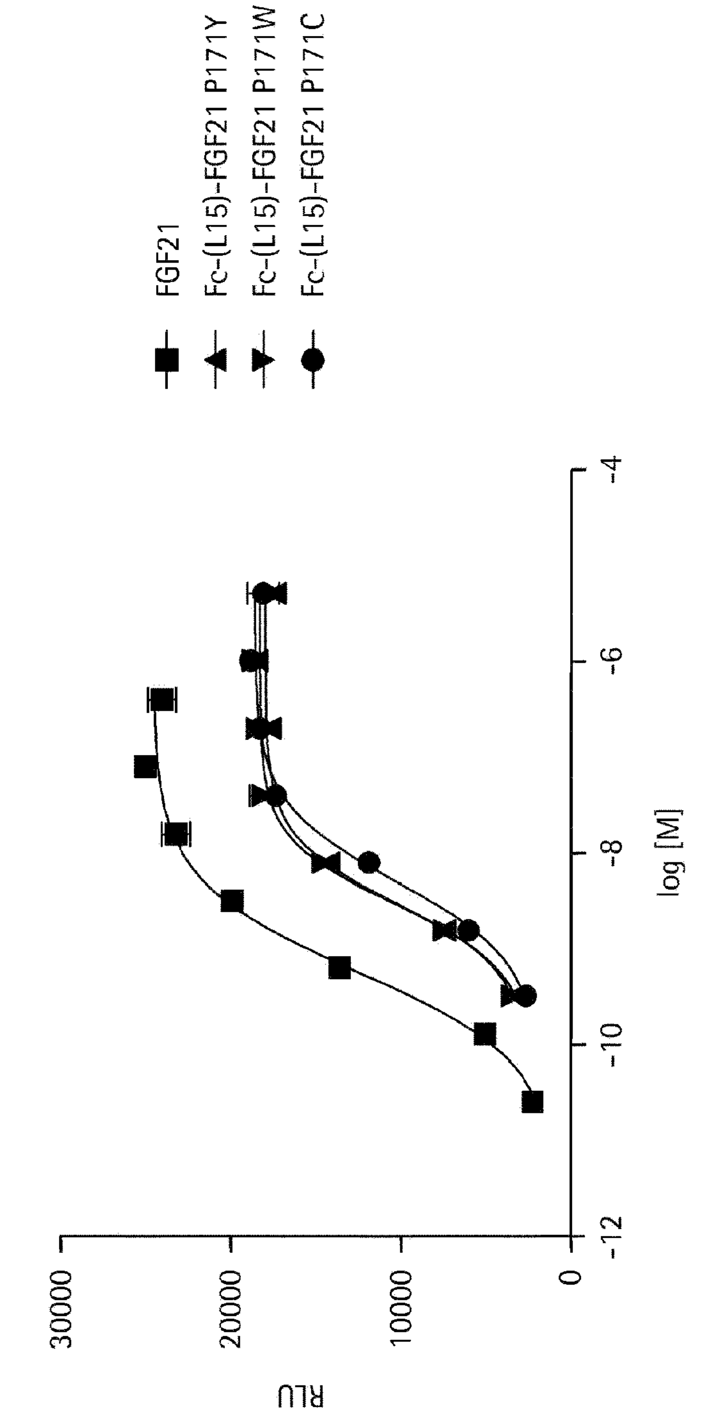

FGF21
Fc-(L15)-FGF21 P171Y
Fc-(L15)-FGF21 P171W
Fc-(L15)-FGF21 P171C
RLU
30000
20000
10000
0
-12
-10
-8
-6
-4
log [M]

FIG. 25C

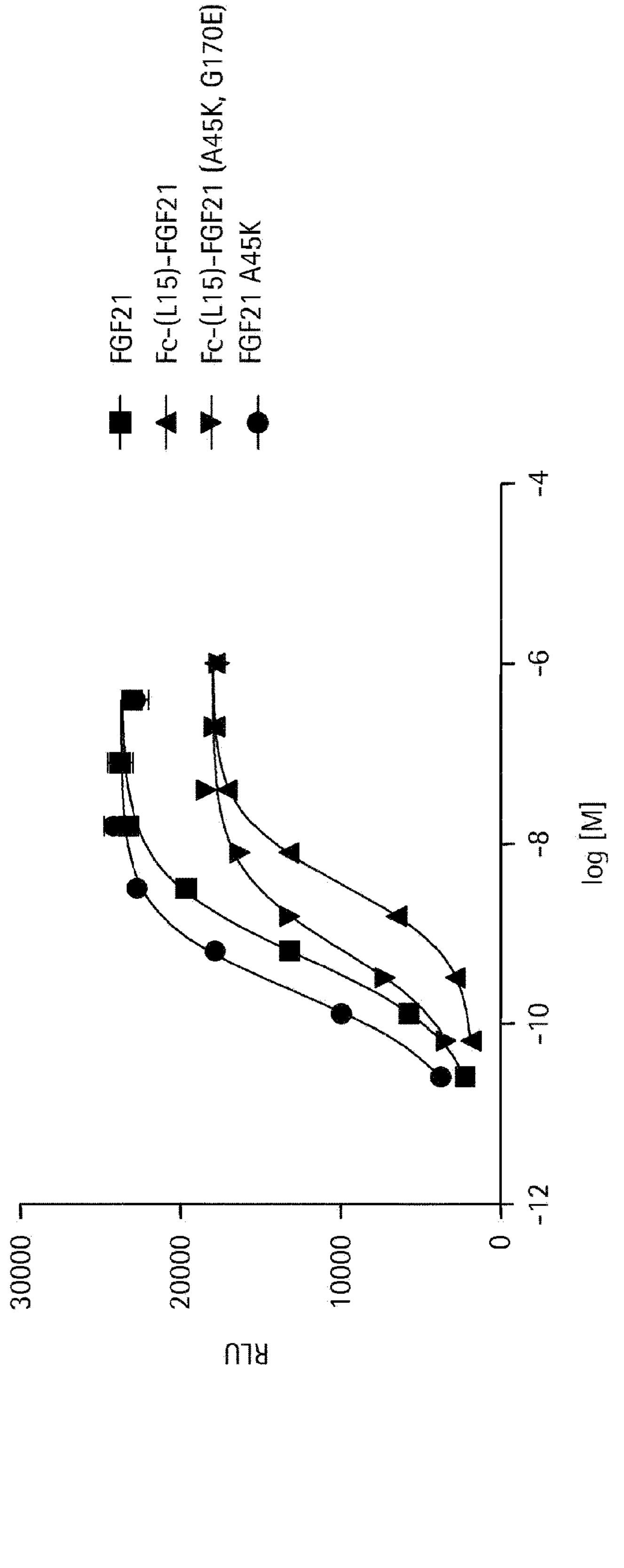

FGF21
Fc-(L15)-FGF21
Fc-(L15)-FGF21 (A45K, G170E)
FGF21 A45K
RLU
30000
20000
10000
0
-12
-10
-8
-6
-4
log [M]

FIG. 25D

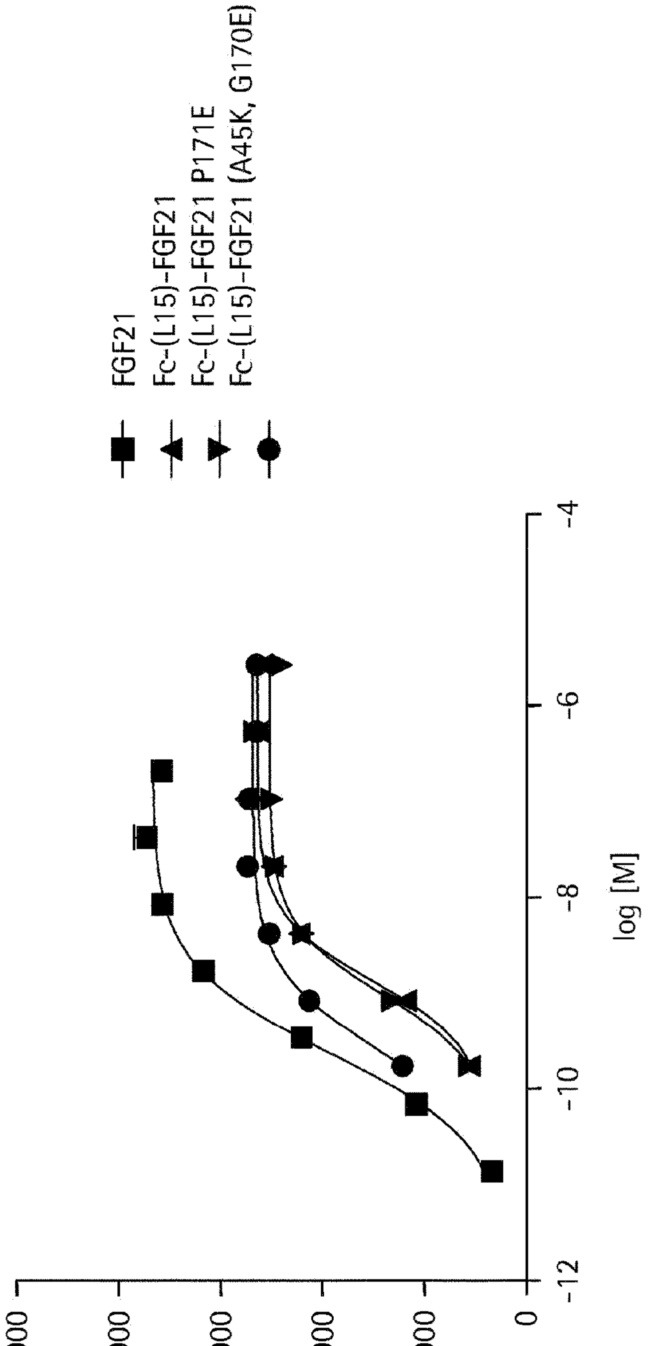

RLU
25000
20000
15000
10000
5000
0
-12
-10
-8
-6
-4
log [M]
FGF21
Fc-(L15)-FGF21
Fc-(L15)-FGF21 P171E
Fc-(L15)-FGF21 (A45K, G170E)

FIG. 26A

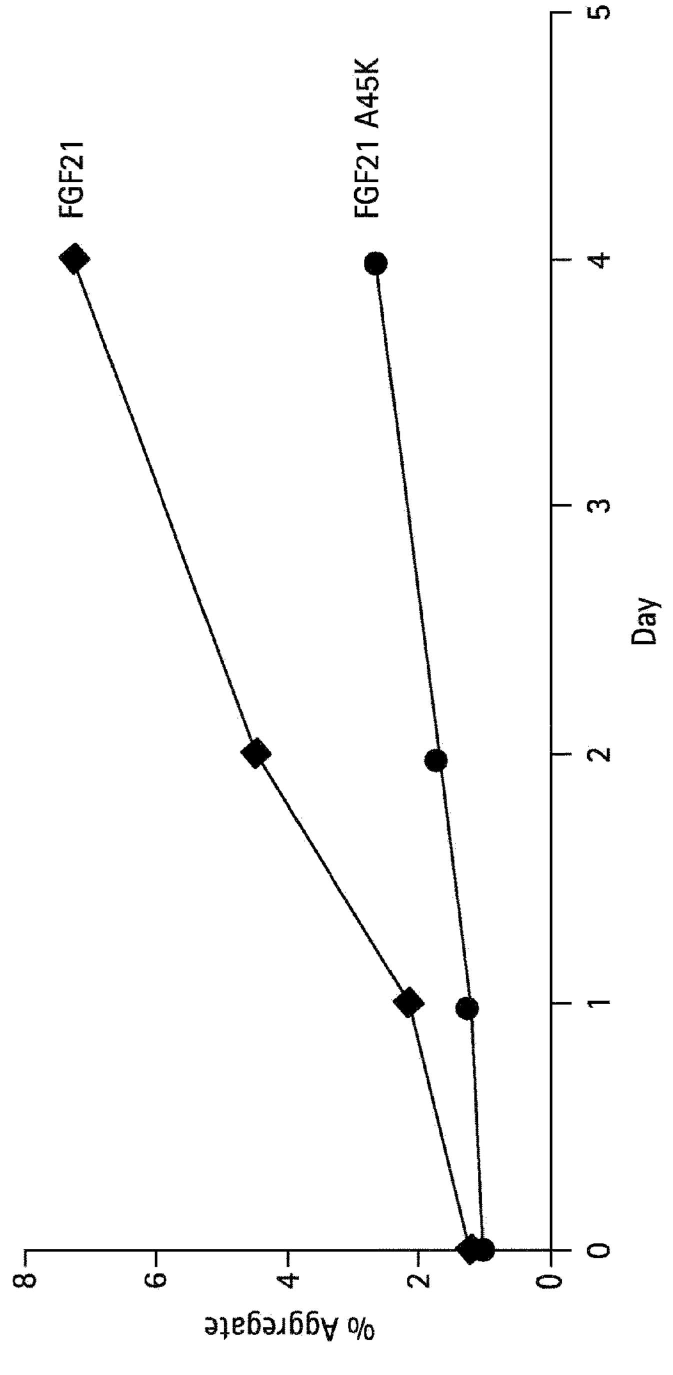


FIG. 26B

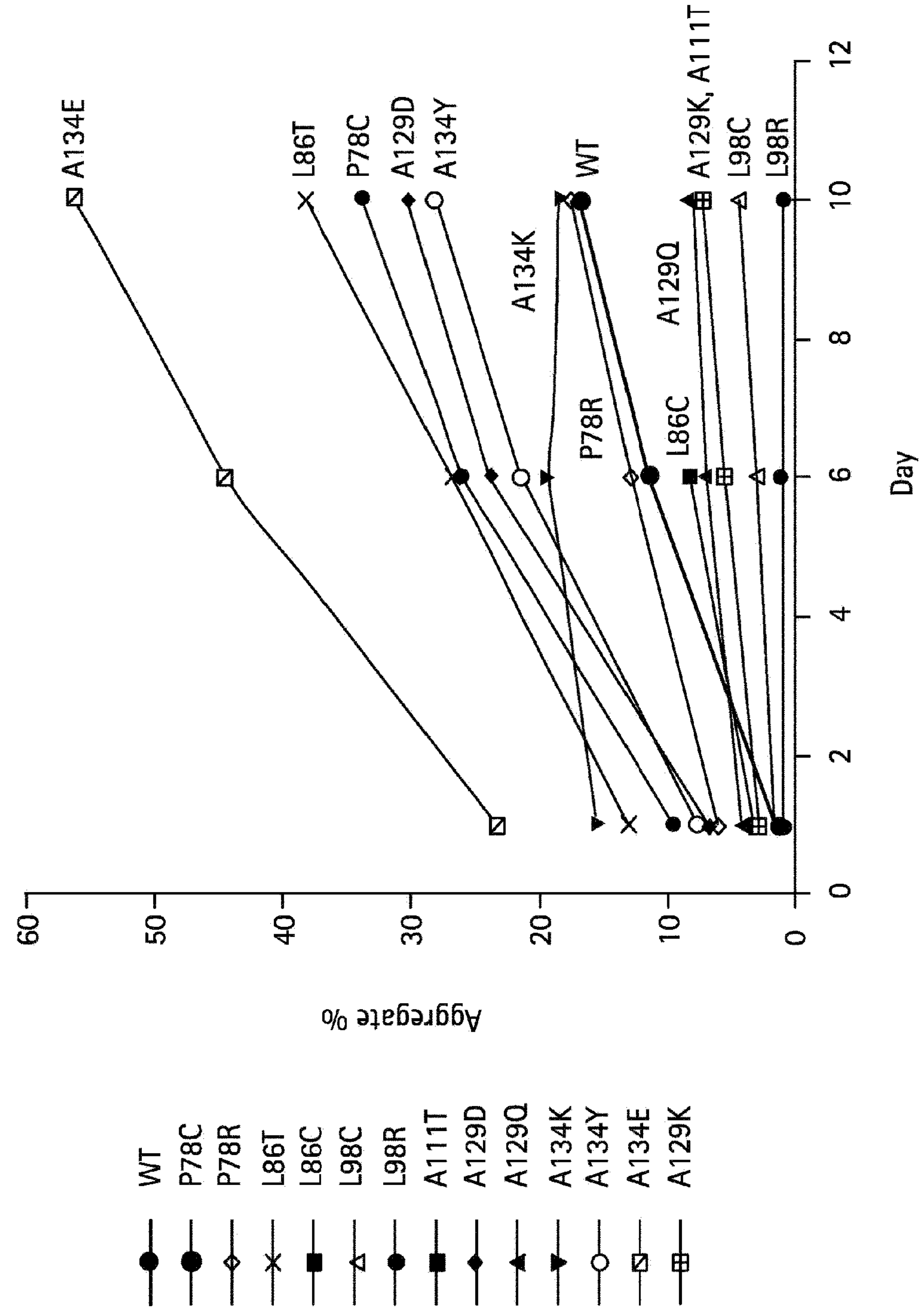

Aggregate %
Day
0
10
20
30
40
50
60
2
4
6
8
12
A134E
L86T
P78C
A129D
A134Y
WT
A134K
P78R
L86C
A129Q
A129K, A111T
L98C
L98R
WT
P78C
P78R
L86T
L86C
L98C
L98R
A111T
A129D
A129Q
A134K
A134Y
A134E
A129K

FIG. 27

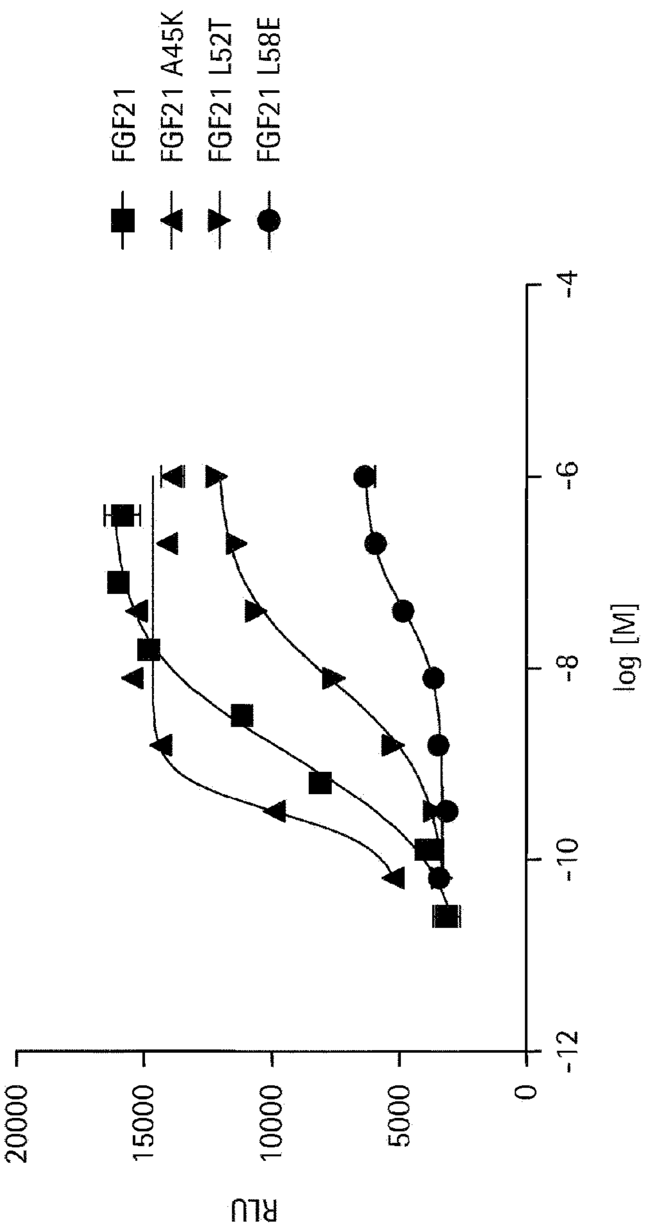

FGF21
FGF21 A45K
FGF21 L52T
FGF21 L58E
RLU
20000
15000
10000
5000
0
-12
-10
-8
-6
-4
log [M]

FIG. 28A

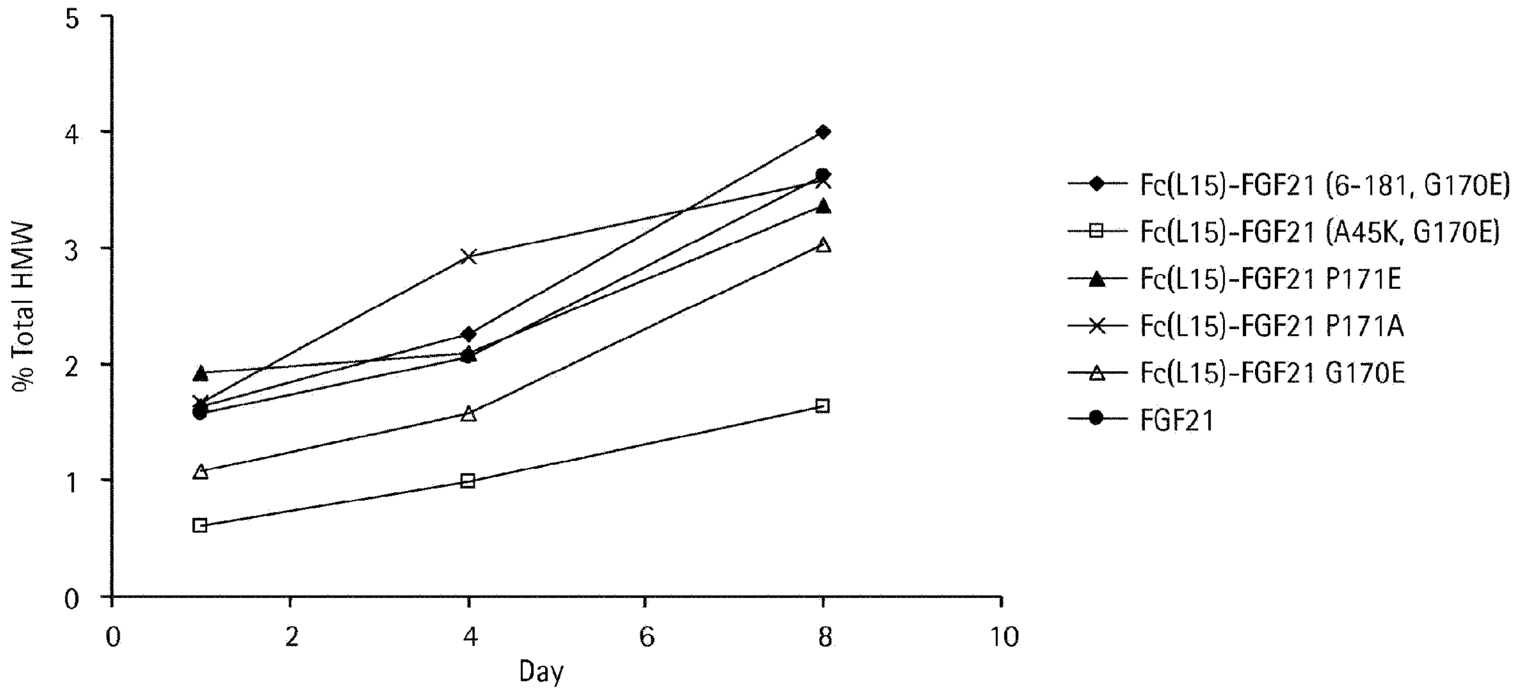
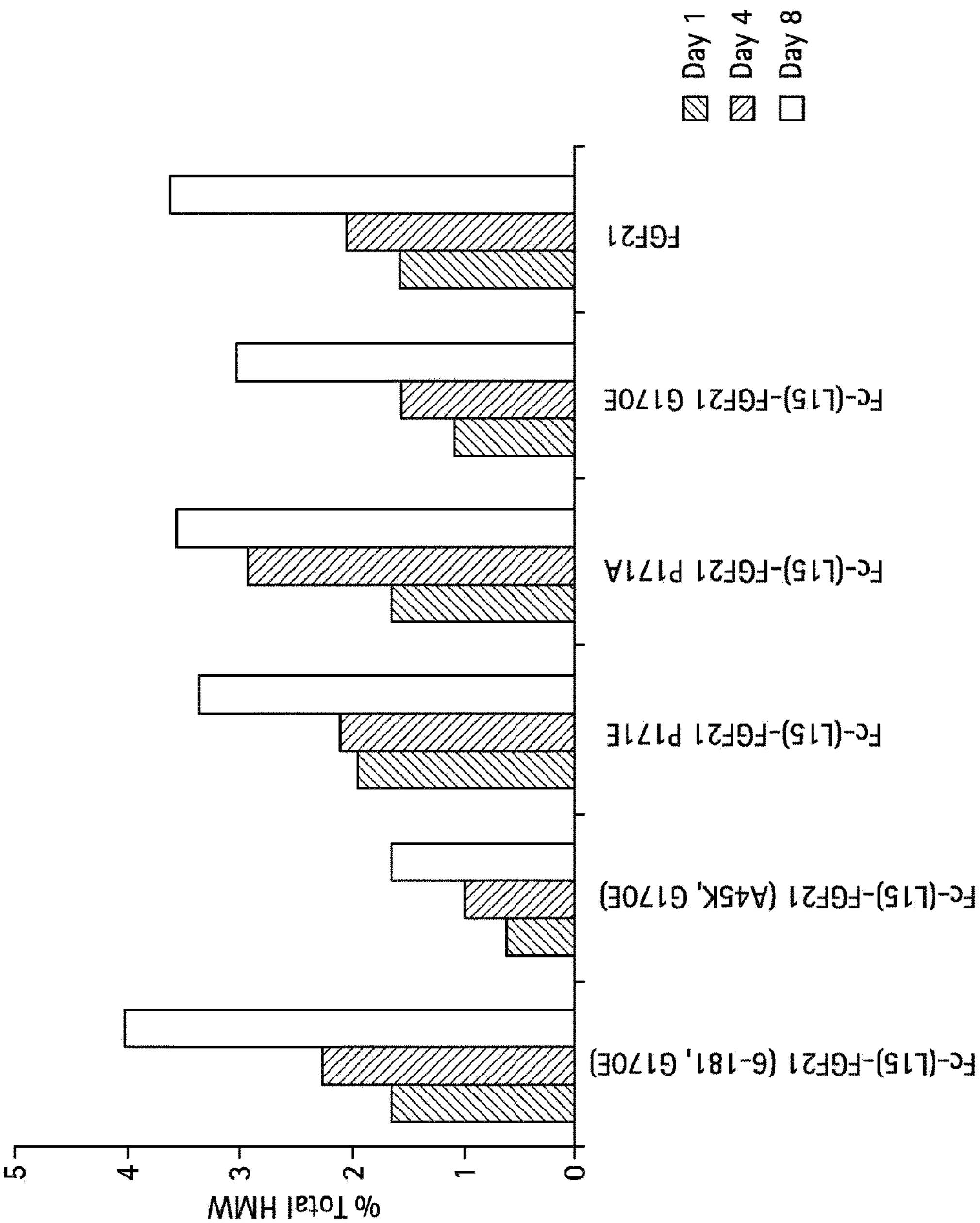
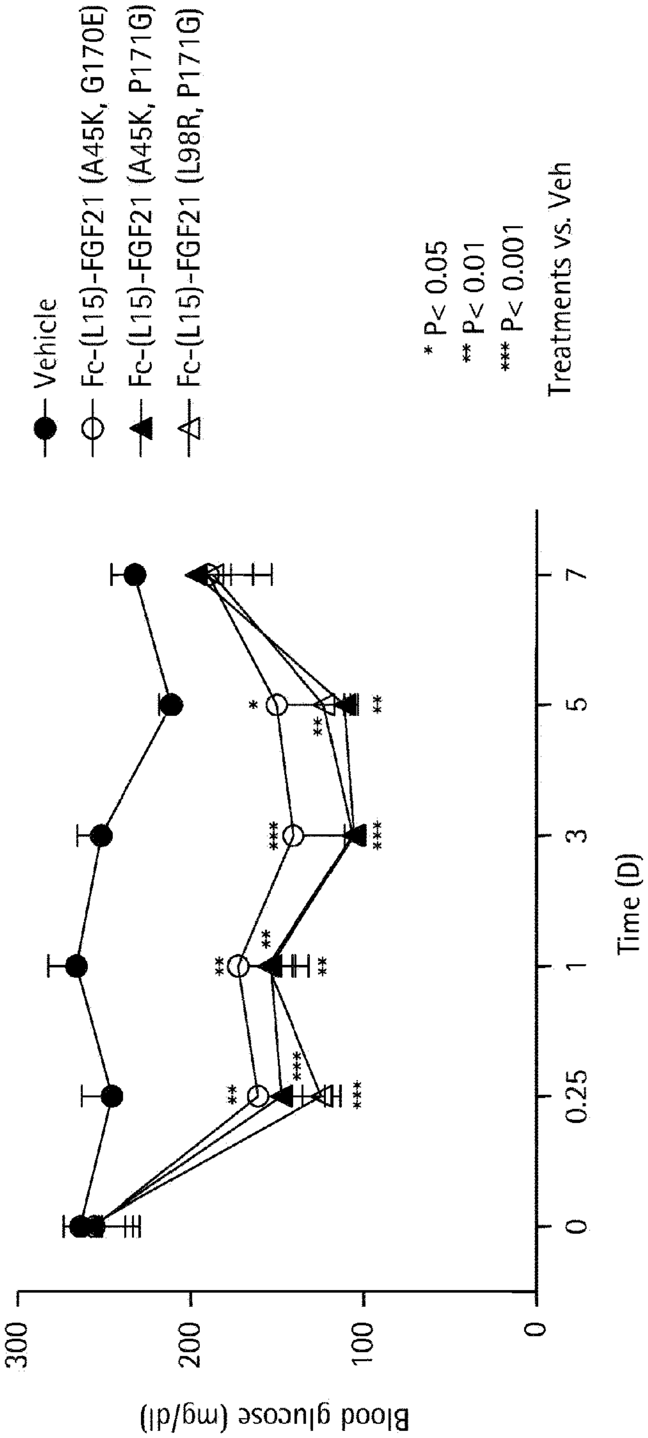

