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(54) Title: GENERATION OF FUNCTIONAL BETA CELLS FROM HUMAN PLURIPOTENT STEM CELL-DERIVED ENDOCRINE PROGENITORS

(57) Abstract: The present invention relates to generation of functional beta cells from human pluripotent stem cell-derived endocrine progenitors. The present invention also relates to functional beta cells produced by said methods and uses of said beta cells.

DESCRIPTION

TITLE: GENERATION OF FUNCTIONAL BETA CELLS FROM HUMAN PLURIPOTENT STEM CELL-DERIVED ENDOCRINE PROGENITORS

TECHNICAL FIELD

The present invention relates to methods of generating functional mature beta cells from human pluripotent stem cells derived endocrine progenitors.

BACKGROUND

Islet cell transplantation has been used to treat type 1 diabetic patients showing superior glucose homeostasis compared with insulin therapy but this therapy is limited by organ donations. Human Pluripotent stem cells (hPSCs) such as human embryonic stem cells (hESCs) can proliferate infinitively and differentiate into many cell types, including beta cells (BCs) and may address the shortage of donor islets. Protocols to differentiate hPSC into definitive endoderm, (DE), pancreatic endoderm (PE) cells and endocrine progenitors (EP) in vitro have been provided in WO2012/175633, WO 2014/033322 and WO2015/028614 respectively. It is challenging to make glucose-responsive insulin-secreting BCs in vitro from hPSCs. Most protocols result in insulin-producing cells that fail to recapitulate the phenotype of BCs as they also co-express other hormones such as glucagon and are unresponsive to glucose stimulation.

Rezania, A. et al. “Reversal of diabetes with insulin-producing cells derived in vitro from human pluripotent stem cells” Nature Biotechnology 32, 1121–1133 (2014) and Pagliuca, F.W. et al. “Generation of Functional Human Pancreatic b Cells In Vitro” Cell 159(2), 428–439, October 9, 2014, reported the in vitro differentiation of hESCs into insulin-secreting cells. Using static incubation studies, cells from both groups were sensitive to glucose stimulation showing approximately 2-fold increase in insulin output after glucose stimulation. This response varied however qualitatively and quantitatively from that of primary adult beta cells. As comparison, human islet stimulation index is reported to be two to ten or higher (Shapiro, J. A. M. et al. “Islet Transplantation in seven patients with type 1 diabetes mellitus using a glucocorticoid-free immunosuppressive regimen” New England Journal of Medicine 343, 230-238, July 27 (2000).

The reported stem cell-derived BCs also failed to display insulin response to glucose in a dynamic cell perfusion assay and are thus functionally immature relative to primary human BCs.

Efficient protocol for making functional mature BCs from hPSC-derived endocrine progenitors that can respond to glucose in a dynamic cell perfusion assay is not known. It is critical to improve current protocols to generate fully functional mature BCs for a more consistent cell product similar to human islets to obtain a predictable outcome following transplantation as well as for screening purposes in vitro.

SUMMARY

The present invention relates to improved methods for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors. The present invention also relates to glucose responsive fully differentiated beta-cells. The present invention further relates to functional mature beta cells obtainable by the methods of the present invention. The present invention further relates to medical use of said cells *inter alia* in the treatment of type I diabetes. The present invention may also solve further problems that will be apparent from the disclosure of the exemplary embodiments.

BRIEF DESCRIPTION OF DRAWINGS

Fig. 1 shows the screening approach where undifferentiated human embryonic stem cells (hESCs) were differentiated into Definitive Endoderm (DE) and reseeded in T75 flasks, where the cells were further differentiated into Pancreatic Endoderm (PE) and Endocrine Progenitor (EP). The Beta cells (BC) step 1 screen was started at the EP stage and continued for 4-7 days, and analysed by qICC monitoring and/or flow cytometry of NKX6.1+/INS+/GCG- cell number. BC step 2 screen was started at the end of BC step 1 screen and continued for 3-7 day period in 3D suspension cultures by dissociating to single cells at the end of BC step 1 and re-aggregation to clusters on orbital shaker at 50rpm. Cells were analysed by static and/or dynamic GSIS, INS protein content, ICC, and qPCR.

Fig. 2 shows effect of compounds on INS+/NKX6.1+/GCG- expression at day 4 of BC step 1 measured by Flow cytometry (FC).

Fig. 3 shows additive effect when combining hits during BC step 1 on INS+/NKX6.1+ cell number.

Fig. 4 shows timing studies of BC step 1 method.

Fig. 5 shows effect of compounds added for 7 days during BC step 2 method on static GSIS.

Fig. 6 A shows presence of glucose responsive insulin secreting cells at day 3 of BC step 2.

Fig. 6 B shows presence of glucose responsive insulin secreting cells at day 7 of BC step 2.

Fig. 7 shows functionality of hESC-derived beta cells demonstrated by dose dependent glucose and sulfonylurea mediated insulin release in a dynamic fashion

Fig. 8 shows robust protocol induced functional beta cells from independent pluripotent cell lines.

Fig. 9 Beta cell specific genes expressed in stem cell-derived beta cells at day 9 of BC step 2

Fig. 10 shows enrichment of beta cell markers by sorting for INS+/NKX6.+ cells

Fig. 11 shows diabetic mice transplanted with stem cell-derived beta cells show rapid lowering of blood glucose and reversal of diabetes

Fig. 12 shows intraperitoneal glucose tolerance test (IPGTT) of transplanted cells

Fig. 13 shows stem cell derived beta cells protect against hyperglycemia post-streptozotocin treatment

Fig. 14 shows high levels of circulating human C-peptide in transplanted mice

DESCRIPTION

The inventors of the present invention have performed extensive small-molecule screens and identified a novel and simple two-step method that generates functional mature Beta cells (BC) from the human pluripotent stem cell -derived endocrine progenitor stage. The first step of the protocol (BC step 1) induces high fraction of INS+ and NKX6.1+ double positive cells and only few GCG positive cells. The second step of the protocol (BC step 2) generates functional mature BC that respond strongly to repeated glucose challenges *in vitro.* Importantly, the hPSC-derived BC cells respond to repeated glucose +/- Exendin4

challenges in a dynamic perfusion assay. The resulting functional mature BC also respond to increased glucose levels *in vivo* 3 weeks after transplantation to the kidney capsule of non-diabetic mice.

The inventors of the present invention have found that gamma-Aminobutyric acid (GABA) administration *in vivo* following cell transplantation can potentially potentiate functional effect of transplanted BC.The resulting fully functional BC population can be used as an *in vitro*-based BC product to study human BC function, screening compounds for regulating insulin secretion, insulin protein processing, insulin secretion and – mechanism, GSIS studies, calcium influx signaling, autoimmune BC destruction, and BC trans differentiation. Throughout this application terms method or protocol or process may be used interchangeably.

PARTICULAR EMBODIMENTS

1. A method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors comprising the steps of (1) culturing the stem cell-derived endocrine progenitor cells in a medium comprising histone methyltransferase EZH2 inhibitor, transforming growth factor beta (TGF)-beta signaling pathway inhibitor, Heparin and Nicotinamide in basal medium , to obtain INS+ and NKX6.1+ double positive immature beta cells and (2) culturing the beta cells obtained in step (1) with 12% KOSR and GABA , to obtain functional mature beta cells.

2. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to embodiment 1, wherein histone methyltransferase EZH2 inhibitor is 3-Deazaneplanocin A (DZNep).

3. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to embodiment 2, wherein concentration of DZNep is below 1μM.

4. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to embodiment 2, wherein concentration of DZNep is 1μM.

5. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to embodiment 2, wherein concentration of DZNep is in a range of 1-10 μM.

6. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to embodiment 2, wherein concentration of DZNep is 10 μM.

7. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to embodiment 1, wherein transforming growth factor beta (TGF)-beta signaling pathway inhibitor is Alk5iII.

8. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to embodiment 7, wherein concentration of Alk5iII is below 1 μM.

9. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to embodiment 7, wherein concentration of Alk5iII is 1 μM.

10. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to embodiment 7, wherein concentration of Alk5iII is in a range of 1 -10 μM.

11. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to embodiment 7, wherein concentration of Alk5iII is 10 μM.

12. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to embodiment 1, wherein concentration of Heparin is below 1μg/ml.

13. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to embodiment 1, wherein concentration of Heparin is 1μg/ml.

14. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to embodiment 1, wherein concentration of Heparin is in a range of 1-10µg/ml.

15. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to embodiment 1, wherein concentration of Heparin is 10µg/ml.

16. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to embodiment 1, wherein the concentration of Nicotinamide is below 1mM.

17. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to embodiment 1, wherein the concentration of Nicotinamide is 1mM.

18. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to embodiment 1, wherein the concentration of Nicotinamide is in a range of 1-10mM.

19. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to embodiment 1, wherein the concentration of Nicotinamide is 10mM.

20. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to embodiment 1, comprising the step of (1) culturing the stem cell-derived endocrine progenitor cells in a medium comprising DZNep, Alk5iII, Heparin and Nicotinamide.

21. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to embodiment 1, comprising the step of (1) culturing the stem cell –derived endocrine progenitor cells in a medium comprising 1µM DZNep, 10 µM Alk5iII, 10 µg/ml Heparin and 10 mM Nicotinamide.

22. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to embodiment 1, comprising step (1) in combination with one or more additional agent.

23. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to embodiment 22, wherein the additional agent is selected from a group consisting of gamma-secretase inhibitor, cAMP-elevating agent, thyroid hormone signaling pathway activator and combinations thereof.

24. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to embodiment 23, wherein the additional agent is gamma-secretase inhibitor.

25. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to embodiment 24, wherein gamma-secretase inhibitor is N-[(3,5-Difluorophenyl)acetyl]-L-alanyl-2-phenyl]glycine-1,1-dimethylethyl ester (DAPT).

26. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to embodiment 25, wherein the concentration of DAPT is below 2.5 μM.

27. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to embodiment 25, wherein the concentration of DAPT is 2.5 μM.

28. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to embodiment 25, wherein the concentration of DAPT is in a range of 2.5 -10μM.

29. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to embodiment 25, wherein the concentration of DAPT is 5μM.

30. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to embodiment 25, wherein the concentration of DAPT is 10μM.

31. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to embodiment 23, wherein the additional agent is cAMP-elevating agent.

32. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to embodiment 31, wherein cAMP-elevating agent is Dibutyryl-cAMP (dbcAMP).

33. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to embodiment 32, wherein the concentration of dbcAMP is below 250 μM.

34. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to embodiment 32, wherein the concentration of dbcAMP is 250 μM.

35. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to embodiment 32, wherein the concentration of dbcAMP is in a range of 250 -500μM.

36. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to embodiment 32, wherein the concentration of dbcAMP is 500 μM.

37. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to embodiment 23, wherein the additional agent is thyroid hormone signaling pathway activator.

38. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to embodiment 37, wherein thyroid hormone signaling pathway activator is T3.

39. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to embodiment 38, wherein the concentration of T3 is below 1μM.

40. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to embodiment 38, wherein the concentration of T3 is 1μM.

41. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to embodiment 38, wherein the concentration of T3 is in a range of 1-10μM.

42. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to embodiment 38, wherein the concentration of T3 is 10μM.

43. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to embodiment 1, comprising the step of (1) culturing the stem cell –derived endocrine progenitor cells in a medium comprising DZNep, Alk5iII, Heparin and Nicotinamide in combination with DAPT.

44. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to embodiment 1, comprising step of (1)culturing the stem cell –derived endocrine progenitor cells in a medium comprising 1μM DZNep, 10 μM Alk5iII, 10 μg/ml Heparin and 10 mM Nicotinamide in combination with 2.5 μM DAPT.

45. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to embodiment 1, comprising step of (1) culturing the stem cell –derived endocrine progenitor cells in a medium comprising DZNep, Alk5iII, Heparin and Nicotinamide in combination with dbcAMP.

46. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to embodiment 1, comprising step (1)

culturing the stem cell –derived endocrine progenitor cells in a medium comprising 1μM DZNep, 10 μM Alk5iII, 10 μg/ml Heparin and 10 mM Nicotinamide in combination with 250 μM dbcAMP.

47. The method for generation of functional beta cells from human pluripotent stem cell-derived endocrine progenitors according to embodiment 23, wherein the additional agent gamma-secretase inhibitor is in combination with thyroid hormone signaling pathway activator.

48. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to embodiment 47, wherein the additional agent DAPT is in combination with T3.

49. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to embodiment 48, wherein the concentration of DAPT is 2.5 μM and concentration of T3 is 1μM.

50. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to embodiment 23, wherein the additional agent gamma-secretase inhibitor is in combination with cAMP elevating agent.

51. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to embodiment 50, wherein the additional agent is DAPT in combination with dbcAMP.

52. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to embodiment 51, wherein the concentration of DAPT is 2.5 μM and concentration of dbcAMP is 250 μM.

53. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to embodiment 1, wherein the stem cell-derived endocrine progenitor cells are cultured in step (1) for 1- 4 days.

54. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to embodiment 1, wherein the stem cell-derived endocrine progenitor cells are cultured in step (1) for 4 days.

55. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to embodiment 1, wherein the stem cell-derived endocrine progenitor cells are cultured in step (1) for 4-7 days.

56. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to any of one preceding embodiments, wherein 10-60% INS+ and NKX6.1+ double positive immature beta cells are obtained in step 1.

57. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to any one the preceding embodiments , wherein 20-50% INS+ and NKX6.1+ double positive immature beta cells are obtained in step (1).

58. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to any of one preceding embodiments, wherein 25-45% INS+ and NKX6.1+ double positive immature beta cells are obtained in step 1.

59. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to any of one preceding embodiments, wherein 30-40% INS+ and NKX6.1+ double positive immature beta cells are obtained in step 1.

60. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to embodiment 1, comprising culturing the beta cells obtained in step (1) with 12% KOSR and GABA, in combination with one or more additional agent to obtain functional mature beta cells.

61. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to embodiment 60, wherein the concentration of GABA is 50 μM.

62. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to embodiment 60, wherein the concentration of GABA is in a range of 50 -250 μM.

63. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to embodiment 60, wherein the concentration of GABA is 250 μM.

61. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to embodiment 60, wherein additional agent is TGF-beta signaling pathway inhibitor.

62. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to embodiment 61, wherein TGF-beta signaling pathway inhibitor is Alk5iII.

63. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to embodiment 62, wherein the concentration of Alk5iII is below 1μM.

64. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to embodiment 62, wherein the concentration of Alk5iII is 1μM.

65. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to embodiment 62, wherein the concentration of Alk5iII is in a range of 1-10μM.

66. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to embodiment 62, wherein the concentration of Alk5iII is 10μM.

67. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to embodiment 60, wherein additional agent is thyroid hormone signaling pathway activator.

68. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to embodiment 67, wherein thyroid hormone signaling pathway activator is T3.

69. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to embodiment 68, wherein the concentration of T3 is below 1μM.

70. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to embodiment 68, wherein the concentration of T3 is 1μM.

71. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to embodiment 68, wherein the concentration of T3 is in a range of 1-10μM.

72. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to embodiment 68, wherein the concentration of T3 is 10μM.

73. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to embodiment 60, wherein additional agent is histone methyltransferase EZH2 inhibitor.

74. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to embodiment 73, wherein histone methyltransferase EZH2 inhibitor is DZNep.

75. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to embodiment 74, wherein the concentration of DZNep is below 1μM.

76. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to embodiment 74, wherein the concentration of DZNep is in a range of 1-10 μM.

77. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to embodiment 74, wherein the concentration of DZNep is 10 μM.

78. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to embodiment 60, wherein additional agent TGF-beta signaling pathway inhibitor is in combination with thyroid hormone signaling pathway activator and histone methyltransferase EZH2 inhibitor is DZNep.

79. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to embodiment 78, wherein additional agent Alk5iII in combination with T3 and DZNep.

80. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to embodiment 79, wherein additional agent 10μM Alk5iII in combination with 1 μM T3 and 1 μM DZNep.

81. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to embodiment 60, wherein additional agent TGF-beta signaling pathway inhibitor is in combination with thyroid hormone signaling pathway activator.

82. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to embodiment 81, wherein additional agent Alk5iII in combination with T3.

83. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to embodiment 82, wherein 10μM Alk5iII is in combination with 1μM T3.

84. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to embodiment 60, wherein additional agent TGF-beta signaling pathway inhibitor is in combination with histone methyltransferase EZH2 inhibitor is DZNep.

85. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to embodiment 84, wherein additional agent Alk5iII in combination with DZNEP.

86. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to embodiment 85, wherein 10μM Alk5iII is in combination with 1μM DZNEP.

87. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to any of one preceding embodiments 60-86, wherein INS+ and NKX6.1+ double positive immature beta cells obtained in step (1) are cultured in step (2) for 3-7 days.

88. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to any of one preceding embodiments 60-86, wherein INS+ and NKX6.1+ double positive immature beta cells obtained in step (1) are cultured in step (2) for 7-11 days.

89. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to any of one embodiments 60-86, wherein 10-60% functional mature beta cells are obtained in step 2.

90. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to any of one embodiments 60-86, wherein 20-50% functional mature beta cells are obtained in step 2.

91. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to any of one embodiments 60-86, wherein 25-45% functional mature beta cells are obtained in step 2.

92. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to any of one embodiments 60-86, wherein 30-40% functional mature beta cells are obtained in step 2.

93. Functional mature beta cells obtainable by method according to any one of embodiments 1-92.

94. Functional mature beta cells obtained in embodiment 93 express MAFA, IAPP and G6PC2.

In one embodiment, the cells obtainable by the method according to the invention are insulin producing cells, optionally together with cells differentiated towards glucagon, somatostatin, pancreatic polypeptide, and/or ghrelin producing cells. As used herein, "insulin producing cells" refers to cells that produce and store or secrete detectable amounts of insulin. "Insulin producing cells" can be individual cells or collections of cells.

In another embodiment, the cell population comprising pancreatic cells is obtained from a somatic cell population. In some aspects the somatic cell population has been induced to de-differentiate into an embryonic-like stem (ES, e.g., a pluripotent) cell. Such de-differentiated cells are also termed induced pluripotent stem cells (iPSC).

In another embodiment, the cell population comprising pancreatic cells is obtained from embryonic stem (ES, e.g., pluripotent) cells. In some aspects the cell population comprising pancreatic cells is pluripotent cells such as ES like-cells.

In another embodiment, the cell population comprising pancreatic cells is embryonic differentiated stem (ES or pluripotent) cells. Differentiation takes place in embryoid bodies and/or in monolayer cell cultures or a combination thereof.

In another embodiment, the cell population is a population of stem cells. In some aspects the cell population is a population of stem cells differentiated to the pancreatic endocrine lineage.

