DIFFERENTIATION OF HUMAN EMBRYONIC STEM CELLS

CROSS REFERENCE TO RELATED APPLICATION

[0001] The present application claims the benefit of U.S. Provisional Patent Application Serial No. 61/378,448, filed August 31, 2010, which is incorporated herein by reference in its entirety for all purpose.

FIELD OF THE INVENTION

[0002] The present invention provides methods to promote the differentiation of pluripotent stem cells into insulin producing cells. In particular, the present invention provides a method to produce a population of cells, wherein greater than 80% of the cells in the population express markers characteristic of the definitive endoderm lineage.

BACKGROUND

[0003] Advances in cell-replacement therapy for Type I diabetes mellitus and a shortage of transplantable islets of Langerhans have focused interest on developing sources of insulin-producing cells, or β cells, appropriate for engraftment. One approach is the generation of functional β cells from pluripotent stem cells, such as, for example, embryonic stem cells.

[0004] In vertebrate embryonic development, a pluripotent cell gives rise to a group of cells comprising three germ layers (ectoderm, mesoderm, and endoderm) in a process known as gastrulation. Tissues such as, for example, thyroid, thymus, pancreas, gut, and liver, will develop from the endoderm, via an intermediate stage. The intermediate stage in this process is the formation of definitive endoderm. Definitive endoderm cells express a number of markers, such as, HNF3 beta, GATA4, MIXL1, CXCR4 and SOX17.

[0005] Formation of the pancreas arises from the differentiation of definitive endoderm into pancreatic endoderm. Cells of the pancreatic endoderm express the pancreatic-duodenal homeobox gene, PDX1. In the absence of PDX1, the pancreas fails to develop beyond the formation of ventral and dorsal buds. Thus, PDX1 expression marks a critical step in pancreatic organogenesis. The mature pancreas contains,

among other cell types, exocrine tissue and endocrine tissue. Exocrine and endocrine tissues arise from the differentiation of pancreatic endoderm.

[0006] Cells bearing the features of islet cells have reportedly been derived from embryonic cells of the mouse. For example, Lumelsky *et al.* (Science 292:1389, 2001) report differentiation of mouse embryonic stem cells to insulin-secreting structures similar to pancreatic islets. Soria *et al.* (Diabetes 49:157, 2000) report that insulin-secreting cells derived from mouse embryonic stem cells normalize glycemia in streptozotocin-induced diabetic mice.

[0007] In one example, Hori *et al.* (PNAS 99: 16105, 2002) disclose that treatment of mouse embryonic stem cells with inhibitors of phosphoinositide 3-kinase (LY294002) produced cells that resembled β cells.

[0008] In another example, Blyszczuk *et al.* (PNAS 100:998, 2003) reports the generation of insulin-producing cells from mouse embryonic stem cells constitutively expressing Pax4.

[0009] Micallef *et al.* reports that retinoic acid can regulate the commitment of embryonic stem cells to form PDX1 positive pancreatic endoderm. Retinoic acid is most effective at inducing Pdx1 expression when added to cultures at day 4 of embryonic stem cell differentiation during a period corresponding to the end of gastrulation in the embryo (Diabetes 54:301, 2005).

[00010] Miyazaki *et al.* reports a mouse embryonic stem cell line over-expressing Pdx1. Their results show that exogenous Pdx1 expression clearly enhanced the expression of insulin, somatostatin, glucokinase, neurogenin3, p48, Pax6, and Hnf6 genes in the resulting differentiated cells (Diabetes 53: 1030, 2004).

[0010] Skoudy *et al.* reports that activin A (a member of the TGF-β superfamily) upregulates the expression of exocrine pancreatic genes (p48 and amylase) and endocrine genes (Pdx1, insulin, and glucagon) in mouse embryonic stem cells. The maximal effect was observed using 1nM activin A. They also observed that the expression level of insulin and Pdx1 mRNA was not affected by retinoic acid; however, 3nM FGF7 treatment resulted in an increased level of the transcript for Pdx1 (Biochem. J. 379: 749, 2004).

[0011] Shiraki *et al.* studied the effects of growth factors that specifically enhance differentiation of embryonic stem cells into PDX1 positive cells. They observed that TGF-β2 reproducibly yielded a higher proportion of PDX1 positive cells (Genes Cells. 2005 Jun; 10(6): 503-16.).

[0012] Gordon *et al.* demonstrated the induction of brachyury [positive]/ HNF3 beta [positive] endoderm cells from mouse embryonic stem cells in the absence of serum and in the presence of activin along with an inhibitor of Wnt signaling (US 2006/0003446A1).

[0013] Gordon *et al.* (PNAS, Vol 103, page 16806, 2006) states "Wnt and TGF-beta/ nodal/ activin signaling simultaneously were required for the generation of the anterior primitive streak".

[0014] However, the mouse model of embryonic stem cell development may not exactly mimic the developmental program in higher mammals, such as, for example, humans.

[0015] Thomson *et al.* isolated embryonic stem cells from human blastocysts (Science 282:114, 1998). Concurrently, Gearhart and coworkers derived human embryonic germ (hEG) cell lines from fetal gonadal tissue (Shamblott *et al.*, Proc. Natl. Acad. Sci. USA 95:13726, 1998). Unlike mouse embryonic stem cells, which can be prevented from differentiating simply by culturing with Leukemia Inhibitory Factor (LIF), human embryonic stem cells must be maintained under very special conditions (U.S. Pat. No. 6,200,806; WO 99/20741; WO 01/51616).

[0016] D'Amour *et al.* describes the production of enriched cultures of human embryonic stem cell-derived definitive endoderm in the presence of a high concentration of activin and low serum (Nature Biotechnology 2005). Transplanting these cells under the kidney capsule of mice resulted in differentiation into more mature cells with characteristics of some endodermal organs. Human embryonic stem cell-derived definitive endoderm cells can be further differentiated into PDX1 positive cells after addition of FGF-10 (US 2005/0266554A1).

[0017] D'Amour *et al.* (Nature Biotechnology - 24, 1392 - 1401 (2006)) states: "We have developed a differentiation process that converts human embryonic stem (hES) cells to endocrine cells capable of synthesizing the pancreatic hormones insulin, glucagon,

somatostatin, pancreatic polypeptide and ghrelin. This process mimics *in vivo* pancreatic organogenesis by directing cells through stages resembling definitive endoderm, gut-tube endoderm, pancreatic endoderm and endocrine precursor en route to cells that express endocrine hormones".

[0018] In another example, Fisk *et al.* reports a system for producing pancreatic islet cells from human embryonic stem cells (US2006/0040387A1). In this case, the differentiation pathway was divided into three stages. Human embryonic stem cells were first differentiated to endoderm using a combination of sodium butyrate and activin A. The cells were then cultured with TGF-β antagonists such as Noggin in combination with EGF or betacellulin to generate PDX1 positive cells. The terminal differentiation was induced by nicotinamide.

[0019] There still remains a significant need to develop *in vitro* methods to generate a functional insulin expressing cell, that more closely resemble a β cell. The present invention takes an alternative approach to improve the efficiency of differentiating human embryonic stem cells toward insulin expressing cells, by generating a population of cells wherein greater than 80% of the cells in the population express markers characteristic of the definitive endoderm lineage.

SUMMARY

[0020] In one embodiment, the present invention provides a population of cells, wherein greater than 80% of the cells in the population express markers characteristic of the definitive endoderm lineage.

[0021] In one embodiment, the present invention A method for generating a population of cells wherein greater than 80% of the cells in the population express markers characteristic of the definitive endoderm lineage, comprising the steps of:

a. Culturing a population of pluripotent stem cells,

b. Differentiating the population of pluripotent stem cells to a population of cells wherein greater than 80% of the cells in the population express markers characteristic of the definitive endoderm lineage in medium wherein the concentration of glucose does not exceed 10.5 mM.