5
4
3
2
1
0
% Total HMW
0
2
4
6
8
10
Day
Fc(L15)-FGF21 (6-181, G170E)
Fc(L15)-FGF21 (A45K, G170E)
Fc(L15)-FGF21 P171E
Fc(L15)-FGF21 P171A
Fc(L15)-FGF21 G170E
FGF21

FIG. 28B



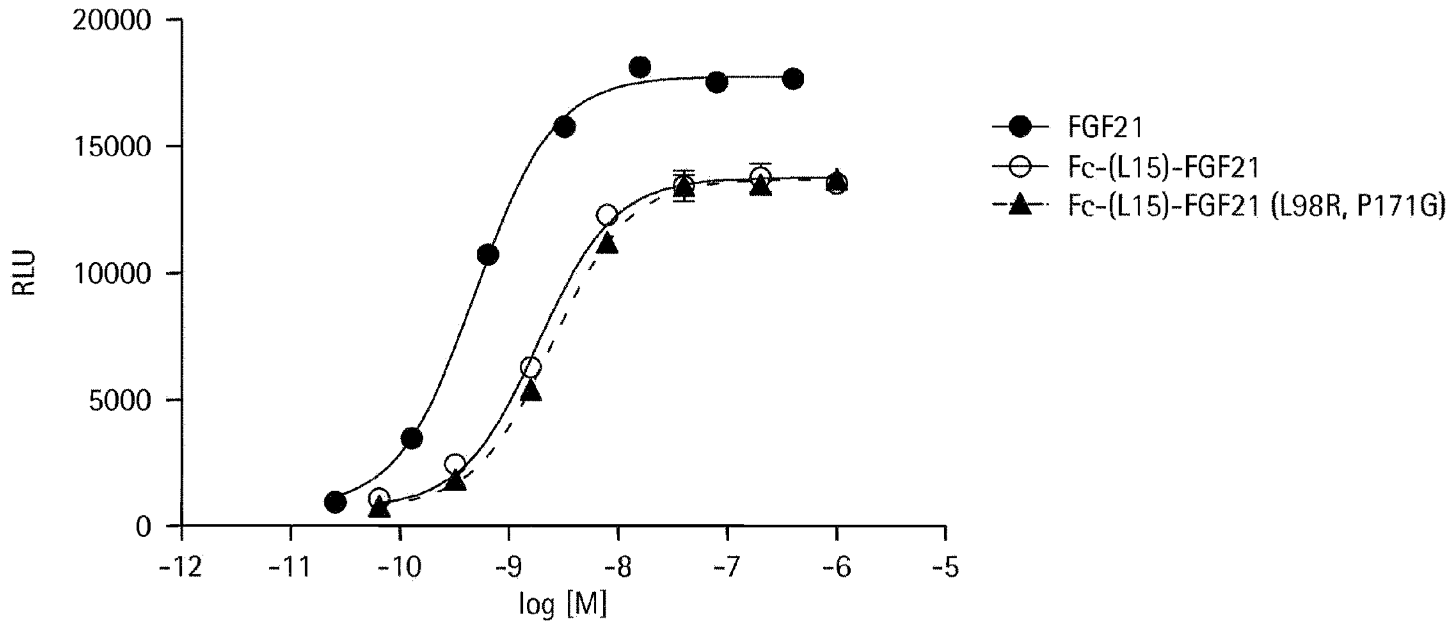
Day 1
Day 4
Day 8
% Total HMW
0
1
2
3
4
5
FGF21
Fc-(L15)-FGF21 G170E
Fc-(L15)-FGF21 P171A
Fc-(L15)-FGF21 P171E
Fc-(L15)-FGF21 (A45K, G170E)
Fc-(L15)-FGF21 (6-181, G170E)

FIG. 29



Vehicle
Fc-(L15)-FGF21 (A45K, G170E)
Fc-(L15)-FGF21 (A45K, P171G)
Fc-(L15)-FGF21 (L98R, P171G)
* P< 0.05
** P< 0.01
*** P< 0.001
Treatments vs. Veh
Blood glucose (mg/dl)
Time (D)

FIG. 30



20000
15000
10000
5000
0
RLU
-12
-11
-10
-9
-8
-7
-6
-5
log [M]
FGF21
Fc-(L15)-FGF21
Fc-(L15)-FGF21 (L98R, P171G)

FIG. 31A

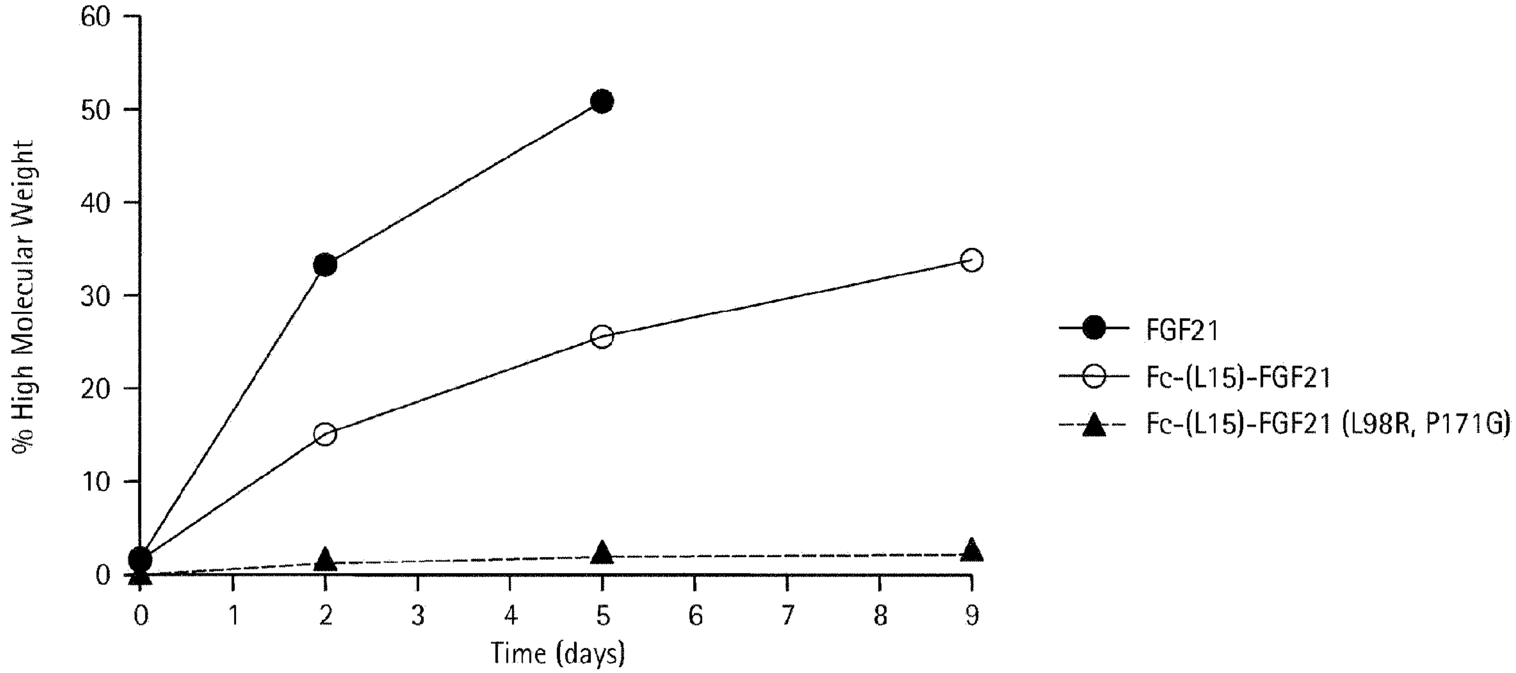

% High Molecular Weight
60
50
40
30
20
10
0
0
1
2
3
4
5
6
7
8
9
Time (days)
FGF21
Fc-(L15)-FGF21
Fc-(L15)-FGF21 (L98R, P171G)

FIG. 31B

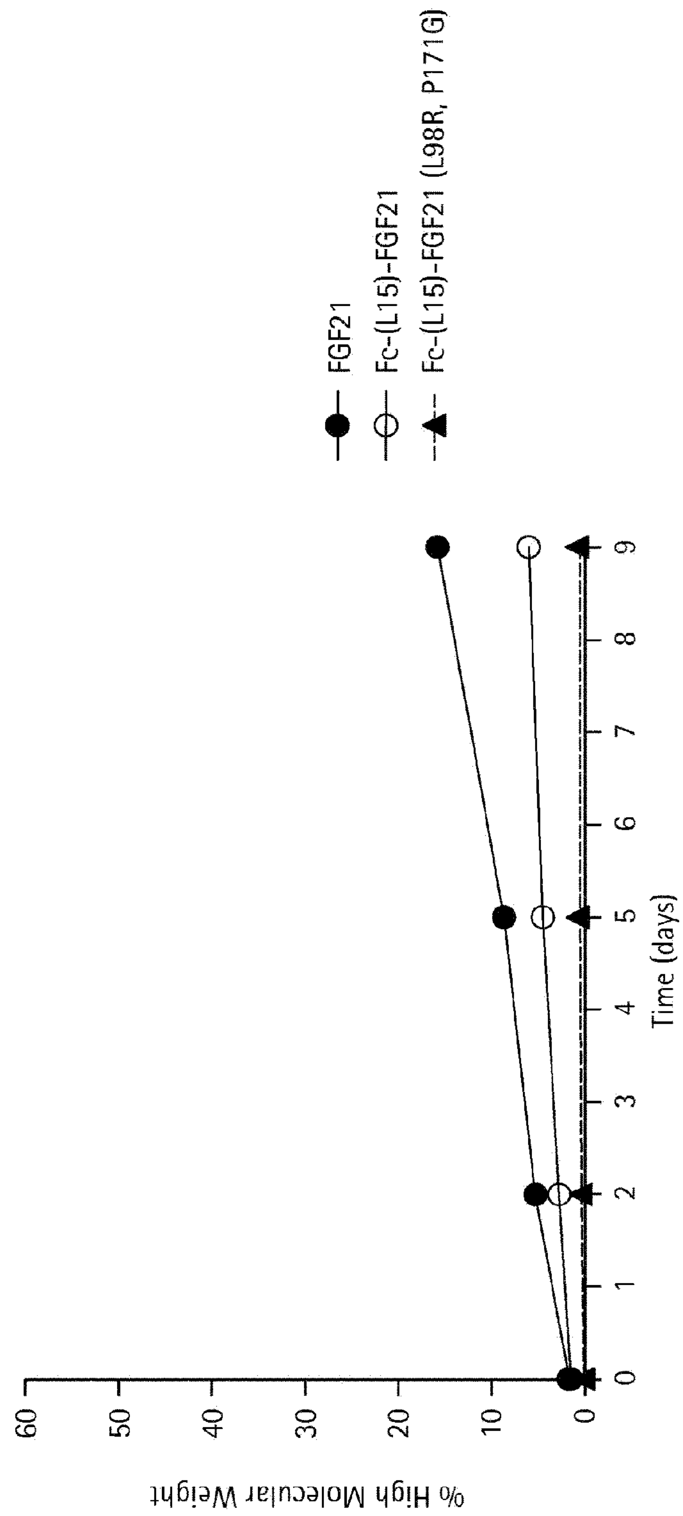

% High Molecular Weight
0
10
20
30
40
50
60
0
1
2
3
4
5
6
7
8
9
Time (days)
FGF21
Fc-(L15)-FGF21
Fc-(L15)-FGF21 (L98R, P171G)

FIG. 32

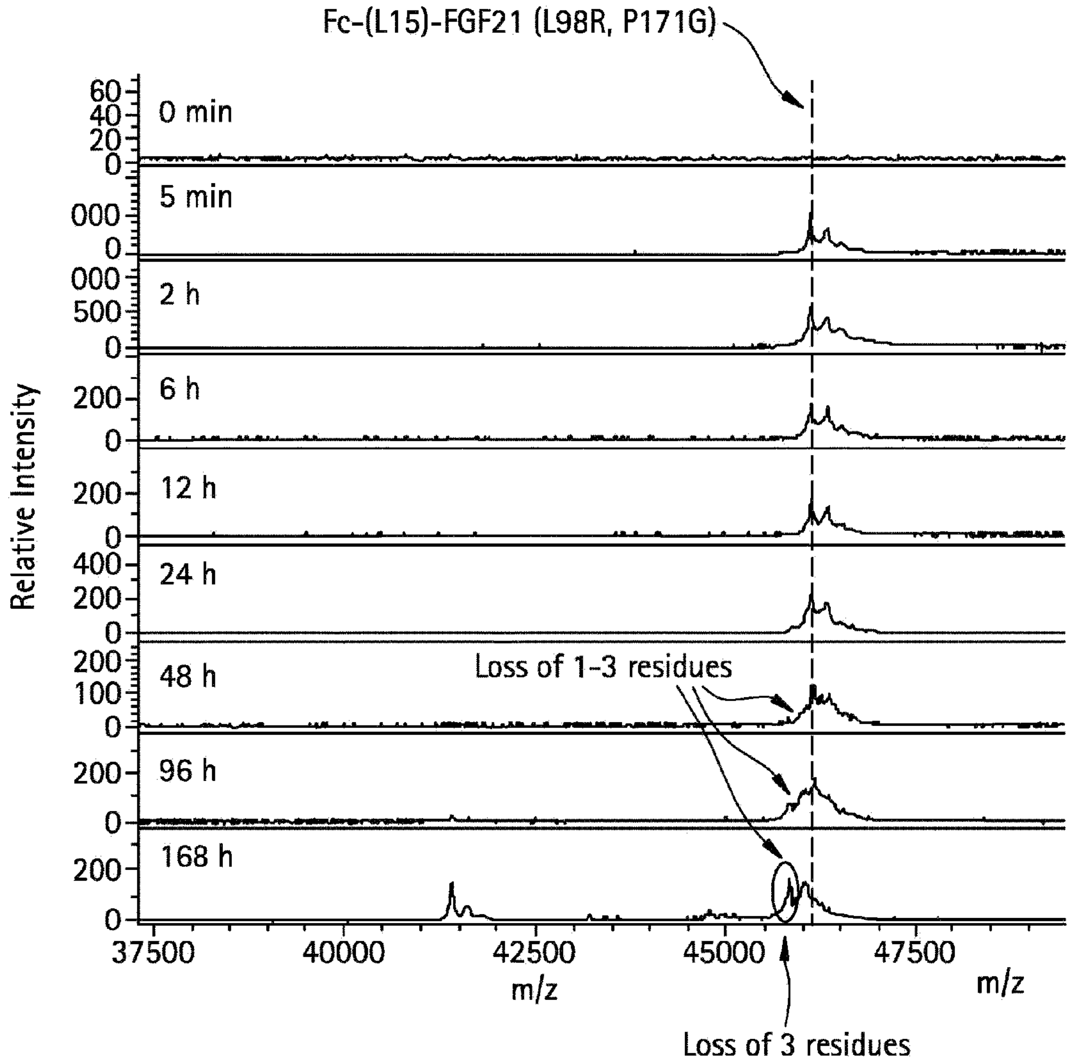

Fc-(L15)-FGF21 (L98R, P171G)
Relative Intensity
0 min
5 min
2 h
6 h
12 h
24 h
48 h
96 h
168 h
Loss of 1-3 residues
Loss of 3 residues
37500
40000
42500
45000
47500
m/z
m/z

FIG. 33

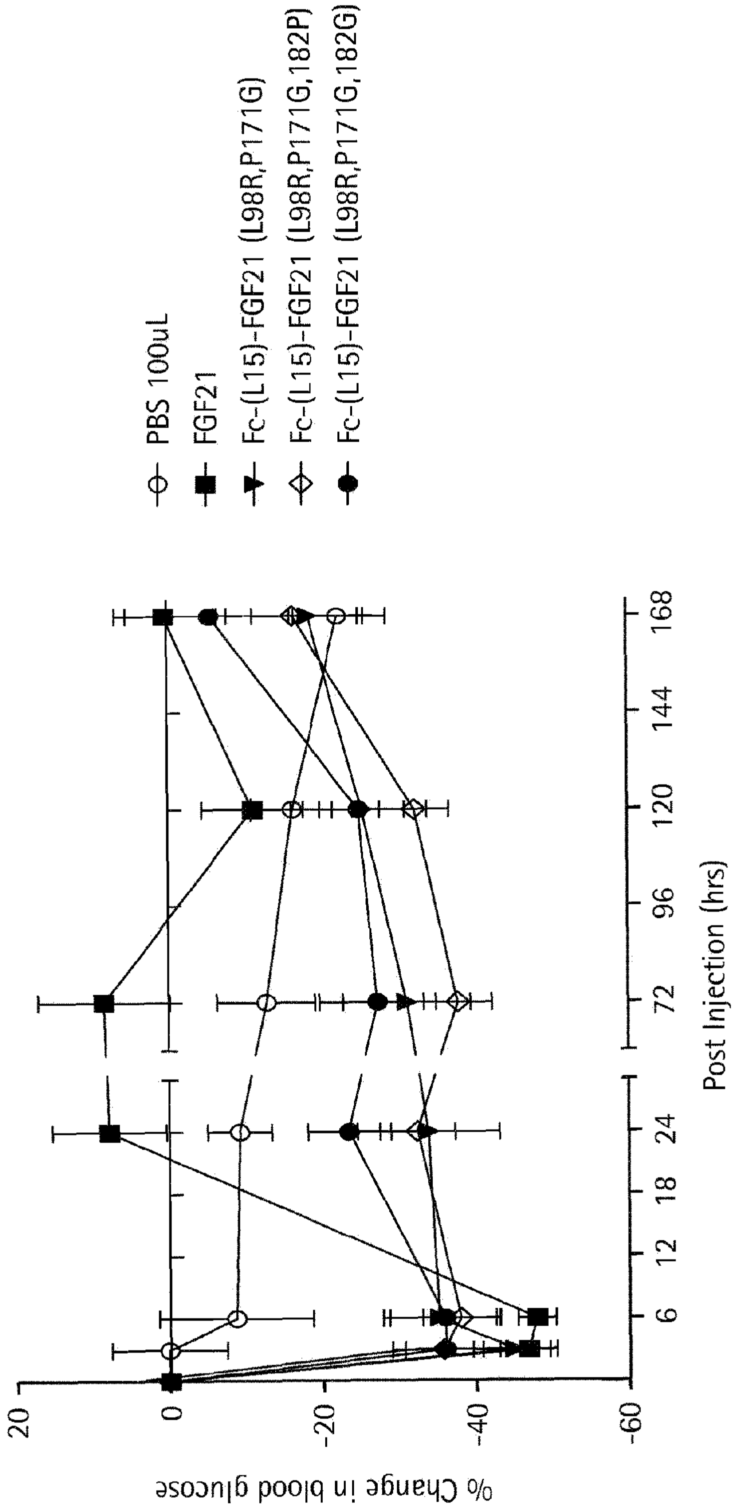

PBS 100uL
FGF21
Fc-(L15)-FGF21 (L98R,P171G)
Fc-(L15)-FGF21 (L98R,P171G,182P)
Fc-(L15)-FGF21 (L98R,P171G,182G)
% Change in blood glucose
20
0
-20
-40
-60
6
12
18
24
72
96
120
144
168
Post Injection (hrs)

FIG. 34

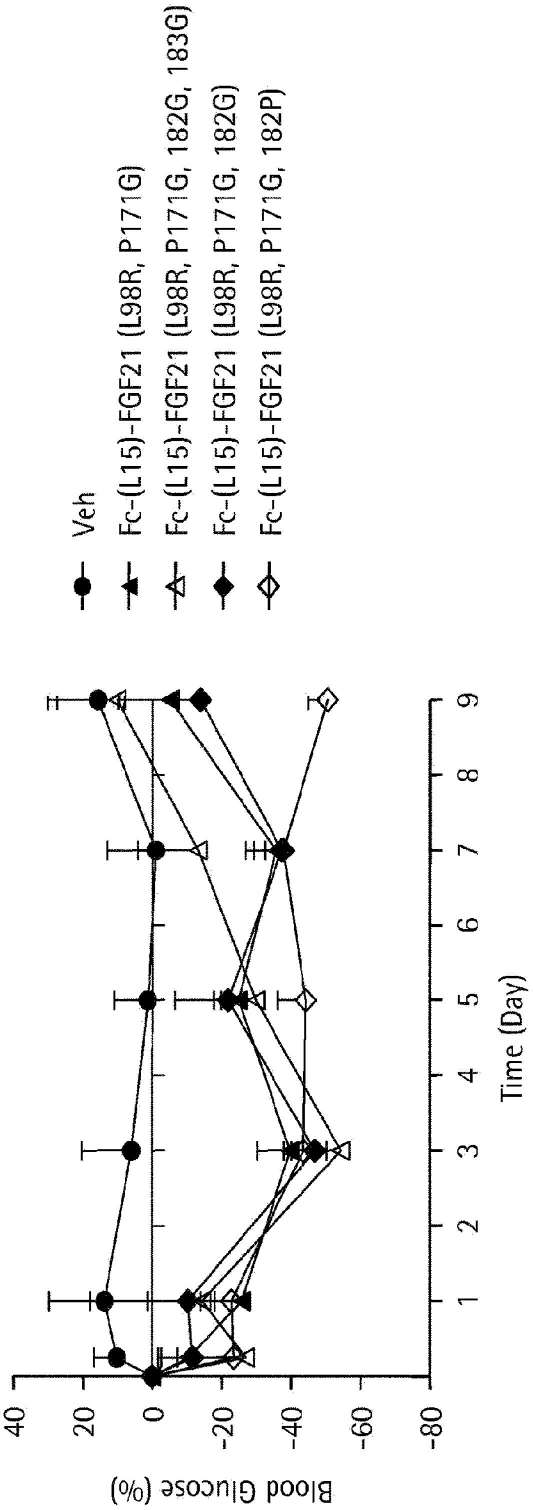

Blood Glucose (%)
40
20
0
-20
-40
-60
-80
1
2
3
4
5
6
7
8
9
Time (Day)
Veh
Fc-(L15)-FGF21 (L98R, P171G)
Fc-(L15)-FGF21 (L98R, P171G, 182G, 183G)
Fc-(L15)-FGF21 (L98R, P171G, 182G)
Fc-(L15)-FGF21 (L98R, P171G, 182P)