Stem cells are undifferentiated cells defined by their ability at the single cell level to both self-renew and differentiate to produce progeny cells, including self-renewing progenitors, non-renewing progenitors, and terminally differentiated cells. Stem cells are also characterized by their ability to differentiate *in vitro* into functional cells of various cell lineages from multiple germ layers (endoderm, mesoderm and ectoderm), as well as to give rise to tissues of multiple germ layers following transplantation and to contribute substantially to most, if not all, tissues following injection into blastocysts.

Stem cells are classified by their developmental potential as: (1) totipotent, meaning able to give rise to all embryonic and extraembryonic cell types; (2) pluripotent, meaning able to give rise to all embryonic cell types; (3) multi-potent, meaning able to give rise to a subset of cell lineages, but all within a particular tissue, organ, or physiological system (for example, hematopoietic stem cells (HSC) can produce progeny that include HSC (self-renewal), blood cell restricted oligopotent progenitors and all cell types and elements (e.g., platelets) that are normal components of the blood); (4) oligopotent, meaning able to give rise to a more restricted subset of cell lineages than multi-potent stem cells; and (5) unipotent, meaning able to give rise to a single cell lineage (e.g., spermatogenic stem cells).

As used herein "differentiate" or "differentiation" refers to a process where cells progress from an undifferentiated state to a differentiated state, from an immature state to a less immature state or from an immature state to a mature state. For example, early undifferentiated embryonic pancreatic cells are able to proliferate and express characteristics markers, like PDX1, NKX6.1, and PTF1a. Mature or differentiated pancreatic cells do not proliferate and do secrete high levels of pancreatic endocrine hormones or digestive enzymes. E.g., fully differentiated beta cells secrete insulin at high levels in response to glucose. Changes in cell interaction and maturation occur as cells lose markers of undifferentiated cells or gain markers of differentiated cells. Loss or gain of a single marker can indicate that a cell has "matured or fully differentiated." The term "differentiation factor" refers to a compound added to pancreatic cells to enhance their differentiation to mature endocrine cells also containing insulin producing beta cells. Exemplary differentiation factors include hepatocyte growth factor, keratinocyte growth factor, exendin-4, basic fibroblast growth factor, insulin-like growth factor-1, nerve growth factor, epidermal growth factor platelet-derived growth factor, and glucagon-like peptide 1. In some aspects differentiation of the cells comprises culturing the cells in a medium comprising one or more differentiation factors.

As used herein, "human pluripotent stem cells" (hPSC) refers to cells that may be derived from any source and that are capable, under appropriate conditions, of producing human progeny of different cell types that are derivatives of all of the 3 germinal layers (endoderm, mesoderm, and ectoderm). hPSC may have the ability to form a teratoma in 8-12 week old SCID mice and/or the ability to form identifiable cells of all three germ layers in tissue culture. Included in the definition of human pluripotent stem cells are embryonic cells of various types including human blastocyst derived stem (hBS) cells in 30 literature often denoted as human embryonic stem (hES) cells, (see, e.g., Thomson *et al*. (1998), Heins *et al.* (2004), as well as induced pluripotent stem cells (see, e.g. Yu *et al*. (2007); Takahashi *et*

al. (2007)). The various methods and other embodiments described herein may require or utilise hPSC from a variety of sources. For example, hPSC suitable for use may be obtained from developing embryos. Additionally or alternatively, suitable hPSC may be obtained from established cell lines and/or human induced pluripotent stem (hiPS) cells.

As used herein "hiPSC" refers to human induced pluripotent stem cells.

As used herein, the term "blastocyst-derived stem cell" is denoted BS cell, and the human form is termed "hBS cells". In literature the cells are often referred to as embryonic stem cells, and more specifically human embryonic stem cells (hESC). The pluripotent stem cells used in the present invention can thus be embryonic stem cells prepared from blastocysts, as described in e.g. WO 03/055992 and WO 2007/042225, or be commercially available hBS cells or cell lines. However, it is further envisaged that any human pluripotent stem cell can be used in the present invention, including differentiated adult cells which are reprogrammed to pluripotent cells by e.g. the treating adult cells with certain transcription factors, such as OCT4, SOX2, NANOG, and LIN28 as disclosed in Yu, *et al*. (2007); Takahashi *et al*. (2007) and Yu *et al.* (2009).

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

All headings and sub-headings are used herein for convenience only and should not be construed as limiting the invention in any way.

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

While certain features of the invention have been illustrated and described herein, many modifications, substitutions, changes, and equivalents will now occur to those of ordinary skill in the art. It is, therefore, to be understood that the appended claims are intended to cover all such modifications and changes as fall within the true spirit of the invention.

List of Abbreviations

AA: Activin A

BC: Beta cells

bFGF: basic fibroblast growth factor (FGF2)

D'Am: D'Amour protocol (Kroon et al., 2008)

DAPT: N-[(3,5-Difluorophenyl)acetyl]-L-alanyl-2-phenyl]glycine-1,1-dimethylethyl ester

DE: definitive endoderm

DZNep : 3-Deazaneplanocin A

EP: Endocrine Progenitor

FC : Flow cytometry

GABA: gamma-Aminobutyric acid

GSIS : glucose stimulated insulin secretion

hESC: human embryonic stem cells

hIPSC: human induced pluripotent cells

hPSC: human pluripotent stem cells

KOSR: knockout serum replacement

PE: Pancreatic Endoderm

RNA: ribonucleic acid

PCR: polymerase chain reaction

PS: primitive streak

Examples

In general, the process of differentiating hPSCs to functional mature beta cells goes through various stages. An exemplary method for generating functional beta cells from hPSCs in vitro is outlined in Fig 1.

Example 1: Preparation of endocrine progenitor cells

hESCs (SA121) were cultured in DEF media (Cellectis) supplemented with 30ng/mLbFGF (Peprotech #100-18B) and 10ng/mL noggin (Peprotech #120-10C).

For adherent cultures, the hESCs were differentiated into DE in T75 flasks using a Chir99021 and ActivinA based protocol in WO2012/175633. DE was trypsinized using Tryple Select (Invitrogen #12563-029) and reseeded as single cells in RPMI1640 supplemented with 100ng/ml ActivinA (Peprotech #120-14E), 2% B27 (Invitrogen #17504-044) and 0,1% PEST (Gibco#15140) in T75 flasks at 200K/cm2. DE cells were allowed to attach and differentiated into PE using a LDN, AM508 based protocol in WO 2014/033322 followed by a four day EP protocol in WO2015/028614.

To produce large numbers of beta cells, a scalable suspension-based culture system was utilized by differentiating clusters of hESCs into DE in shaker flasks in Multitron

Standard incubators (Infors) as suspension cultures (1 million/ml) at 70 RPM using a Chir99021 and ActivinA based protocol in WO2012/175633 without requirement of a reseeding step. DE cells were further differentiated into PE using a LDN, AM508 based protocol in WO 2014/033322 with the following slight modification: LDN is not added at PE day 4-10. Generation of PE was followed by a four day EP protocol WO2015/028614.

Example 2: Screening for factors that induce INS+/NKX6.1+ co-expression during BC step 1

As a first step towards generating fully functional mature beta cells, we screened for factors to generate maximal numbers of immature INS+/NKX6.1+ cells (BC step 1 screen). BC step 1 screen was initiated at the EP stage using library of kinase inhibitors, epigenetic regulators, redox and bioactive lipids supplemented with some literature based compounds (in total 650 compounds of interests) added on top of RPMI1640 + 2%B27 + 10mM Nicotinamide.

Compounds were screened for their ability to induce INS+, NKX6.1+ double positive immature BCs and few GCG positive cells within a 7 days period. Media change was performed daily. Cells were fixed at day 4 and day 7 of BC step 1 and analysed for INS NKX6.1 and GCG expression using flow cytometry (see Table 1 and Fig 2). Briefly, cells were dispersed into single-cell suspension by incubation with TrypLE Express at 37° C for 10 min. Cells were resuspended in 4% paraformaldehyde, washed in PBS followed by incubation with primary antibodies overnight and then secondary antibodies for 1 hour. The differentiated hPSCs co-expressed C-peptide+/NKX6-1+ with few cells expressing the α-cell hormone glucagon (Fig 2). When quantified by flow cytometry, 48% of the cells co-expressed C-peptide+/NKX6-1, more than previously reported with stem cell-derived beta cells (reference Melton, Kieffer).

Table 1. FC analysis of BC step 1 method at BC day 7

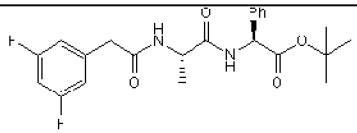
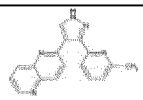
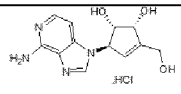
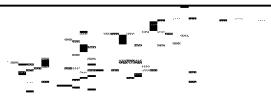
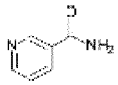
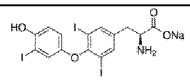
	#1
INS+/NKX6.1+	**20,8%**
INS+/NKX6.1-	19,8%
INS-/NKX6+	16,4%
INS/GCG	12,3%
INS+/GCG-	25,6%

INS-/GCG+	2%

#1:DZNEP 1uM + Alk5i 10 uM + 10 ug/ml Heparin

Hits identified in a primary screen were then combined individually and added on top of the BC step 1 medium (see Table 2 and Fig 3). Timing of studies revealed that BC step 1 has an optimal length of 4-7 days based on mRNA expression of Ins and Gcg (see Fig 4).