BRIEF DESCRIPTION OF THE DRAWINGS

[0022] Figure 1 shows the FACS analysis of the expression of the proteins indicated in cells of the human embryonic stem cell line H1, differentiated according to the methods disclosed in Example 1.

[0023] Figure 2 shows the effect of medium glucose concentration on CXCR4 expression levels (panel B) and cell number and viability (panel B) in cells of the human embryonic stem cell line H1, differentiated according to the methods disclosed in Example 2.

[0024] Figure 3 shows the effect of medium glucose concentration on CXCR4 expression levels and culture appearance (Panel A), and SOX17 expression in cells of the human embryonic stem cell line H1, differentiated according to the methods disclosed in Example 2.

[0025] Figure 4 shows the real-time PCR analysis of the expression of the genes indicated in cells of the human embryonic stem cell line H1, differentiated according to the first method disclosed in Example 2.

[0026] Figure 5 shows the real-time PCR analysis of the expression of the genes indicated in cells of the human embryonic stem cell line H1, differentiated according to the second method disclosed in Example 2.

[0027] Figure 6 shows the pH level of the various media following a 24 hour exposure to cells on days 1 through 4 of the methods disclosed in Example 2.

[0028] Figure 7 shows the effect of medium pH levels on the expression of the genes indicated in cells of the human embryonic stem cell line H1, differentiated according to the second method disclosed in Example 3.

[0029] Figure 8 shows the real-time PCR analysis of the expression of the genes indicated in cells of the human embryonic stem cell line H1, differentiated according to the method disclosed in Example 4.

DETAILED DESCRIPTION

[0030] For clarity of disclosure, and not by way of limitation, the detailed description of the invention is divided into the following subsections that describe or illustrate certain features, embodiments or applications of the present invention.

Definitions

[0031] 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.

[0032] 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) multipotent, 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 multipotent stem cells; and (5) unipotent, meaning able to give rise to a single cell lineage (e.g., spermatogenic stem cells).

[0033] Differentiation is the process by which an unspecialized ("uncommitted") or less specialized cell acquires the features of a specialized cell such as, for example, a nerve cell or a muscle cell. A differentiated or differentiation-induced cell is one that has taken on a more specialized ("committed") position within the lineage of a cell. The term “committed”, when applied to the process of differentiation, refers to a cell that has proceeded in the differentiation pathway to a point where, under normal circumstances, it will continue to differentiate into a specific cell type or subset of cell types, and cannot, under normal circumstances, differentiate into a different cell type

or revert to a less differentiated cell type. De-differentiation refers to the process by which a cell reverts to a less specialized (or committed) position within the lineage of a cell. As used herein, the lineage of a cell defines the heredity of the cell, i.e., which cells it came from and what cells it can give rise to. The lineage of a cell places the cell within a hereditary scheme of development and differentiation. A lineage-specific marker refers to a characteristic specifically associated with the phenotype of cells of a lineage of interest and can be used to assess the differentiation of an uncommitted cell to the lineage of interest.

[0034] "Cells expressing markers characteristic of the definitive endoderm lineage", or "Stage 1 cells", or "Stage 1", as used herein, refers to cells expressing at least one of the following markers: SOX17, GATA4, HNF3 beta, GSC, CER1, Nodal, FGF8, Brachyury, Mix-like homeobox protein, FGF4 CD48, eomesodermin (EOMES), DKK4, FGF17, GATA6, CXCR4, C-Kit, CD99, or OTX2. Cells expressing markers characteristic of the definitive endoderm lineage include primitive streak precursor cells, primitive streak cells, mesendoderm cells and definitive endoderm cells.

[0035] "Cells expressing markers characteristic of the pancreatic endoderm lineage", as used herein, refers to cells expressing at least one of the following markers: PDX1, NKX6.1, HNF1 beta, PTF1 alpha, HNF6, HNF4 alpha, SOX9, HB9 or PROX1. Cells expressing markers characteristic of the pancreatic endoderm lineage include pancreatic endoderm cells, primitive gut tube cells, and posterior foregut cells.

[0036] "Definitive endoderm", as used herein, refers to cells which bear the characteristics of cells arising from the epiblast during gastrulation and which form the gastrointestinal tract and its derivatives. Definitive endoderm cells express the following markers: HNF3 beta, GATA4, SOX17, Cerberus, OTX2, goosecoid, C-Kit, CD99, and MIXL1.

[0037] "Markers", as used herein, are nucleic acid or polypeptide molecules that are differentially expressed in a cell of interest. In this context, differential expression means an increased level for a positive marker and a decreased level for a negative marker. The detectable level of the marker nucleic acid or polypeptide is sufficiently higher or lower in the cells of interest compared to other cells, such that the cell of interest can be identified and distinguished from other cells using any of a variety of methods known in the art.

[0038] "Pancreatic endocrine cell", or "Pancreatic hormone expressing cell", or "Cells expressing markers characteristic of the pancreatic endocrine lineage" as used herein, refers to a cell capable of expressing at least one of the following hormones: insulin, glucagon, somatostatin, and pancreatic polypeptide.

Isolation, Expansion and Culture of Pluripotent Stem Cells

Characterization of Pluripotent Stem Cells

[0039] Pluripotent stem cells may express one or more of the stage-specific embryonic antigens (SSEA) 3 and 4, and markers detectable using antibodies designated Tra-1-60 and Tra-1-81 (Thomson *et al.*, Science 282:1145, 1998). Differentiation of pluripotent stem cells *in vitro* results in the loss of SSEA-4, Tra 1-60, and Tra 1-81 expression (if present) and increased expression of SSEA-1. Undifferentiated pluripotent stem cells typically have alkaline phosphatase activity, which can be detected by fixing the cells with 4% paraformaldehyde, and then developing with Vector Red as a substrate, as described by the manufacturer (Vector Laboratories, Burlingame Calif.). Undifferentiated pluripotent stem cells also typically express OCT4 and TERT, as detected by RT-PCR.

[0040] Another desirable phenotype of propagated pluripotent stem cells is a potential to differentiate into cells of all three germinal layers: endoderm, mesoderm, and ectoderm tissues. Pluripotency of pluripotent stem cells can be confirmed, for example, by injecting cells into severe combined immunodeficient (SCID) mice, fixing the teratomas that form using 4% paraformaldehyde, and then examining them histologically for evidence of cell types from the three germ layers. Alternatively, pluripotency may be determined by the creation of embryoid bodies and assessing the embryoid bodies for the presence of markers associated with the three germinal layers.

[0041] Propagated pluripotent stem cell lines may be karyotyped using a standard G-banding technique and compared to published karyotypes of the corresponding primate species. It is desirable to obtain cells that have a "normal karyotype," which means that the cells are euploid, wherein all human chromosomes are present and not noticeably altered.

Sources of Pluripotent Stem Cells

[0042] The types of pluripotent stem cells that may be used include established lines of pluripotent cells derived from tissue formed after gestation, including pre-embryonic tissue (such as, for example, a blastocyst), embryonic tissue, or fetal tissue taken any time during gestation, typically but not necessarily before approximately 10 to 12 weeks gestation. Non-limiting examples are established lines of human embryonic stem cells or human embryonic germ cells, such as, for example the human embryonic stem cell lines H1, H7, and H9 (WiCell). Also contemplated is use of the compositions of this disclosure during the initial establishment or stabilization of such cells, in which case the source cells would be primary pluripotent cells taken directly from the source tissues. Also suitable are cells taken from a pluripotent stem cell population already cultured in the absence of feeder cells. Also suitable are mutant human embryonic stem cell lines, such as, for example, BG01v (BresaGen, Athens, GA).