FIG. 35

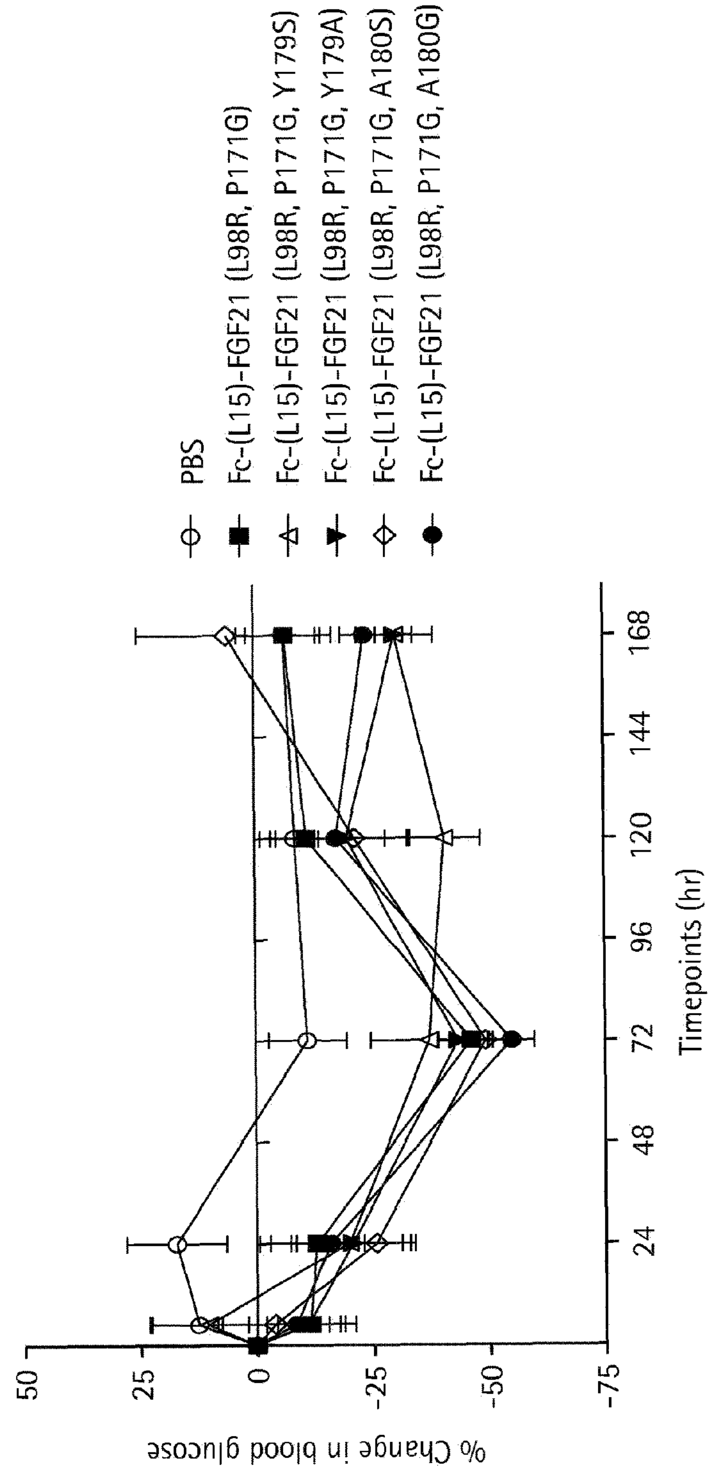

% Change in blood glucose
50
25
0
-25
-50
-75
24
48
72
96
120
144
168
Timepoints (hr)
PBS
Fc-(L15)-FGF21 (L98R, P171G)
Fc-(L15)-FGF21 (L98R, P171G, Y179S)
Fc-(L15)-FGF21 (L98R, P171G, Y179A)
Fc-(L15)-FGF21 (L98R, P171G, A180S)
Fc-(L15)-FGF21 (L98R, P171G, A180G)

FIG. 36

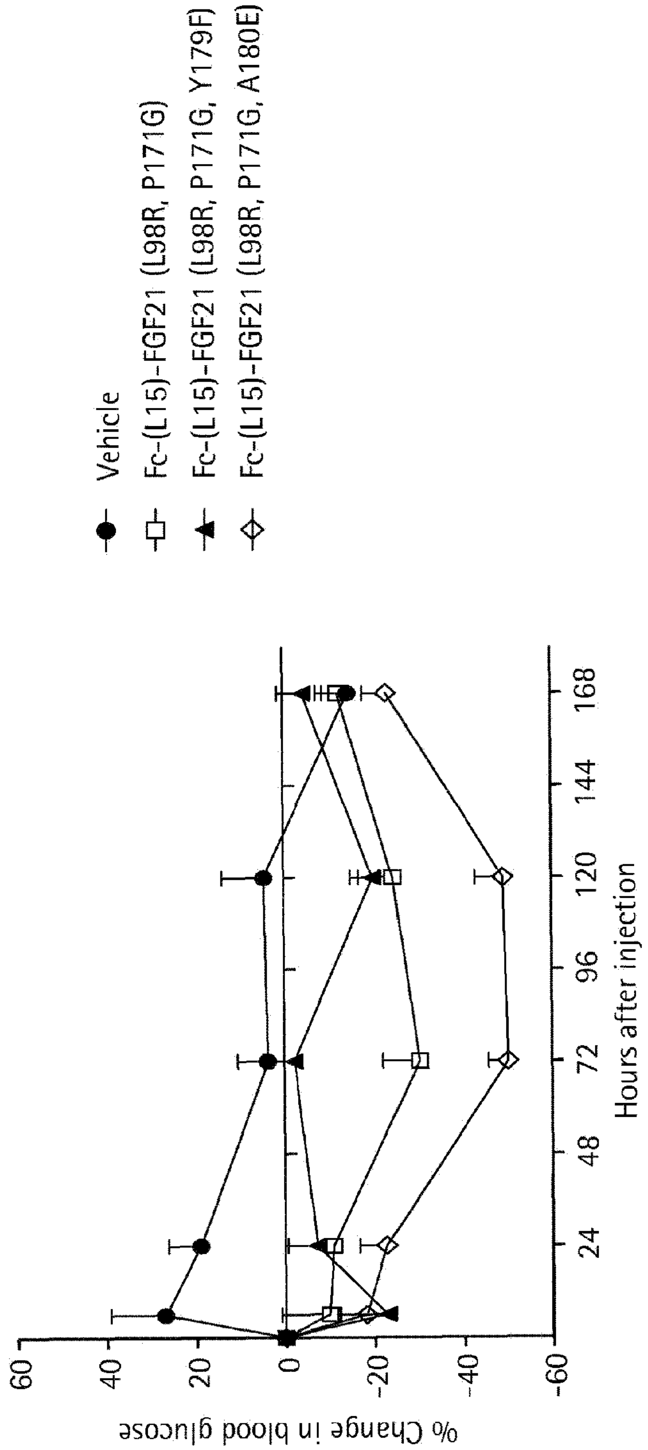

Vehicle
Fc-(L15)-FGF21 (L98R, P171G)
Fc-(L15)-FGF21 (L98R, P171G, Y179F)
Fc-(L15)-FGF21 (L98R, P171G, A180E)
% Change in blood glucose
60
40
20
0
-20
-40
-60
24
48
72
96
120
144
168
Hours after injection

FIG. 37

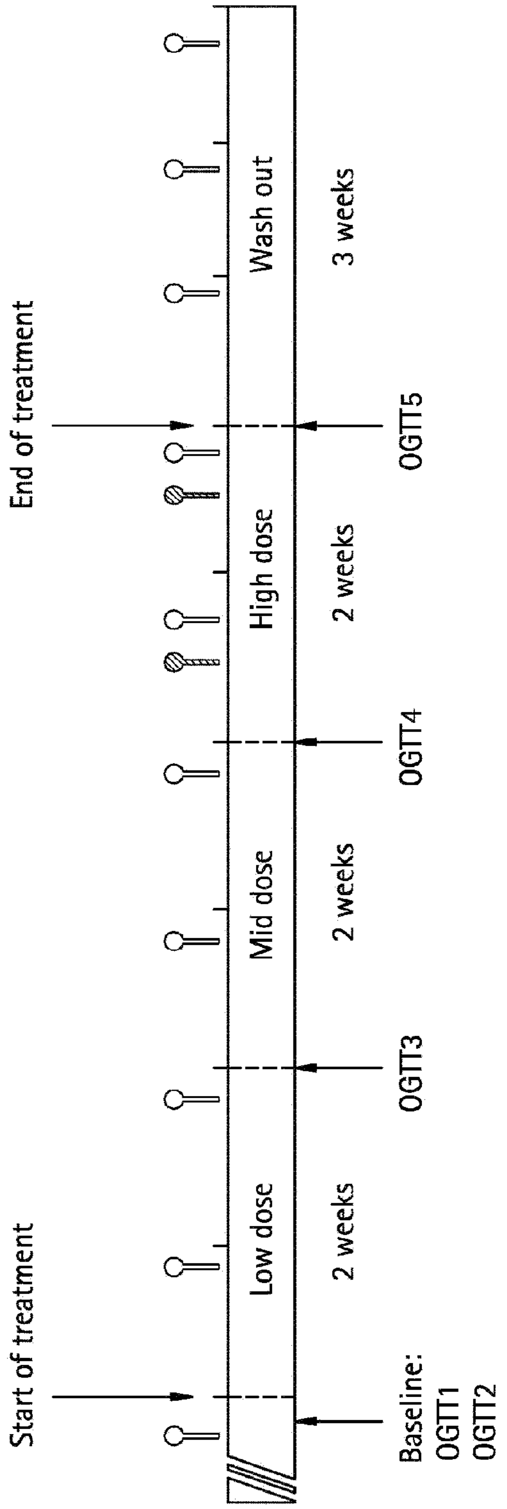

Start of treatment
End of treatment
Low dose
2 weeks
Mid dose
2 weeks
High dose
2 weeks
Wash out
3 weeks
Baseline:
OGTT1
OGTT2
OGTT3
OGTT4
OGTT5

FIG. 38A

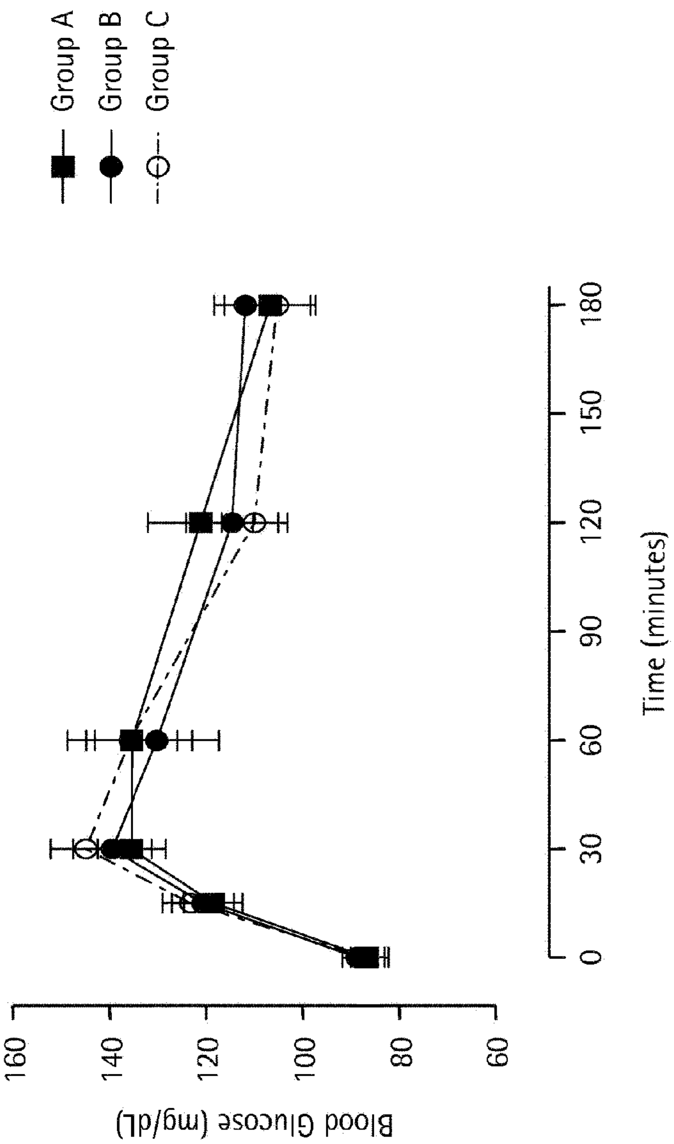

Group A
Group B
Group C
Blood Glucose (mg/dL)
160
140
120
100
80
60
0
30
60
90
120
150
180
Time (minutes)

FIG. 38B

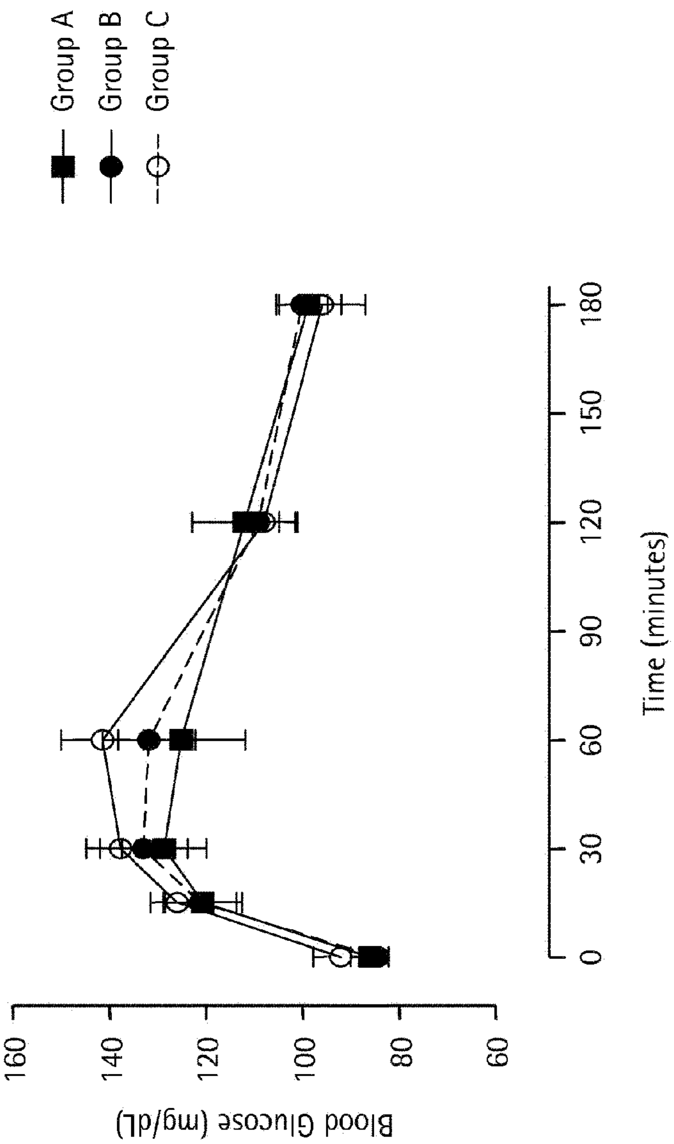

Group A
Group B
Group C
Blood Glucose (mg/dL)
160
140
120
100
80
60
0
30
60
90
120
150
180
Time (minutes)

FIG. 38C

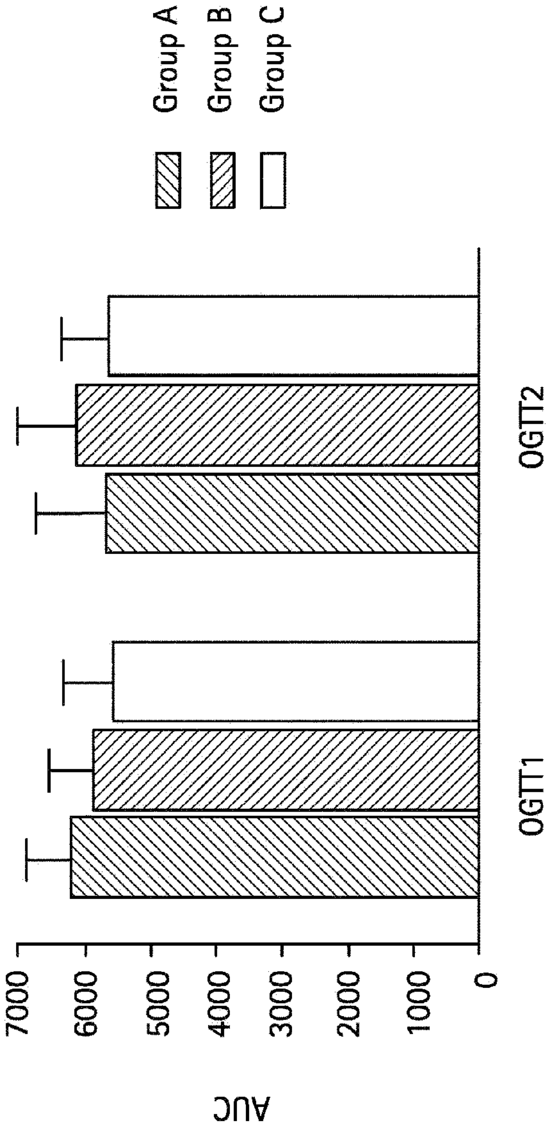

Group A
Group B
Group C
AUC
7000
6000
5000
4000
3000
2000
1000
0
OGTT1
OGTT2

FIG. 38D

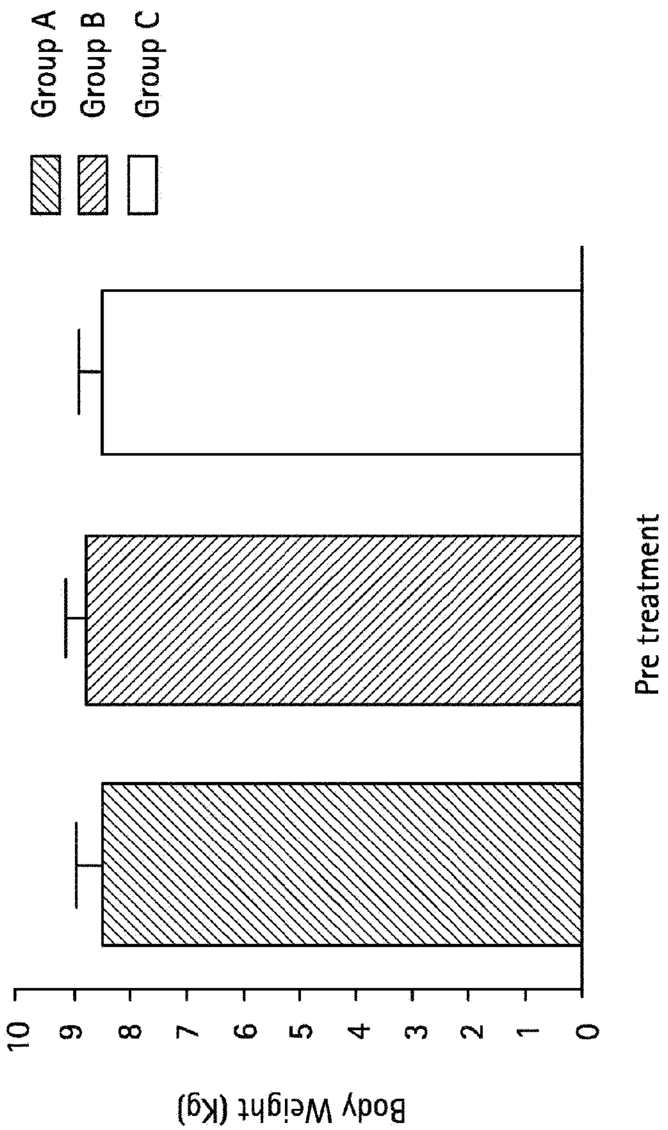

Group A
Group B
Group C
Body Weight (Kg)
0
1
2
3
4
5
6
7
8
9
10
Pre treatment

FIG. 39

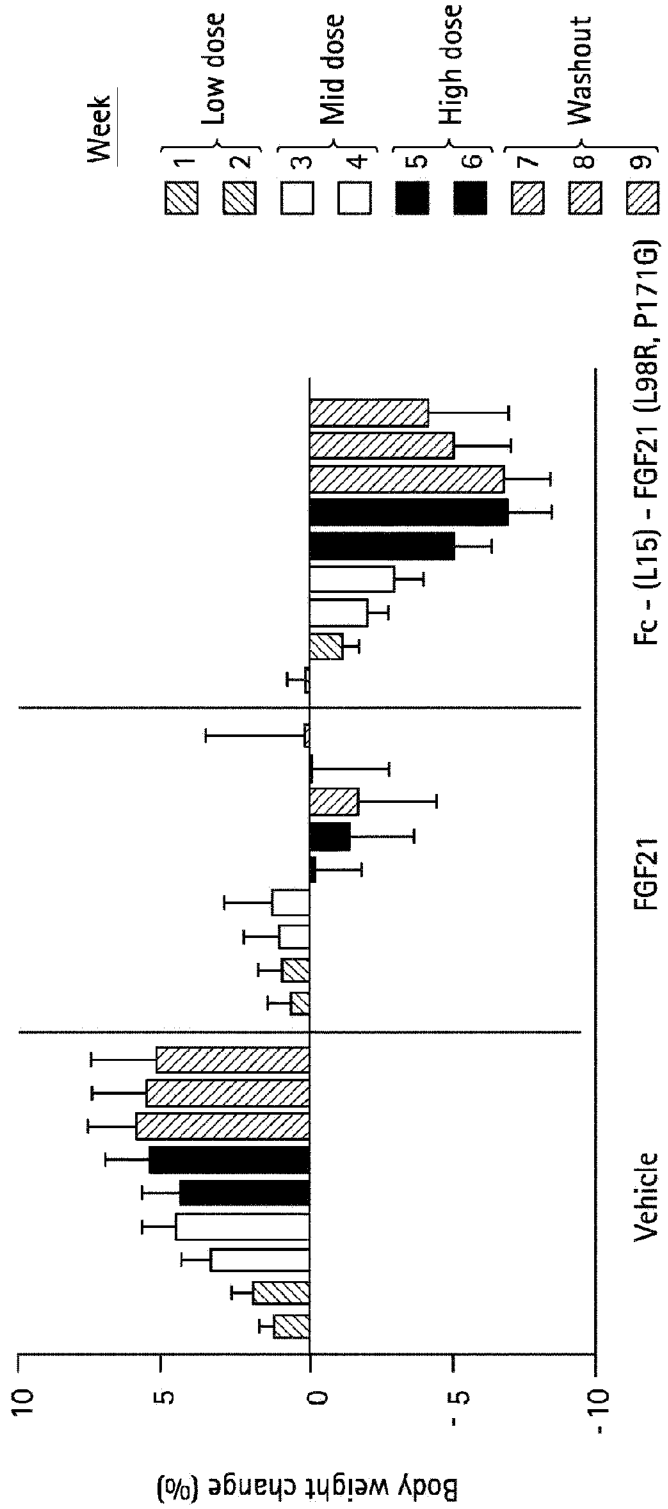

Body weight change (%)
10
5
0
-5
-10
Vehicle
FGF21
Fc - (L15) - FGF21 (L98R, P171G)
Week
1
2
Low dose
3
4
Mid dose
5
6
High dose
7
8
9
Washout

FIG. 40

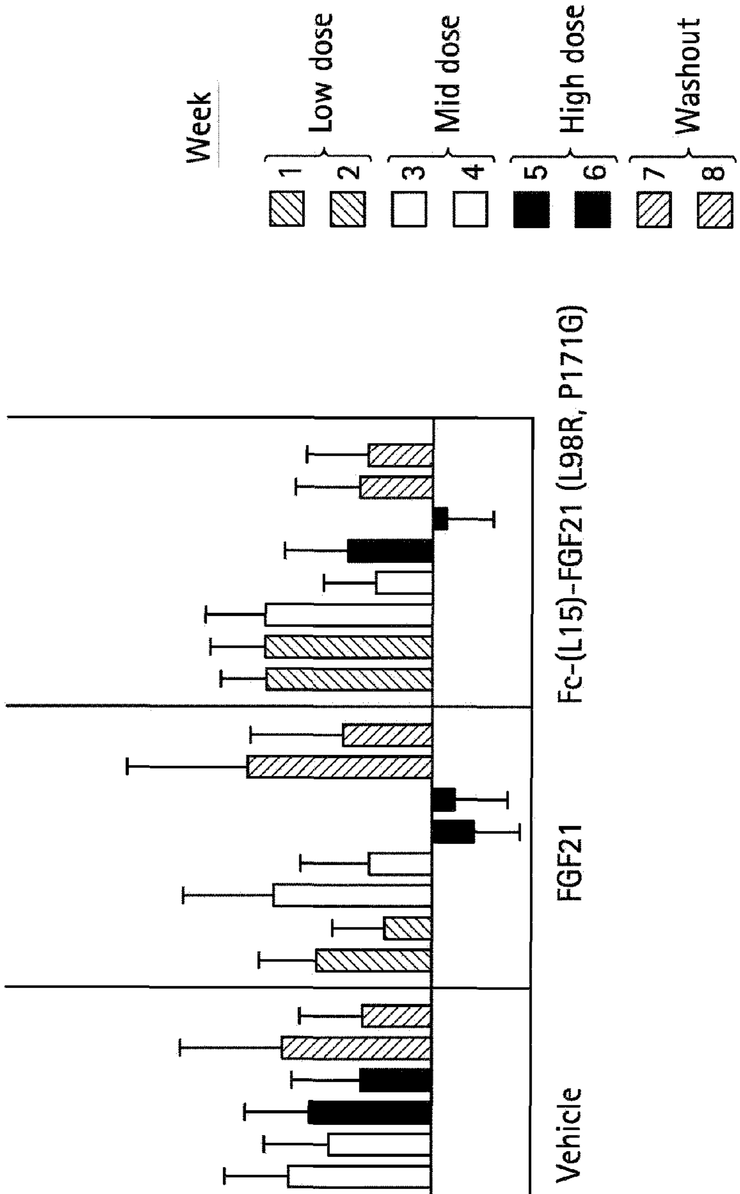

Insulin Change from baseline (%)
125
100
75
50
25
0
-25
Vehicle
FGF21
Fc-(L15)-FGF21 (L98R, P171G)
Week
1
2
Low dose
3
4
Mid dose
5
6
High dose
7
8
Washout

