COMPOSITIONS AND METHODS USEFUL FOR CULTURING DIFFERENTIABLE CELLS

Inventors:

Allan Robins

Thomas Schulz

Cross-Reference to Related Applications

[0001] This application claims priority to United States Serial No. 60/776,113, filed 23 February 2006, which is incorporated by reference.

Statement Regarding Federally Sponsored Research or Development

[0002] Part of the work performed during development of this invention utilized U.S. Government funds from National Institutes of Health Grant No. 5 R24 RR021313-05. The U.S. Government has certain rights in this invention.

Background of the Invention

Field of the Invention

[0003] The present invention relates to cell culture methods and compositions that are essentially serum-free and comprise a basal salt nutrient solution and an ErbB3 ligand.

Background of the Invention

[0004] Human pluripotent cells offer unique opportunities for investigating early stages of human development as well as for therapeutic intervention in several disease states, such as diabetes mellitus and Parkinson's disease. For example, the use of insulin-producing β-cells derived from human embryonic stem cells (hESCs) would offer a vast improvement over current cell therapy procedures that utilize cells from donor pancreases. Currently cell therapy treatments for diabetes mellitus, which utilize cells from donor pancreases, are limited by the scarcity of high quality islet cells needed for transplant. Cell therapy for a single Type I diabetic patient requires a transplant of approximately 8×10^8 pancreatic islet cells (Shapiro *et al.*, 2000, N Engl J Med 343:230-238; Shapiro *et al.*, 2001a, Best Pract Res Clin Endocrinol Metab 15:241-

264; Shapiro *et al.*, 2001, British Medical Journal 322:861). As such, at least two healthy donor organs are required to obtain sufficient islet cells for a successful transplant.

[0005] Embryonic stem (ES) cells thus represent a powerful model system for the investigation of mechanisms underlying pluripotent cell biology and differentiation within the early embryo, as well as providing opportunities for genetic manipulation of mammals and resultant commercial, medical and agricultural applications. Furthermore, appropriate proliferation and differentiation of ES cells can potentially be used to generate an unlimited source of cells suited to transplantation for treatment of diseases that result from cell damage or dysfunction. Other pluripotent cells and cell lines including early primitive ectoderm-like (EPL) cells as described in International Patent Application WO 99/53021, in vivo or in vitro derived ICM/epiblast, in vivo or in vitro derived primitive ectoderm, primordial germ cells (EG cells), teratocarcinoma cells (EC cells), and pluripotent cells derived by dedifferentiation or by nuclear transfer will share some or all of these properties and applications. International Patent Application WO 97/32033 and U.S. Patent No. 5,453,357 describe pluripotent cells including cells from species other than rodents. Human ES cells have been described in International Patent Application WO 00/27995, and in U.S. Patent No. 6,200,806, and human EG cells have been described in International Patent Application WO 98/43679.

[0006] The biochemical mechanisms regulating ES cell pluripotency and differentiation are very poorly understood. However, the limited empirical data available (and much anecdotal evidence) suggests that the continued maintenance of pluripotent ES cells under *in vitro* culture conditions is dependent upon the presence of cytokines and growth factors present in the extracellular milieu.

[0007] While human ESCs offer a source of starting material from which to develop substantial quantities of high quality differentiated cells for human cell therapies, these cells must be obtained and/or cultured in conditions that are compatible with the expected regulatory guidelines governing clinical safety and efficacy. Such guidelines likely will require the use of a chemically defined media. The development of such chemically defined/GMP standard conditions is necessary to facilitate the use of hESCs and cells derived from hESCs for therapeutic purposes in humans.

[0008] In addition, the eventual application of hESC based cell replacement therapies will require the development of methods that enable large scale culture and differentiation conditions that are compliant with regulatory guidelines. While several groups have reported simplified growth conditions for hESCs, there are substantial limitations with these studies. To date, however, the successful isolation, long-term clonal maintenance, genetic manipulation and germ line transmission of pluripotent cells has generally been difficult.

[0009] Most of the cell culture conditions for stem cells still contain serum replacer (KSR) in the media (Xu et al., 2005 Stem Cells, 23:315-323; Xu et al., 2005 Nature Methods, 2:185-189; Beattie et al., 2005 Stem Cells, 23:489-495; Amit et al., 2004 Biol. Reprod., 70:837-845; James et al., 2005 Development, 132:1279-1282). KSR contains a crude fraction of bovine serum albumin (BSA) rather than a highly purified source. Others have only performed short-term studies, and therefore it is not clear if their conditions would enable the maintenance of pluripotency over extended periods (Sato et al., (2004) Nature Med., 10:55-63; U.S. Patent Publication Nos. 2006/0030042 and 2005/0233446). Others have shown long-term maintenance of pluripotency in a chemically defined media with FGF2, activin A, and insulin, but the cells were grown on plates that were coated with human serum, which was "washed off" before plating of cells (Vallier et al., 2005 J Cell Sci., 118(Pt 19):4495-509). While FGF2 has been a component of all these media, it is not clear if it is an absolute necessity, particularly as in some formulations it is necessary to use it at a high concentration (up to 100 ng/ml, Xu et al., 2005 Nature Methods, 2:185-189).

[0010] Furthermore, all of these groups have either included insulin in their media at μg/ml levels, or have insulin present due to the use of KSR. Insulin is typically considered to function in glucose metabolism and "cell survival" signaling via binding to the insulin receptor. At levels above physiological concentrations, however, insulin can also bind to the IGF1 receptor with a lower efficiency and confer classical growth factor activity through the PI3 Kinase/AKT pathway. The presence/requirement for such high levels of insulin (μg/ml levels) in KSR or these other media conditions suggests that the major activity is elicited *via* binding to the IGF1 receptor, which is expressed by hESCs (Sperger et al., 2003 PNAS, 100(23):13350-13355). Others have noted the expression of a full complement of IGF1R and intracellular signaling pathway members in hESCs, which is likely to signify the functional activity of this pathway

(Miura et al., 2004 Aging Cell, 3:333-343). Insulin or IGF1 may elicit a major signal required for the self-renewal of hESCs, as is suggested by the fact that all conditions developed thus far for the culture of hESC contain either insulin, insulin provided by KSR, or IGF1 provided by serum. In support of this concept, it has been shown that if PI3 Kinase is inhibited in hESC cultures, the cells differentiate (D'Amour et al., 2005 Nat. Biotechnol., 23(12):1534-41; McLean et al., 2007 Stem Cells 25:29-38).

[0011] A recent publication outlines a humanized, defined media for hESCs (Ludwig et al., Nature Biotechnology, published online January 1, 2006, doi:10.1038/nbt1177). This recent formulation, however, includes several factors that are suggested to influence the proliferation of hESCs, including FGF2, TGFβ, LiCl, γ-aminobutyric acid and pipecolic acid. It is noted that this recently defined cell culture medium also contains insulin.