[0043] In one embodiment, human embryonic stem cells are prepared as described by Thomson *et al.* (U.S. Pat. No. 5,843,780; Science 282:1145, 1998; Curr. Top. Dev. Biol. 38:133 ff., 1998; Proc. Natl. Acad. Sci. U.S.A. 92:7844, 1995).

Culture of Pluripotent Stem Cells

[0044] In one embodiment, pluripotent stem cells are cultured on a layer of feeder cells that support the pluripotent stem cells in various ways. Alternatively, pluripotent stem cells are cultured in a culture system that is essentially free of feeder cells, but nonetheless supports proliferation of pluripotent stem cells without undergoing substantial differentiation. The growth of pluripotent stem cells in feeder-free culture without differentiation is supported using a medium conditioned by culturing previously with another cell type. Alternatively, the growth of pluripotent stem cells in feeder-free culture without differentiation is supported using a chemically defined medium.

[0045] In one embodiment, pluripotent stem cells may be cultured on a mouse embryonic fibroblast feeder cell layer according to the methods disclosed in Reubinoff *et al* (Nature Biotechnology 18: 399 - 404 (2000)). Alternatively, pluripotent stem cells may be cultured on a mouse embryonic fibroblast feeder cell layer according to the

methods disclosed in Thompson *et al* (Science 6 November 1998: Vol. 282. no. 5391, pp. 1145 – 1147). Alternatively, pluripotent stem cells may be cultured on any one of the feeder cell layers disclosed in Richards *et al*, (Stem Cells 21: 546-556, 2003).

[0046] In one embodiment, pluripotent stem cells may be cultured on a human feeder cell layer according to the methods disclosed in Wang *et al* (Stem Cells 23: 1221-1227, 2005). In an alternate embodiment, pluripotent stem cells may be cultured on the human feeder cell layer disclosed in Stojkovic *et al* (Stem Cells 2005 23: 306-314, 2005). Alternatively, pluripotent stem cells may be cultured on the human feeder cell layer disclosed in Miyamoto *et al* (Stem Cells 22: 433-440, 2004). Alternatively, pluripotent stem cells may be cultured on the human feeder cell layer disclosed in Amit *et al* (Biol. Reprod 68: 2150-2156, 2003). Alternatively, pluripotent stem cells may be cultured on the human feeder cell layer disclosed in Inzunza *et al* (Stem Cells 23: 544-549, 2005).

[0047] In one embodiment, pluripotent stem cells may be cultured in culture media derived according to the methods disclosed in US20020072117. Alternatively, pluripotent stem cells may be cultured in culture media derived according to the methods disclosed in US6642048. Alternatively, pluripotent stem cells may be cultured in culture media derived according to the methods disclosed in WO2005014799. Alternatively, pluripotent stem cells may be cultured in culture media derived according to the methods disclosed in Xu *et al* (Stem Cells 22: 972-980, 2004). Alternatively, pluripotent stem cells may be cultured in culture media derived according to the methods disclosed in US20070010011. Alternatively, pluripotent stem cells may be cultured in culture media derived according to the methods disclosed in US20050233446. Alternatively, pluripotent stem cells may be cultured in culture media derived according to the methods disclosed in US6800480. Alternatively, pluripotent stem cells may be cultured in culture media derived according to the methods disclosed in WO2005065354.

[0048] In one embodiment, pluripotent stem cells may be cultured in the culture media disclosed in WO2005065354. Alternatively, pluripotent stem cells may be cultured in the culture media disclosed in WO2005086845.

[0049] In one embodiment, pluripotent stem cells may be cultured according to the methods disclosed in Cheon *et al* (BioReprod DOI:10.1095/biolreprod.105.046870, October 19, 2005). Alternatively, pluripotent stem cells may be cultured according to the methods disclosed in Levenstein *et al* (Stem Cells 24: 568-574, 2006). Alternatively, pluripotent stem cells may be cultured according to the methods disclosed in US20050148070. Alternatively, pluripotent stem cells may be cultured according to the methods disclosed in US20050244962. Alternatively, pluripotent stem cells may be cultured according to the methods disclosed in WO2005086845.

[0050] The pluripotent stem cells may be plated onto a suitable culture substrate. In one embodiment, the suitable culture substrate is an extracellular matrix component, such as, for example, those derived from basement membrane or that may form part of adhesion molecule receptor-ligand couplings. In one embodiment, the suitable culture substrate is MATRIGEL® (Becton Dickenson). MATRIGEL® is a soluble preparation from Engelbreth-Holm Swarm tumor cells that gels at room temperature to form a reconstituted basement membrane.

[0051] Other extracellular matrix components and component mixtures are suitable as an alternative. Depending on the cell type being proliferated, this may include laminin, fibronectin, proteoglycan, entactin, heparan sulfate, and the like, alone or in various combinations.

[0052] The pluripotent stem cells may be plated onto the substrate in a suitable distribution and in the presence of a medium that promotes cell survival, propagation, and retention of the desirable characteristics. All these characteristics benefit from careful attention to the seeding distribution and can readily be determined by one of skill in the art.

[0053] Suitable culture media may be made from the following components, such as, for example, Dulbecco's modified Eagle's medium (DMEM), Gibco # 11965-092; Knockout Dulbecco's modified Eagle's medium (KO DMEM), Gibco #10829-018; Ham's F12/50% DMEM basal medium; 200 mM L-glutamine, Gibco # 15039-027; non-essential amino acid solution, Gibco 11140-050; β-mercaptoethanol, Sigma # M7522; human recombinant basic fibroblast growth factor (bFGF), Gibco # 13256-029.

Formation of Cells Expressing Markers Characteristic of the Definitive Endoderm Lineage from Pluripotent Stem Cells

[0054] The present invention provides methods for the formation of populations of cells expressing markers characteristic of the definitive endoderm lineage from populations of pluripotent stem cells. In one embodiment, the present invention provides methods to further differentiate the cells expressing markers characteristic of the definitive endoderm lineage into cells expressing markers of the pancreatic endocrine lineage. In one embodiment, this is achieved utilizing a step-wise differentiation protocol, wherein populations of pluripotent stem cells are first differentiated into populations of cells expressing markers characteristic of the definitive endoderm lineage. Next, the populations of cells expressing markers characteristic of the definitive endoderm lineage are then differentiated into populations of cells expressing markers characteristic of the pancreatic endoderm lineage. Next, the populations of cells expressing markers characteristic of the pancreatic endoderm lineage are then differentiated into populations of cells expressing markers characteristic of the pancreatic endocrine lineage.

[0055] The present invention provides a population of cells wherein greater than 80% of the cells express markers characteristic of the definitive endoderm lineage. The population of cells may be further treated to form a population of cells expressing markers characteristic of the pancreatic endoderm lineage. The population of cells expressing markers characteristic of the pancreatic endoderm lineage may be further treated to form a population of cells expressing markers characteristic of the pancreatic endocrine lineage.

[0056] The efficiency of differentiation may be determined by exposing a treated cell population to an agent (such as an antibody) that specifically recognizes a protein marker expressed by cells expressing markers characteristic of the desired cell type.

[0057] Methods for assessing expression of protein and nucleic acid markers in cultured or isolated cells are standard in the art. These include quantitative reverse transcriptase polymerase chain reaction (RT-PCR), Northern blots, *in situ* hybridization (see, e.g., Current Protocols in Molecular Biology (Ausubel *et al.*, eds. 2001 supplement)), and immunoassays such as immunohistochemical analysis of sectioned material, Western

blotting, and for markers that are accessible in intact cells, flow cytometry analysis (FACS) (see, e.g., Harlow and Lane, Using Antibodies: A Laboratory Manual, New York: Cold Spring Harbor Laboratory Press (1998)).