FIG. 41

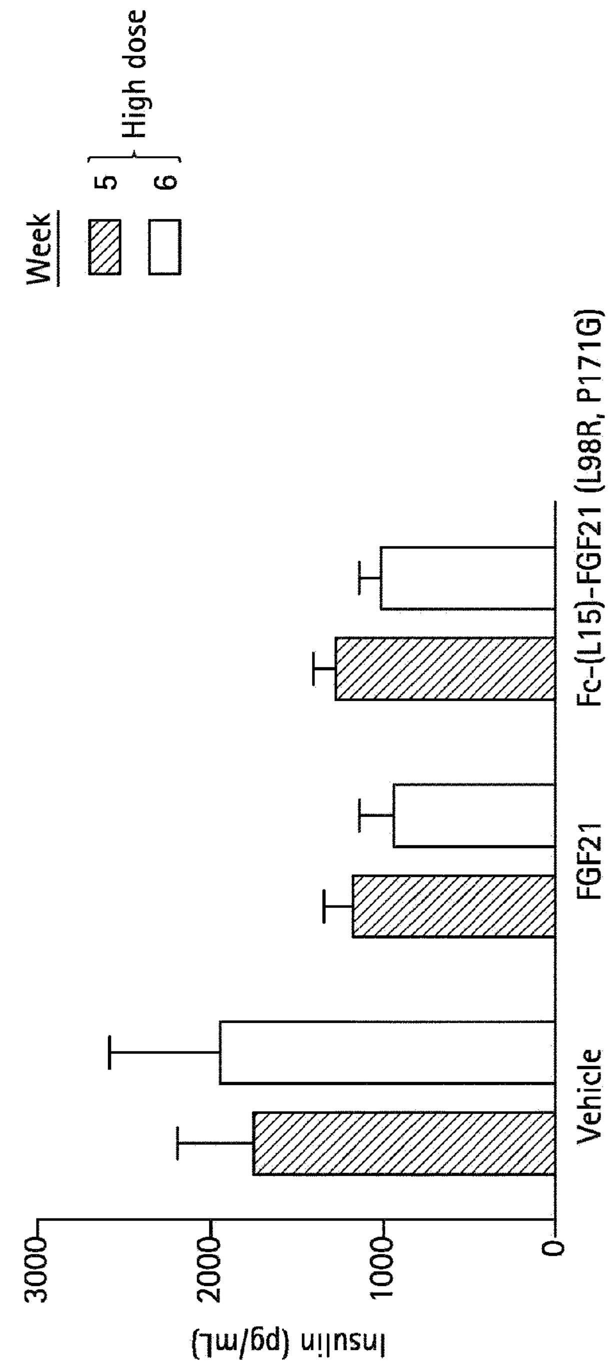
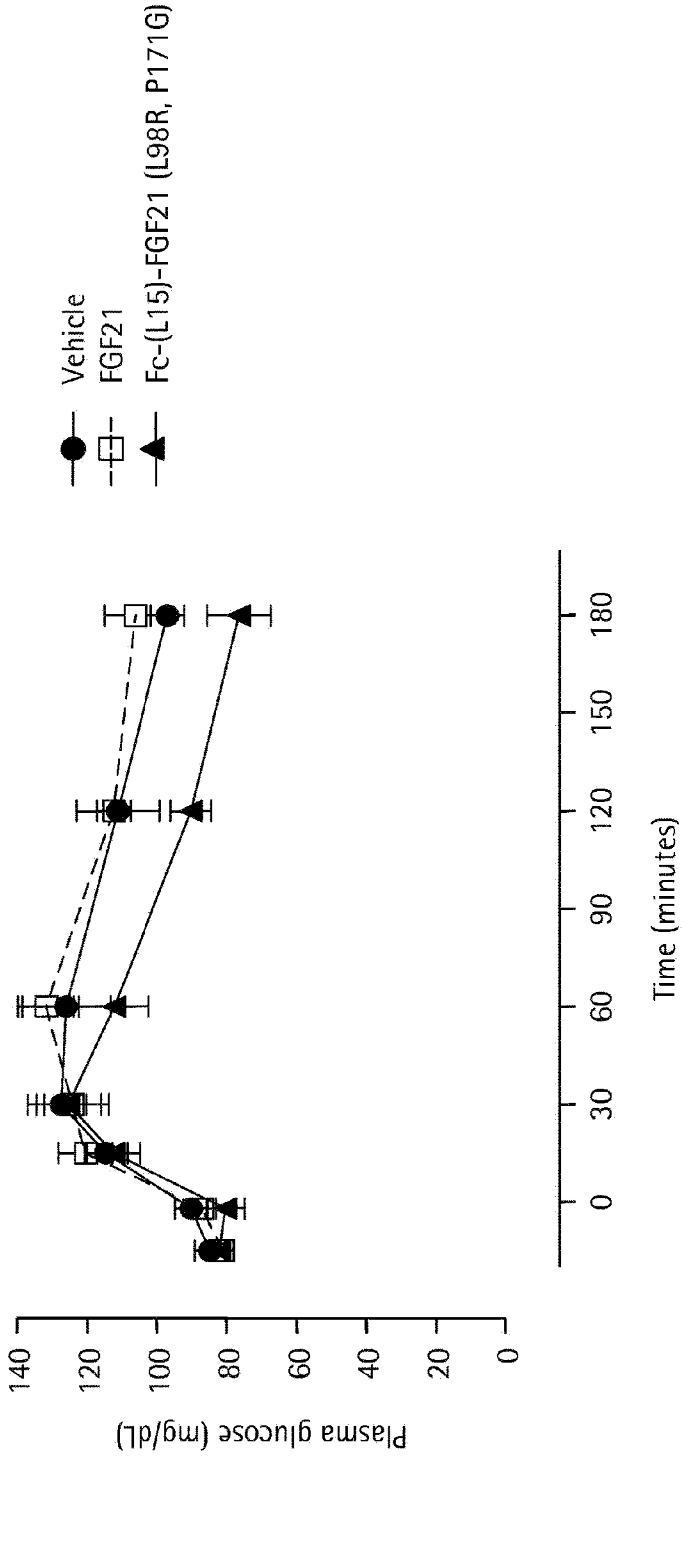

Week
5
6
High dose
Insulin (pg/mL)
3000
2000
1000
0
Vehicle
FGF21
Fc-(L15)-FGF21 (L98R, P171G)

FIG. 42



Vehicle
FGF21
Fc-(L15)-FGF21 (L98R, P171G)
Plasma glucose (mg/dL)
140
120
100
80
60
40
20
0
0
30
60
90
120
150
180
Time (minutes)

FIG. 43

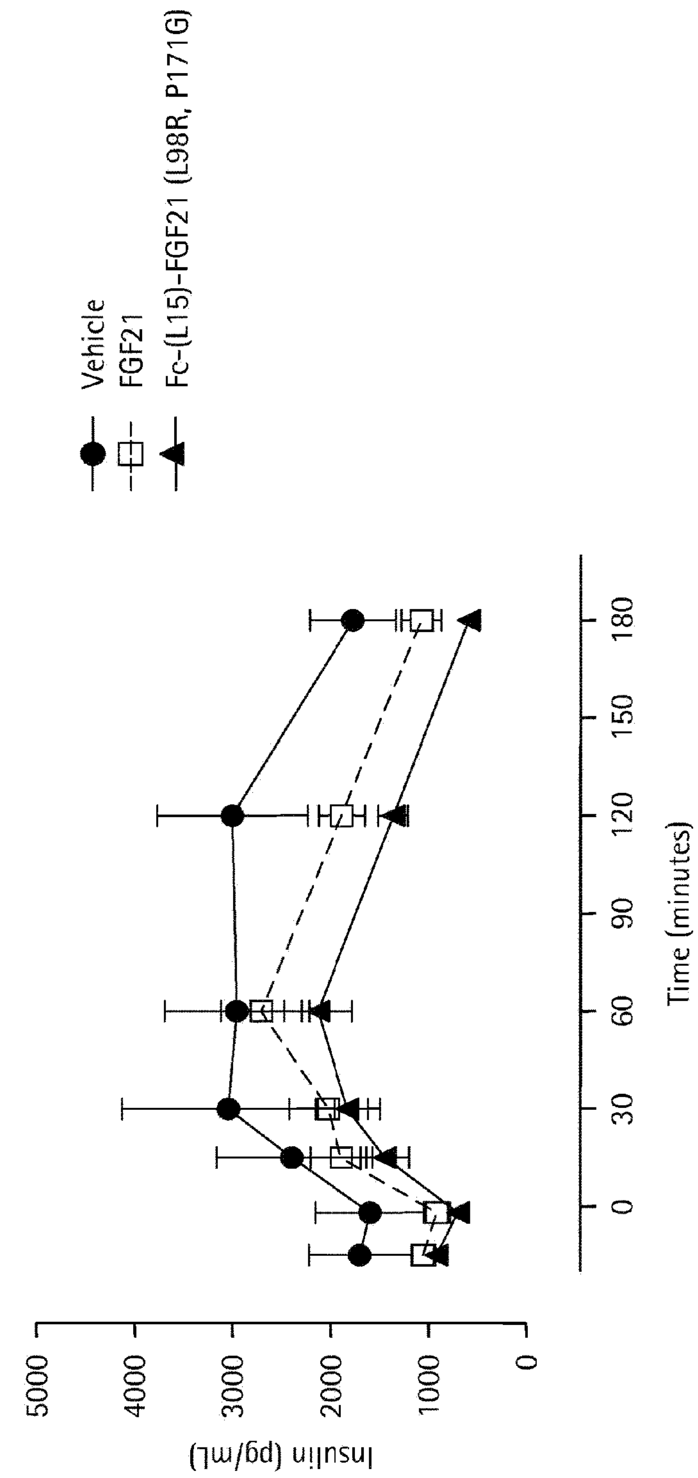
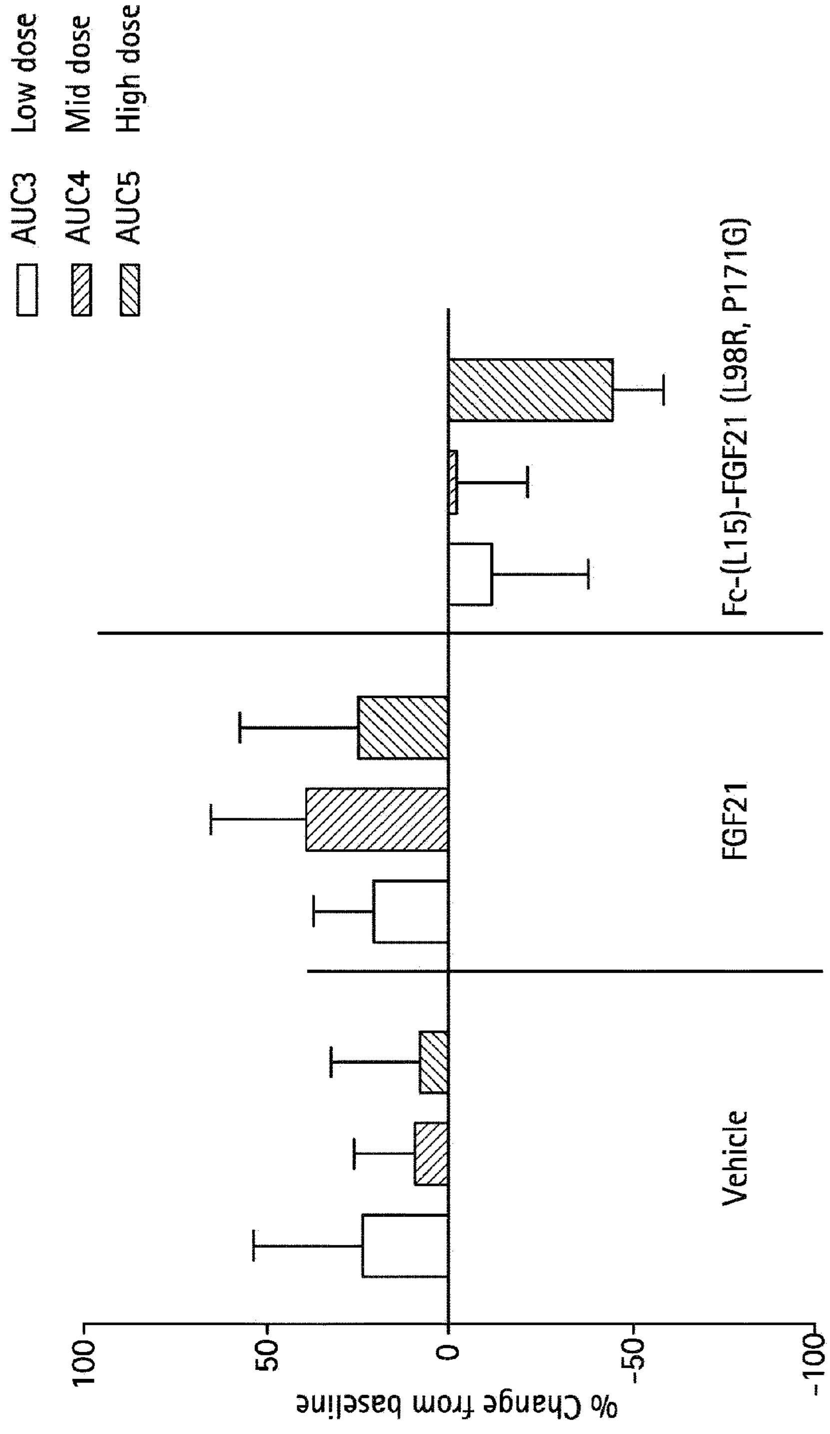

Vehicle
FGF21
Fc-(L15)-FGF21 (L98R, P171G)
Insulin (pg/mL)
5000
4000
3000
2000
1000
0
Time (minutes)
0
30
60
90
120
150
180

FIG. 44



AUC3 Low dose
AUC4 Mid dose
AUC5 High dose
% Change from baseline
100
50
0
-50
-100
Vehicle
FGF21
Fc-(L15)-FGF21 (L98R, P171G)

FIG. 45

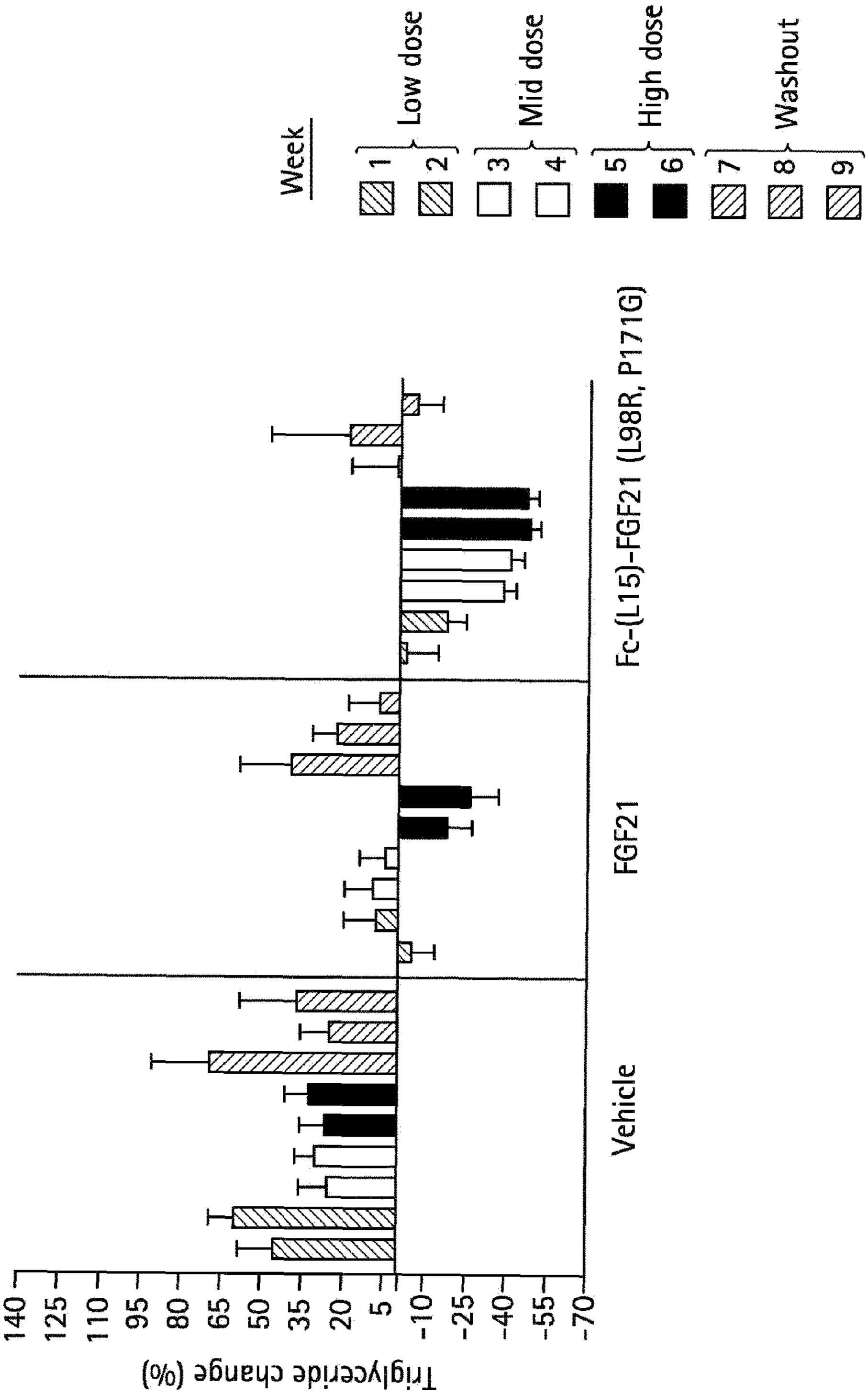

Triglyceride change (%)
140
125
110
95
80
65
50
35
20
5
-10
-25
-40
-55
-70
Vehicle
FGF21
Fc-(L15)-FGF21 (L98R, P171G)
Week
1
2
Low dose
3
4
Mid dose
5
6
High dose
7
8
9
Washout

FIG. 46

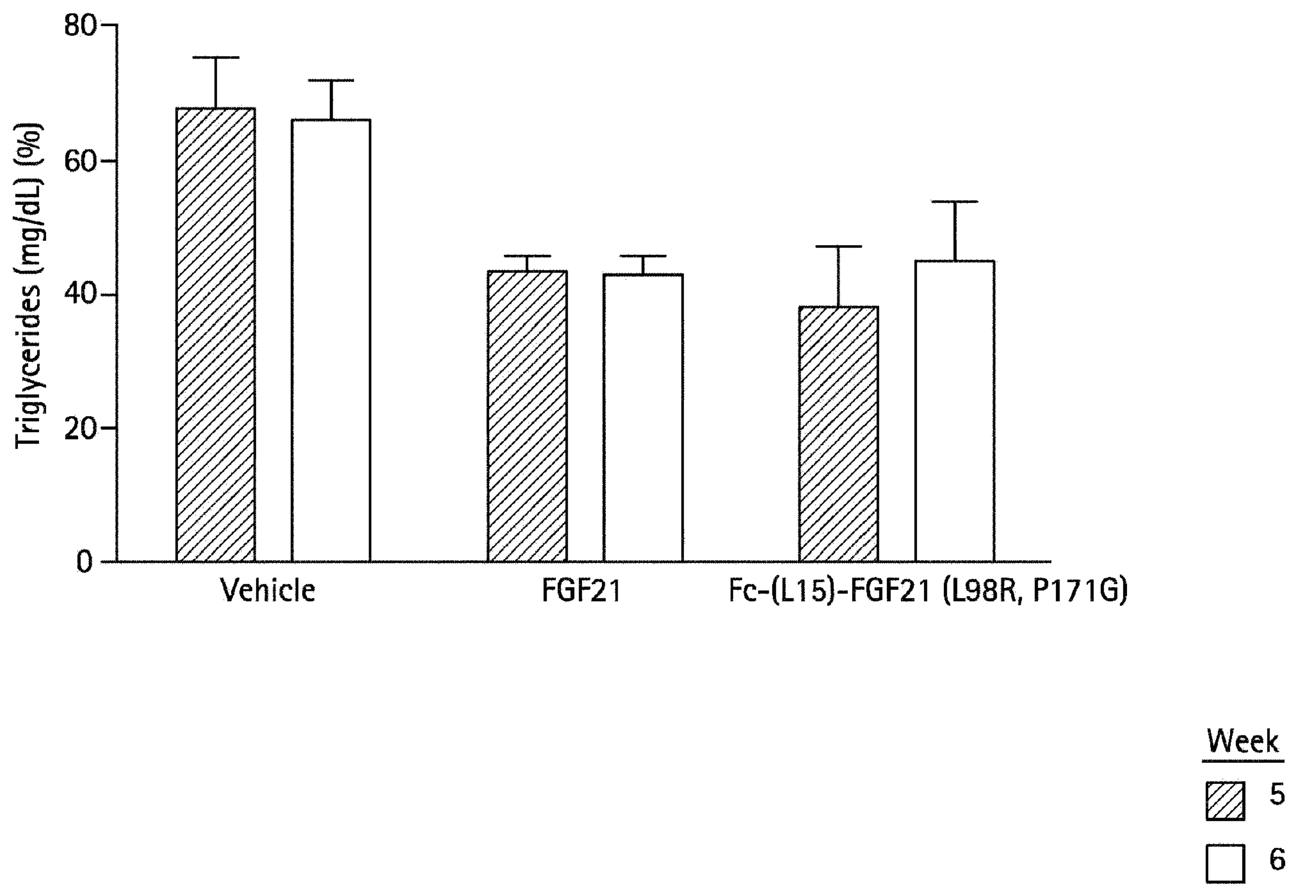
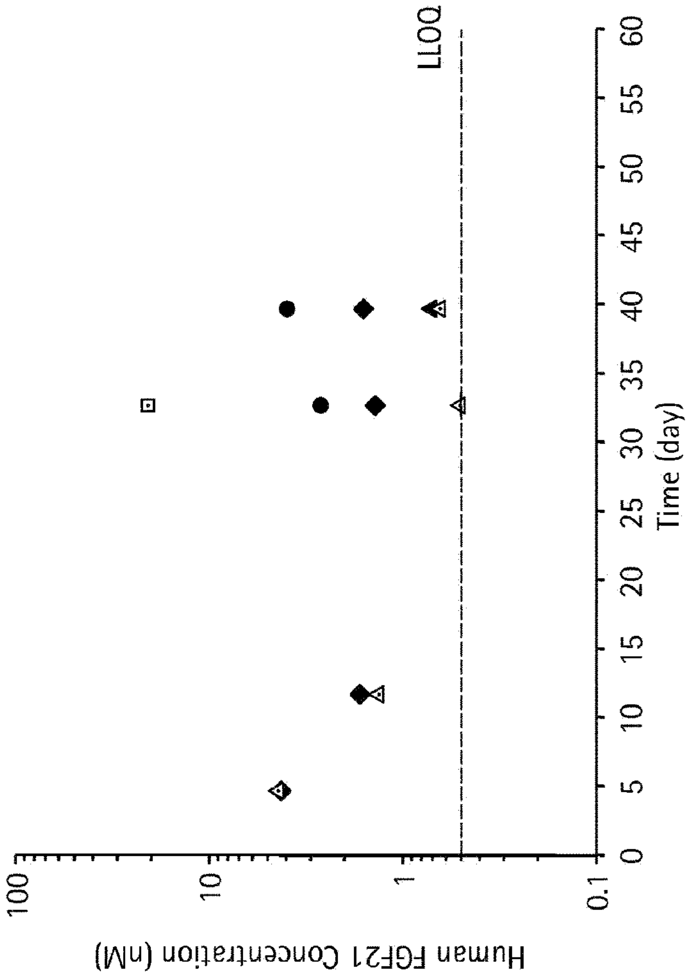

Triglycerides (mg/dL) (%)
80
60
40
20
0
Vehicle
FGF21
Fc-(L15)-FGF21 (L98R, P171G)
Week
5
6

FIG. 47



Human FGF21 Concentration (nM)
100
10
1
0.1
LLOQ
0
5
10
15
20
25
30
35
40
45
50
55
60
Time (day)

FIG. 48

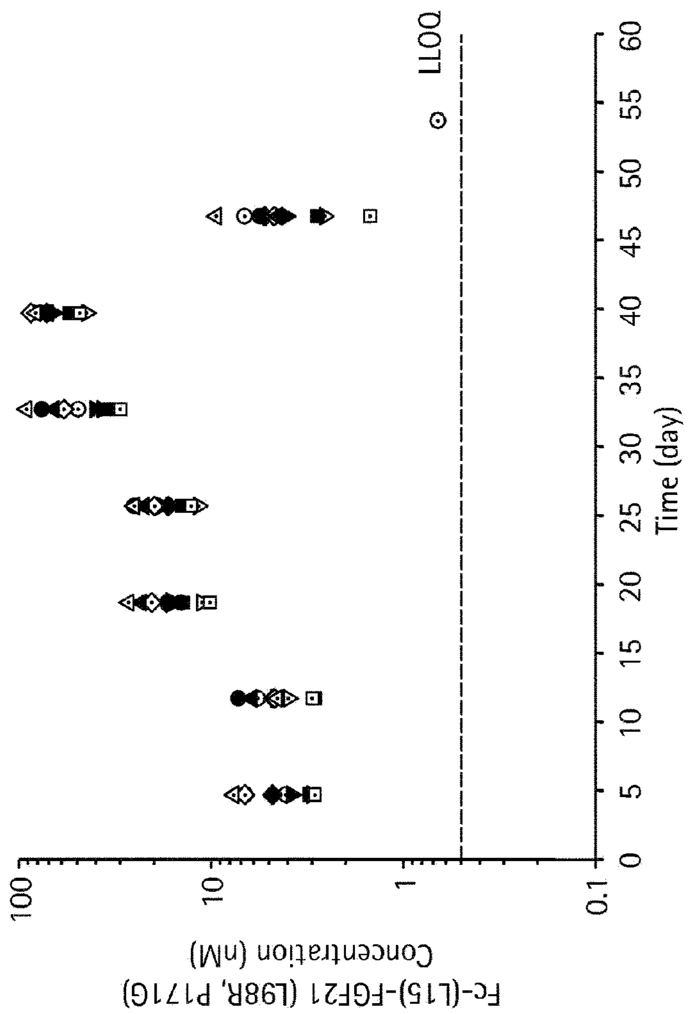

LLOQ
Time (day)
Fc-(L15)-FGF21 (L98R, P171G)
Concentration (nM)
100
10
1
0.1
0
5
10
15
20
25
30
35
40
45
50
55
60