[0012] The EGF growth factor family has at least 14 members, including, but not limited to, EGF, TGFβ, heparin binding-EGF (hb-EGF), neuregulin-β (also named heregulin-β (HRG-β), glial growth factor and others), HRG-α, amphiregulin, betacellulin, and epiregulin. All these growth factors contain an EGF domain and are typically first expressed as transmembrane proteins that are processed by metalloproteinase (specifically, ADAM) proteins to generate soluble ectodomain growth factors. EGF family members interact with either homo- or hetero-dimers of the ErbB1, 2, 3 and 4 cell surface receptors with different affinities (Jones et al., FEBS Lett, 1999, 447:227-231). EGF, TGFα and hbEGF bind ErbB1/1 (EGFR) homodimers and ErbB1/2 heterodimers at high affinity (1-100 nM range), whereas HRG-β binds ErbB3 and ErbB4 at very high affinity (<1 nM range). Activated ErbB receptors signal through the PI3 Kinase/AKT pathway and also the MAPK pathway. ErbB2 and ErbB3 are amongst the most highly expressed growth factor receptors in hESCs (Sperger et al., 2003 PNAS, 100(23):13350-13355) and HRG-β has been shown previously to support the expansion of mouse primordial germ cells (Toyoda-Ohno et al., 1999 Dev. Biol., 215(2):399-406). Furthermore, overexpression and subsequent inappropriate activation of ErbB2 is associated with tumorigenesis (Neve et al., 2001 Ann. Oncol., 12 Suppl 1:S9-13; Zhou & Hung, 2003 Semin. Oncol., 30(5 Suppl 16):38-48; Yarden, 2001 Oncology, 61 Suppl 2:1-13). Human ErbB2 (Chromosome 17q), and ErbB3 (Chromosome 12q) are present on chromosomes that have been observed to accumulate as trisomies in some hESCs (Draper et al., 2004 Nat. Biotechnol., 22(1):53-4; Cowan et al., 2004 N

Engl. J. Med., 350(13):1353-6; Brimble et al., 2004 Stem Cells Dev., 13(6):585-97; Maitra et al., 2005 Nat. Genet. 37(10):1099-103; Mitalipova et al., 2005 Nat. Biotechnol. 23(1): 19-20; Draper et al., 2004 Stem Cells Dev., 13(4):325-36; Ludwig et al., Nature Biotechnology, published online January 1, 2006, doi:10.1038/nbt1177).

[0013] ErbB2 and ErbB3 (Brown et al., 2004 Biol. Reprod., 71:2003-2011; Salas-Vidal & Lomeli, 2004, Dev Biol., 265:75-89) are expressed in the mouse blastocyst, although not specifically restricted to the inner cell mass (ICM), and ErbB1, EGF and TGFβ are expressed in the human blastocyst (Chia et al., 1995 Development, 1221(2):299-307). HB-EGF has proliferative effects in human IVF blastocyst culture (Martin et al., 1998 Hum. Reprod., 13(6):1645-52; Sargent et al., 1998 Hum. Reprod. 13 Suppl 4:239-48), and modest additional effects on mouse ES cells grown in 15% serum (Heo et al., 2005, Am. J. Phy. Cell Physiol., in press). Pre- and early post-implantation development does not appear to be affected in ErbB2-/-, ErbB3-/-, Neuregulin1-/- (Britsch et al., 1998 Genes Dev., 12:1825-36), ADAM17-/- (Peschon, et al., 1998 Science, 282: 1281-1284) and ADAM19-/- (Horiuchi, 2005 Dev. Biol., 283(2):459-71) null embryos. Therefore, the importance of signaling through the ErbB receptor family in hESCs is, up to now, unclear.

[0014] Neuregulin-1 (NRG1) is a large gene that exhibits multiple splicing and protein processing variants. This generates a large number of protein isoforms, which are referred to herein collectively as neuregulin. Neuregulin is predominantly expressed as a cell surface transmembrane protein. The extracellular region contains an immunoglobulin-like domain, a carbohydrate modified region and the EGF domain. NRG1 expression isoforms have been reviewed previously (Falls, 2003 Exp. Cell Res., 284:14-30). The cell membrane metalloproteases ADAM17 and ADAM19 have been shown to process the transmembrane form(s) of neuregulin-1 to soluble neuregulin/heregulin. HRG-α and -β are the cleaved ectodomains of neuregulin, containing the EGF and other domains. As the EGF domain is responsible for binding and activation of the ErbB receptors, a recombinant molecule containing only this domain can exhibit essentially all of the soluble growth factor effects of this protein (Jones et al., 1999 FEBS Lett., 447:227-231). Also, there are processed transmembrane isoforms of neuregulin that are thought to trigger juxtacrine signaling in adjacent cells via interaction of the EGF domain with ErbB receptors.

[0015] An important development in the progression of hESC research toward maintaining pluripotency in culture will be the elucidation of media and cell culture conditions that are compatible with the expected regulatory guidelines governing clinical safety and efficacy. While the best outcome would be the availability of chemically defined media for hESCs, components that are not chemically defined would be acceptable if they were produced to GMP standard. There is a need, therefore, to identify methods and compositions for the culture and stabilization of a population of pluripotent stem cells that are able to be used for therapeutic purposes, wherein the culture compositions are defined and/or produced to GMP standard.

Summary of the Invention

[0016] The invention relates to compositions comprising a basal salt nutrient solution and an ErbB3 ligand, with the compositions being essentially free of serum.

[0017] The invention also relates to compositions comprising a basal salt nutrient solution and a means for stimulating ErbB2-directed tyrosine kinase activity in differentiable cells.

[0018] The invention relates to methods of culturing differentiable cells, with the methods comprising plating the differentiable cells on a cell culture surface, providing a basal salt nutrient solution to the differentiable cells and providing a ligand that specifically binds ErbB3.

[0019] The invention relates to methods of culturing differentiable cells, with the methods comprising plating the differentiable cells on a cell culture surface and providing a basal salt nutrient solution to the differentiable cells and a means for stimulating ErbB2-directed tyrosine kinase activity in the differentiable cells.

[0020] The invention also relates to methods of culturing differentiable cells, with the methods comprising providing a digest solution to a layer of differentiable cells that are contained in a culture chamber prior to digestion, where the digestion breaks apart the layer of cells into single cells. After digestion, the single cells are placed into a new tissue culture chamber with a differentiable cell culture solution, wherein the differentiable cell culture solution comprises a basal salt nutrient solution and an ErbB3 ligand. Once cultured, the single differentiable cells are placed in conditions that permit growth and division of the single cells.

Brief Description of the Drawings

[0021] FIGURE 1 depicts real time RT-PCR expression analysis of ADAM19, Neuregulin1, and ErbB1-3 in BG01v grown in defined conditions (8 ng/ml FGF2, 100 ng/ml LR-IGF1, 1 ng/ml Activin A). GAPDH and OCT4 control reactions are indicated.

[0022] FIGURE 2 depicts the inhibition of proliferation of BG01v cells using AG879. BG01v cells were plated in 6-well trays and exposed to DMSO (A), 50 nM-20 μM AG1478 (B), or 100 mM-20 μM AG879 (C) 24 hours after plating. After 5 days in culture, the cultures were fixed and stained for alkaline phosphatase activity. AG1478 did not appear to affect proliferation at these concentrations (20 μM shown in B), but AG879 substantially slowed cell growth at 5 μM (C).

[0023] FIGURE 3 depicts the morphology of BG01v cells cultured in DC-HAIF, which is defined culture media containing 10 ng/ml HRG-β, 10 ng/ml Activin A, 200 ng/ml LR-IGF1 and 8 ng/ml FGF2 (A and B), and in defined culture media (DC) containing 10 ng/ml HRG-β, 10 ng/ml Activin A, and 200 ng/ml LR-IGF1 (C and D).

[0024] FIGURE 4 depicts the expression of ADAM19, Neuregulin1, and ErbB1-4 by RT-PCR in mouse ES cells (A) and MEFs (B).