[0058] Characteristics of pluripotent stem cells are well known to those skilled in the art, and additional characteristics of pluripotent stem cells continue to be identified. Pluripotent stem cell markers include, for example, the expression of one or more of the following: ABCG2, cripto, FOXD3, CONNEXIN43, CONNEXIN45, OCT4, SOX2, Nanog, hTERT, UTF1, ZFP42, SSEA-3, SSEA-4, Tra 1-60, Tra 1-81.

[0059] After treating pluripotent stem cells with the methods of the present invention, the differentiated cells may be purified by exposing a treated cell population to an agent (such as an antibody) that specifically recognizes a protein marker, such as CXCR4, expressed by cells expressing markers characteristic of the definitive endoderm lineage.

[0060] Pluripotent stem cells suitable for use in the present invention include, for example, the human embryonic stem cell line H9 (NIH code: WA09), the human embryonic stem cell line H1 (NIH code: WA01), the human embryonic stem cell line H7 (NIH code: WA07), and the human embryonic stem cell line SA002 (Cellartis, Sweden). Also suitable for use in the present invention are cells that express at least one of the following markers characteristic of pluripotent cells: ABCG2, cripto, CD9, FOXD3, CONNEXIN43, CONNEXIN45, OCT4, SOX2, Nanog, hTERT, UTF1, ZFP42, SSEA-3, SSEA-4, Tra 1-60, and Tra 1-81.

[0061] Markers characteristic of the definitive endoderm lineage are selected from the group consisting of SOX17, GATA4, HNF3 beta, GSC, CER1, Nodal, FGF8, Brachyury, Mix-like homeobox protein, FGF4, CD48, eomesodermin (EOMES), DKK4, FGF17, GATA6, CXCR4, C-Kit, CD99, and OTX2. Suitable for use in the present invention is a cell that expresses at least one of the markers characteristic of the definitive endoderm lineage. In one aspect of the present invention, a cell expressing markers characteristic of the definitive endoderm lineage is a primitive streak precursor cell. In an alternate aspect, a cell expressing markers characteristic of the definitive endoderm lineage is a mesendoderm cell. In an alternate aspect, a cell expressing

markers characteristic of the definitive endoderm lineage is a definitive endoderm cell.

[0062] Markers characteristic of the pancreatic endoderm lineage are selected from the group consisting of PDX1, NKX6.1, HNF1 beta, PTF1 alpha, HNF6, HNF4 alpha, SOX9, HB9 and PROX1. Suitable for use in the present invention is a cell that expresses at least one of the markers characteristic of the pancreatic endoderm lineage. In one aspect of the present invention, a cell expressing markers characteristic of the pancreatic endoderm lineage is a pancreatic endoderm cell.

[0063] Markers characteristic of the pancreatic endocrine lineage are selected from the group consisting of NGN3, NEUROD, ISL1, PDX1, NKX6.1, PAX4, NGN3, and PTF-1 alpha. In one embodiment, a pancreatic endocrine cell is capable of expressing at least one of the following hormones: insulin, glucagon, somatostatin, and pancreatic polypeptide. Suitable for use in the present invention is a cell that expresses at least one of the markers characteristic of the pancreatic endocrine lineage. In one aspect of the present invention, a cell expressing markers characteristic of the pancreatic endocrine lineage is a pancreatic endocrine cell. The pancreatic endocrine cell may be a pancreatic hormone-expressing cell. Alternatively, the pancreatic endocrine cell may be a pancreatic hormone-secreting cell.

[0064] In one aspect of the present invention, the pancreatic endocrine cell is a cell expressing markers characteristic of the β cell lineage. A cell expressing markers characteristic of the β cell lineage expresses PDX1 and at least one of the following transcription factors: NGN3, NKX2.2, NKX6.1, NEUROD, ISL1, HNF3 beta, MAFA, PAX4, and PAX6. In one aspect of the present invention, a cell expressing markers characteristic of the β cell lineage is a β cell.

Formation of Cells Expressing Markers Characteristic of the Definitive Endoderm Lineage from Pluripotent Stem Cells

[0065] In one aspect of the present invention, populations of pluripotent stem cells may be differentiated into populations of cells expressing markers characteristic of the definitive endoderm lineage by culturing the pluripotent stem cells in a medium wherein the concentration of glucose does not exceed 10.5 mM. In one embodiment,

differentiation of the population of pluripotent stem cells toward a population of cells expressing markers characteristic of the definitive endoderm lineage is achieved by treating the pluripotent stem cells with activin A and a Wnt ligand.

[0066] In an alternate embodiment, differentiation of the population of pluripotent stem cells toward a population of cells expressing markers characteristic of the definitive endoderm lineage is achieved by treating the pluripotent stem cells with GDF-8 and at least one other factor is selected from the group consisting of: an aniline-pyridinotriazine, a cyclic aniline-pyridinotriazine, N-{[1-(Phenylmethyl)azepan-4-yl]methyl}-2-pyridin-3-ylacetamide, 4-{[4-(4-{[2-(Pyridin-2-ylamino)ethyl]amino}-1,3,5-triazin-2-yl)pyridin-2-yl]oxy}butan-1-ol, 3-({3-[4-({2-[Methyl(pyridin-2-yl)amino]ethyl}amino)-1,3,5-triazin-2-yl]pyridin-2-yl}amino)propan-1-ol, N~4~-[2-(3-Fluorophenyl)ethyl]-N~2~-[3-(4-methylpiperazin-1-yl)propyl]pyrido[2,3-d]pyrimidine-2,4-diamine, 1-Methyl-N-[(4-pyridin-3-yl-2-{[3-(trifluoromethyl)phenyl]amino}-1,3-thiazol-5-yl)methyl]piperidine-4-carboxamide, 1,1-Dimethylethyl {2-[4-({5-[3-(3-hydroxypropyl)phenyl]-4H-1,2,4-triazol-3-yl}amino)phenyl]ethyl}carbamate, 1,1-Dimethylethyl {[3-({5-[5-(3-hydroxypropyl)-2-(methyloxy)phenyl]-1,3-oxazol-2-yl}amino)phenyl]methyl}carbamate, 1-({5-[6-({4-[(4-Methylpiperazin-1-yl)sulfonyl]phenyl}amino)pyrazin-2-yl]thiophen-2-yl}methyl)piperidin-4-ol, 1-({4-[6-({4-[(4-Methylpiperazin-1-yl)sulfonyl]phenyl}amino)pyrazin-2-yl]thiophen-2-yl}methyl)piperidine-4-carboxamide, and 2-{[4-(1-Methylethyl)phenyl]amino}-N-(2-thiophen-2-ylethyl)-7,8-dihydropyrido[4,3-d]pyrimidine-6(5H)-carboxamide. Examples of the factors suitable for use may be found in US Patent Application Serial Number 12/494,789. In one embodiment, the at least one other factor is 14-Prop-2-en-1-yl-3,5,7,14,17,23,27-heptaazatetracyclo[19.3.1.1~2,6~.1~8,12~]heptacosa-1(25),2(27),3,5,8(26),9,11,21,23-nonaen-16-one.