FIG. 49

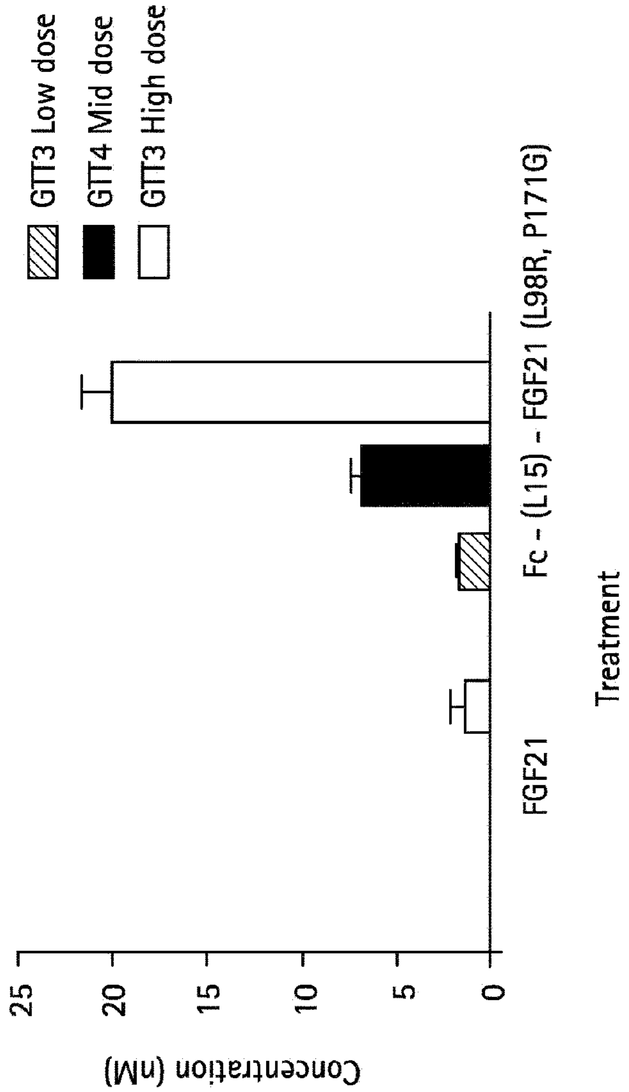
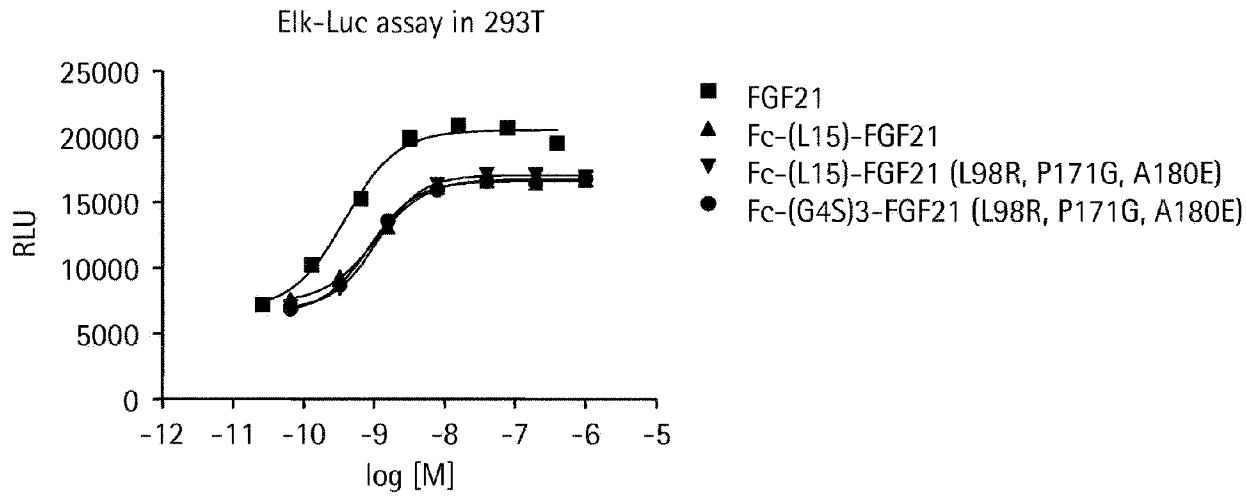

GTT3 Low dose
GTT4 Mid dose
GTT3 High dose
Concentration (nM)
25
20
15
10
5
0
FGF21
Fc – (L15) – FGF21 (L98R, P171G)
Treatment

FIG. 50

Fc-(G4S)3-FGF21 (L98R, P171G, A190E)

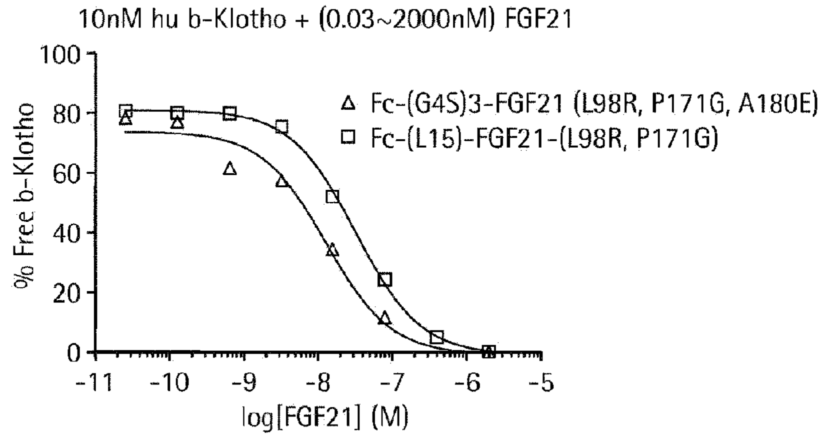
MDKTHTCPPCPAPELLGGPSVFLFPPKPKDTLMISRTPEVTCVVVDVSHEDPEVKFNWYVDGVEVHNAKTKPREEQYNST
YRVVSVLTVLHQDWLNGKEYKCKVSNKALPAPIEKTISKAKGQPREPQVYTLPPSRDELTKNQVSLTCLVKGFYPSDIAV
EWESNGQPENNYKTTPPVLDSDGSFFLYSKLTVDKSRWQQGNVFSCSVMHEALHNHYTQKSLSLSPGK*GGGGSGGGGSGG*
*GGS*HPIPDSSPLLQFGGQVRQRYLYTDDAQQTEAHLEIREDGTVGGAADQSPESLLQLKALKPGVIQILGVKTSRFLCQR
PDGALYGSLHFDPEACSFRE**R**LLEDGYNVYQSEAHGLPLHLPGNKSPHRDPAPRGPARFLPLPGLPPAPPEPPGILAPQP
PDVGSSDPLSMVG**G**SQGRSPSY**E**S

FIG. 51

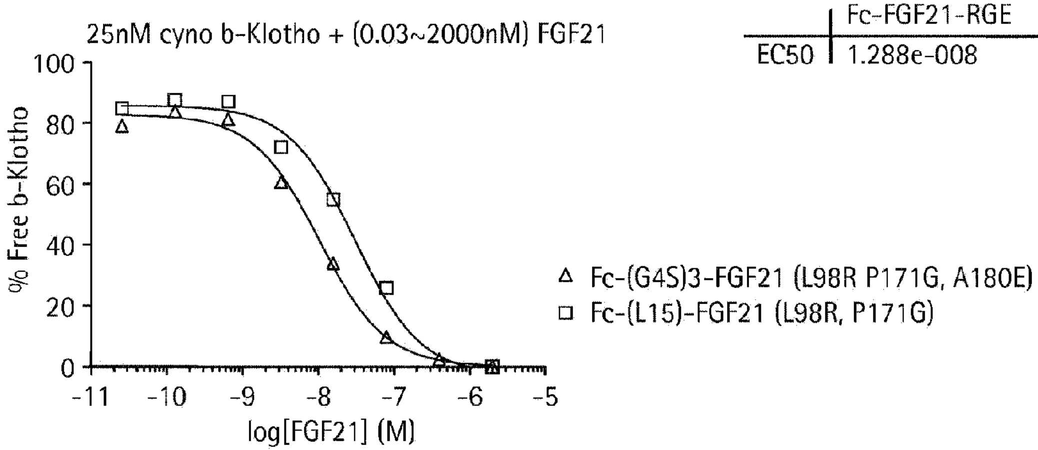


	FGF21	Fc-(L15)-FGF21	Fc-L15-FGF21(L98R/P171G/A180E)	Fc-G4S-FGF21(L98R/P171G/A180E)
EC50	3.831e-010	1.034e-009	1.095e-009	8.515e-010

FIG. 52



	Fc-FGF21-RGE	Fc-FGF21-RG
EC50	1.288e-008	3.225e-008



	Fc-(L15)-FGF21 (L98R P171G, AE	Fc-(L15)-FGF21 (L98R, P171G)
EC50	1.038e-008	3.081e-008

FIG. 53A

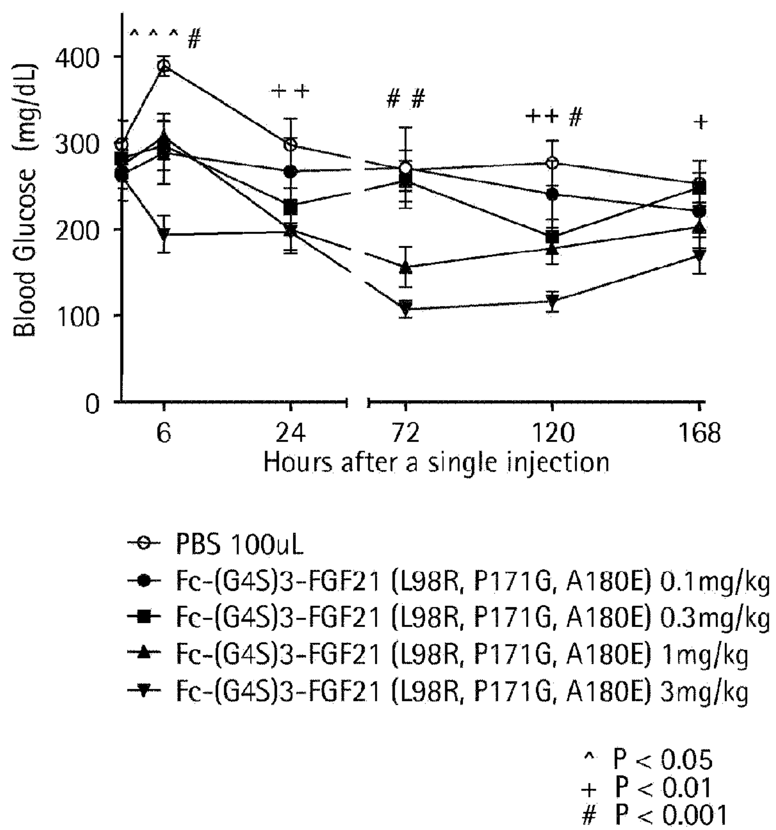


FIG. 53B

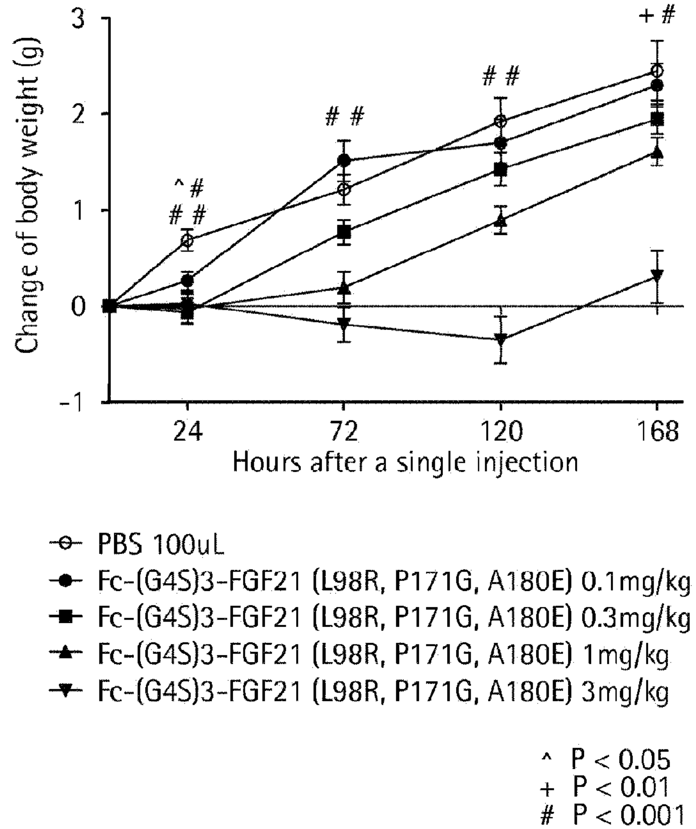
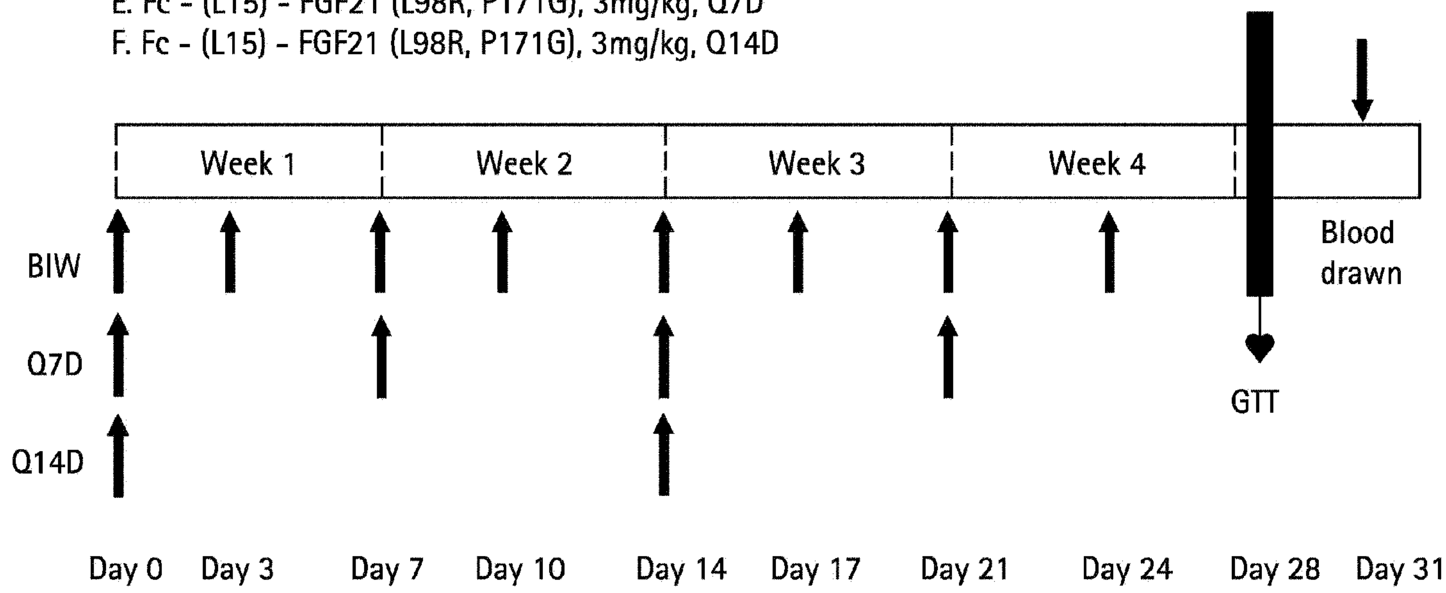


FIG. 54

A. Vehicle Q7D
B. Fc - (G4S)3 - FGF21 (L98R, P171G, A180E), 3mg/kg, Q7D
C. Fc - (G4S)3 - FGF21 (L98R, P171G, A180E), 3mg/kg, Q14D
D. Fc - (L15) - FGF21 (L98R, P171G), 3mg/kg, BIW
E. Fc - (L15) - FGF21 (L98R, P171G), 3mg/kg, Q7D
F. Fc - (L15) - FGF21 (L98R, P171G), 3mg/kg, Q14D



Buffer: 10mM Tris, 2.2% sucrose, 3.3% Sorbitol; pH 8.5

FIG. 55

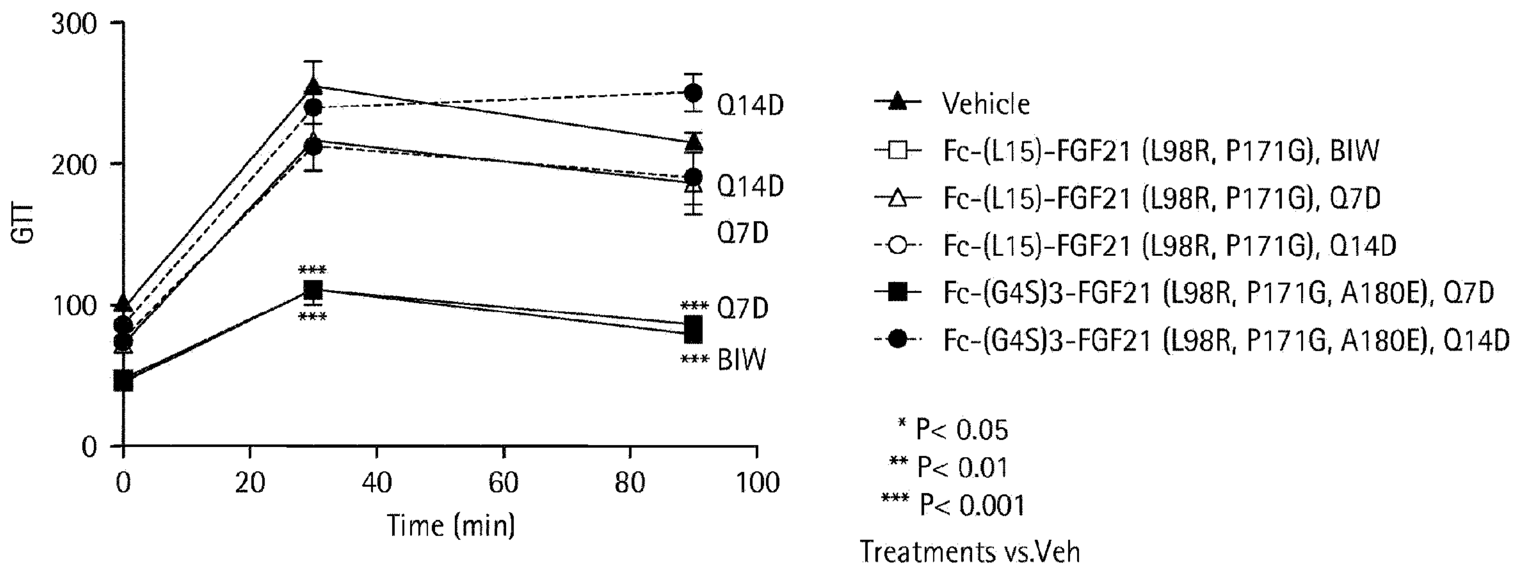

300
200
100
0
GTT
0
20
40
60
80
100
Time (min)
***
***
Q14D
Q14D
Q7D
*** Q7D
*** BIW
Vehicle
Fc-(L15)-FGF21 (L98R, P171G), BIW
Fc-(L15)-FGF21 (L98R, P171G), Q7D
Fc-(L15)-FGF21 (L98R, P171G), Q14D
Fc-(G4S)3-FGF21 (L98R, P171G, A180E), Q7D
Fc-(G4S)3-FGF21 (L98R, P171G, A180E), Q14D
* P< 0.05
** P< 0.01
*** P< 0.001
Treatments vs.Veh

FIG. 56

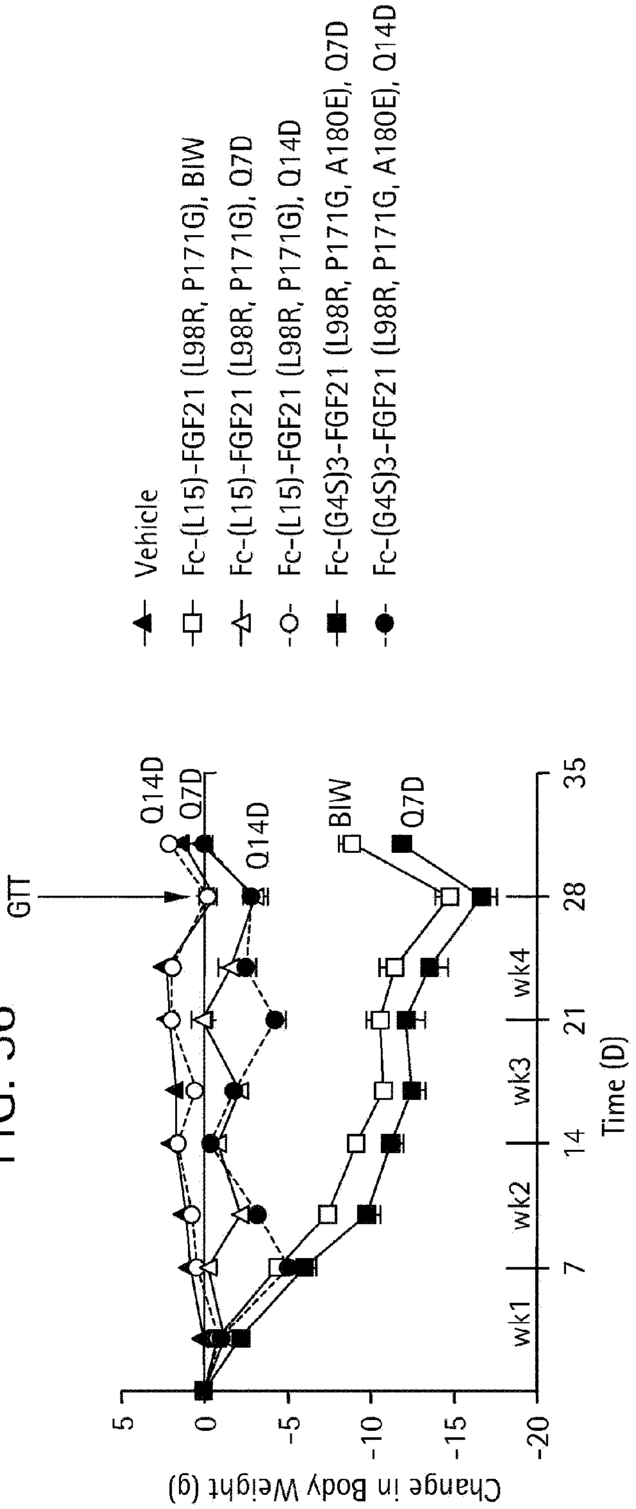

GTT
Q14D
Q7D
Q14D
BIW
Q7D
Change in Body Weight (g)
5
0
-5
-10
-15
-20
wk1
wk2
wk3
wk4
7
14
21
28
35
Time (D)
Vehicle
Fc-(L15)-FGF21 (L98R, P171G), BIW
Fc-(L15)-FGF21 (L98R, P171G), Q7D
Fc-(L15)-FGF21 (L98R, P171G), Q14D
Fc-(G4S)3-FGF21 (L98R, P171G, A180E), Q7D
Fc-(G4S)3-FGF21 (L98R, P171G, A180E), Q14D

FIG. 57

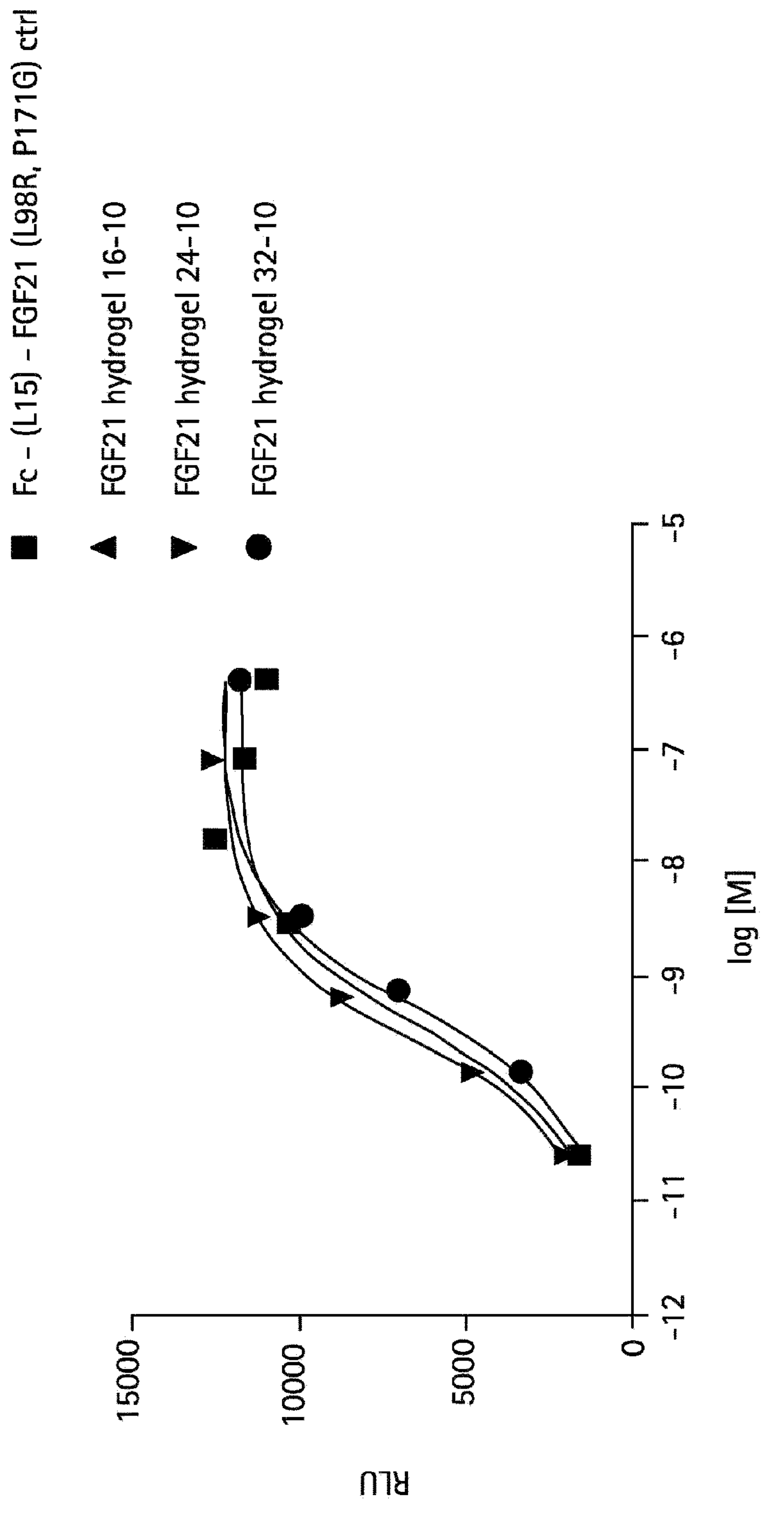

Fc – (L15) – FGF21 (L98R, P171G) ctrl
FGF21 hydrogel 16-10
FGF21 hydrogel 24-10
FGF21 hydrogel 32-10
RLU
15000
10000
5000
0
-12
-11
-10
-9
-8
-7
-6
-5
log [M]