[0025] FIGURE 5 depicts the inhibition of ErbB1 and ErbB2 signaling in mouse ES cells. $2x10^5$ Mouse R1 ES cells were plated on 1:1000 MATRIGEL™ in 10% FBS, 10% KSR with 1000 U/ml mouse LIF (ESGRO). The following day, DMSO (carrier control), 1-50 μM AG1478, or 1-50 μM AG879 was added with fresh medium. The cultures were fixed on day 8, and stained for alkaline phosphatase activity. DMSO (A) and 1-50 μM AG1478 (B and C) did not overtly inhibit proliferation. AG879 substantially inhibited cell growth at 50 μM (compare D and F) and may have slowed proliferation at 20 μM (E).

[0026] FIGURE 6 depicts the inhibition of proliferation of BG02 cells grown in conditioned media (CM). (A) 50 μM AG825 inhibited proliferation of BG02 hESCs growing in CM. (B) AG825 inhibits ErbB2 Y1248 phosphorylation in hESCs. (C) Colony counting of serial passaging of CyT49 hESCs in different combinations of growth factors. (D) Cell counting analysis of the role of IGF1 and HRG in hESC proliferation using BG02 cells (left). (E)

OCT4/DAPI immunostaining of a duplicate repeated experiment demonstrated that IGF1 and HRG significantly increased the proportion of $OCT4^+$ cells compared to ActA/FGF2 conditions. (F) RTK blotting analysis of BG01 DC-HAIF hESCs starved of growth factors overnight; starved, then pulsed with DC-HAIF for 15 minutes; or steady-state cultures are shown (left). The mean and range of normalized relative intensity is plotted (right).

[0027] FIGURE 7 depicts mouse ES cells grown in defined conditions with different growth factor combinations. (A) shows the scoring of AP^+ colonies after $2x10^5$ cells were grown in different growth factor combinations for 8 days. (B-G) show 4x magnification images of AP^+ colonies grown in different growth factor combinations.

[0028] FIGURE 8 depicts the characterization of human ES cells that are maintained in DC-HAIF medium. (A) Analysis of teratomas from BG02 DC-HAIF p25 cells demonstrated pluripotent differentiation potential to ectoderm, mesoderm and endoderm. (B) Immunostaining of BG02 cells cultured in 15% FCS/5% KSR that have differentiated. (C) Venn diagram of the distribution of transcripts detected using high density Illumina Sentrix Human-6 Expression Beadchips containing 47,296 transcript probes in BG02 cells maintained in CM (64 passages) or DC-HAIF (10 or 32 passages in defined media). (D) Scatterplot analysis demonstrating that the transcriptional profile of BG02 DC-HAIF p32 cells is highly similar to that of BG02 cells maintained in CM (top), and was not substantially altered in early and late passage cultures in DC-HAIF (bottom). (E) Hierarchical clustering dendrogram of relative gene expression in different populations generated using the Beadstudio software.

[0029] FIGURE 9 depicts the morphology of cells cultured on humanized extracellular matrices (ECMs) in the presence of DC-HAIF medium. (A) CyT49 cells (diluted 1:200) growing on growth factor-reduced MATRIGEL™ (diluted 1:200). CyT49 cells could also grow on tissue culture dishes coated with (B) whole human serum, (C) human fibronectin, and (D) VITROGRO™.

[0030] FIGURE 10 depicts the single-cell passaging of human ES cells. (A-D) Staged imaging of BG02 cells after passaging with ACCUTASE™ and plating about $5x10^5$ cells in a 60 mm culture dish. (A) 1.5 hours after initial plating, showing viable cells adhering to the dish. (B) At 20 hours post-plating, the large majority of cells have aggregated to form small colonies. These

colonies expand by proliferation by day 4, post-plating (C), and over the course of 5-6 days to form an epithelial-like monolayer covering the entire dish (D). (E) Normal male karyotype demonstrated in a BG02 culture passaged 19 times with ACCUTASE™ in DC-HAIF.

[0031] FIGURE 11 depicts cell morphology after single cell passaging of human ES cells using (A) ACCUTASE™, (B) 0.25% Trypsin/EDTA, (C) TrypLE, or (D) Versene.

[0032] FIGURE 12 depicts the large-scale growth of human ES cells cultured in DC-HAIF. (A) Flow cytometric analysis of BG02 cells after expansion to $>10^{10}$ cells. >85% of cells expressed OCT4, CD9, SSEA-4, TRA-1-81. (B) RT-PCR analysis of expression of markers of pluripotency OCT4, NANOG, REX1, SOX2, UTF1, CRIPTO, FOXD3, TERT and DPPA5. Markers of differentiated lineages, α-fetoprotein (AFP), MSX1 and HAND1 were not detected. (C) Fluorescence *in situ* hybridization (FISH) using human chromosome-specific repeats demonstrated maintenance of normal copy numbers for hChr 12, 17, X and Y.

[0033] FIGURE 13 depicts the morphology (A) and normal karyotype (B) of hESC BG02 cells grown in defined media comprising HRG-β and IGF1, but in the absence of FGF2 for 7 passages, or >2 months.

[0034] FIGURE 14 depicts a scatterplot analysis of transcripts from hESCs (BG02) that are maintained in DC-HAIF (32 passages) or DC-HAI (10 passages). A large proportion of the expressed transcripts were detected in both samples, and transcription was not substantially altered by culturing hESCs in the absence of exogenous FGF2. Correlation coefficients (R^2) were generated using all detected transcripts with an expression level of >0 (all dots), or with transcripts exhibiting a detection confidence level of >0.99 (R^2 select, dots indicated by dashed oval). Angled lines delineate the mean and limits of a 2-fold difference.

[0035] FIGURE 15 depicts a hierarchical clustering dendrogram of relative gene expression in different populations of early and late passage BG02 cells maintained in DC-HAIF. Cells clustered tightly (~0.0075) and retained a close similarity to BG02 and BG03 cells maintained in conditioned medium (CM) (~0.037). BG02 cells maintained in DC-HAI also clustered tightly with the other hESC populations examined. By way of explanation in FIGURE 15, CM is Conditioned Medium; DC is defined culture medium, DC-HAIF as defined above; ap is

ACCUTASE™ single cell passaging; DC-HAI is identical to DC-HAIF as defined herein, except without FGF2.

[0036] FIGURE 16 depicts the morphology and alkaline phsophatase staining of BG02 cells cultured in DC-HAIF in 96-well and 384-well plates. (A) Phase contrast imaging and (B) alkaline phosphatase staining of BG02 cells (10^4 cells/well) growing in one well of a 96-well plate. (C) Phase contrast imaging and (D) alkaline phosphatase staining of BG02 cells (10^3 cells/well) growing in one well of a 384-well plate.

Detailed Description of the Invention

[0037] Unless otherwise noted, the terms used herein are to be understood according to conventional usage by those of ordinary skill in the relevant art. In addition to the definitions of terms provided below, definitions of common terms in molecular biology may also be found in Rieger *et al.*, 1991 Glossary of genetics: classical and molecular, 5th Ed., Berlin: Springer-Verlag; and in Current Protocols in Molecular Biology, F.M. Ausubel *et al.*, Eds., Current Protocols, a joint venture between Greene Publishing Associates, Inc. and John Wiley & Sons, Inc., (1998 Supplement). It is to be understood that as used in the specification and in the claims, "a" or "an" can mean one or more, depending upon the context in which it is used. Thus, for example, reference to "a cell" can mean that at least one cell can be utilized.

[0038] As used herein, the term "contacting" (i.e., contacting a cell *e.g.,* a differentiable cell, with a compound) is intended to include incubating the compound and the cell together *in vitro* (*e.g.,* adding the compound to cells in culture). The term "contacting" is not intended to include the *in vivo* exposure of cells to a defined cell medium comprising an ErbB3 ligand, and optionally, a member of the TGF-β family, that may occur naturally in a subject (i.e., exposure that may occur as a result of a natural physiological process). The step of contacting the cell with a defined cell medium comprising an ErbB3 ligand, and optionally, a member of the TGF-β family, can be conducted in any suitable manner. For example, the cells may be treated in adherent culture, or in suspension culture. It is understood that the cells contacted with the defined medium can be further treated with a cell differentiation environment to stabilize the cells, or to differentiate the cells.