[0067] The population of pluripotent stem cells may be cultured in the medium wherein the concentration of glucose does not exceed 10.5 mM for about one day to about seven days. Alternatively, the population of pluripotent stem cells may be cultured in the medium wherein the concentration of glucose does not exceed 10.5 mM for about one day to about six days. Alternatively, the population of pluripotent stem cells may cultured in the medium wherein the concentration of glucose does not exceed 10.5

mM for about one day to about five days. Alternatively, the population of pluripotent stem cells may cultured in the medium wherein the concentration of glucose does not exceed 10.5 mM for about one day to about four days. Alternatively, the population of pluripotent stem cells may be cultured in the medium wherein the concentration of glucose does not exceed 10.5 mM for about four days.

[0068] In one embodiment, the GDF-8 is used at a concentration from about 5 ng/ml to about 500 ng/ml. In an alternate embodiment, the GDF-8 is used at a concentration from about 5 ng/ml to about 50 ng/ml. In an alternate embodiment, the GDF-8 is used at a concentration from about 5 ng/ml to about 25 ng/ml. In an alternate embodiment, the GDF-8 is used at a concentration of about 25 ng/ml.

[0069] Activin-A may be used at a concentration from about 1pg/ml to about 100μg/ml. In an alternate embodiment, the concentration may be about 1pg/ml to about 1μg/ml. In another alternate embodiment, the concentration may be about 1pg/ml to about 100ng/ml. In another alternate embodiment, the concentration may be about 50ng/ml to about 100ng/ml. In another alternate embodiment, the concentration may be about 100ng/ml.

[0070] The Wnt ligand may be selected from the group consisting of Wnt-1, Wnt-3a, Wnt-5a and Wnt-7a. In one embodiment, the Wnt ligand is Wnt-1. In an alternate embodiment, the Wnt ligand is Wnt-3a.

[0071] The Wnt ligand may be used at a concentration of about 1ng/ml to about 1000ng/ml. In an alternate embodiment, the Wnt ligand may be used at a concentration of about 10ng/ml to about 100ng/ml. In one embodiment, the concentration of the Wnt ligand is about 20ng/ml.

Formation of Cells Expressing Markers Characteristic of the Pancreatic Endoderm Lineage

[0072] In one embodiment, populations of cells expressing markers characteristic of the definitive endoderm lineage formed by the methods of the present invention are further differentiated into populations of cells expressing markers characteristic of the pancreatic endoderm lineage by any method in the art.

[0073] For example, populations of cells expressing markers characteristic of the definitive endoderm lineage obtained according to the methods of the present invention may be further differentiated into populations of cells expressing markers characteristic of the pancreatic endoderm lineage by treating the population of cells expressing markers characteristic of the definitive endoderm lineage according to the methods disclosed in D'Amour *et al*, Nature Biotechnology 24, 1392 - 1401 (2006).

[0074] For example, populations of cells expressing markers characteristic of the definitive endoderm lineage obtained according to the methods of the present invention may be further differentiated into populations of cells expressing markers characteristic of the pancreatic endoderm lineage by treating the population of cells expressing markers characteristic of the definitive endoderm lineage according to the methods disclosed in US patent application Ser. No. 11/736,908.

Formation of Cells Expressing Markers Characteristic of the Pancreatic Endocrine Lineage

[0075] In one embodiment, populations of cells expressing markers characteristic of the pancreatic endoderm lineage are further differentiated into populations of cells expressing markers characteristic of the pancreatic endocrine lineage by any method in the art.

[0076] For example, populations of cells expressing markers characteristic of the pancreatic endoderm lineage may be further differentiated into populations of cells expressing markers characteristic of the pancreatic endocrine lineage, by treating the population of cells expressing markers characteristic of the pancreatic endoderm lineage according to the methods disclosed in D' Amour *et al*, Nature Biotechnology, 2006.

[0077] For example, populations of cells expressing markers characteristic of the pancreatic endoderm lineage may be further differentiated into populations of cells expressing markers characteristic of the pancreatic endocrine lineage, by treating the population of cells expressing markers characteristic of the pancreatic endoderm lineage according to the methods disclosed d in D' Amour *et al*, Nature Biotechnology, 2006.

[0078] For example, populations of cells expressing markers characteristic of the pancreatic endoderm lineage may be further differentiated into populations of cells expressing

markers characteristic of the pancreatic endocrine lineage, by treating the population of cells expressing markers characteristic of the pancreatic endoderm lineage according to the methods disclosed in US patent application Ser. No. 11/736,908.

[0079] For example, populations of cells expressing markers characteristic of the pancreatic endoderm lineage may be further differentiated into populations of cells expressing markers characteristic of the pancreatic endocrine lineage, by treating the population of cells expressing markers characteristic of the pancreatic endoderm lineage according to the methods disclosed in US patent application Ser. No. 11/779,311.

[0080] For example, populations of cells expressing markers characteristic of the pancreatic endoderm lineage may be further differentiated into populations of cells expressing markers characteristic of the pancreatic endocrine lineage, by treating the population of cells expressing markers characteristic of the pancreatic endoderm lineage according to the methods disclosed in US patent application Ser. No. 60/953,178.

[0081] For example, populations of cells expressing markers characteristic of the pancreatic endoderm lineage may be further differentiated into populations of cells expressing markers characteristic of the pancreatic endocrine lineage, by treating the population of cells expressing markers characteristic of the pancreatic endoderm lineage according to the methods disclosed in US patent application Ser. No. 60/990,529.

[0082] The present invention is further illustrated, but not limited by, the following examples.

EXAMPLES

Example 1

The Role of Media and Seeding Protocol in the Differentiation of Human Pluripotent Stem Cells to Cells Expressing Markers Characteristic of the Definitive Endoderm Lineage

[0083] Cells of the human embryonic stem cell line H1 at passage 41 (p41) were lifted by TrypLE (Catalog# 12604-013, Invitrogen, CA) and seeded as single cells at a density of 100,000 cells/cm^2 on MATRIGEL® coated dishes (1:30 dilution) in MEF-CM (mouse embryonic fibroblast conditioned media) supplemented with 20 ng/ml FGF2

(Catalog# 100-18B, PeproTech, NJ) and 10 μM of Y-27632 (a Rho Kinase Inhibitor, Catalog# Y0503, Sigma, MO).

[0084] In parallel, cells of the human embryonic stem cell line H1 at passage 41 were seeded as cell colonies MATRIGEL® coated dishes (1:30 dilution) at a 1 to 3 passage ratio by lifting cells with Dispase (Catalog# 17105-041, Invitrogen, CA) and plating the cells in MEF-CM with 20 ng/ml FGF2. For both single cell and colony format cultures the media was changed 24 and 48 hours post seeding with fresh MEF-CM with 20 ng/ml FGF2.

[0085] At 72 hrs post seeding, the cultures were differentiated into cells expressing markers characteristic of the definitive endoderm lineage as follows:

a. MCDB-131 (Catalog# 10372-019, Invitrogen, CA) containing an additional 0.0025 g/ml sodium bicarbonate (Catalog# S3187, Sigma, MO), was supplemented with 2% fatty acid-free BSA (Catalog# 68700, Proliant, IA), 1X GlutaMax™ (Catalog # 35050-079, Invitrogen, Ca) and 100 ng/ml activin A (R&D Systems, MN) plus 20 ng/ml WNT-3a (Catalog# 1324-WN-002, R&D Systems, MN) for one day, then MCDB-131 with an additional 0.0025 g/ml sodium bicarbonate, 2% BSA , Glutamax, and 100 ng/ml activin A for three days (Condition 1); or,

b. RPMI-1640 (Catalog #22400-105, Invitrogen, CA), was supplemented with 2% fatty acid-free BSA (Catalog# 68700, Proliant, IA), and 100 ng/ml activin A (R&D Systems, MN) plus 20 ng/ml WNT-3a (Catalog# 1324-WN-002, R&D Systems, MN), for one day, then RPMI-1640 medium supplemented with 2% BSA, and 100 ng/ml activin A each day for an additional three days (Condition 2).