FIG. 58

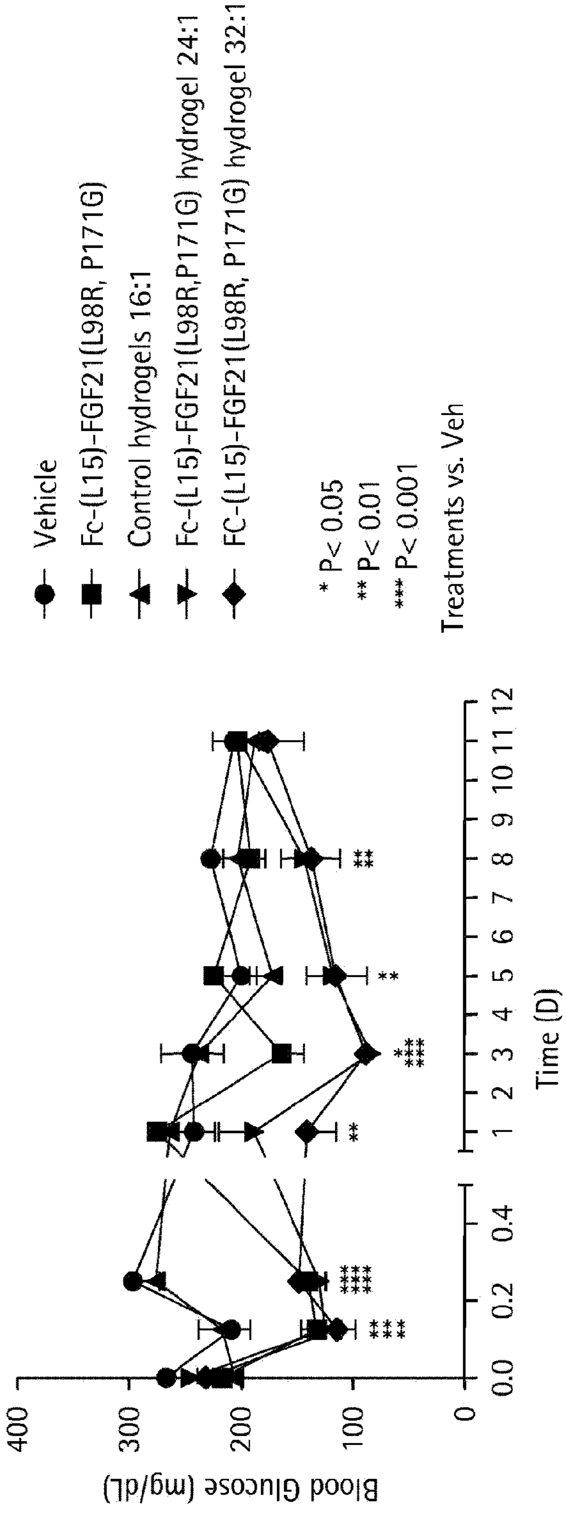

Blood Glucose (mg/dL)
400
300
200
100
0
0.0
0.2
0.4
1 2 3 4 5 6 7 8 9 10 11 12
Time (D)
Vehicle
Fc-(L15)-FGF21(L98R, P171G)
Control hydrogels 16:1
Fc-(L15)-FGF21(L98R,P171G) hydrogel 24:1
FC-(L15)-FGF21(L98R, P171G) hydrogel 32:1
* P< 0.05
** P< 0.01
*** P< 0.001
Treatments vs. Veh

FIG. 59

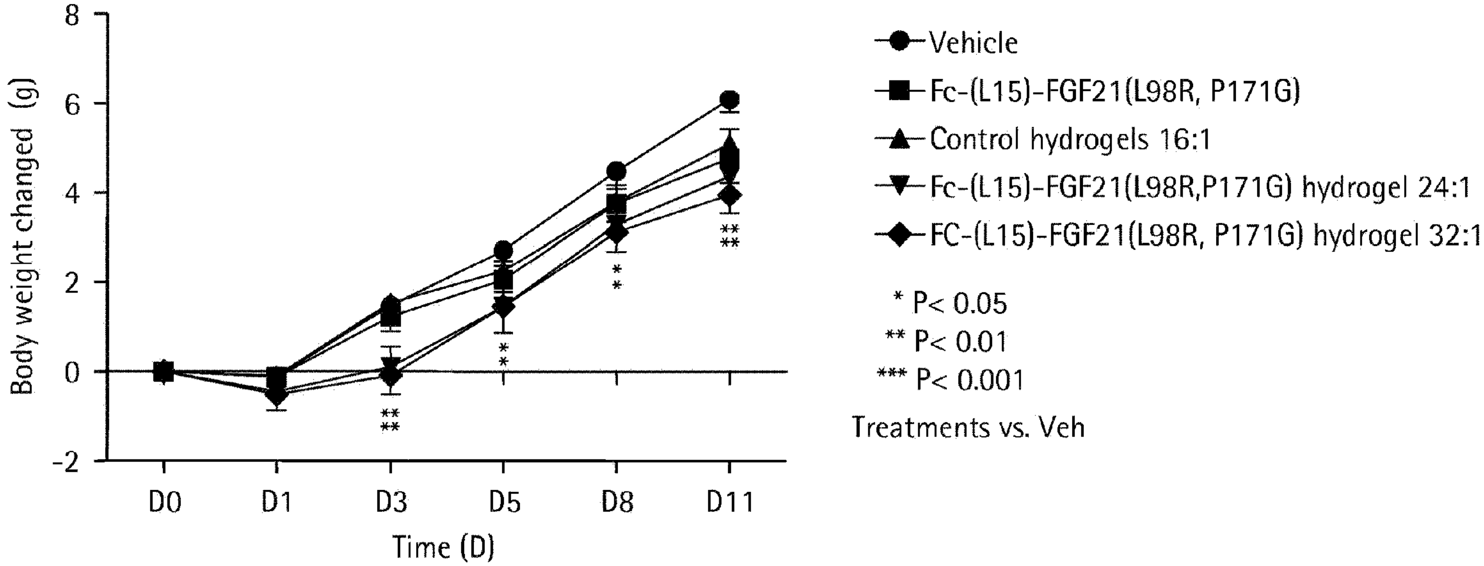

8
6
4
2
0
-2
Body weight changed (g)
D0
D1
D3
D5
D8
D11
Time (D)
Vehicle
Fc-(L15)-FGF21(L98R, P171G)
Control hydrogels 16:1
Fc-(L15)-FGF21(L98R,P171G) hydrogel 24:1
FC-(L15)-FGF21(L98R, P171G) hydrogel 32:1
* P< 0.05
** P< 0.01
*** P< 0.001
Treatments vs. Veh

FIG. 60

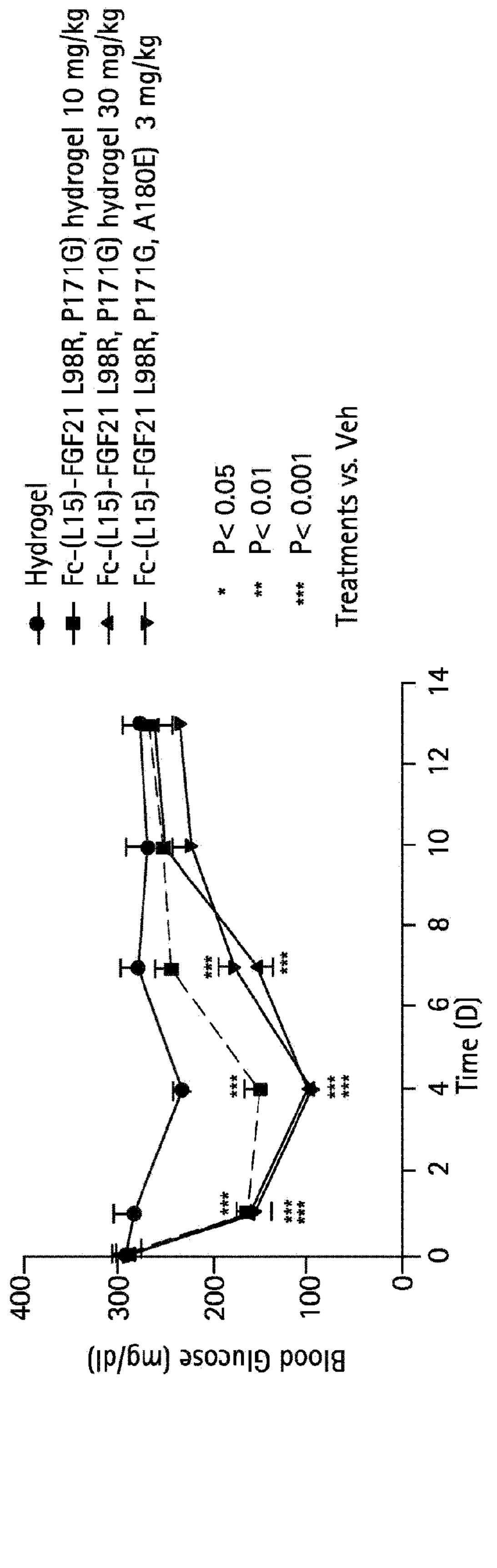

Hydrogel
Fc-(L15)-FGF21 L98R, P171G) hydrogel 10 mg/kg
Fc-(L15)-FGF21 L98R, P171G) hydrogel 30 mg/kg
Fc-(L15)-FGF21 L98R, P171G, A180E) 3 mg/kg
* P< 0.05
** P< 0.01
*** P< 0.001
Treatments vs. Veh
Blood Glucose (mg/dl)
Time (D)
0
100
200
300
400
0
2
4
6
8
10
12
14
***

FIG. 61

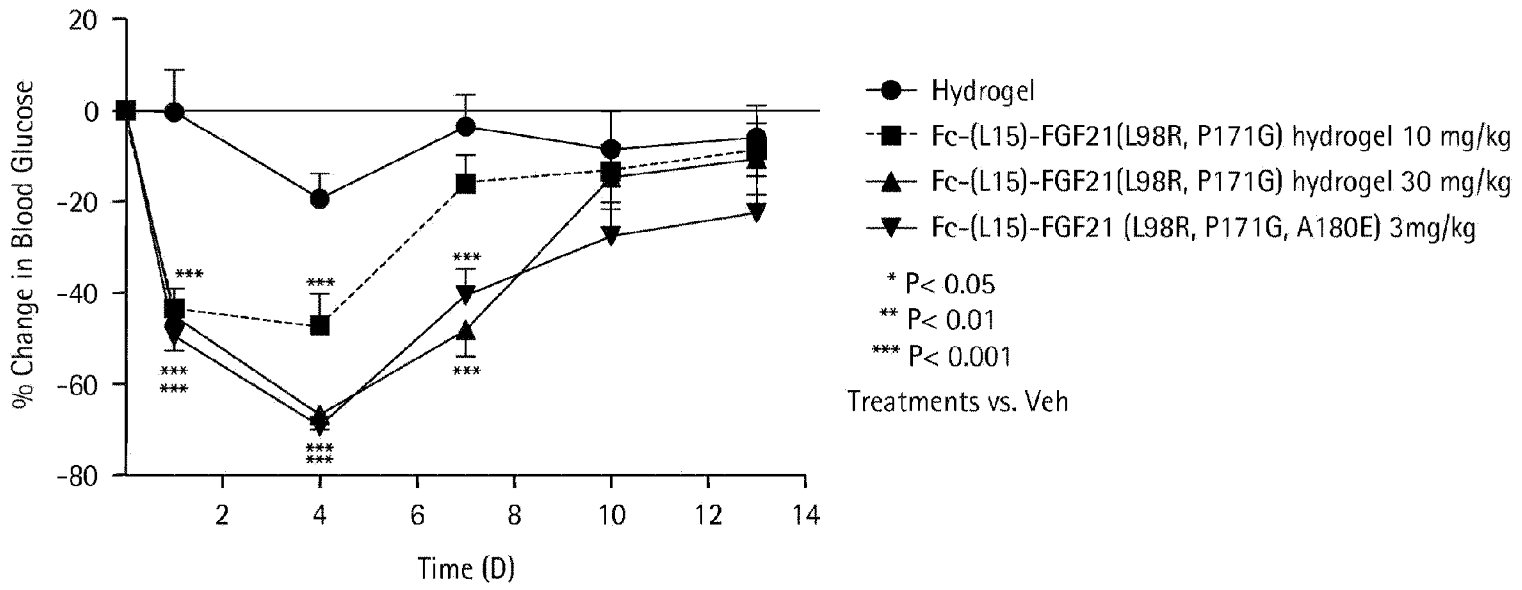

20
0
-20
-40
-60
-80
% Change in Blood Glucose
2
4
6
8
10
12
14
Time (D)
***
Hydrogel
Fc-(L15)-FGF21(L98R, P171G) hydrogel 10 mg/kg
Fc-(L15)-FGF21(L98R, P171G) hydrogel 30 mg/kg
Fc-(L15)-FGF21 (L98R, P171G, A180E) 3mg/kg
* P< 0.05
** P< 0.01
*** P< 0.001
Treatments vs. Veh

FIG. 62

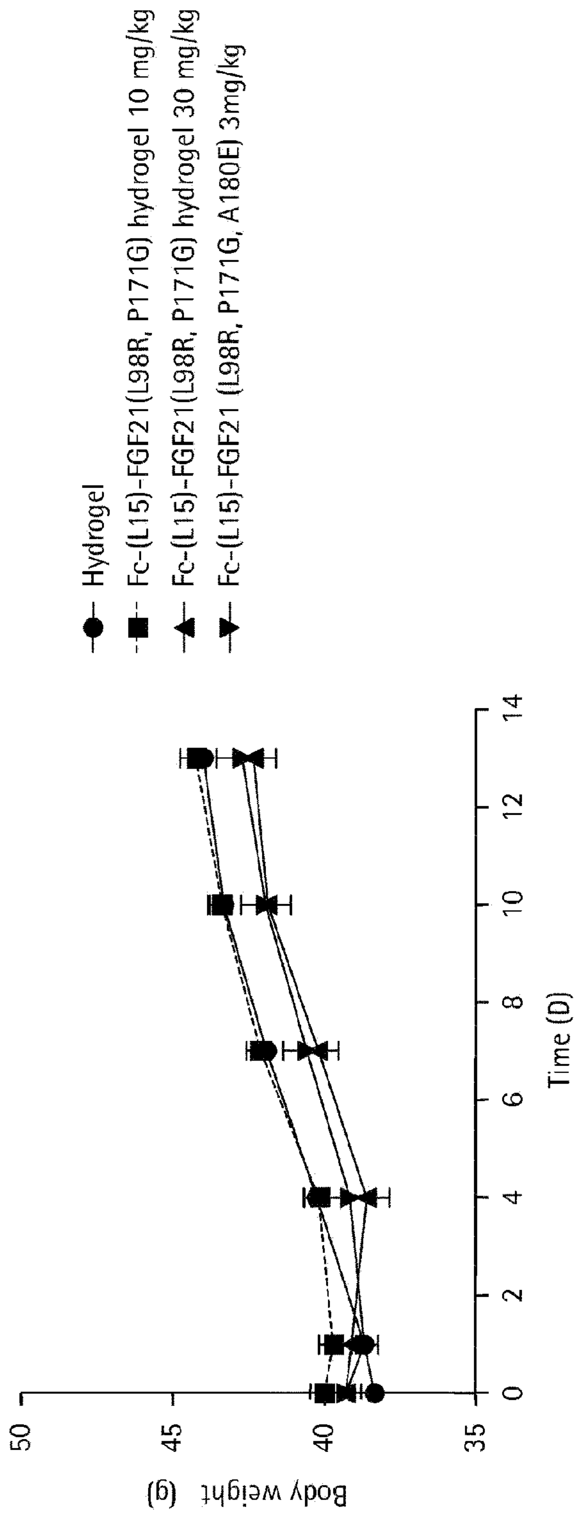

Body weight (g)
50
45
40
35
0
2
4
6
8
10
12
14
Time (D)
Hydrogel
Fc-(L15)-FGF21(L98R, P171G) hydrogel 10 mg/kg
Fc-(L15)-FGF21(L98R, P171G) hydrogel 30 mg/kg
Fc-(L15)-FGF21 (L98R, P171G, A180E) 3mg/kg

FIG. 63

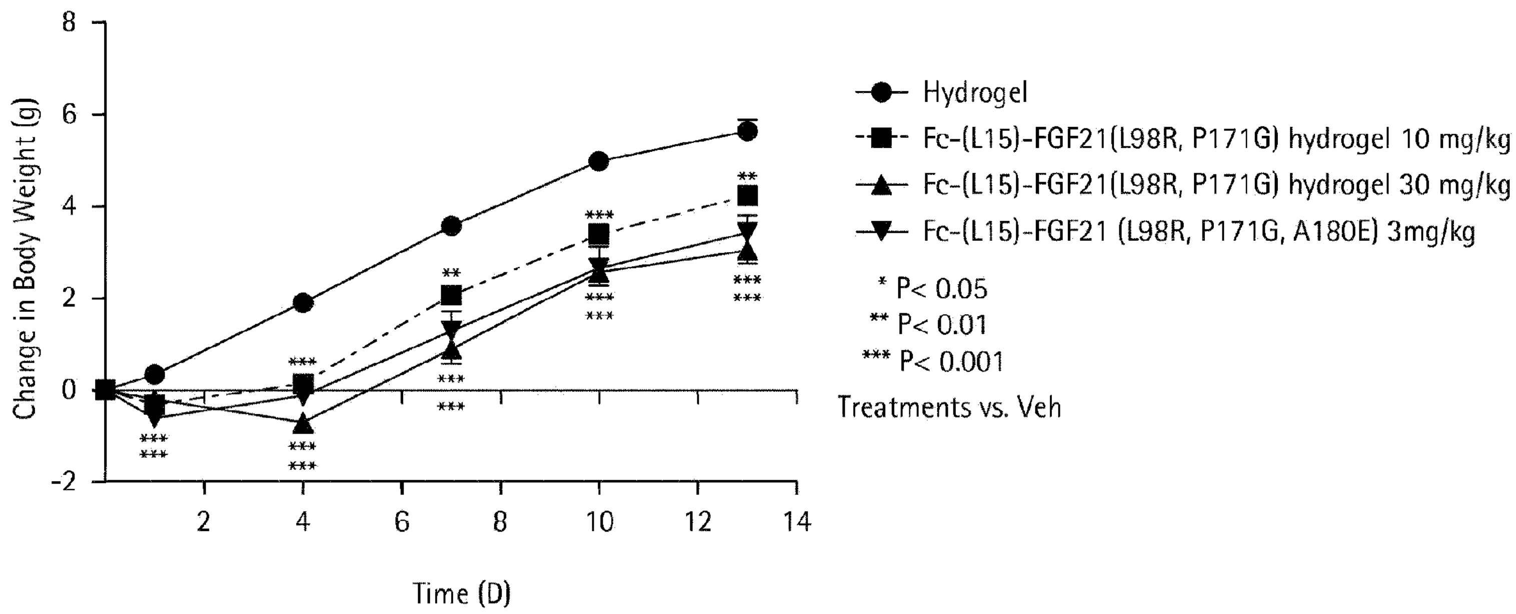

Change in Body Weight (g)
8
6
4
2
0
-2
2
4
6
8
10
12
14
Time (D)
Hydrogel
Fc-(L15)-FGF21(L98R, P171G) hydrogel 10 mg/kg
Fc-(L15)-FGF21(L98R, P171G) hydrogel 30 mg/kg
Fc-(L15)-FGF21 (L98R, P171G, A180E) 3mg/kg
* P< 0.05
** P< 0.01
*** P< 0.001
Treatments vs. Veh

FIG. 64

Monkey Study Design: Dose Escalation

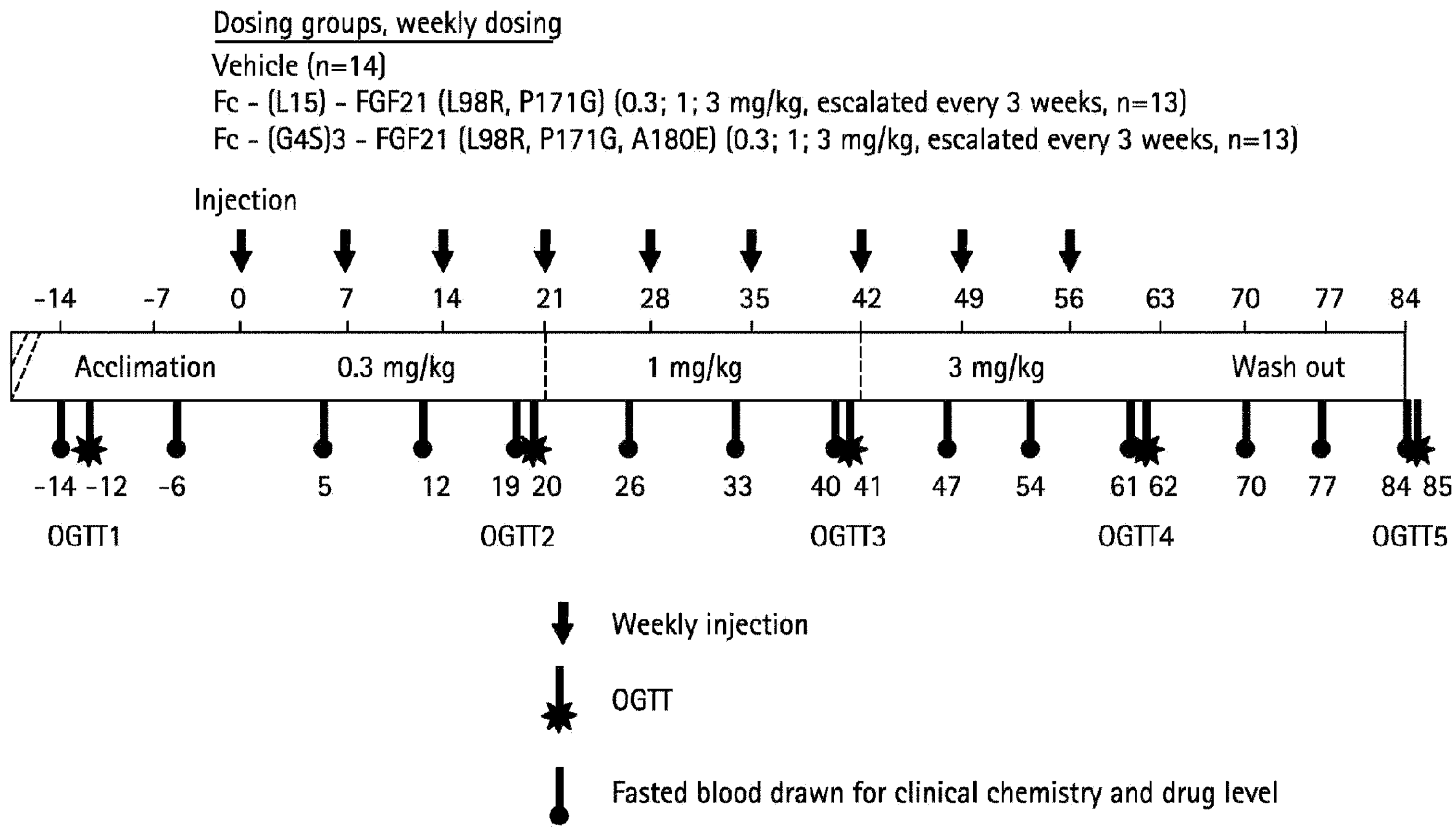


FIG. 65

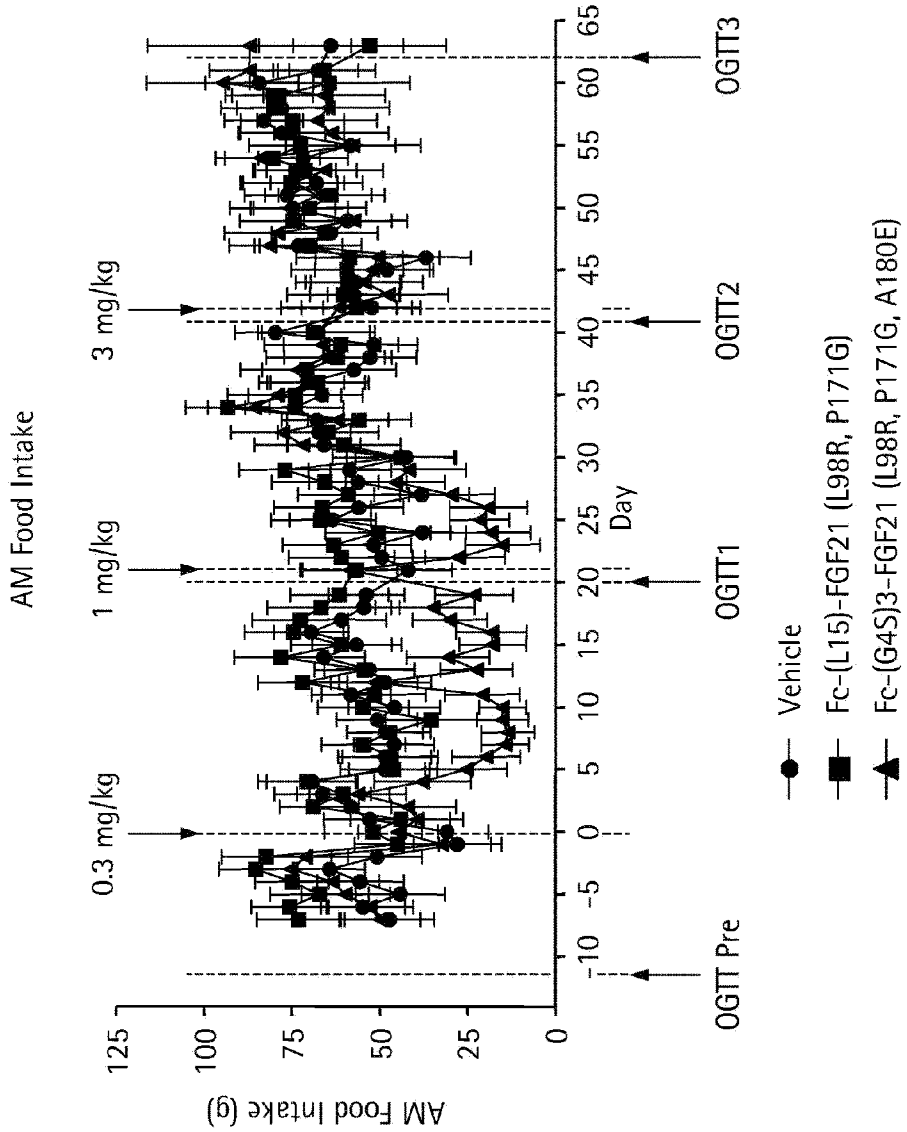

AM Food Intake
AM Food Intake (g)
Day
0.3 mg/kg
1 mg/kg
3 mg/kg
OGTT Pre
OGTT1
OGTT2
OGTT3
Vehicle
Fc-(L15)-FGF21 (L98R, P171G)
Fc-(G4S)3-FGF21 (L98R, P171G, A180E)