[0039] As used herein, the term "differentiate" refers to the production of a cell type that is more differentiated than the cell type from which it is derived. The term therefore encompasses cell types that are partially and terminally differentiated.

[0040] In certain embodiments of the present invention, the term "enriched" refers to a cell culture that contains more than approximately 50%, 55%, 60%, 65%, 70%, 75%, 80%, 85%, 90%, or 95% of the desired cell lineage.

[0041] As used herein, the term "effective amount" of a compound refers to that concentration of the compound that is sufficient in the presence of the remaining components of the defined medium to effect the stabilization of the differentiable cell in culture for greater than one month in the absence of a feeder cell and in the absence of serum or serum replacement. This concentration is readily determined by one of ordinary skill in the art.

[0042] As used herein, the term "express" refers to the transcription of a polynucleotide or translation of a polypeptide in a cell, such that levels of the molecule are measurably higher in a cell that expresses the molecule than they are in a cell that does not express the molecule. Methods to measure the expression of a molecule are well known to those of ordinary skill in the art, and include without limitation, Northern blotting, RT-PCR, *in situ* hybridization, Western blotting, and immunostaining.

[0043] As used herein when referring to a cell, cell line, cell culture or population of cells, the term "isolated" refers to being substantially separated from the natural source of the cells such that the cell, cell line, cell culture, or population of cells are capable of being cultured *in vitro*. In addition, the term "isolating" is used to refer to the physical selection of one or more cells out of a group of two or more cells, wherein the cells are selected based on cell morphology and/or the expression of various markers.

[0044] The present invention may be understood more readily by reference to the following detailed description of the preferred embodiments of the invention and the Examples included herein. However, before the present compositions and methods are disclosed and described, it is to be understood that this invention is not limited to specific nucleic acids, specific polypeptides, specific cell types, specific host cells, specific conditions, or specific methods, etc., as such may,

of course, vary, and the numerous modifications and variations therein will be apparent to those skilled in the art.

[0045] Standard techniques for cloning, DNA isolation, amplification and purification, for enzymatic reactions involving DNA ligase, DNA polymerase, restriction endonucleases and the like, and various separation techniques are those known and commonly employed by those skilled in the art. A number of standard techniques are described in Sambrook *et al.*, 1989 Molecular Cloning, Second Edition, Cold Spring Harbor Laboratory, Plainview, New York; Maniatis *et al.*, 1982 Molecular Cloning, Cold Spring Harbor Laboratory, Plainview, New York; Wu (Ed.) 1993 Meth. Enzymol. 218, Part I; Wu (Ed.) 1979 Meth. Enzymol. 68; Wu *et al.*, (Eds.) 1983 Meth. Enzymol. 100 and 101; Grossman and Moldave (Eds.) 1980 Meth. Enzymol. 65; Miller (ed.) 1972 Experiments in Molecular Genetics, Cold Spring Harbor Laboratory, Cold Spring Harbor, New York; Old and Primrose, 1981 Principles of Gene Manipulation, University of California Press, Berkeley; Schleif and Wensink, 1982 Practical Methods in Molecular Biology; Glover (Ed.) 1985 DNA Cloning Vol. I and II, IRL Press, Oxford, UK; Hames and Higgins (Eds.) 1985 Nucleic Acid Hybridization, IRL Press, Oxford, UK; and Setlow and Hollaender 1979 Genetic Engineering: Principles and Methods, Vols. 1-4, Plenum Press, New York. Abbreviations and nomenclature, where employed, are deemed standard in the field and commonly used in professional journals such as those cited herein.

[0046] The invention relates to compositions and methods comprising a basal salt nutrient solution and an effective amount of an ErbB3 ligand, with the compositions being essentially free of serum. The compositions and methods of the present invention are useful for culturing cells, in particular, differentiable cells. It is understood that at different points during culturing the differentiable cells, various components may be added to the cell culture such that the medium can contain components other than those described herein. It is, however, contemplated that at least at one point during the preparation of the culture, or during the culture of the differentiable cells, the defined medium comprises a basal salt nutrient solution and a means for activating ErbB2-directed tyrosine kinase.

[0047] As used herein, the term "differentiable cell" is used to describe a cell or population of cells that can differentiate into at least partially mature cells, or that can participate in the

differentiation of cells, *e.g.,* fuse with other cells, that can differentiate into at least partially mature cells. As used herein, "partially mature cells" are cells that exhibit at least one characteristic of the phenotype, such as morphology or protein expression, of a mature cell from the same organ or tissue. For example, a normal, mature hepatocyte typically expresses such proteins as albumin, fibrinogen, alpha-1-antitrypsin, prothrombin clotting factors, transferrin, and detoxification enzymes such as the cytochrome P-450s, among others. Thus, as defined in the present invention, a "partially mature hepatocyte" may express albumin or another one or more proteins, or begin to take the appearance or function of a normal, mature hepatocyte. Additionally, a "partially mature pancreatic beta cell" may produce or express the proinsulin protein, among others. The ability of the cells to differentiate into at least partially mature cells will not be dependent upon recombinant engineering techniques, such as transfection, though the cells may, of course, be genetically engineered.

[0048] The invention contemplates compositions and methods useful for differentiable cells, regardless of their source or of their plasticity. The "plasticity" of a cell is used herein roughly as it is in the art. Namely, the plasticity of a cell refers to a cell's ability to differentiate into a particular cell type found in tissues or organs from an embryo, fetus or developed organism. The "more plastic" a cell, the more tissues into which the cell may be able to differentiate. "Pluripotent cells" include cells and their progeny, which may be able to differentiate into, or give rise to, pluripotent, multipotent, oligopotent and unipotent cells, and/or several, if not all, of the mature or partially mature cell types found in an embryo, fetus or developed organism. "Multipotent cells" include cells and their progeny, which may be able to differentiate into, or give rise to, multipotent, oligopotent and unipotent progenitor cells, and/or one or more mature or partially mature cell types, except that the mature or partially mature cell types derived from multipotent cells are limited to cells of a particular tissue, organ or organ system. For example, a multipotent hematopoietic progenitor cell and/or its progeny possess the ability to differentiate into or give rise to one or more types of oligopotent cells, such as myeloid progenitor cells and lymphoid progenitor cells, and also give rise to other mature cellular components normally found in the blood. "Oligopotent cells" include cells and their progeny whose ability to differentiate into mature or partially mature cells is more restricted than multipotent cells. Oligopotent cells may, however, still possess the ability to differentiate into oligopotent and unipotent cells, and/or one or more mature or partially mature cell types of a given tissue, organ or organ system. One

example of an oligopotent cell is a myeloid progenitor cell, which can ultimately give rise to mature or partially mature erythrocytes, platelets, basophils, eosinophils, neutrophils and monocytes. "Unipotent cells" include cells and their progeny that possess the ability to differentiate or give rise to other unipotent cells and/or one type of mature or partially mature cell type.

[0049] Differentiable cells, as used herein, may be pluripotent, multipotent, oligopotent or even unipotent. In certain embodiments of the present invention, the differentiable cells are pluripotent differentiable cells. In more specific embodiments, the pluripotent differentiable cells are selected from the group consisting of embryonic stem cells, ICM/epiblast cells, primitive ectoderm cells, primordial germ cells, and teratocarcinoma cells. In one particular embodiment, the differentiable cells are mammalian embryonic stem cells. In a more particular embodiment, the differentiable cells are human embryonic stem cells.