Table 2: shows hit compounds in BC step 1 medium

Compound name	Target	Structure	Concentration
DAPT	Notch		2.5μM
ALK5iII	TGF-β RI Kinase		1μM, 10μM
DZNEP	PRC complex?		1μM, 10μM
Heparin			10μg/ml
dbcAMP	Increased cAMP levels		250μM, 500μM
Nicotinamide			10mM
T3	Thyroid receptor		1μM, 10μM

Example 3: Generation of glucose sensing insulin secreting beta cells from BC step 1

The key functional feature of a fully functional mature beta cell is its ability to perform glucose stimulated insulin secretion (GSIS). We screened for factors in BC step 2 that could induce functional beta cells from the immature INS+/NKX6.1+ cells from BC step 1.

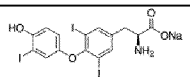
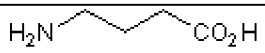
BC step 2 screen was performed in suspension cultures. For adherent cultures, cells in T75 flasks were trypsinized at the end of BC step 1 using Tryple Select and transferring cells into low attachment 9 cm petri dishes in suspension with RPMI1640 medium

(Gibco#61870) containing 12% KOSR (ThermoFisher#10828028) and 0.1% PEST, Gibco#15140.

Effects of selected compounds were then tested for a 7 day period for induction of glucose-responsive cells in a static GSIS setup (see Fig 5). Briefly, cell clusters were sampled and incubated overnight in 2.8 mM glucose media to remove residual insulin. Clusters were washed two times in Krebs buffer, incubated in 2.8 mM Krebs buffer for 30 min, and supernatant collected. Then clusters were incubated in 16 mM glucose Krebs buffer for 30 min, and supernatant collected. This sequence was repeated. Finally, clusters were incubated in Krebs buffer containing 2.8 mM glucose for 30 min and then supernatant collected. Supernatant samples containing secreted insulin were processed using Human Insulin ELISA (Mercodia).

Hits identified in a primary screen were then combined individually and added on top of the 12% KOSR medium to generate the optimal 7-day BC step 2 protocol (see Table 3).

Table 3: shows hit compounds in BC step 2 medium

Compound name	Target	Structure	Concentration
T3	Thyroid receptors		1μM, 10 μM
ALK5iII	TGF-β RI Kinase		1μM, 10 μM
dbcAMP	cAMP		250μM
GABA	GABA receptors		50μM
KOSR			12%

Example 4: Perfusion assay to assay dynamic human insulin secretion in vitro

Mature beta cells are functionally defined by their rapid response to elevated glucose. Secretion of human insulin by beta cells at the end of BC step 2 was measured as repeated responses to 20 mM glucose ± 1 μM exendin-4 or ± the anti-diabetic sulfonylurea compound Tolbutamide within a perfusion system.

Briefly, groups of 300 hand-picked, clusters of hESC- or hiPSC-derived cell clusters were suspended with beads (Bio-Rad #150-4124) in plastic chambers of Biorep PERFUSION SYSTEM (Biorep # PERI-4.2). Under temperature- and CO2-controlled conditions, the cells were perfused at 0.5 ml min-1 with a Krebs buffer. Prior to sample collection, cells were equilibrated under basal (2 mM glucose) conditions for 1 h. During perfusion cells were exposed to repeated challenges with 20 mM glucose ± 1 μM exendin-4

or ± 100 µM Tolbutamide. At the end of perfusion, cells were exposed to cAMP-elevating agents on top of 20 mM glucose. Insulin secretion was measured by human insulin ELISA (Mercodia).

By perfusion analysis, our stem cell-derived beta cells exhibited rapid and robust release of insulin with a 1st and 2nd phase of insulin secretion that was highly synchronized with changes in glucose concentrations (see FIG 6). The GLP-1 analog exendin-4 increased the level of insulin secretion in the hPSC-derived beta cells. Importantly, presence of glucose responsive insulin secreting cells was observed for at least 4 days *in vitro* as measured at day 3 (FIG 6A) and day 7 (FIG 6B) of BC step 2.

Another example of perifusion analysis of our stem cell-derived beta cells at day 7 of BC step 2 demonstrated a significant additive effect of the sulfonylurea tolbutamide on insulin secretion (FIG 7). Robustness of the protocol is demonstrated by induction of functional beta cells from independent pluripotent cell lines (see FIG 8). These data demonstrate collectively the superiority of the protocol for generating stem cell-derived beta cells that display glucose-stimulated insulin release dynamics measured by perifusion as compared to previous reports (Rezania, 2014; Paglucia, 2014 and review Johnson-J, 2016 Diabetologia).

Example 5 Gene expression analysis showed high level of similarities of stem cell-derived beta cells to human islet material

Differentiated cell clusters at BC day 7 of step 2 or human islets were collected and RNA was purified using the RNeasy kit from Qiagen (Cat No./ID: 74134). The quality was assessed using the RNA 6000 Nano Kit and the 2100 Bianalyser instrument (Agilent). 100ng RNA was subjected to an nCounter assay according to instructions from Nanostring Technology. FIG 9 shows the expression profile of beta cell associated genes from human islets and beta cells generated from hiPSC and two different hESC lines. The gene expression analysis showed that the stem cell-derived beta cells had close molecular resemblance to human islets.

Additional gene expression analysis of the specific stem cell-derived INS+/NKX6.1+ cells were performed by FACS cell sorting. Prior to sorting on the BD FACSARIA fusionTM instrument, cell clusters were dissociated and stained for the separation of live and dead cells using a near IR dye (Thermo Scientific). After fixation and permeabilisation the cells were stained using the intracellular markers NKX6.1 and C-peptide. RNA was purified using the RNeasy FFPE Kit (QIAGEN) and quality was assessed using the RNA 6000 Nano Kit and the 2100 Bianalyser instrument (Agilent). FIG 10 shows enrichment of key beta cell

maturity genes after cell sorting for NKX6.1/CPEP double positive cells. Nanostring data was normalized to the unsorted cell population.

Example 6 Stem cell-derived beta cells from step 2 function after transplantation

To evaluate functionality in vivo, stem cell-derived beta cells from day 3-10 of BC step 2 were transplanted into a streptozotocin-induced mouse model of diabetes. In short, diabetes is induced in immunocompromised scid-beige mice (Taconic) using Multiple Low Dose (5x70 mg/kg) Streptozotocin (STZ), the mice are fasted 4h prior to STZ dosing. The mice are monitored over the following weeks with respect to blood glucose, body weight and HbA1c. Diabetes is considered when blood glucose is consistently above 16 mM.

In full anaesthesia and analgesia the diabetic mice are transplanted with 5 x 10^6 human embryonic stem cell derived beta cells (unsorted population) under the kidney capsule. The kidney is exposed trough a small incision through skin and muscle of the left back side of the animal, a pouch between the parenchyma of the kidney and the capsule is created were the cell clusters are injected. The abdominal wall and the skin is closed and the mouse is allowed to recover.

The function of the cells is monitored over the coming weeks with respect to blood glucose, body weight, HbA1c and human c-peptide/insulin secretion. Our stem cell-derived beta cells resulted in rapid reversal of diabetes within the first two weeks after transplantation (FIG 11), more rapidly than previous reports (Rezania, 2014). Importanly, all mice with less than 85% of BW received daily injections with insulin, i.e. non-transplanted diabetic control group. In vivo challenge of transplanted cells with glucose demonstrated in vivo functionality of our stem cell-derived beta cells with better glucose clearance than control mice and increased level of circulating human c-peptide within 60 min of glucose injection (FIG 12). In another diabetes model, 5 million differentiated cells were transplanted to the kidney capsule of non-diabetic SCID/Beige mice. These mice were then treated with streptozotocin 8 weeks after transplantation. FIG 13 demonstrates that the pre-transplanted mice were protected from hyperglycemia post-streptozotocin administration versus non-transplanted control mice, whereas removal of the graft resulted in rapid hyperglycemia in the mice (see FIG 13). High levels of circulating human c-peptide was measured in all transplanted mice from the first data point and until end of study (see FIG 14).

CLAIMS

1. A method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors comprising the steps of (1) culturing the stem cell-derived endocrine progenitor cells in a medium comprising histone methyltransferase EZH2 inhibitor, TGF-beta signaling pathway inhibitor, Heparin and Nicotinamide in basal medium , to obtain INS+ and NKX6.1+ double positive immature beta cells and (2) culturing the beta cells obtained in step (1) with 12% KOSR and GABA , to obtain functional mature beta cells.

2. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to claim 1, wherein histone methyltransferase EZH2 inhibitor is 3-Deazaneplanocin A (DZNep).

3. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to claim 1, wherein TGF-beta signaling pathway inhibitor is Alk5iII.

4. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to claim 1, comprising step (1) in combination with one or more additional agent selected from group consisting of gamma-secretase inhibitor, cAMP-elevating agents, thyroid hormone signaling pathway activator and combinations thereof.

5. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to claim 4, wherein gamma-secretase inhibitor is DAPT.

6. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to claim 4, wherein cAMP-elevating agent is dbcAMP.

7. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to claim 4, wherein thyroid hormone signaling pathway activator is T3.

8. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to claim 4, wherein the additional agent is DAPT is in combination with T3.

9. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to claim 4, wherein the additional agent is DAPT in combination with dbcAMP.

10. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to claim 1, comprising culturing the beta cells obtained in step (1) with 12% KOSR + GABA, in combination with one or more additional agent to obtain functional mature beta cells.

11. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to claim 10, wherein additional agent is Alk5iII.

12. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to claim 10, wherein additional agent is T3.

13. The method for generation of functional mature beta cells from human pluripotent stem cell-derived endocrine progenitors according to claim 10, wherein additional agent Alk5iII is in combination with T3.

14. Functional mature beta cells obtainable by method according to claims 1-13.

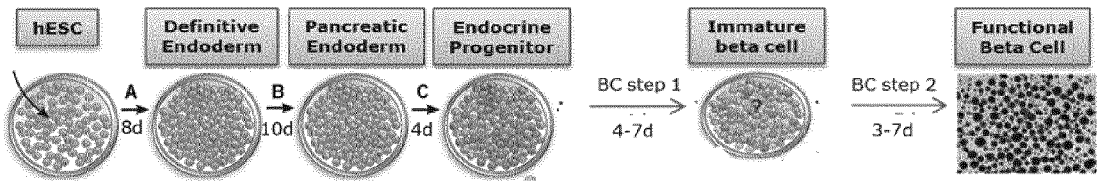
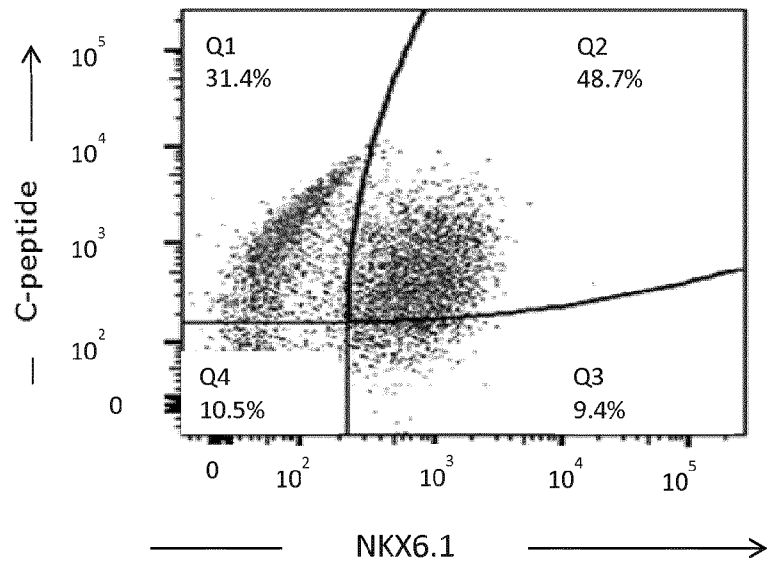

hESC
Definitive Endoderm
Pancreatic Endoderm
Endocrine Progenitor
Immature beta cell
Functional Beta Cell
A
8d
B
10d
C
4d
BC step 1
4-7d
BC step 2
3-7d

Fig. 1

A.


Q1
31.4%
Q2
48.7%
Q4
10.5%
Q3
9.4%
C-peptide
NKX6.1
0
10^2
10^3
10^4
10^5

B.

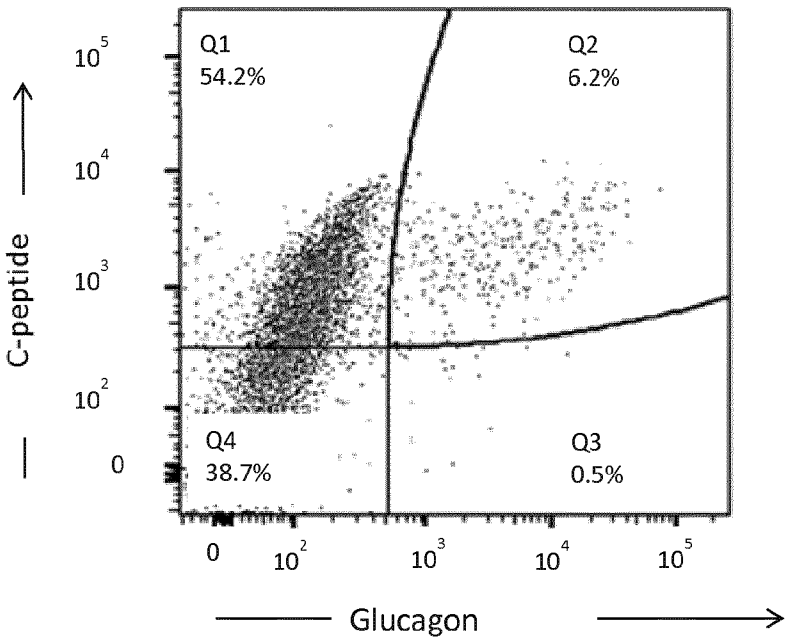
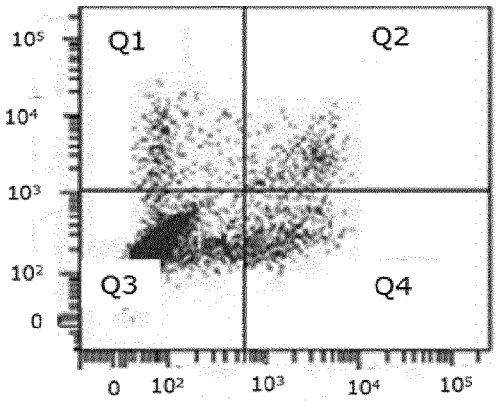

Q1
54.2%
Q2
6.2%
Q4
38.7%
Q3
0.5%
C-peptide
Glucagon
0
10^2
10^3
10^4
10^5

Fig. 2

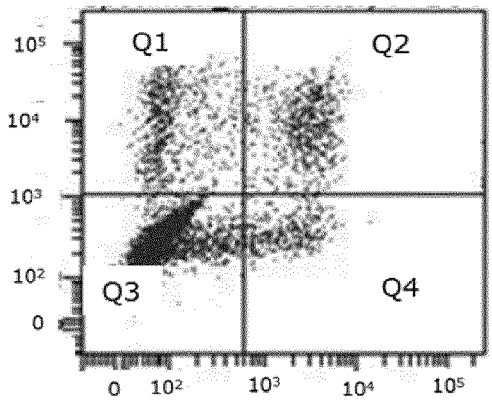
A.

BC step1 protocol: 100% (Q2)

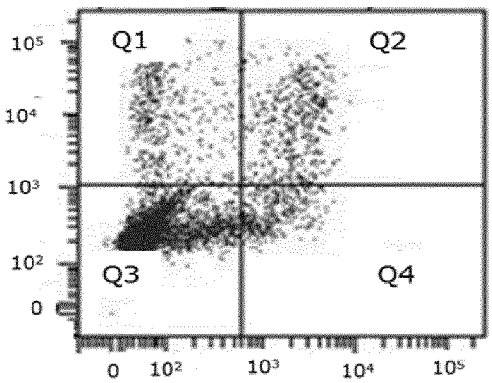


B.

BC step1 protocol+DAPT: 270% (Q2)



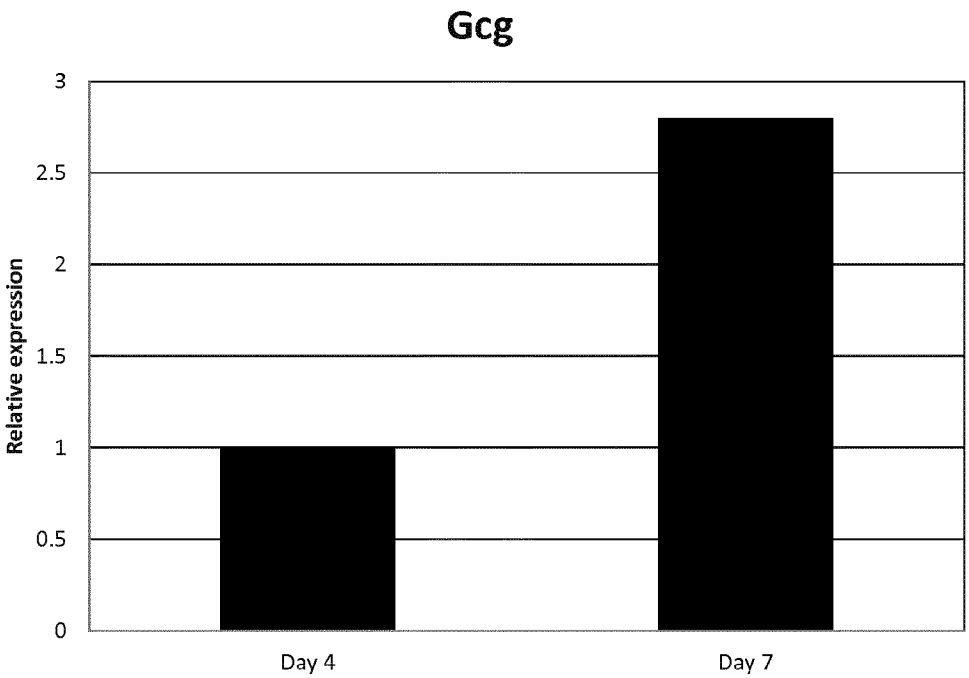
C. BC step1 protocol+dbcAMP: 165% (Q2)