FIG. 66

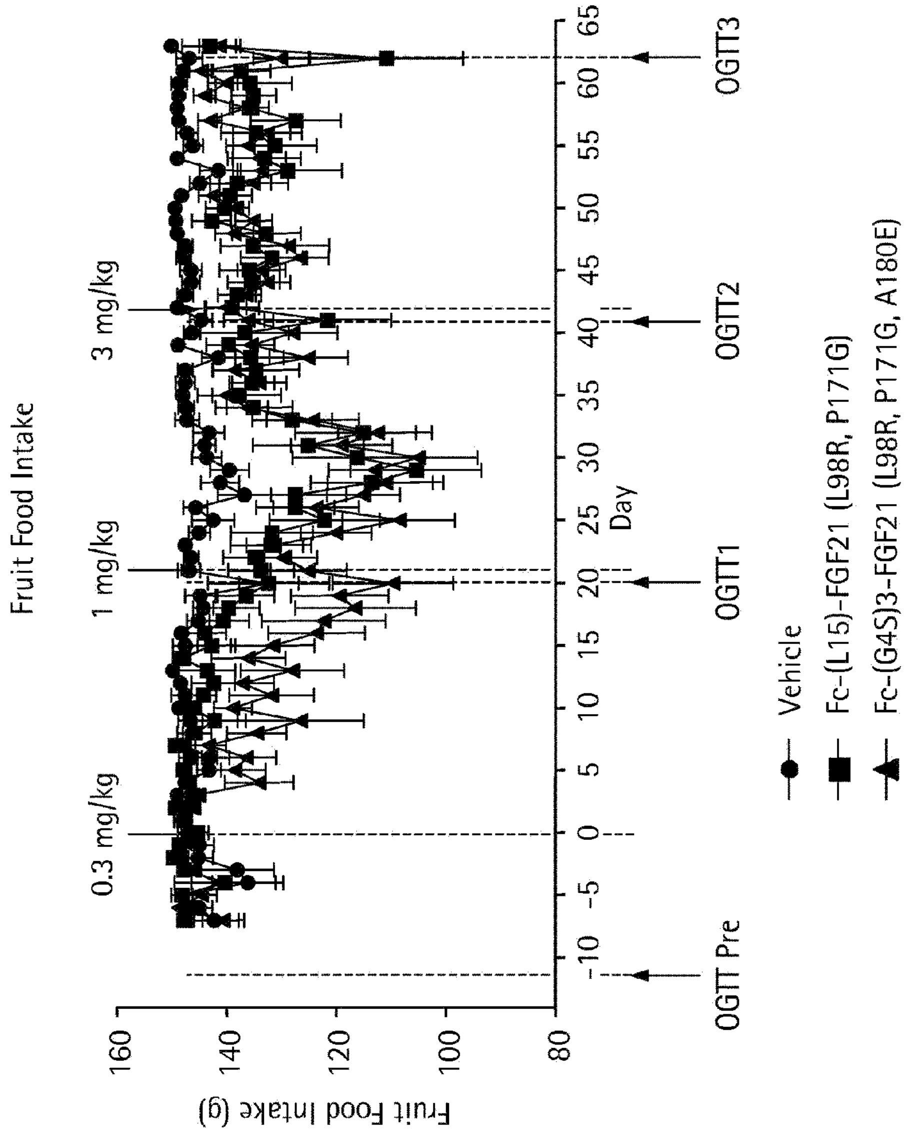

Fruit Food Intake
Fruit Food Intake (g)
160
140
120
100
80
Day
-10
-5
0
5
10
15
20
25
30
35
40
45
50
55
60
65
0.3 mg/kg
1 mg/kg
3 mg/kg
OGTT Pre
OGTT1
OGTT2
OGTT3
Vehicle
Fc-(L15)-FGF21 (L98R, P171G)
Fc-(G4S)3-FGF21 (L98R, P171G, A180E)

FIG. 67

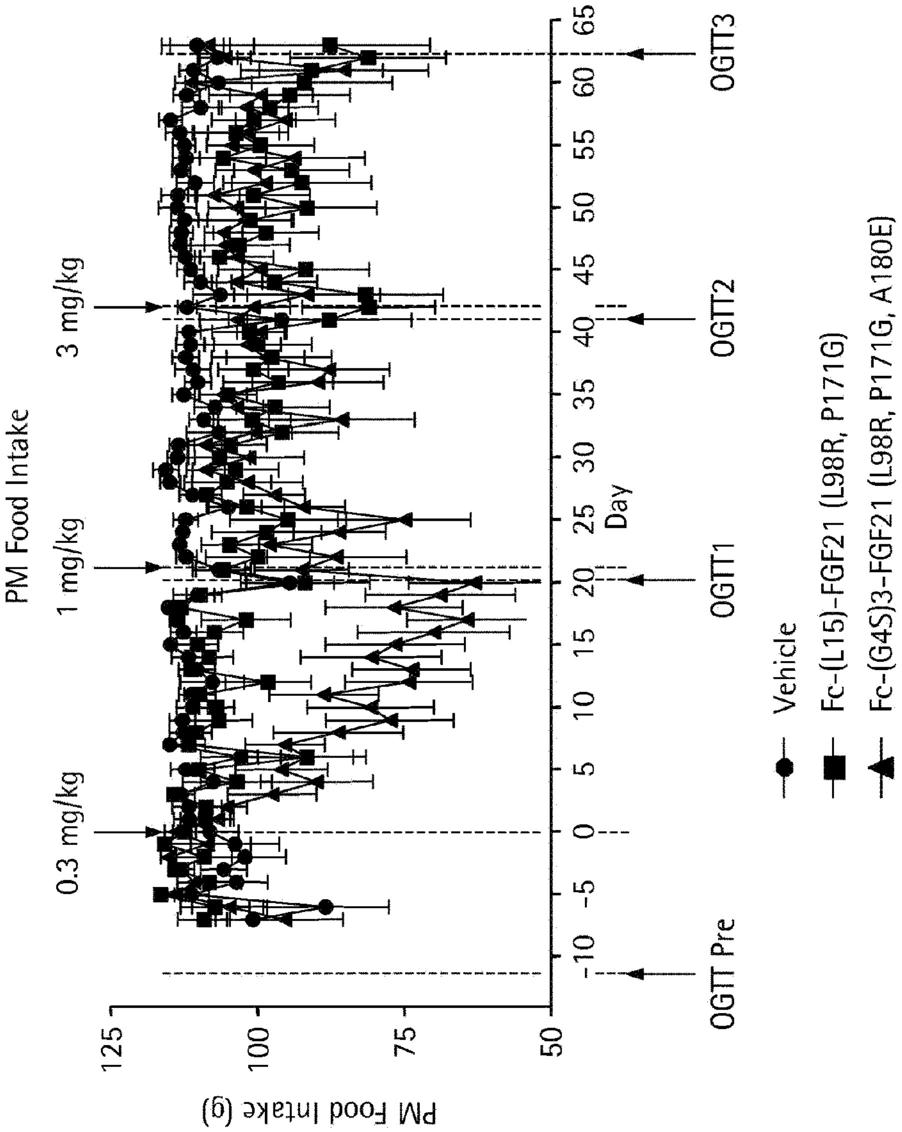

PM Food Intake
0.3 mg/kg
1 mg/kg
3 mg/kg
PM Food Intake (g)
125
100
75
50
-10
-5
0
5
10
15
20
25
30
35
40
45
50
55
60
65
Day
OGTT Pre
OGTT1
OGTT2
OGTT3
Vehicle
Fc-(L15)-FGF21 (L98R, P171G)
Fc-(G4S)3-FGF21 (L98R, P171G, A180E)

FIG. 68

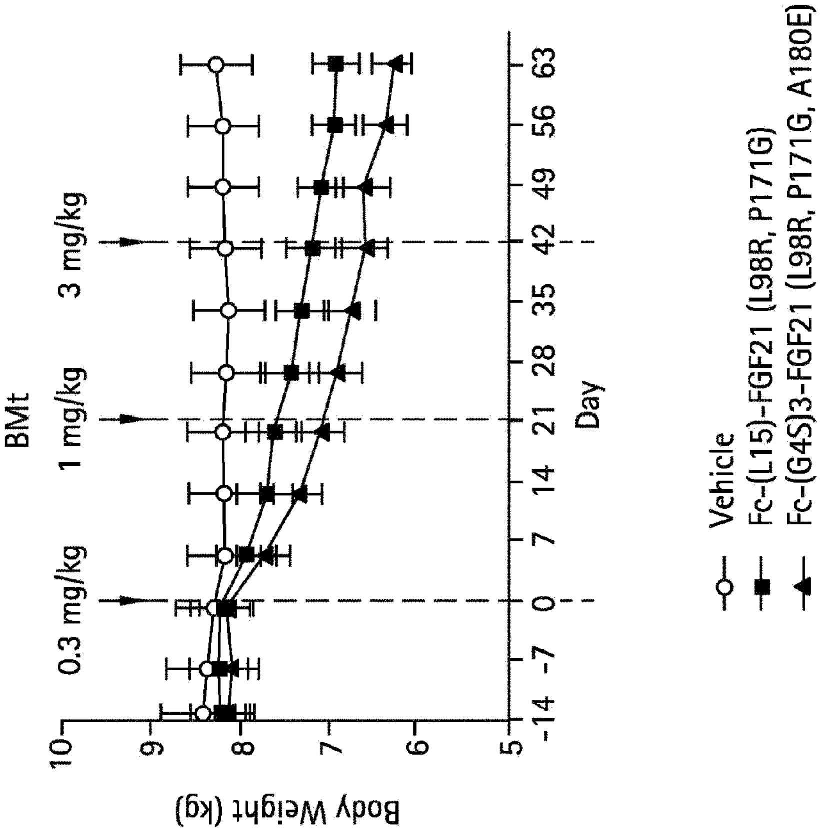
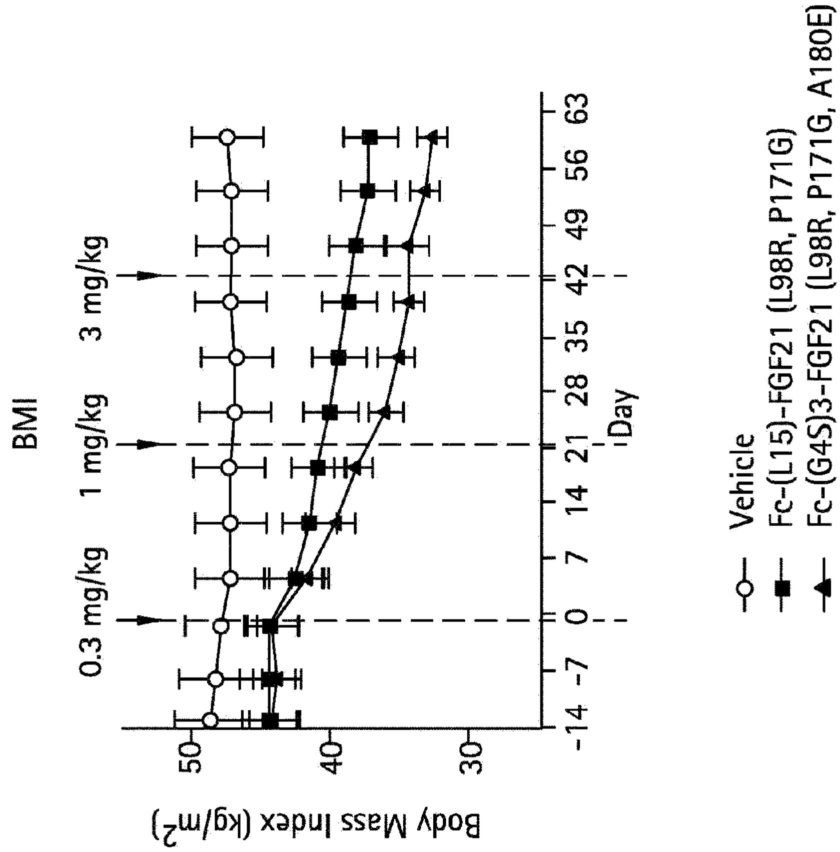

BMt
0.3 mg/kg
1 mg/kg
3 mg/kg
Body Weight (kg)
10
9
8
7
6
5
-14
-7
0
7
14
21
28
35
42
49
56
63
Day
Vehicle
Fc-(L15)-FGF21 (L98R, P171G)
Fc-(G4S)3-FGF21 (L98R, P171G, A180E)

FIG. 69



BMI
0.3 mg/kg
1 mg/kg
3 mg/kg
Body Mass Index (kg/m2)
50
40
30
-14
-7
0
7
14
21
28
35
42
49
56
63
Day
Vehicle
Fc-(L15)-FGF21 (L98R, P171G)
Fc-(G4S)3-FGF21 (L98R, P171G, A180E)

FIG. 70

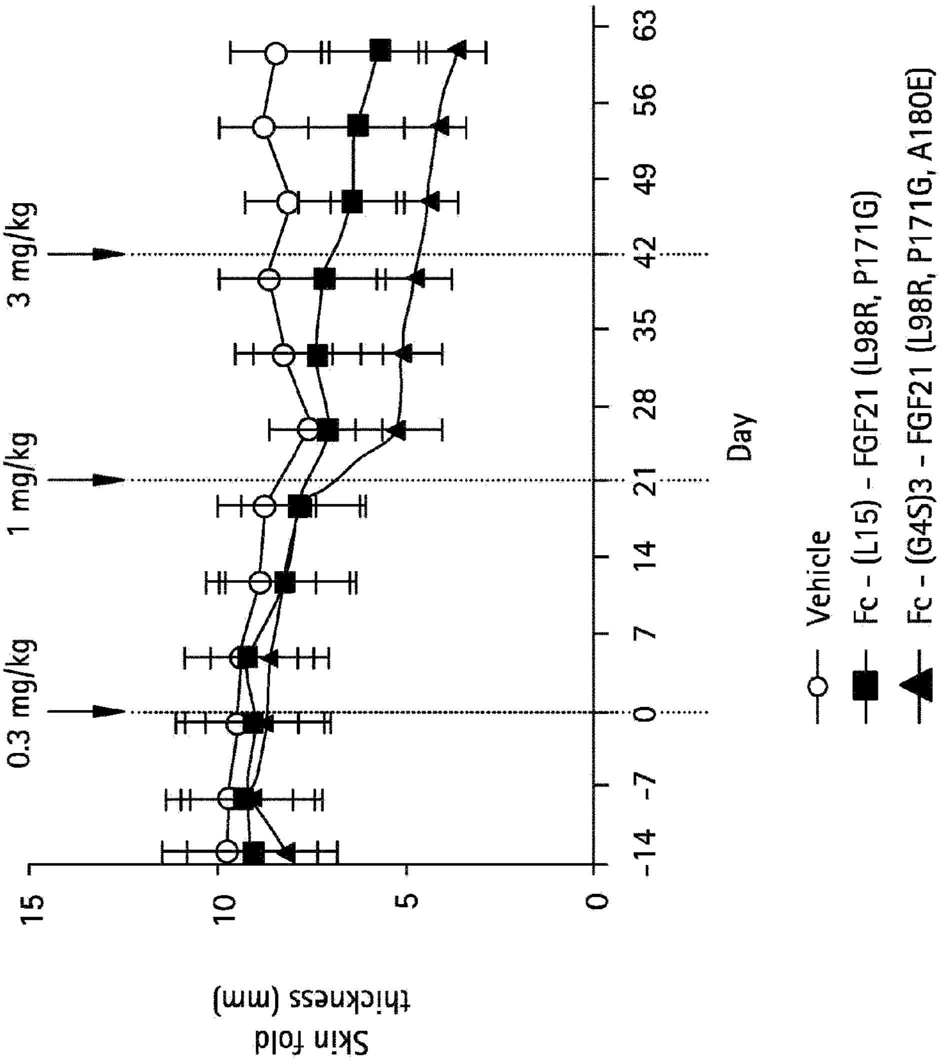
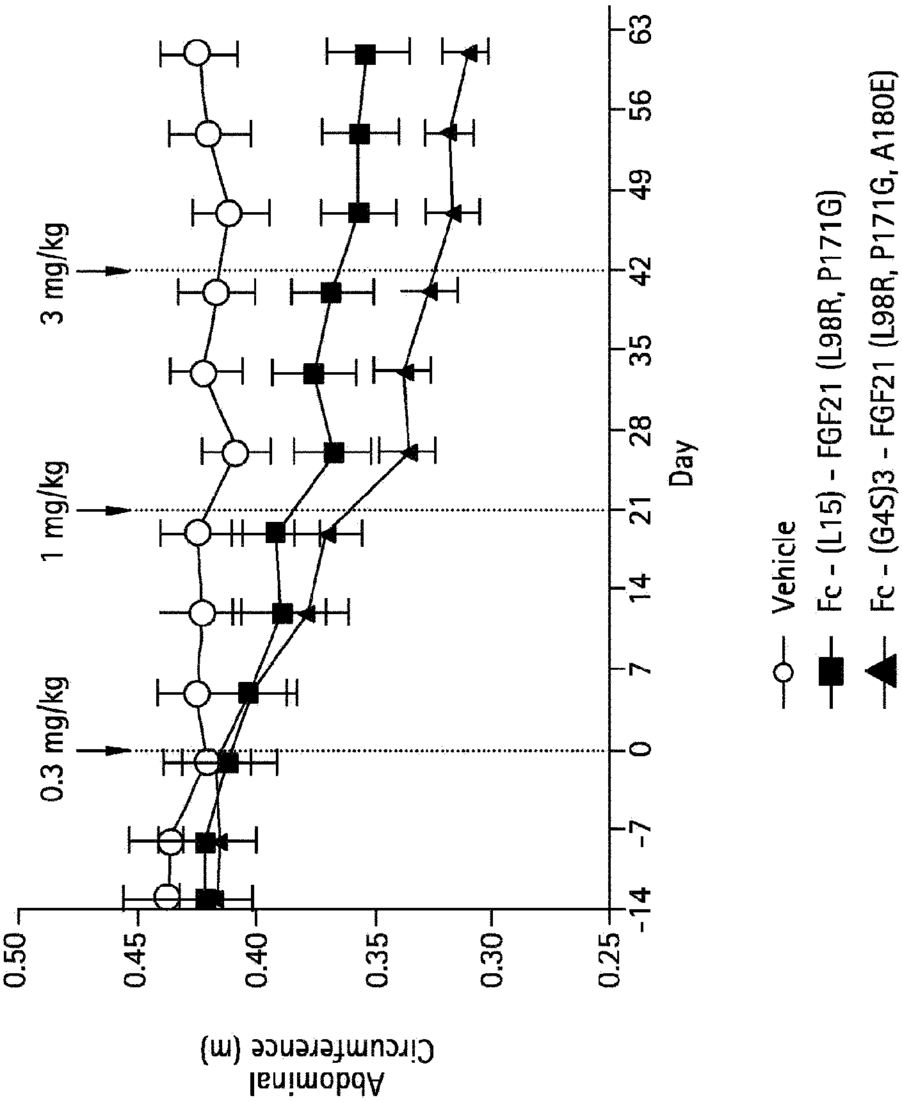

0.3 mg/kg
1 mg/kg
3 mg/kg
Skin fold thickness (mm)
15
10
5
0
-14
-7
0
7
14
21
28
35
42
49
56
63
Day
Vehicle
Fc - (L15) - FGF21 (L98R, P171G)
Fc - (G4S)3 - FGF21 (L98R, P171G, A180E)

FIG. 71

AC



0.3 mg/kg
1 mg/kg
3 mg/kg
Abdominal Circumference (m)
0.50
0.45
0.40
0.35
0.30
0.25
-14
-7
0
7
14
21
28
35
42
49
56
63
Day
Vehicle
Fc - (L15) - FGF21 (L98R, P171G)
Fc - (G4S)3 - FGF21 (L98R, P171G, A180E)

FIG.72

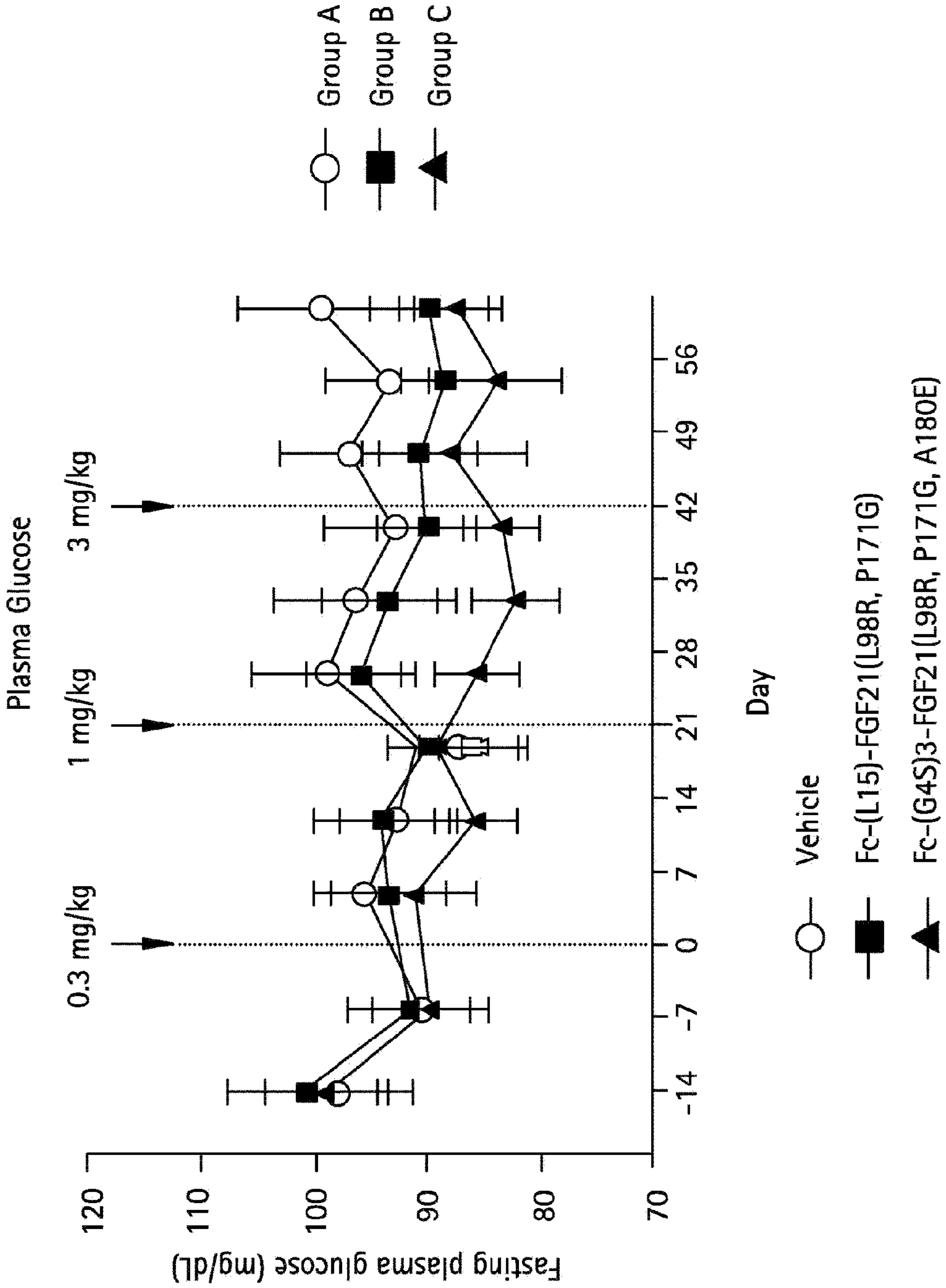

Plasma Glucose
0.3 mg/kg
1 mg/kg
3 mg/kg
Fasting plasma glucose (mg/dL)
120
110
100
90
80
70
-14
-7
0
7
14
21
28
35
42
49
56
Day
Group A
Group B
Group C
Vehicle
Fc-(L15)-FGF21(L98R, P171G)
Fc-(G4S)3-FGF21(L98R, P171G, A180E)

FIG. 73

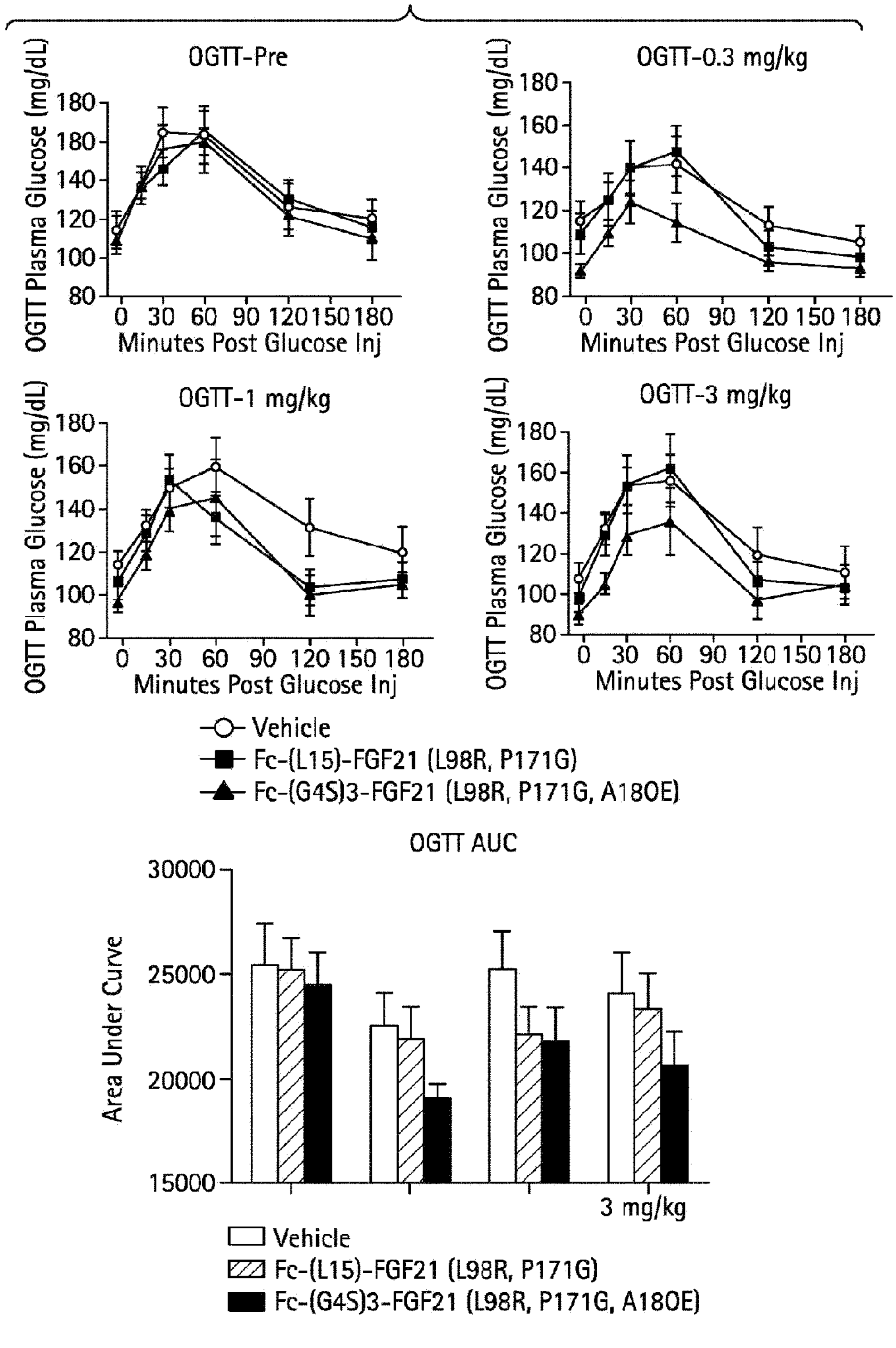

OGTT-Pre
OGTT-0.3 mg/kg
OGTT-1 mg/kg
OGTT-3 mg/kg
OGTT Plasma Glucose (mg/dL)
Minutes Post Glucose Inj
0 30 60 90 120 150 180
80 100 120 140 160 180
Vehicle
Fc-(L15)-FGF21 (L98R, P171G)
Fc-(G4S)3-FGF21 (L98R, P171G, A180E)
OGTT AUC
Area Under Curve
15000 20000 25000 30000
3 mg/kg
Vehicle
Fc-(L15)-FGF21 (L98R, P171G)
Fc-(G4S)3-FGF21 (L98R, P171G, A180E)