[0050] The invention also contemplates differentiable cells from any source within an animal, provided the cells are differentiable as defined herein. For example, differentiable cells may be harvested from embryos, or any primordial germ layer therein, from placental or chorion tissue, or from more mature tissue such as adult stem cells including, but not limited to adipose, bone marrow, nervous tissue, mammary tissue, liver tissue, pancreas, epithelial, respiratory, gonadal and muscle tissue. In specific embodiments, the differentiable cells are embryonic stem cells. In other specific embodiments, the differentiable cells are adult stem cells. In still other specific embodiments, the stem cells are placental- or chorionic-derived stem cells.

[0051] Of course, the invention contemplates using differentiable cells from any animal capable of generating differentiable cells. The animals from which the differentiable cells are harvested may be vertebrate or invertebrate, mammalian or non-mammalian, human or non-human. Examples of animal sources include, but are not limited to, primates, rodents, canines, felines, equines, bovines and porcines.

[0052] The differentiable cells of the present invention can be derived using any method known to those of skill in the art. For example, human pluripotent cells can be produced using de-differentiation and nuclear transfer methods. Additionally, the human ICM/epiblast cell or the primitive ectoderm cell used in the present invention can be derived *in vivo* or *in vitro*. Primitive

ectodermal cells may be generated in adherent culture or as cell aggregates in suspension culture, as described in WO 99/53021. Furthermore, the human pluripotent cells can be passaged using any method known to those of skill in the art, including, manual passaging methods, and bulk passaging methods such as enzymatic or non-enzymatic passaging.

[0053] In certain embodiment, when ES cells are utilized, the embryonic stem cells have a normal karyotype, while in other embodiments, the embryonic stem cells have an abnormal karyotype. In one embodiment, a majority of the embryonic stem cells have a normal karyotype. It is contemplated that greater than 50%, 55%, 60%, 65%, 70%, 75%, 80%, 85%, 90% or greater than 95% of metaphases examined will display a normal karyotype.

[0054] In another embodiment, a majority of the embryonic stem cells have an abnormal karyotype. It is contemplated that greater than 50%, 55%, 60%, 65%, 70%, 75%, 80%, 85%, 90% or greater than 95% of metaphases examined will display an abnormal karyotype. In certain embodiments, the abnormal karyotype is evident after the cells have been cultured for greater than 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, or 20 passages. In one specific embodiment, the abnormal karyotype comprises a trisomy of at least one autosomal chromosome, wherein the autosomal chromosome is selected from the group consisting of chromosomes 1, 7, 8, 12, 14, and 17. In another embodiment, the abnormal karyotype comprises a trisomy of more than one autosomal chromosome, wherein at least one of the more than one autosomal chromosomes is selected from the group consisting of chromosomes 1, 7, 8, 12, 14, and 17. In one embodiment, the autosomal chromosome is chromosome 12 or 17. In another embodiment, the abnormal karyotype comprises an additional sex chromosome. In one embodiment, the karyotype comprises two X chromosomes and one Y chromosome. It is also contemplated that translocations of chromosomes may occur, and such translocations are encompassed within the term "abnormal karyotype." Combinations of the foregoing chromosomal abnormalities and other chromosomal abnormalities are also encompassed by the invention.

[0055] The compositions and methods comprise a basal salt nutrient solution. As used herein, basal salt nutrient solution refers to a mixture of salts that provide cells with water and certain bulk inorganic ions essential for normal cell metabolism, maintain intra- and extra-cellular osmotic balance, provide a carbohydrate as an energy source, and provide a buffering system to

maintain the medium within the physiological pH range. Examples of basal salt nutrient solutions include, but are not limited to, Dulbecco's Modified Eagle's Medium (DMEM), Minimal Essential Medium (MEM), Basal Medium Eagle (BME), RPM1 1640, Ham's F-10, Ham's F-12, α-Minimal Essential Medium (αMEM), Glasgow's Minimal Essential Medium (G-MEM), and Iscove's Modified Dulbecco's Medium, and mixtures thereof. In one particular embodiment, the basal salt nutrient solution is an approximately 50:50 mixture of DMEM and Ham's F12.

[0056] It is contemplated that the composition can further comprise trace elements. Trace elements can be purchased commercially, for example, from Mediatech. Non-limiting examples of trace elements include but are not limited to compounds comprising, aluminum, chlorine, sulfate, iron, cadmium, cobalt, chromium, germanium, sodium, potassium, calcium, phosphate and magnesium. Specific example of compounds containing trace elements include but are not limited to, $AlCl_3$, $AgNO_3$, $Ba(C_2H_3O_2)_2$, $CdCl_2$, $CdSO_4$, $CoCl_2$, $CrCl_3$, $Cr_2(SO_4)_3$, $CuSO_4$, ferric citrate, GeO_2, KI, KBr, LI, molybdic acid, $MnSO_4$, $MnCl_2$, NaF, Na_2SiO_3, $NaVO_3$, NH_4VO_3, $(NH_4)_6Mo_7O_{24}$, $NiSO_4$, RbCl, selenium, Na_2SeO_3, H_2SeO_3, selenite·2Na, selenomethionone, $SnCl_2$, $ZnSO_4$, $ZrOCl_2$, and mixtures and salts thereof. If selenium, selenite or selenomethionone is present, it is at a concentration of approximately 0.002 to approximately 0.02 mg/L. In addition, hydroxylapatite may also be present.

[0057] It is contemplated that amino acids can be added to the defined media. Non-limiting examples of such amino acids are Glycine, L-Alanine, L-Alanyl-L-Glutamine, L-Glutamine/Glutamax, L-Arginine hydrochloride, L-Asparagine-H_2O, L-Aspartic acid, L-Cysteine hydrochloride-H_2O, L-Cystine 2HCl, L-Glutamic Acid, L-Histidine hydrochloride-H_2O, L-Isoleucine, L-Leucine, L-Lysine hydrochloride, L-Methionine, L-Phenylalanine, L-Proline, L-Hydroxyproline, L-Serine, L-Threonine, L-Tryptophan, L-Tyrosine disodium salt dihydrate, and L-Valine. In certain embodiments, the amino acid is L-Isoleucine, L-Phenylalanine, L-Proline, L-Hydroxyproline, L-Valine, and mixtures thereof.

[0058] It is also contemplated that the defined medium can comprise ascorbic acid. Preferably ascorbic acid is present at an initial concentration of approximately 1 mg/L to approximately 1000 mg/L, or from approximately 2 mg/L to approximately 500 mg/L, or from approximately 5

mg/L to approximately 100 mg/L, or from approximately 10 mg/L to approximately 100 mg/L or approximately at 50 mg/L.