[0086] At day 4, samples were collected for FACS analysis. In Figure 1, the flow cytometry results for CXCR4 and CD9 expression are shown in scatter plot format with CXCR4 expression plotted on the Y axis versus CD9 expression plotted on the X axis. The percentage of cells expressing CXCR4, CD9, and CD99 (an additional marker of differentiation) are summarized in Table 1. Differentiation, as measured by the increased expression of the cellular surface markers CXCR4 and CD99, was

improved by the use of MCDB-131 media, and expression of CXCR4 and CD99 was further increased by changing from colony style culture to a single cell culture. Furthermore, these data correlated with decreased expression of CD9, a cellular marker for undifferentiated cells, as measured by flow cytometry.

[0087] Interestingly, with the use of MCDB-131 in either cluster or colony style format, there are fewer co-negative ($CXCR4^-/CD9^-$) cells in Figure 1, indicating less non-specific differentiation, or fewer cells that do not express markers characteristic of the definitive endoderm lineage in cultures treated MCDB-131 medium. As a whole, these data indicate that H1 human embryonic stem cells differentiate more efficiently in the presence of MCDB-131 medium than RPMI-1640 medium, and that differentiation in MCDB-131can be further improved by seeding and culturing the cells as single cells versus colony style seeding and culture.

Table 1.

	CXCR4	CD9	CD99
MCDB (cluster)	88.6	10.1	21.7
RPMI (cluster)	81.8	8.8	30.5
MCDB (single cell)	92.3	6.7	62.2
RPMI (single cell)	72.4	12.7	43.1

Example 2

The Role of Glucose in the Differentiation of Human Pluripotent Stem Cells to Cells Expressing Markers Characteristic of the Definitive Endoderm Lineage

[0088] Glucose is a soluble hexose sugar added to almost all cell culture media including Ames' Medium; Basal Medium Eagle (BME); BGJb Medium Fitton-Jackson Modification; Click's Medium; CMRL-1066 Medium; Dulbecco's Modified Eagle's Medium (DMEM); DMEM/Ham's Nutrient Mixture F-12 (50:50); F-12 Coon's Modification; Fischer's Medium; H-Y Medium (Hybri-Max®); Iscove's Modified

Dulbecco's Medium (IMDM); McCoy's 5A Modified Medium; MCDB Media; Medium 199; Minimum Essential Medium Eagle (EMEM); NCTC Medium; Nutrient Mixture, Ham's F-10; Nutrient Mixture, Ham's F-12; Nutrient Mixture Ham's F-12 Kaighn's Modification (F12K); RPMI-1640; Serum-Free/Protein Free Hybridoma Medium; Waymouth Medium MB; Williams Medium E and various proprietary media. See http://www.sigmaaldrich.com/life-science/cell-culture/learning-center/media-expert/glucose.html.

[0089] The amount of glucose in cell culture formulations varies. While the MCDB media series contain glucose in the range from 3.9 to 10 mM, most media contain from 1 g/L (5.5 mM) to as high as 10 g/L (55 mM) glucose, with RPMI-1640 set at 11 mM glucose. Concentrations of glucose above 10 mM are analogous to a diabetic condition within the cell culture system. This is important because the same processes that can affect cells and molecules *in vivo* can occur *in vitro*. The consequence of growing cells under conditions that are essentially diabetic is that cells and cell products are modified by the processes of glycation and glyoxidation and can be damaged by glucose mediated oxidative and carbonyl stress. See http://www.sigmaaldrich.com/life-science/cell-culture/learning-center/media-expert/glucose.html.

[0090] One medium that is currently used for generating definitive endoderm is Iscove's Modified Dulbecco's Medium (IMDM) which contains 25mM glucose (Kubo *et al*; April 1, 2004, Development 131, 1651-1662), RPMI with 11mM glucose (D'Amour *et al* Nat Biotechnol. 2005 Dec; 23(12):1534-41), or DMEM-F12 with 17.5mM glucose. Each of these media is above the 10 mM glucose concentration analogous to a diabetic condition. Consequently, to reduce stress on the cells that might be induced by high glucose in the culture medium, we attempted to find a glucose concentration lower than 10mM for differentiation of human embryonic stem cells to cells expressing markers characteristic of the definitive endoderm lineage. One such medium with a glucose concentration below 10mM is MCDB-131 which contains a base glucose concentration of 5.5mM.

[0091] Cells of the human embryonic stem cell line H1 at passage 41 (p41) were lifted by TrypLE (Catalog# 12604-0*13, I*nvitrogen, CA) and seeded as single cells at a density of 100,000 cells/cm^2 on *MATR*IGEL® coated dishes (1:*30 di*lution) in MEF-CM

(mouse embryonic fibroblast conditioned media) supplemented with 20 ng/ml of FGF2 (Catalog# 100-18B, PeproTec[h], NJ) and 10 μM of Y-27632 (a Rho Kinase Inhibitor, Catalog# Y0503, Sigma, MO). The media was changed 24 and 48 hours post seeding with fresh MEF-CM with 20 ng/ml of FGF2. The cultures were differentiated into cells expressing markers characteristic of the definitive endoderm lineage 72 hrs post as follows:

a. MCDB-131 (Catalog# 10372-019, Invitrogen, CA) medium supplemented with 2% fatty acid-free BSA (Catalog# 68700, Proliant, IA), 0.0025 g/ml sodium bicarbonate (Catalog# S3187, Sigma, MO), 1X GlutaMax™ (Catalog # 35050-079, Invitrogen, Ca) 100 ng/ml activin A (R&D *Sy*stems, MN), 20 ng/ml WNT-3a (Catalog# 1324-WN-[0]02, R&D Systems, MN), and either *0,* 5, 10, 15, 20, or 25mM of glucose (Catalog# G8769, Sigma, MO) for one day, then

b. MCDB-131 medium supplemented with 2% BSA, sodium bicarbonate, Glutamax, 100 ng/ml activin A, and either 0, 5, 10, 15, 20, or 25mM of glucose for an additional three days.

[0092] At day 4, samples were collected for FACS and gene expression analysis using real-time PCR, and counted by ViaCount® (Guava®, Millipore, Billerica, MA). Consistent with results from Example 1, differentiation of pluripotent stem cells to cells expressing markers characteristic of the definitive endoderm lineage resulted in the robust expression of markers associated with the definitive endoderm lineage (Figure 2A). When the glucose concentration in the media was supplemented with 0, 5, 10, 15, 20, or 25 mM glucose (final concentration: 5.5, 10.5, 15.5, 20.5, 25.5, or 30.5 mM glucose respectively), a modest increase in cell number was observed in samples treated with additional 10mM glucose (15.5mM final glucose concentration) as shown in Figure 2B. A modest increase in CXCR4 expression for cells supplemented with additional 5mM glucose (10.5mM final glucose concentration) was also observed, as shown in Figure 2A. However, these increases in cell number and CXCR4 were offset by a reduction in total cell viability (Figure 2B).

[0093] At the basal level of glucose (5.5mM), almost every cell in the culture was SOX17 positive, and the cells were dispersed in the culture dish in a uniform pattern (Figure 3

A&B). As the glucose concentration increased, the cells maintained a high expression of SOX17, however the cells were observed to cluster. These clustered cells were subsequently less evenly dispersed on the culture surface than populations of cells cultured in the basal level of glucose. This effect correlated with a slight increase in expression of CD9 and OCT4- cellular markers for undifferentiated cells, and SOX7- a cellular marker for extraembryonic ectoderm, and a decrease in the gene expression of pancreatic pancreas homeobox 1 (MNX1) also known as Homeobox HB9 (HLXB9) in the clustered cells (Figure 4).