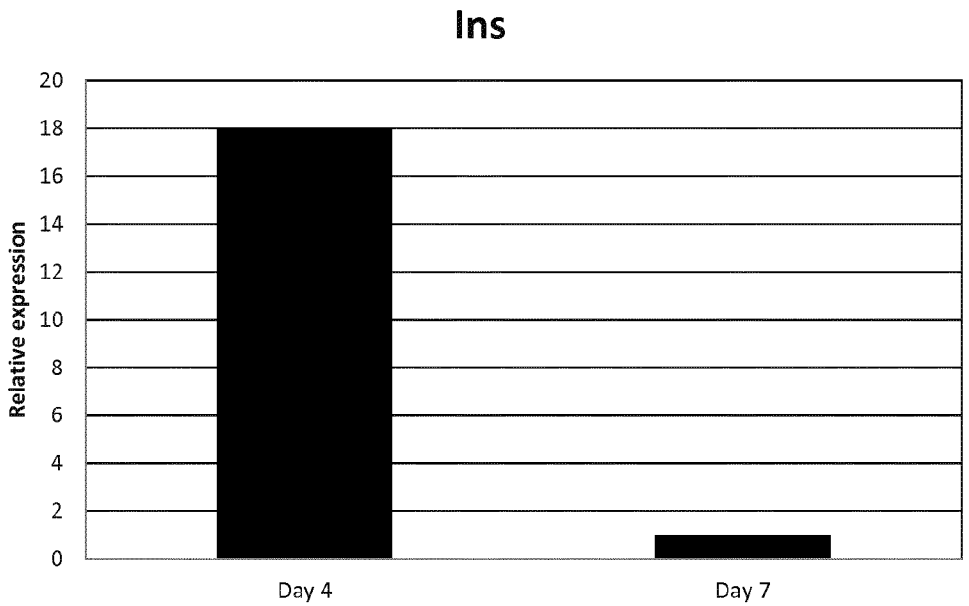
BC step 1: DZNEP 1uM + Alk5i 10 uM + 10 ug/ml Heparin + 10 mM Nicotinamide

Fig. 3

A.

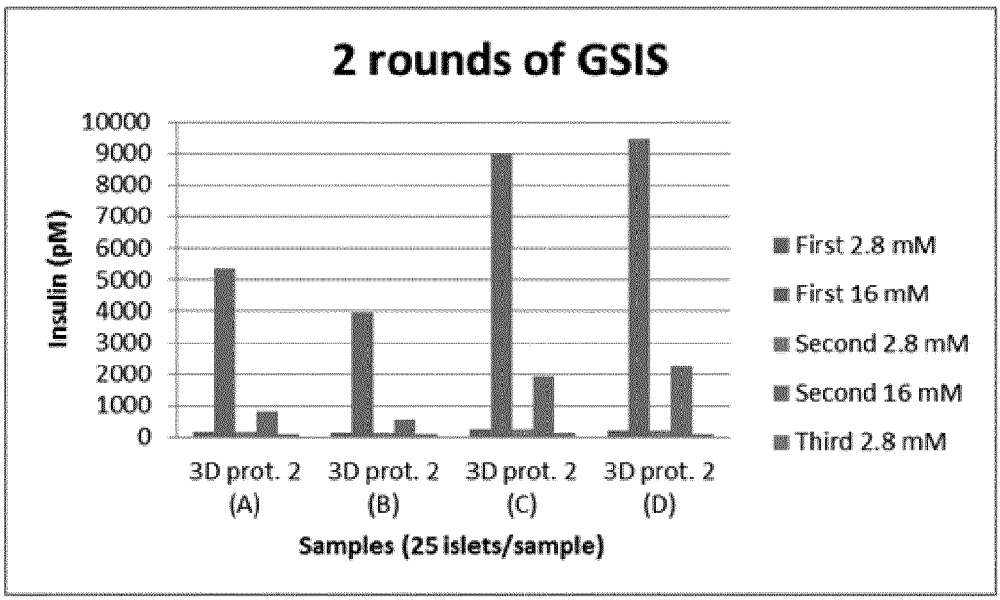


B.



BC step 1: DZNEP 1uM + Alk5i 10 uM + 10 ug/ml Heparin + 10 mM Nicotinamide

Fig. 4



BC step 1 method: DZNEP 1uM + Alk5i 10 uM + 10 ug/ml Heparin + 10 mM Nicotinamide

BC step 2 method: 12% KOSR

Fig. 5

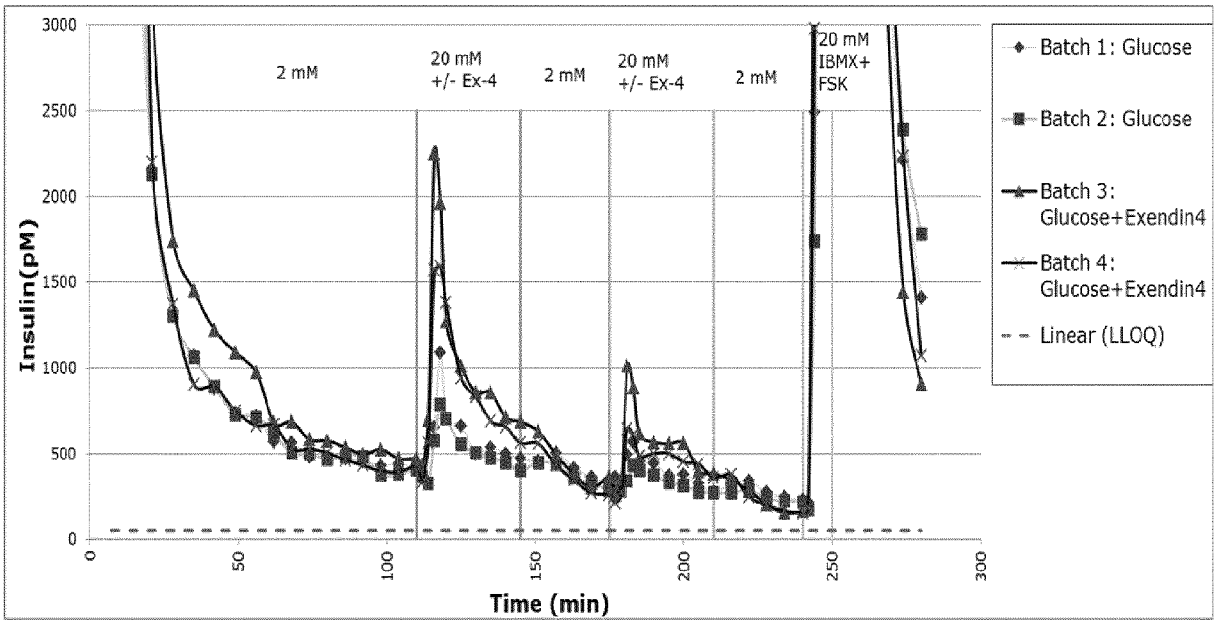

3000
2500
2000
1500
1000
500
0
Insulin(pM)
0
50
100
150
200
250
300
Time (min)
2 mM
20 mM
+/- Ex-4
2 mM
20 mM
+/- Ex-4
2 mM
20 mM
IBMX+
FSK
Batch 1: Glucose
Batch 2: Glucose
Batch 3:
Glucose+Exendin4
Batch 4:
Glucose+Exendin4
Linear (LLOQ)

Fig. 6A

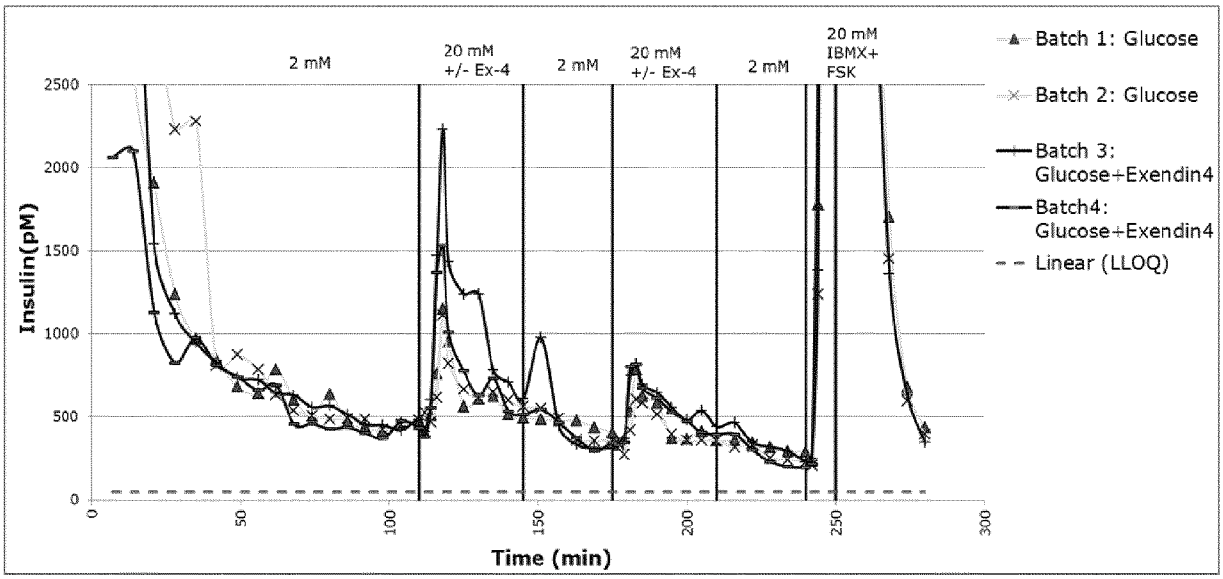

2 mM
20 mM +/- Ex-4
2 mM
20 mM +/- Ex-4
2 mM
20 mM IBMX+ FSK
Batch 1: Glucose
Batch 2: Glucose
Batch 3: Glucose+Exendin4
Batch4: Glucose+Exendin4
Linear (LLOQ)
Insulin(pM)
Time (min)
0
500
1000
1500
2000
2500
0
50
100
150
200
250
300