[0059] In addition, the compositions and methods may also comprise other components such as serum albumin, transferrin, L-glutamine, lipids, antibiotics, β-Mercaptoethanol, vitamins, minerals, ATP and similar components may be present. Examples of vitamins that may be present include, but are not limited to vitamins A, B_1, B_2, B_3, B_5, B_6, B_7, B_9, B_{12}, C, D_1, D_2, D_3, D_4, D_5, E, tocotrienols, K_1 and K_2. One of skill in the art can determine the optimal concentration of minerals, vitamins, ATP, lipids, essential fatty acids, *etc.,* for use in a given culture. The concentration of supplements may, for example, be from about 0.001 μM to about 1mM or more. Specific examples of concentrations at which the supplements may be provided include, but are not limited to about 0.005 μM, 0.01 μM, 0.05 μM, 0.1 μM, 0.5 μM, 1.0 μM, 2.0μM, 2.5μM, 3.0μM 4.0μM, 5.0μM, 10μM, 20 μM, 100μM, *etc.* In one specific embodiment, the compositions and methods comprise vitamin B_6 and glutamine. In another specific embodiment, the compositions and methods comprise vitamin C and an iron supplement. In another specific embodiment, the compositions and methods comprise vitamin K_1 and vitamin A. In another specific embodiment, the compositions and methods comprise vitamin D_3 and ATP. In another specific embodiment, the compositions and methods comprise vitamin B_{12} and transferrin. In another specific embodiment, the compositions and methods comprise tocotrienols and β-Mercaptoethanol. In another specific embodiment, the compositions and methods comprise glutamine and ATP. In another specific embodiment, the compositions and methods comprise an omega-3 fatty acid and glutamine. In another specific embodiment, the compositions and methods comprise an omega-6 fatty acid and vitamin B_1. In another specific embodiment, the compositions and methods comprise α-linolenic acid and B_2.

[0060] The compositions of the present invention are essentially serum free. As used herein, "essentially serum free" refers to the absence of serum in the solutions of the present invention. Serum is not an essential ingredient to the compositions and methods of the present invention. Thus, the presence of serum in any of the compositions should only be attributable to impurities, *e.g.,* from the starting materials or residual serum from the primary cell culture. For example, essentially serum free medium or environment can contain less than 10, 9, 8, 7, 6, 5, 4, 3, 2, or 1% serum wherein the presently improved bioactive maintenance capacity of the medium or

environment is still observed. In a specific embodiment of the present invention, the essentially serum free composition does not contain serum or serum replacement, or only contains trace amounts of serum or serum replacement from the isolation of components of the serum or serum replacement that are added to the defined media.

[0061] The compositions and methods of the present invention also comprise a means for stimulating ErbB2 tyrosine kinase activity within differentiable cells. In one specific embodiment, the compositions and methods of the present invention comprise the presence of at least one ErbB3 ligand. Typically, an ErbB3 ligand will bind the ErbB3 receptor and dimerize with the ErbB2 receptor. The ErbB2 receptor is, in turn, generally responsible for intracellular tyrosine kinase activity within the differentiable cell.

[0062] As used herein, "ErbB3 ligand" refers to a ligand that binds to ErbB3, which in turn dimerizes to ErbB2, thus activating the tyrosine kinase activity of the ErbB2 portion of the ErbB2/ErbB3 heterodimeric receptor. Non-limiting examples of ErbB3 ligands include Neuregulin-1; splice variants and isoforms of Neuregulin-1, including but not limited to HRG-β, HRG-α, Neu Differentiation Factor (NDF), Acetylcholine Receptor-Inducing Activity (ARIA), Glial Growth Factor 2 (GGF2), and Sensory And Motor Neuron-Derived Factor (SMDF); Neuregulin-2; splice variants and isoforms of Neuregulin-2, including but not limited to NRG2-β; Epiregulin; and Biregulin.

[0063] In one embodiment, the means for stimulating ErbB2-directed tyrosine kinase activity comprise at least one ErbB3 ligand that is selected from the group consisting of Neuregulin-1, Heregulin-β (HRG-β), Heregulin-α (HRG-α), Neu differentiation factor (NDF), acetylcholine receptor-inducing activity (ARIA), glial growth factor 2 (GGF2), motor-neuron derived factor (SMDF), Neuregulin-2, Neuregulin-2β (NRG2-β), Epiregulin, Biregulin and variants and functional fragments thereof. In another specific embodiment, the compositions and methods of the present invention comprise more than one means for stimulating ErbB2-directed tyrosine kinase activity, such as, but not limited to, using more than one ErbB3 ligand.

[0064] In a more specific embodiment of the compositions and methods of the present invention, the ErbB3 ligand is HRG-β or a variant or functional fragment thereof. In one embodiment, the species from which the culture additive protein, polypeptide or variant or functional fragment

thereof derives is the same as the species of cells that are cultured. For example, if mouse ES cells are cultured, an HRG-β with an amino acid sequence that is identical to the *mus musculus* HRG-β sequence can be used as an additive in culture and is considered to be "of the same species." In other embodiments, the species from which the biological additive derives is different from the cells being cultures. For example, if mouse ES cells are cultured, an HRG-β with an amino acid sequence that is identical to the human HRG-β sequence from can be used as an additive in culture and is considered to be "of different species."

[0065] As used herein, a "functional fragment" is a fragment or splice variant of a full length polypeptide that exerts a similar physiological or cellular effect as the full length polypeptide. The biological effect of the functional fragment need not be identical in scope or strength as the full-length polypeptide, so long as a similar physiological or cellular effect is seen. For example, a functional fragment of HRG-β can detectably stimulate ErbB2-directed tyrosine kinase.

[0066] As used herein, the term "variant" includes chimeric or fusion polypeptides, homologs, analogs, orthologs, and paralogs. In addition, a variant of a reference protein or polypeptide is a protein or polypeptide whose amino acid sequence is at least about 80% identical to the reference protein or polypeptide. In specific embodiments, the variant is at least about 85%, 90%, 95%, 95%, 97%, 98%, 99% or even 100% identical to the reference protein or polypeptide. As used herein, the terms "correspond(s) to" and "corresponding to," as they relate to sequence alignment, are intended to mean enumerated positions within the reference protein or polypeptide, *e.g.*, wild-type human or mouse neuregulin-1, and those positions in the modified protein or polypeptide that align with the positions on the reference protein or polypeptide. Thus, when the amino acid sequence of a subject protein or polypeptide is aligned with the amino acid sequence of a reference protein or polypeptide, the sequence that "corresponds to" certain enumerated positions of the reference protein or polypeptide sequence are those that align with these positions of the reference sequence, but are not necessarily in these exact numerical positions of the reference sequence. Methods for aligning sequences for determining corresponding amino acids between sequences are described below.

[0067] A polypeptide having an amino acid sequence at least, for example, about 95% "identical" to a reference an amino acid sequence encoding, for example TGF-β, is understood to

mean that the amino acid sequence of the polypeptide is identical to the reference sequence except that the amino acid sequence may include up to about five modifications per each 100 amino acids of the reference amino acid sequence encoding the reference TGF-β. In other words, to obtain a peptide having an amino acid sequence at least about 95% identical to a reference amino acid sequence, up to about 5% of the amino acid residues of the reference sequence may be deleted or substituted with another amino acid or a number of amino acids up to about 5% of the total amino acids in the reference sequence may be inserted into the reference sequence. These modifications of the reference sequence may occur at the N- terminus or C-terminus positions of the reference amino acid sequence or anywhere between those terminal positions, interspersed either individually among amino acids in the reference sequence or in one or more contiguous groups within the reference sequence.