[0094] Similar glucose related effects on differentiation were also observed in cultures differentiated with DMEM containing either 5.5mM (low) or 25mM (high) glucose concentration (Cat#s 10567-014 and 21063-029, Invitrogen, CA). As described above, for controls, cells were seeded as single cells, cultured 3 days in MEF conditioned media and differentiated in MCDB-131 with 5.5mM or 25mM glucose supplemented media, or in DMEM high or low glucose media supplemented with 2% fatty acid free BSA, 100 ng/ml activin A, and 20 ng/ml WNT-3a on the first day, and 2% fatty acid free BSA and 100 ng/ml activin A for the next three days with daily media change.

[0095] Similar to results with MCDB-131 media, where elevated glucose inhibits definitive endoderm formation as compared to low glucose media treated cells, we observed that a high glucose concentration in DMEM reduced hES cell differentiation. By flow cytometry, following differentiation to definitive endoderm, 88.6% of cells were positive for CXCR4 in media containing 5.5mM glucose versus 80% CXCR4 positive cells in media containing 25mM glucose. Additionally, markers of differentiation to definitive endoderm as measured by qRT-PCR (SOX17) were decreased while markers of undifferentiated cells (OCT4) or alternative differentiation fates (CDX2) were increased (Figure 5) in cells fed media containing high glucose versus those fed low glucose media. This effect was due at least in part to the pH of the media as we noted that over the four day differentiation, media pH dropped after 48 hours of differentiation day. Furthermore, the higher the starting and ending pH of culture media (8.1>pH>7.6) (Figure 6) during definitive endoderm formation, the more complete the conversion to definitive endoderm.

[0096] In summary, our results indicate that basal levels of glucose (5.5mM) in differentiation media are sufficient to generate a population of cells wherein greater than 80% of cells express markers characteristic of the definitive endoderm lineage. Increasing glucose concentrations in the differentiation medium to 10.5mM is sufficient to generate a similar population, however increasing glucose concentrations above 10.5mM can result in increasing expression of markers of pluripotency/reduced differentiation such as CD9 or OCT4, or increased expression of markers associated with alternative fate differentiation/extraembryonic ectoderm such as SOX7 or CDX2.

Example 3

The Role of pH Control in the Differentiation of Human Pluripotent Stem Cells to Cells Expressing Markers Characteristic of the Definitive Endoderm Lineage

[0097] Cells of the human embryonic stem (hES) cell line H1 at passage 46 (p46) were seeded as cell colonies to MATRIGEL (1:30 dilution) coated dishes at a 1 to 3 passage ratio by lifting cells with Dispase (Catalog# 17105-041, Invitrogen, CA) and plating the cells in MEF-CM with 20 ng/ml of FGF2. The media was changed daily with fresh MEF-CM with 20 ng/ml of FGF2, until initiation of differentiation into definitive endoderm (DE) as follows:

a. MCDB-131 (Catalog# 10372-019, Invitrogen, CA) medium supplemented with 2% fatty acid-free BSA (Catalog# 68700, Proliant, IA), 1X GlutaMax™ (Catalog # 35050-079, Invitrogen, Ca) and 100 ng/ml activin A (R&D Systems, MN) plus 20 ng/ml WNT-3a (Catalog# 1324-WN-002, R&D Systems, MN) for one day, followed by treatment with MCDB-131 supplemented with 2% BSA, Glutamax, and 100 ng/ml activin A each day for an additional three days; or

b. MCDB131 containing an additional 0.0025 g/ml sodium bicarbonate (Catalog# S3187, Sigma, MO) medium supplemented with 2% fatty acid-free BSA (Catalog# 68700, Proliant, IA), 1X GlutaMax™ (Catalog # 35050-079, Invitrogen, Ca) and 100 ng/ml activin A (R&D Systems, MN) plus 20 ng/ml WNT-3a (Catalog# 1324-WN-002, R&D Systems, MN) for one day, followed by treatment with MCDB-131 with an additional 0.0025

g/ml sodium bicarbonate supplemented with 2% BSA, Glutamax, and 100 ng/ml activin A each day for an additional three days.

[0098] At day 4, samples were collected for FACS and gene expression analysis using real-time PCR, and counted by ViaCount® (Guava®, Millipore, Billerica, MA). As shown in Example2, we noted that a relatively more acidic pH of differentiation media (<7.6pH) can reduce CXCR4 expression due to less directed differentiation and increased alternative differentiation.

[0099] In order to test if this effect was due to pH, we differentiated cells in basal MCDB-131 that contains the published concentration of 1gram/liter of sodium bicarbonate and we differentiated cells in media supplemented to the bicarbonate concentration of DMEM, which is 3.7grams/liter. We observed that differentiation, as measured by the increased expression of the cellular surface markers CXCR4 and decreased expression of CD9, was improved by the use of a buffering agent. MCDB-131 media with 3.7g/l of Sodium Bicarbonate for a buffer had significantly higher CXCR4 expression and lower CD9 expression levels versus cells differentiated in MCDB-131 that contained only the base level of Bicarbonate (1g/l) (Figure 7A and B). This is due in part to the fact that MCDB-131 media has a pH level of 7.5, and addition of 2.7g/l of Sodium Bicarbonate raises the pH to 7.6.

[0100] Furthermore, at the end of differentiation, the media (containing the pH color sensor phenol red) from cultures grown in undifferentiated media were significantly more yellow and acidic than cultures with supplemental sodium bicarbonate buffered media which remained red in color. These results indicate that increasing media pH to 7.6 or higher promotes more efficient definitive endoderm differentiation from pluripotent stem cells, and raising and stabilizing media pH could be achieved by alternatives to bicarbonate buffering including, but not limited to, increasing incubator CO_2 levels and other soluble buffer systems like HEPES, or phosphate.

Example 4

The Role of RPMI-1640 or MCDB-131 Media and the TGF-Beta superfamily members Activin A and GDF-8 in the Differentiation of Human Pluripotent Stem Cells to Cells Expressing Markers Characteristic of the Definitive Endoderm Lineage

[0101] Cells of the human embryonic stem cell line H1 at passage 47 (p47) were lifted by TrypLE (Catalog# 12604-013, Invitrogen, CA) and seeded as single cells at a density of 100,000 cells/cm^2 on MATRIGEL® coated dishes (1:30 dilution) in MEF-CM (mouse embryonic fibroblast conditioned media) supplemented with 20 ng/ml FGF2 (Catalog# 100-18B, PeproTech, NJ) and 3 μM of H-1152, glycyl (a Rho Kinase Inhibitor, Catalog# 555554, EMD chemicals, Gibbstown, NJ).