Fig. 6B

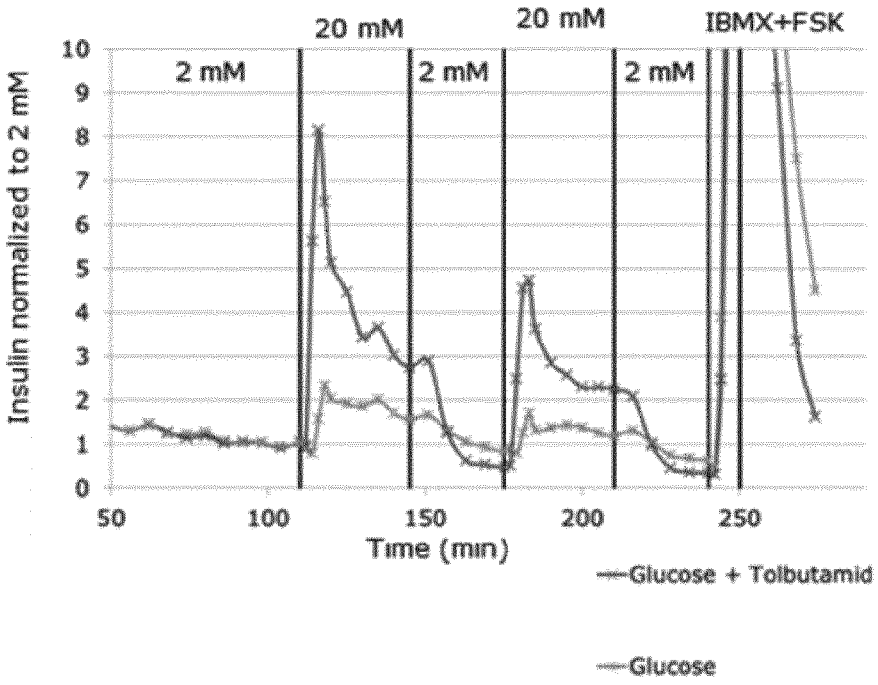
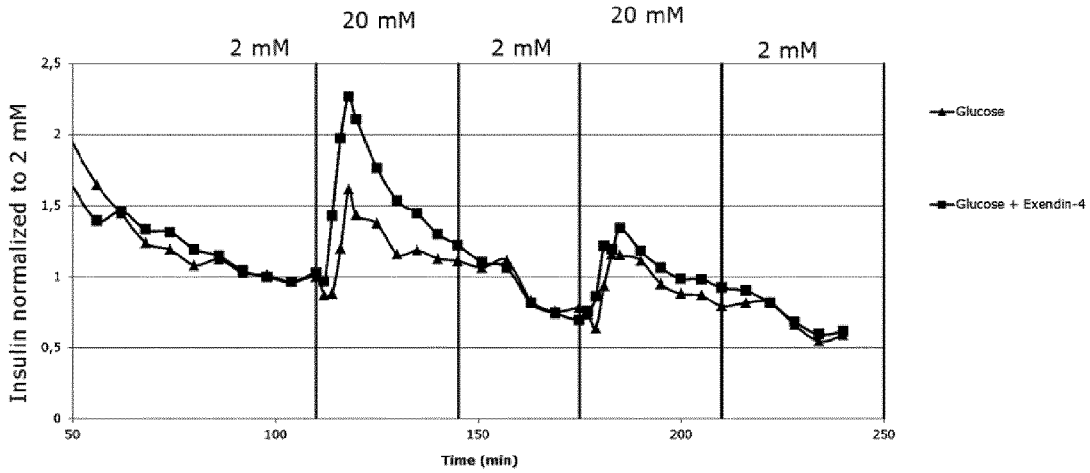

20 mM
20 mM
IBMX+FSK
2 mM
2 mM
2 mM
Insulin normalized to 2 mM
10
9
8
7
6
5
4
3
2
1
0
50
100
150
200
250
Time (min)
Glucose + Tolbutamid
Glucose

Fig. 7

A.


20 mM
20 mM
2 mM
2 mM
2 mM
Insulin normalized to 2 mM
Time (min)
Glucose
Glucose + Exendin-4

B.

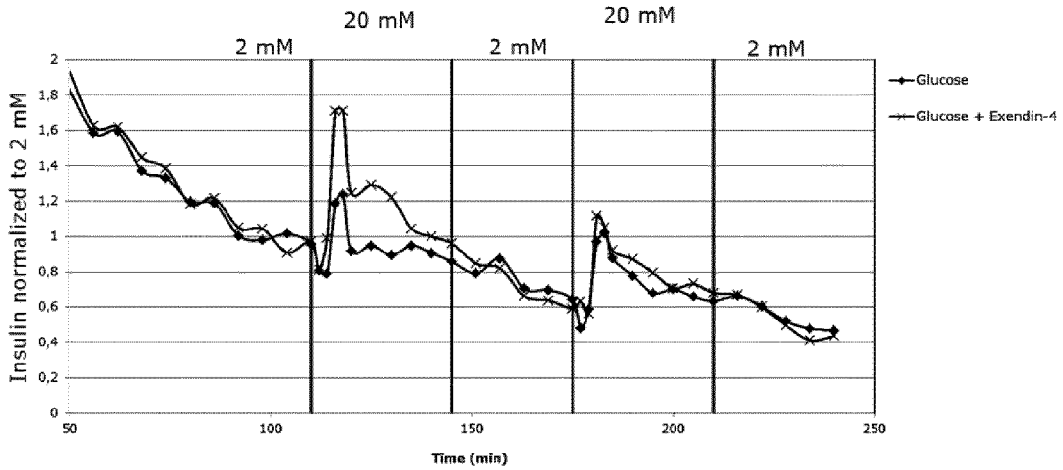

20 mM
20 mM
2 mM
2 mM
2 mM
Insulin normalized to 2 mM
Time (min)
Glucose
Glucose + Exendin-4

Fig. 8

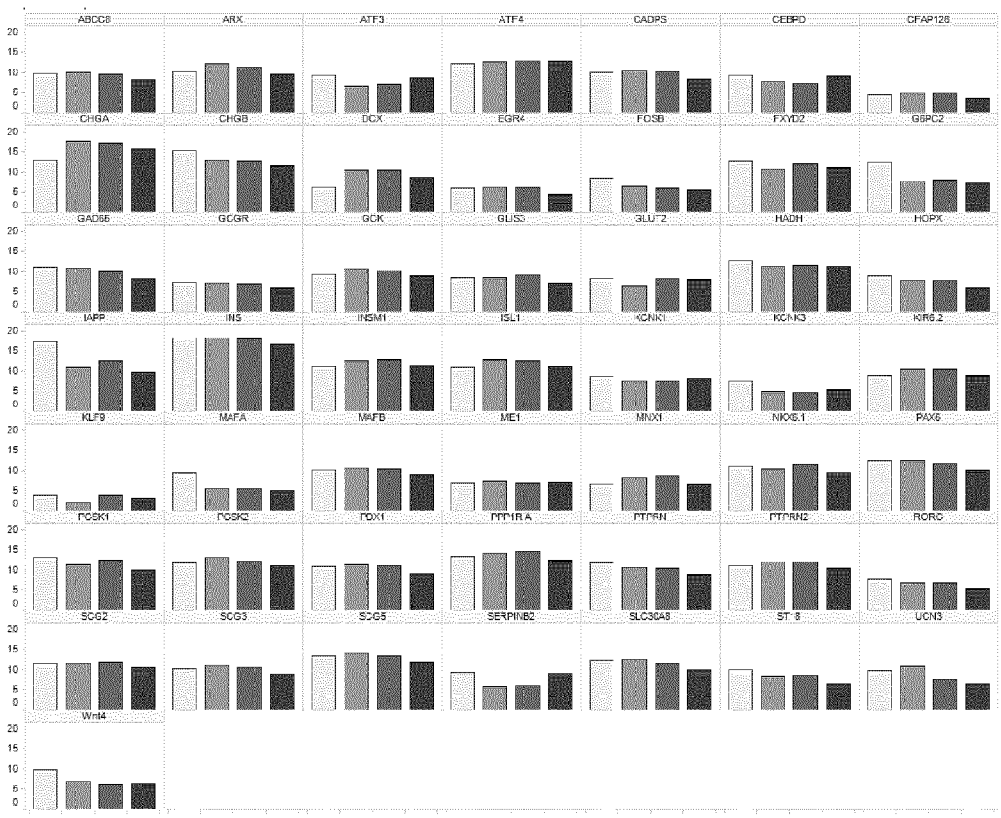

ABCC8
ARX
ATF3
ATF4
CADPS
CEBPD
CFAP126
CHGA
CHGB
DCX
EGR4
FOSB
FXYD2
G6PC2
GAD65
GCGR
GCK
GLIS3
GLUT2
HADH
HOPX
IAPP
INS
INSM1
ISL1
KCNK1
KCNK3
KIR6.2
KLF9
MAFA
MAFB
ME1
MNX1
NKX6.1
PAX6
PDK1
PDK2
PDX1
PPM1A
PTPRN
PTPRN2
RORC
SCG2
SCG3
SCG5
SERPINB2
SLC30A8
ST18
UCN3
Wnt4