[0068] As used herein, "identity" is a measure of the identity of nucleotide sequences or amino acid sequences compared to a reference nucleotide or amino acid sequence. In general, the sequences are aligned so that the highest order match is obtained. "Identity" per se has an art-recognized meaning and can be calculated using published techniques. (See, e.g., Computational Molecular Biology, Lesk, A. M., ed., Oxford University Press, New York (1988); Biocomputing: Informatics And Genome Projects, Smith, D. W., ed., Academic Press, New York (1993); Computer Analysis of Sequence Data, Part I, Griffin, A. M., and Griffin, H. G., eds., Humana Press, New Jersey (1994); von Heinje, G., Sequence Analysis In Molecular Biology, Academic Press (1987); and Sequence Analysis Primer, Gribskov, M. and Devereux, J., eds., M Stockton Press, New York (1991)). While there exist several methods to measure identity between two polynucleotide or polypeptide sequences, the term "identity" is well known to skilled artisans (Carillo, H. & Lipton, D., Siam J Applied Math 48:1073 (1988)). Methods commonly employed to determine identity or similarity between two sequences include, but are not limited to, those disclosed in Guide to Huge Computers, Martin J. Bishop, ed., Academic Press, San Diego (1994) and Carillo, H. & Lipton, D., Siam J Applied Math 48:1073 (1988). Computer programs may also contain methods and algorithms that calculate identity and similarity. Examples of computer program methods to determine identity and similarity between two sequences include, but are not limited to, GCG program package (Devereux, J., et al., Nucleic Acids Research 12(i):387 (1984)), BLASTP, ExPASy, BLASTN, FASTA (Atschul, S. F., et al., J Molec Biol

215:403 (1990)) and FASTDB. Examples of methods to determine identity and similarity are discussed in Michaels, G. and Garian, R., Current Protocols in Protein Science, Vol 1, John Wiley & Sons, Inc. (2000), which is incorporated by reference. In one embodiment of the present invention, the algorithm used to determine identity between two or more polypeptides is BLASTP.

[0069] In another embodiment of the present invention, the algorithm used to determine identity between two or more polypeptides is FASTDB, which is based upon the algorithm of Brutlag et al. (Comp. App. Biosci. 6:237-245 (1990), incorporated by reference). In a FASTDB sequence alignment, the query and subject sequences are amino sequences. The result of sequence alignment is in percent identity. Parameters that may be used in a FASTDB alignment of amino acid sequences to calculate percent identity include, but are not limited to: Matrix=PAM, k-tuple=2, Mismatch Penalty=1, Joining Penalty=20, Randomization Group Length=0, Cutoff Score=1, Gap Penalty=5, Gap Size Penalty 0.05, Window Size=500 or the length of the subject amino sequence, whichever is shorter.

[0070] If the subject sequence is shorter or longer than the query sequence because of N-terminus or C-terminus additions or deletions, not because of internal additions or deletions, a manual correction can be made, because the FASTDB program does not account for N-terminus and C-terminus truncations or additions of the subject sequence when calculating percent identity. For subject sequences truncated at the 5' or 3' ends, relative to the query sequence, the percent identity is corrected by calculating the number of bases of the query sequence that are N- and C- terminus to the reference sequence that are not matched/aligned, as a percent of the total bases of the query sequence. The results of the FASTDB sequence alignment determine matching/alignment. The alignment percentage is then subtracted from the percent identity, calculated by the above FASTDB program using the specified parameters, to arrive at a final percent identity score. This corrected score can be used for the purposes of determining how alignments "correspond" to each other, as well as percentage identity. Residues of the query (subject) sequences or the reference sequence that extend past the N- or C-termini of the reference or subject sequence, respectively, may be considered for the purposes of manually adjusting the percent identity score. That is, residues that are not matched/aligned with the N- or

C-termini of the comparison sequence may be counted when manually adjusting the percent identity score or alignment numbering.

[0071] For example, a 90 amino acid residue subject sequence is aligned with a 100 residue reference sequence to determine percent identity. The deletion occurs at the N-terminus of the subject sequence and therefore, the FASTDB alignment does not show a match/alignment of the first 10 residues at the N-terminus. The 10 unpaired residues represent 10% of the sequence (number of residues at the N- and C-termini not matched/total number of residues in the query sequence) so 10% is subtracted from the percent identity score calculated by the FASTDB program. If the remaining 90 residues were perfectly matched the final percent identity would be 90%. In another example, a 90 residue subject sequence is compared with a 100 reference sequence. This time the deletions are internal deletions so there are no residues at the N- or C-termini of the subject sequence which are not matched/aligned with the query. In this case the percent identity calculated by FASTDB is not manually corrected.

[0072] The invention also provides chimeric or fusion polypeptides. As used herein, a "chimeric polypeptide" or "fusion polypeptide" comprises at least a portion of a member of the reference polypeptide operatively linked to a second, different polypeptide. The second polypeptide has an amino acid sequence corresponding to a polypeptide which is not substantially identical to the reference polypeptide, and which is derived from the same or a different organism. With respect to the fusion polypeptide, the term "operatively linked" is intended to indicate that the reference polypeptide and the second polypeptide are fused to each other so that both sequences fulfill the proposed function attributed to the sequence used. The second polypeptide can be fused to the N-terminus or C-terminus of the reference polypeptide. For example, in one embodiment, the fusion polypeptide is a GST-IGF-1 fusion polypeptide in which an IGF-1 sequence is fused to the C-terminus of the GST sequences. Such fusion polypeptides can facilitate the purification of recombinant polypeptides. In another embodiment, the fusion polypeptide can contain a heterologous signal sequence at its N-terminus. In certain host cells (*e.g.*, mammalian host cells), expression and/or secretion of a polypeptide can be increased through use of a heterologous signal sequence.

[0073] In addition to fragments and fusion polypeptides, the present invention includes homologs and analogs of naturally occurring polypeptides. "Homologs" are defined herein as two nucleic acids or polypeptides that have similar, or "identical," nucleotide or amino acid sequences, respectively. Homologs include allelic variants, orthologs, paralogs, agonists, and antagonists as defined hereafter. The term "homolog" further encompasses nucleic acid molecules that differ from a reference nucleotide sequence due to degeneracy of the genetic code and thus encode the same polypeptide as that encoded by the reference nucleotide sequence. As used herein, "naturally occurring" refers to a nucleic or amino acid sequence that occurs in nature.

[0074] An agonist of a polypeptide can retain substantially the same, or a subset, of the biological activities of the polypeptide. An antagonist of a polypeptide can inhibit one or more of the activities of the naturally occurring form of the polypeptide.

[0075] In another more specific embodiment of the compositions and methods of the present invention, the ErbB3 ligand is HRG-β or a variant or a functional fragment thereof. Additional, non-limiting examples of ErbB3 ligands are disclosed in United States Patent No. 6,136,558, 6,387,638, and 7,063,961, which are incorporated by reference.

[0076] Heregulins are generally classified into two major types, alpha and beta, based on two variant EGF-like domains that differ in their C-terminal portions. These EGF-like domains, however, are identical in the spacing of six cysteine residues contained therein. Based on an amino acid sequence comparison, Holmes et al. found that between the first and sixth cysteines in the EGF-like domain, HRGs were 45% similar to heparin-binding EGF-like growth factor (HB-EGF), 35% identical to amphiregulin (AR), 32% identical to TGF-α, and 27% identical to EGF.

[0077] The 44 kDa neu differentiation factor (NDF) is the rat equivalent of human HRG. Like the HRG polypeptides, NDF has an immunoglobulin (Ig) homology domain followed by an EGF-like domain and lacks a N-terminal signal peptide. Presently, there are at least six distinct fibroblastic pro-NDFs, classified as either alpha or beta polypeptides, based on the sequences of the EGF-like domains. Isoforms 1 to 4 are characterized on the basis of a variable stretch between the EGF-like domain and transmembrane domain. Thus it appears that different NDF

isoforms are generated by alternative splicing and may perform distinct tissue-specific functions. See EP 505 148; WO 93/22424; and WO 94/28133, which are incorporated by reference.