[0102] At 72 hrs post seeding, the cultures were differentiated into cells expressing markers characteristic of the definitive endoderm lineage as follows:

a. MCDB-131 (Catalog# 10372-019, Invitrogen, CA) containing an additional 0.0025 g/ml sodium bicarbonate (Catalog# S3187, Sigma, MO), was supplemented with 2% fatty acid-free BSA (Catalog# 68700, Proliant, IA), 1X GlutaMax™ (Catalog # 35050-079, Invitrogen, Ca) and 100 ng/ml activin A (R&D Systems, MN) plus 20 ng/ml WNT-3a (Catalog# 1324-WN-002, R&D Systems, MN) for one day, then MCDB-131 with an additional 0.0025 g/ml sodium bicarbonate, 2% BSA , Glutamax, and 100 ng/ml activin A for three days , or,

b. MCDB-131 (Catalog# 10372-019, Invitrogen, CA) containing an additional 0.0025 g/ml sodium bicarbonate (Catalog# S3187, Sigma, MO), was supplemented with 2% fatty acid-free BSA (Catalog# 68700, Proliant, IA), 1X GlutaMax™ (Catalog # 35050-079, Invitrogen, Ca) and 100 ng/ml GDF-8 (R&D Systems, MN) plus 2.5μM of the GSK3B inhibitor 14-Prop-2-en-1-yl-3,5,7,14,17,23,27-heptaazatetracyclo[19.3.1.1~2,6~.1~8,12~]heptacosa-1(25),2(27),3,5,8(26),9,11,21,23-nonaen-16-one for one day, then MCDB-131 with an additional 0.0025 g/ml sodium bicarbonate, 2% BSA , Glutamax, and 100 ng/ml GDF-8 for three days, or,

c. MCDB-131 (Catalog# 10372-019, Invitrogen, CA) containing an additional 0.0025 g/ml sodium bicarbonate (Catalog# S3187, Sigma, MO), was supplemented with 2% fatty acid-free BSA (Catalog# 68700, Proliant, IA), 1X GlutaMax™ (Catalog # 35050-079,

Invitrogen, Ca) and 100 ng/ml GDF-8 (R&D Systems, MN) for four days, or,

d. RPMI-1640 (Catalog #22400-105, Invitrogen, CA), was supplemented with 2% fatty acid-free BSA (Catalog# 68700, Proliant, IA), and 100 ng/ml activin A (R&D Systems, MN) plus 20 ng/ml WNT-3a (Catalog# 1324-WN-002, R&D Systems, MN), for one day, then RPMI-1640 medium supplemented with 2% BSA, and 100 ng/ml activin A each day for an additional three days.

e. RPMI-1640 (Catalog #22400-105, Invitrogen, CA), was supplemented with 2% fatty acid-free BSA (Catalog# 68700, Proliant, IA), and 100 ng/ml GDF-8 (R&D Systems, MN) plus 2.5μM of the GSK3B inhibitor 14-Prop-2-en-1-yl-3,5,7,14,17,23,27-heptaazatetracyclo[19.3.1.1~2,6~.1~8,12~]heptacosa-1(25),2(27),3,5,8(26),9,11,21,23-nonaen-16-one for one day, then RPMI-1640 medium supplemented with 2% BSA, and 100 ng/ml GDF-8 each day for an additional three days.

[0103] At day 4, samples were collected for FACS analysis and qRT-PCR. In Table 2, the percentage of cells expressing CXCR4, CD9, and CD99 (an additional marker of differentiation) are summarized in Table 2. Differentiation, as measured by the increased expression of the cellular surface marker CXCR4 was improved by the use of MCDB-131 media compared to RPMI-1640, and expression of CXCR4 was further increased by using GDF-8 in combination with GSK3B inhibitor, compared to cells treated with activin A and Wnt3a. Similar results, showing improved differentiation with the use of MCDB-131 media compared to RPMI-1640, and by using GDF-8 in combination with a GSK3B inhibitor compared to cells treated with activin A and Wnt3a were observed by qRT-PCR for the gene MNX-1 (Figure 8). Furthermore, these data correlated with decreased expression of CD9, a cellular marker for undifferentiated cells, as measured by flow cytometry (Table 2) or OCT4 and CD9, as measured by qRT-PCR (Figure 8). These data indicate that H1 human embryonic stem cells differentiate more efficiently in the presence of MCDB-131 medium than RPMI-1640 medium, and that differentiation in MCDB-131can be further improved

by differentiating the cells in the presence of GDF-8 and a GSK3B inhibitor versus differentiation with activin A and Wnt3a.

Table 2.

Media Treatment	CD184	CD9	CD99
RPMI+AA+Wnt	77.8	20.9	77.8
RPMI+GDF8+GSK3B inhibitor	81.6	13.8	83.4
MCDB131+AA+Wnt	81.2	21.1	60.0
MCDB131+GDF8+ GSK3B inhibitor	87.1	14.3	50.9
MCDB131+GDF8	43.2	31.2	23.7

[0104] Publications cited throughout this document are hereby incorporated by reference in their entirety. Although the various aspects of the invention have been illustrated above by reference to examples and preferred embodiments, it will be appreciated that the scope of the invention is defined not by the foregoing description but by the following claims properly construed under principles of patent law.

What is claimed is:

1. A population of cells, wherein greater than 80% of the cells in the population express markers characteristic of the definitive endoderm lineage.

2. A method for generating a population of cells wherein greater than 80% of the cells in the population express markers characteristic of the definitive endoderm lineage, comprising the steps of:

    a. Culturing a population of pluripotent stem cells,

    b. Differentiating the population of pluripotent stem cells to a population of cells wherein greater than 80% of the cells in the population express markers characteristic of the definitive endoderm lineage in medium wherein the concentration of glucose does not exceed 10.5 mM.

3. The method of claim 2, wherein the population of pluripotent stem cells are differentiated to a population of cells wherein greater than 80% of the cells in the population express markers characteristic of the definitive endoderm lineage using activin A and a Wnt ligand.

4. The method of claim 2, wherein the population of pluripotent stem cells are differentiated to a population of cells wherein greater than 80% of the cells in the population express markers characteristic of the definitive endoderm lineage using GDF-8 and at least one other factor is selected from the group consisting of: an aniline-pyridinotriazine, a cyclic aniline-pyridinotriazine, N-{[1-(Phenylmethyl)azepan-4-yl]methyl}-2-pyridin-3-ylacetamide, 4-{[4-(4-{[2-(Pyridin-2-ylamino)ethyl]amino}-1,3,5-triazin-2-yl)pyridin-2-yl]oxy}butan-1-ol, 3-({3-[4-({2-[Methyl(pyridin-2-yl)amino]ethyl}amino)-1,3,5-triazin-2-yl]pyridin-2-yl}amino)propan-1-ol, N~4~-[2-(3-Fluorophenyl)ethyl]-N~2~-[3-(4-methylpiperazin-1-yl)propyl]pyrido[2,3-d]pyrimidine-2,4-diamine, 1-Methyl-N-[(4-pyridin-3-yl-2-{[3-(trifluoromethyl)phenyl]amino}-1,3-thiazol-5-yl)methyl]piperidine-4-carboxamide, 1,1-Dimethylethyl {2-[4-({5-[3-(3-hydroxypropyl)phenyl]-4H-1,2,4-triazol-3-yl}amino)phenyl]ethyl}carbamate, 1,1-Dimethylethyl {[3-({5-[5-(3-hydroxypropyl)-2-(methyloxy)phenyl]-1,3-oxazol-2-

yl}amino)phenyl]methyl}carbamate, 1-({5-[6-({4-[(4-Methylpiperazin-1-yl)sulfonyl]phenyl}amino)pyrazin-2-yl]thiophen-2-yl}methyl)piperidin-4-ol, 1-({4-[6-({4-[(4-Methylpiperazin-1-yl)sulfonyl]phenyl}amino)pyrazin-2-yl]thiophen-2-yl}methyl)piperidine-4-carboxamide, and 2-{[4-(1-Methylethyl)phenyl]amino}-N-(2-thiophen-2-ylethyl)-7,8-dihydropyrido[4,3-d]pyrimidine-6(5H)-carboxamide.

5. The method of claim 4, wherein the at least one other factor is 14-Prop-2-en-1-yl-3,5,7,14,17,23,27-heptaazatetracyclo[19.3.1.1~2,6~.1~8,12~]heptacosa-1(25),2(27),3,5,8(26),9,11,21,23-nonaen-16-one.

6. The method of claim 2, wherein the concentration of glucose does not exceed 5.5 mM.