FIG. 74

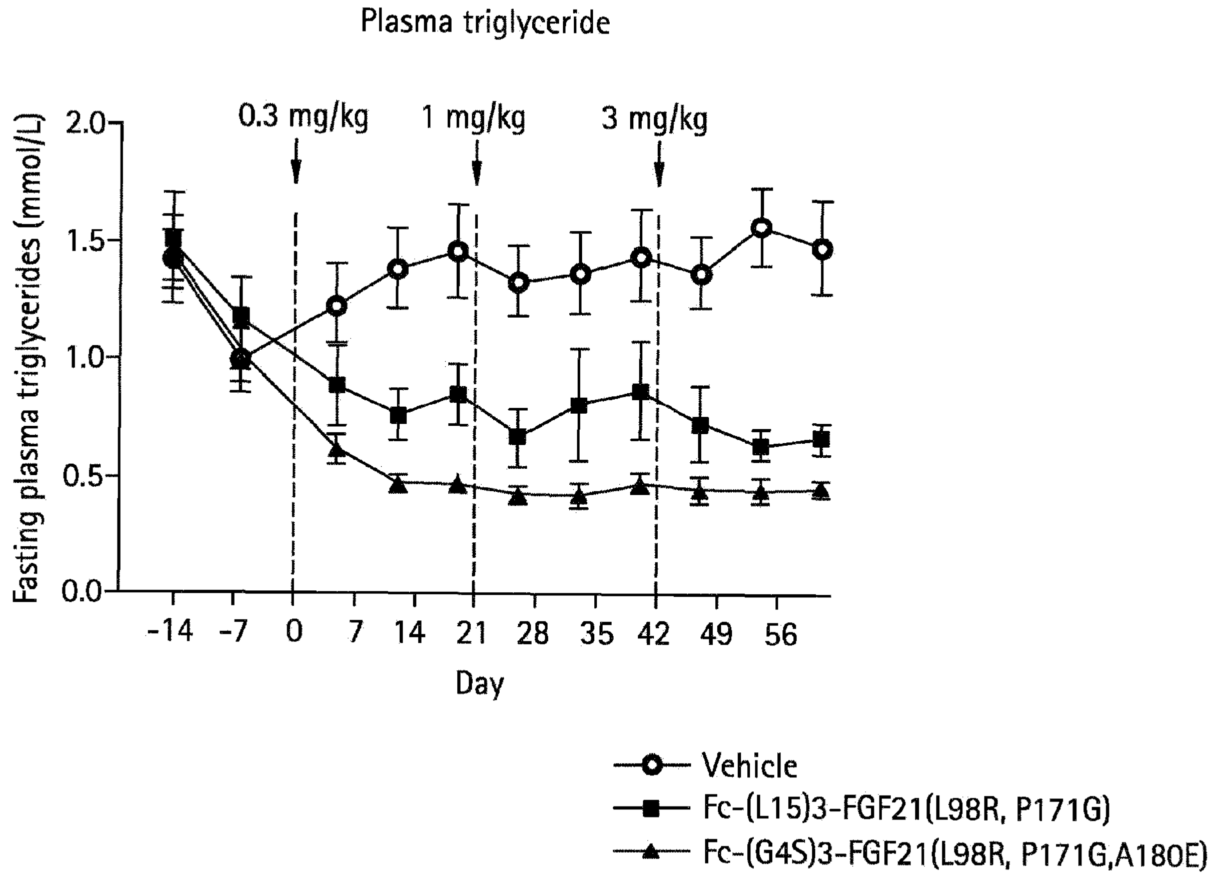

Plasma triglyceride
Fasting plasma triglycerides (mmol/L)
2.0
1.5
1.0
0.5
0.0
0.3 mg/kg
1 mg/kg
3 mg/kg
-14
-7
0
7
14
21
28
35
42
49
56
Day
Vehicle
Fc-(L15)3-FGF21(L98R, P171G)
Fc-(G4S)3-FGF21(L98R, P171G,A180E)

FIG. 75

Total Cholesterol

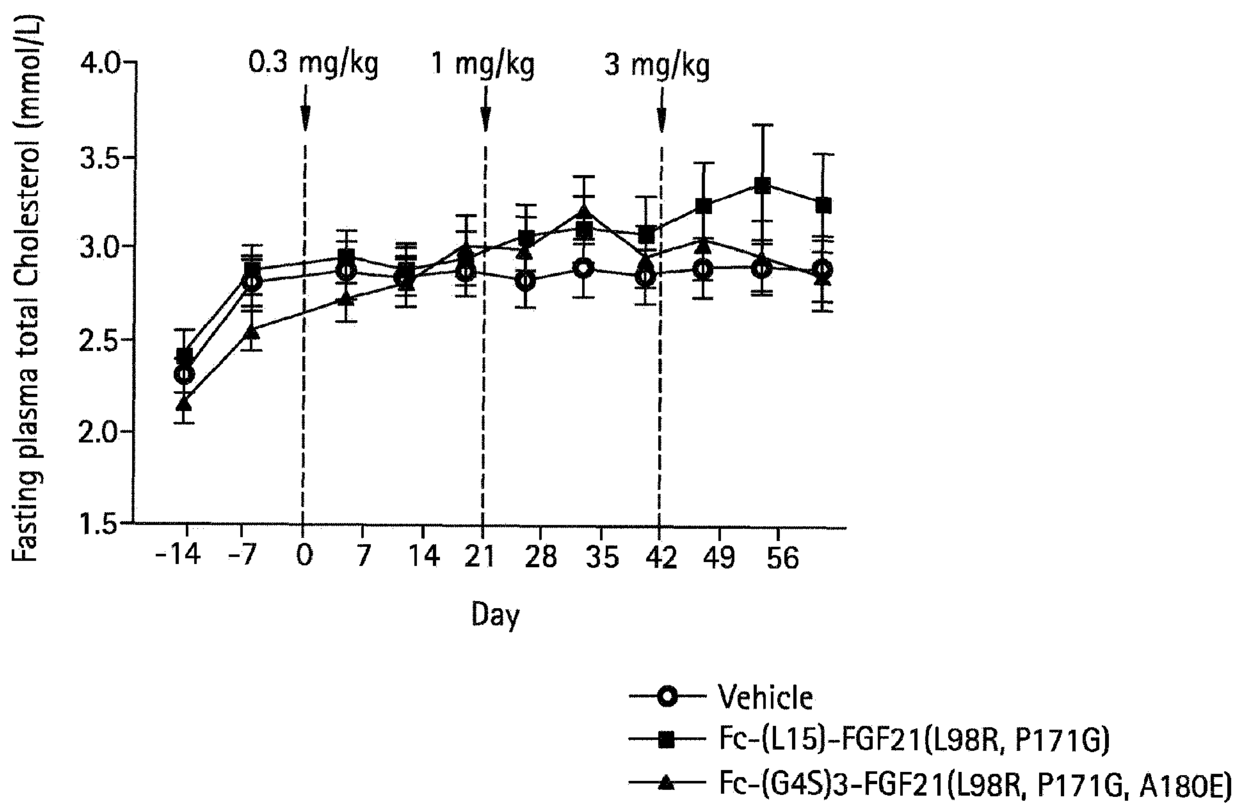


FIG. 76

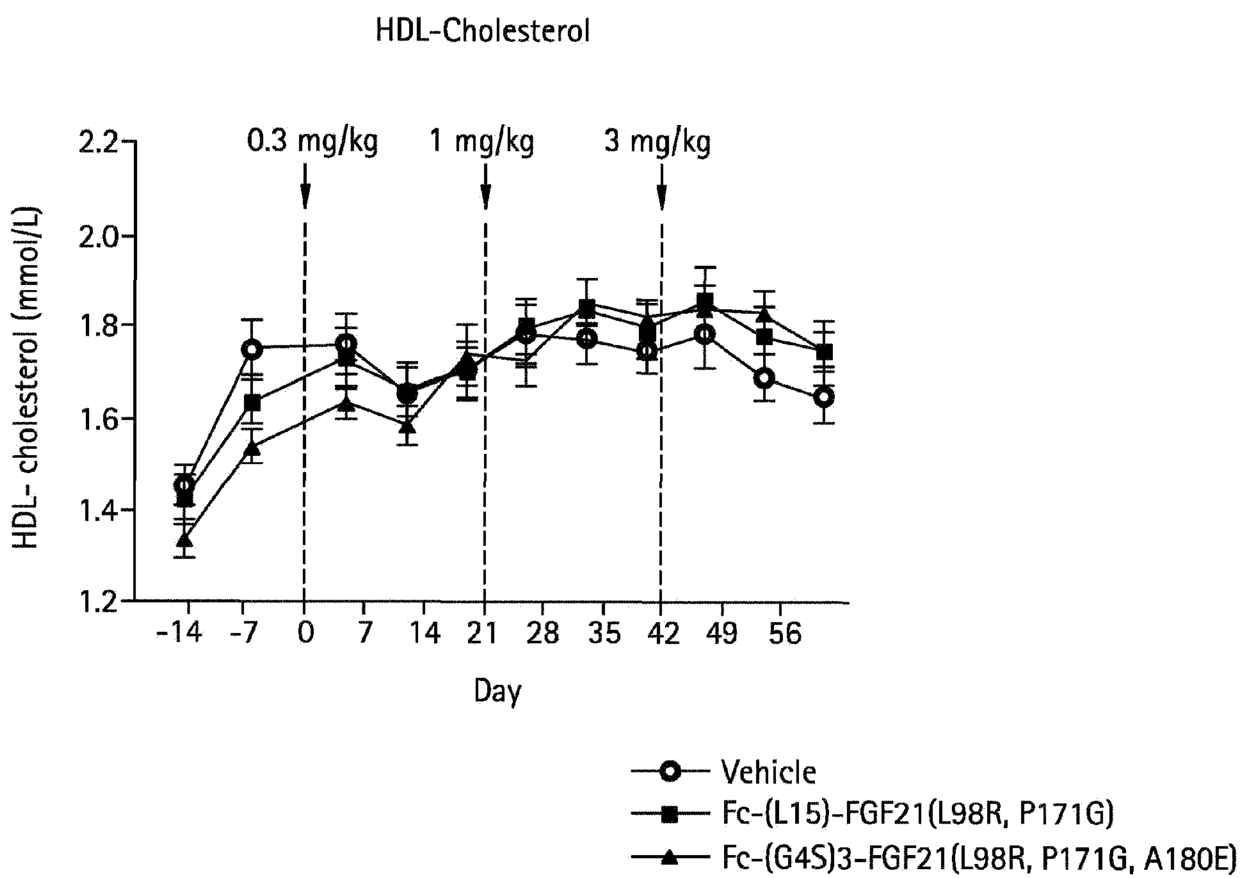

HDL-Cholesterol
0.3 mg/kg
1 mg/kg
3 mg/kg
HDL- cholesterol (mmol/L)
2.2
2.0
1.8
1.6
1.4
1.2
-14
-7
0
7
14
21
28
35
42
49
56
Day
Vehicle
Fc-(L15)-FGF21(L98R, P171G)
Fc-(G4S)3-FGF21(L98R, P171G, A180E)

FIG. 77

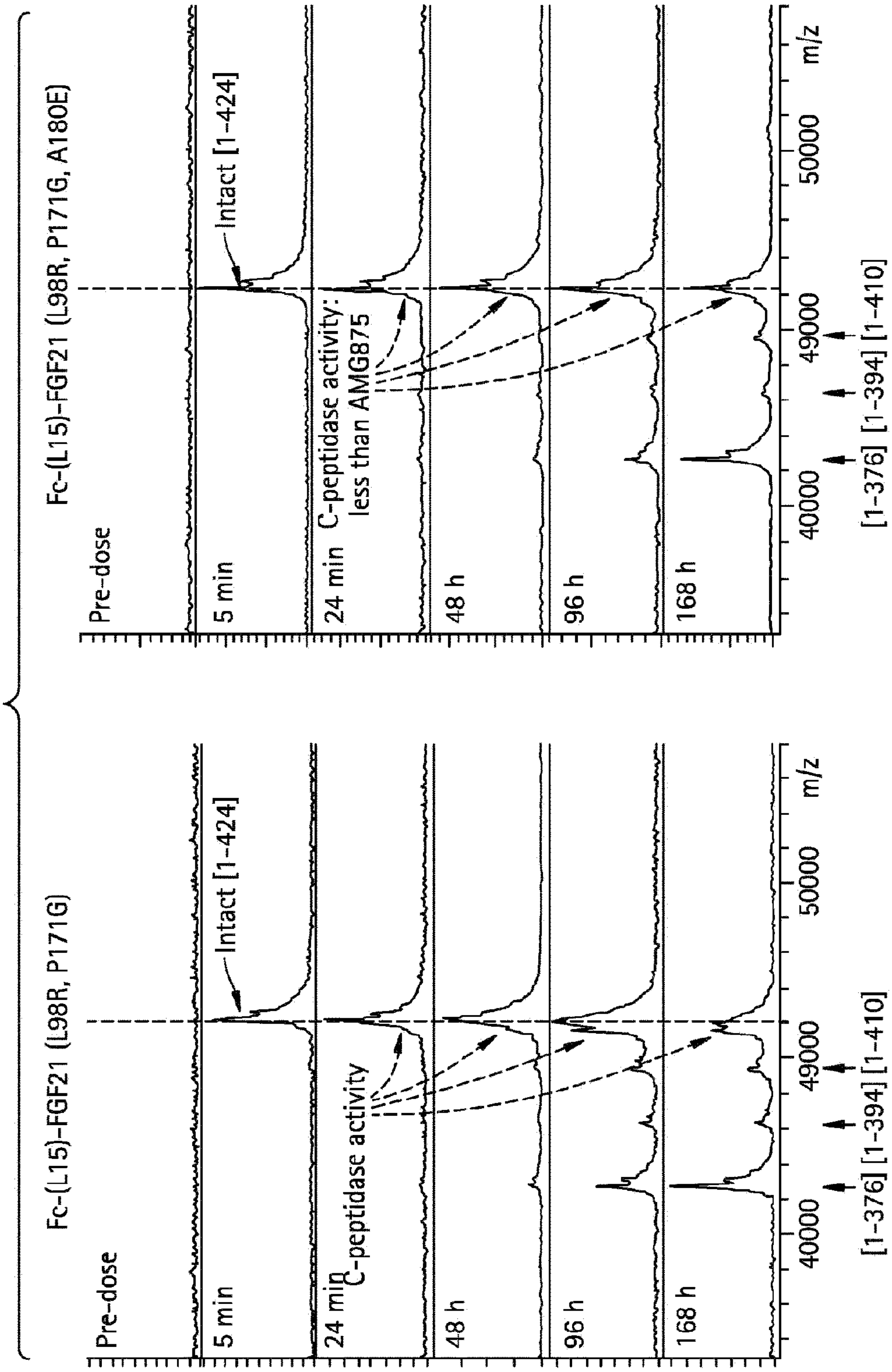
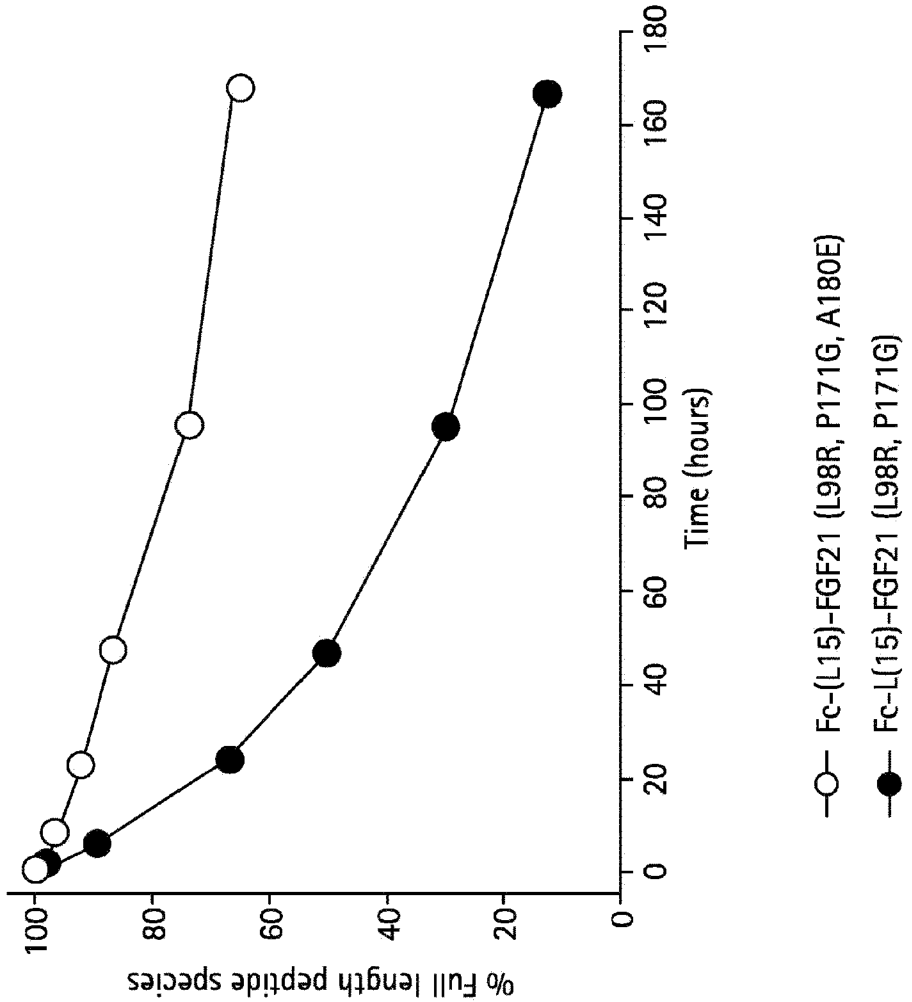
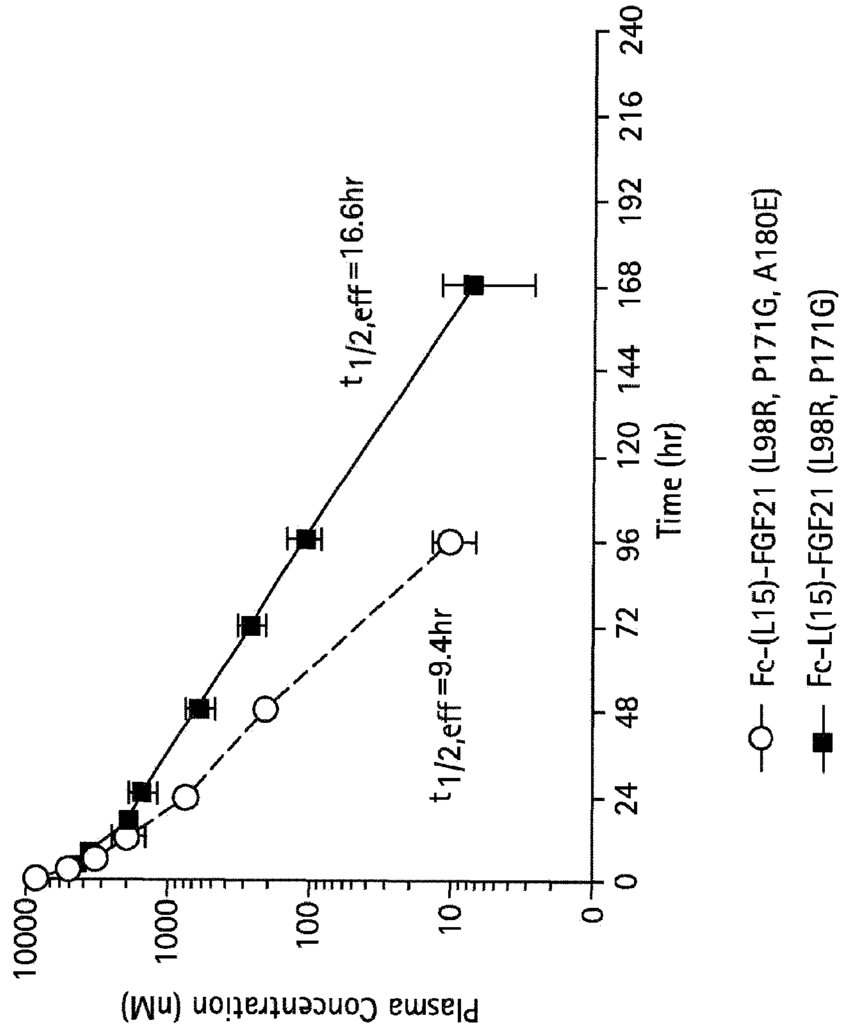

Fc-(L15)-FGF21 (L98R, P171G)
Fc-(L15)-FGF21 (L98R, P171G, A180E)
Pre-dose
5 min
24 min
48 h
96 h
168 h
Intact [1-424]
C-peptidase activity
C-peptidase activity:
less than AMG875
40000
49000
50000
m/z
[1-376] [1-394] [1-410]

FIG. 78



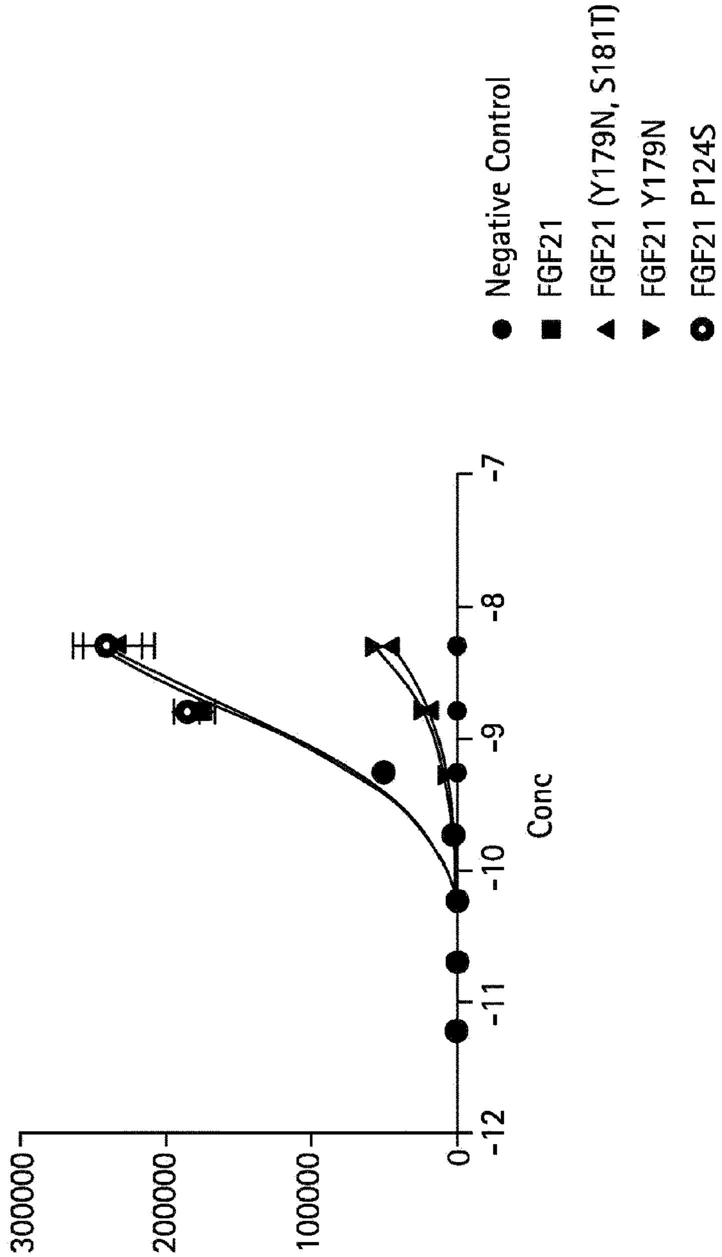
% Full length peptide species
0
20
40
60
80
100
Time (hours)
0
20
40
60
80
100
120
140
160
180
Fc-(L15)-FGF21 (L98R, P171G, A180E)
Fc-L(15)-FGF21 (L98R, P171G)

FIG. 79



Plasma Concentration (nM)
10000
1000
100
10
0
0
24
48
72
96
120
144
168
192
216
240
Time (hr)
t 1/2,eff =9.4hr
t 1/2,eff =16.6hr
Fc-(L15)-FGF21 (L98R, P171G, A180E)
Fc-L(15)-FGF21 (L98R, P171G)

FIG. 80


RLU
300000
200000
100000
0
-12
-11
-10
-9
-8
-7
Conc
Negative Control
FGF21
FGF21 (Y179N, S181T)
FGF21 Y179N
FGF21 P124S

SEKVENSLISTE

Sekvenslisten er udeladt af skriftet og kan hentes fra det Europæiske Patent Register.

The Sequence Listing was omitted from the document and can be downloaded from the European Patent Register.