Fig. 9

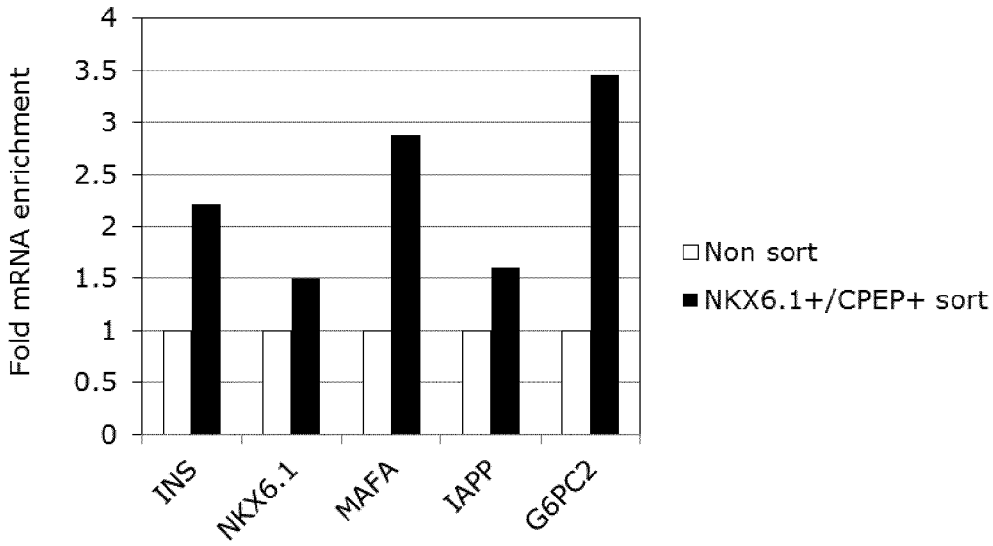

Fold mRNA enrichment
4
3.5
3
2.5
2
1.5
1
0.5
0
INS
NKX6.1
MAFA
IAPP
G6PC2
Non sort
NKX6.1+/CPEP+ sort

Fig. 10

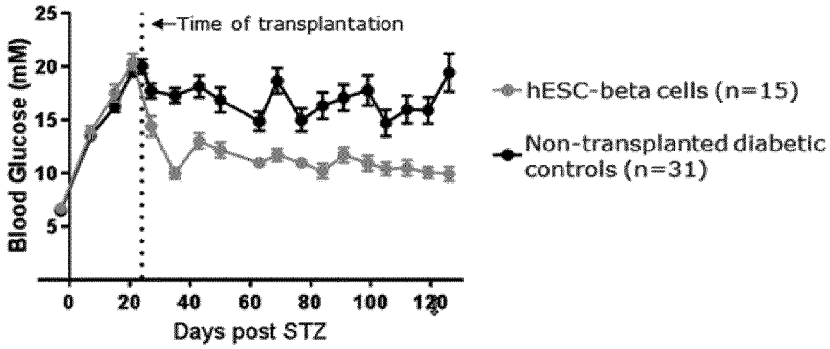

Time of transplantation
Blood Glucose (mM)
25
20
15
10
5
0
20
40
60
80
100
120
Days post STZ
hESC-beta cells (n=15)
Non-transplanted diabetic controls (n=31)

Fig. 11

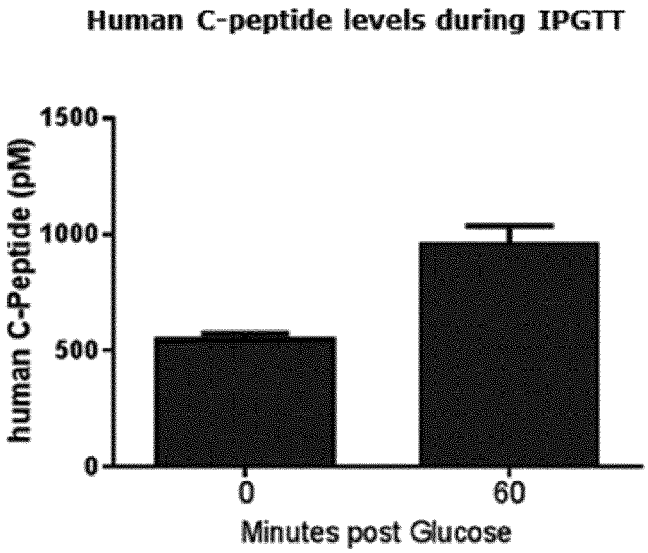

Human C-peptide levels during IPGTT
human C-Peptide (pM)
1500
1000
500
0
0
60
Minutes post Glucose

Fig. 12

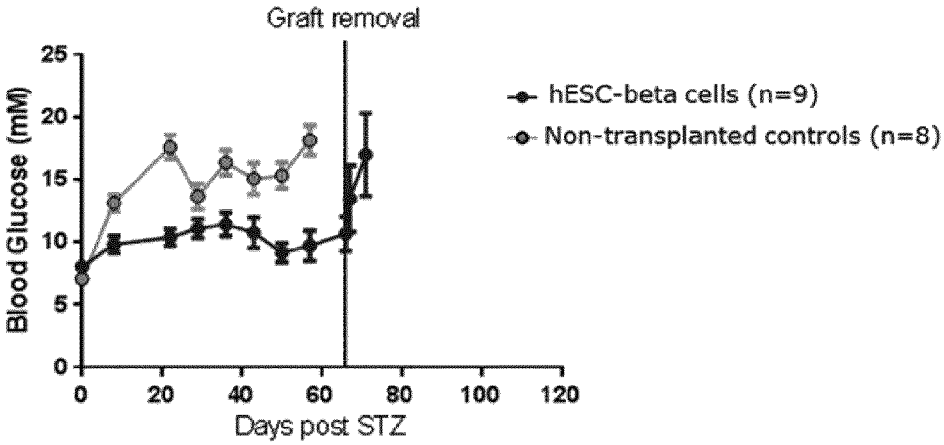

Graft removal
Blood Glucose (mM)
25
20
15
10
5
0
0
20
40
60
80
100
120
Days post STZ
hESC-beta cells (n=9)
Non-transplanted controls (n=8)

Fig. 13

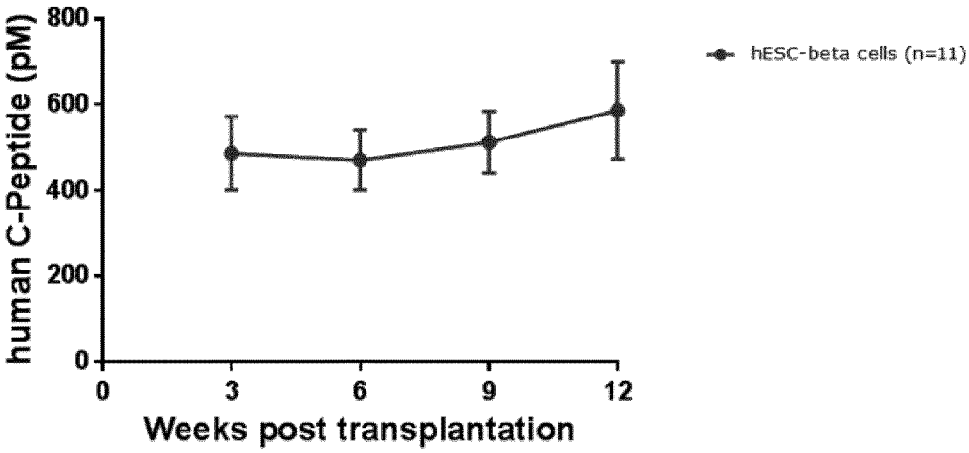

human C-Peptide (pM)
800
600
400
200
0
0
3
6
9
12
Weeks post transplantation
hESC-beta cells (n=11)

Fig. 14

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2017/054390

A. CLASSIFICATION OF SUBJECT MATTER
INV. C12N5/071
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
C12N

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2013/163739 A1 (UNIV HEALTH NETWORK [CA]) 7 November 2013 (2013-11-07)	14
Y	paragraphs [0058], [0062], [0078]; claims 7,14	1-13

X	WO 2015/028614 A1 (NOVO NORDISK AS [DK]; CELLECTIS AB [SE]) 5 March 2015 (2015-03-05)	14
Y	page 1; claims 1-15; example 1	1-13

X	WO 2014/033322 A1 (NOVO NORDISK AS [DK]; CELLECTIS SA [FR]) 6 March 2014 (2014-03-06)	14
Y	examples 1-3; tables 1,2	1-13

X	US 2015/250824 A1 (MA YUPO [US]) 10 September 2015 (2015-09-10)	14
Y	claims 1, 18-19,34	1-13

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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

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"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
30 March 2017	11/04/2017

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Novak-Giese, Sabine

1

Form PCT/ISA/210 (second sheet) (April 2005)

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	JACQUELINE V. SCHIESSER ET AL: "Generation of [beta] cells from human pluripotent stem cells: Are we there yet?", ANNALS OF THE NEW YORK ACADEMY OF SCIENCES, vol. 1311, no. 1, 24 February 2014 (2014-02-24), pages 124-137, XP055287691, US ISSN: 0077-8923, DOI: 10.1111/nyas.12369 page 6, last paragraph -----	1-14
Y	PAGLIUCA FELICIA W ET AL: "Generation of Functional Human Pancreatic [beta] Cells In Vi", CELL, CELL PRESS, US, vol. 159, no. 2, 9 October 2014 (2014-10-09), pages 428-439, XP029073423, ISSN: 0092-8674, DOI: 10.1016/J.CELL.2014.09.040 page 435, last paragraph -----	1-14

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Information on patent family members

International application No
PCT/EP2017/054390

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