[0078] In one embodiment of the present invention, the compositions and methods are free of exogenous insulin and insulin substitutes. The phrase "exogenous insulin or insulin substitutes" is used herein to indicate insulin or insulin substitutes that is/are not intentionally added to the compositions or methods of the present invention. Thus, in certain embodiments of the present invention, the methods and compositions are free of insulin or insulin substitutes that are intentionally supplied. The compositions or methods may, however, not necessarily be free of endogenous insulin. As used herein, "endogenous insulin" indicates that the cultured cells may be producing insulin of their own accord when cultured according to the methods of the present invention. Endogenous insulin also may be used to indicate residual impurities from the primary cell culture or impurities from the starting materials. In specific examples, the compositions and methods of the present contain less than 50, 45, 40, 35, 30, 25, 20, 15, 10, 9, 8, 7, 6, 5, 4, 3, 2, or 1 μg/ml of insulin.

[0079] As used herein, the term "insulin" refers to the protein, or variant or fragment thereof that binds to the insulin receptor in normal physiological concentrations and can induce signaling through the insulin receptor. The term "insulin" encompasses a protein having the polypeptide sequence of native human insulin, or of other mammalian insulin, or of any homologs or variants to these sequences. Additionally, the term insulin encompasses polypeptide fragments that are capable of binding to the insulin receptor to induce signaling through the insulin receptor. The term "insulin substitute" refers to any zinc containing compound that may be used in place of insulin to give substantially similar results as insulin. Examples of insulin substitutes include, but are not limited to zinc chloride, zinc nitrate, zinc bromide, and zinc sulfate.

[0080] To be clear, insulin-like growth factors are not insulin substitutes or homologs of insulin, as contemplated in the present invention. Accordingly, in another specific embodiment, the compositions and methods of the present invention comprise the use of at least one insulin-like growth factor (IGF) or a variant or a functional fragment thereof. In another embodiment, the compositions and methods of the present invention are free of any exogenous insulin-like growth

factors (IGFs). In specific embodiments, the compositions and methods of the present invention contain less than 200, 150, 100, 75, 50, 25, 20, 15, 10, 9, 8, 7, 6, 5, 4, 3, 2, or 1 ng/ml of IGF-1.

[0081] As used herein, the term "activator of IGF-1R" refers to mitogens that play a pivotal role in regulating cell proliferation, differentiation, and apoptosis. The effects of an activator of IGF-1R are typically mediated through IGF-1R, although they can be mediated through other receptors. The IGF-1R is also involved in cell transformation induced by tumor virus proteins and oncogene products, and the interaction is regulated by a group of specific binding proteins (IGFBPs). In addition, a large group of IGFBP proteases hydrolyze IGFBPs, resulting in the release of bound IGFs that then resume their ability to interact with IGF-IR. For the purpose of this invention, the ligands, the receptors, the binding proteins, and the proteases are all considered to be activators of IGF-1R. In one embodiment, the activator of IGF-1R is IGF-1, or IGF-2. In a further embodiment, the activators of IGF-1R is an IGF-1 analog. Non-limiting examples of IGF-1 analogs include LongR3-IGF1, Des(1-3)IGF-1, [Arg^3]IGF-1, [Ala^{31}]IFG-1, Des(2,3)[Ala^{31}]IGF-1, [Leu^{24}]IGF1, Des(2,3)[Leu^{24}]IGF-1, [Leu^{60}]IGF-1, [Ala^{31}][Leu^{60}]IGF-1, [Leu^{24}][Ala^{31}]IGF-1, and combinations thereof. In a further embodiment, the IFG-1 analog is LongR3-IGF1, which is a recombinant analog of human insulin growth factor-1. It is contemplated that LongR3-IGF1 is initially present at a concentration of approximately 1 ng/ml to approximately 1000 ng/ml, more preferably approximately 5 ng/ml to approximately 500 ng/ml, more preferably approximately 50 ng/ml to approximately 500 ng/ml, more preferably approximately 100 ng/ml to approximately 300 ng/ml, or at a concentration of approximately 100 ng/ml.

[0082] In certain embodiments, the compositions and methods of the present invention comprise transforming growth factor beta (TGF-β) or a TGF-β family member or variants or functional fragments thereof. As used herein, the term "member of the TGF-β family" or the like refers to growth factors that are generally characterized by one of skill in the art as belonging to the TGF-β family, either due to homology with known members of the TGF-β family, or due to similarity in function with known members of the TGF-β family. In particular embodiments of the invention, if the member of the TGF-β family is present, the TGF-β family member of variant or functional fragment thereof activates SMAD 2 or 3. In certain embodiments, the member of the TGF-β family is selected from the group consisting of Nodal, Activin A, Activin B, TGF-β, bone

morphogenic protein-2 (BMP2) and bone morphogenic protein-4 (BMP4). In one embodiment, the member of the TGF-β family is Activin A.

[0083] It is contemplated that if Nodal is present, it is initially present at a concentration of approximately 0.1 ng/ml to approximately 2000 ng/ml, more preferably approximately 1 ng/ml to approximately 1000 ng/ml, more preferably approximately 10 ng/ml to approximately 750 ng/ml, or more preferably approximately 25 ng/ml to approximately 500 ng/ml. It is contemplated that if used, Activin A is initially present at a concentration of approximately 0.01 ng/ml to approximately 1000 ng/ml, more preferably approximately 0.1 ng/ml to approximately 100 ng/ml, more preferably approximately 0.1 ng/ml to approximately 25 ng/ml, or most preferably at a concentration of approximately 10 ng/ml. It is contemplated that if present, TGF-β is initially present at a concentration of approximately 0.01 ng/ml to approximately 100 ng/ml, more preferably approximately 0.1 ng/ml to approximately 50 ng/ml, or more preferably approximately 0.1 ng/ml to approximately 20 ng/ml.

[0084] In additional embodiments of the present invention, the compositions and methods of the present invention are free of activators of FGF receptors. There are currently at least 22 known members of the family of fibroblast growth factors, with these factors binding to one of at least one of four FGF receptors. As used herein, the term "activator of an FGF receptor" refers to growth factors that are generally characterized by one of skill in the art as belonging to the FGF family, either due to homology with known members of the FGF family, or due to similarity in function with known members of the FGF family. In certain embodiments, the activator of an FGF receptor is an FGF, such as, but not limited to α-FGF and FGF2. In particular embodiments, the compositions and methods are free of exogenous FGF2. The phrase "exogenous FGF2" is used herein to indicate fibroblast growth factor 2, *i.e.,* basic FGF, that is not intentionally added to the compositions or methods of the present invention. Thus, in certain embodiments of the present invention, the methods and compositions are free of intentionally supplied FGF2. The compositions or methods may, however, not necessarily be free of endogenous FGF2. As used herein, "endogenous FGF2" indicates that the cultured cells may be producing FGF2 of their own accord when cultured according to the methods of the present invention. "Endogenous FGF2" also may be used to indicate residual impurities from the primary cell culture or impurities from the starting materials. In specific examples, the

compositions and methods of the present contain less than 10, 9, 8, 7, 6, 5, 4, 3, 2, or 1 ng/ml of FGF2.

[0085] It is contemplated, however, that the compositions and methods of the invention can include at least one activator of an FGF receptor, including any of the FGF polypeptides, functional fragments thereof or variants thereof. It is contemplated that if FGF2 is present, it is initially present at a concentration of approximately 0.1 ng/ml to approximately 100 ng/ml, more preferably approximately 0.5 ng/ml to approximately 50 ng/ml, more preferably approximately 1 ng/ml to approximately 25 ng/ml, more preferably approximately 1 ng/ml to approximately 12 ng/ml, or most preferably at a concentration of approximately 8 ng/ml. In another specific embodiment, the compositions and methods of the invention can include at least one activator of an FGF receptor, other than FGF2. For example, the compositions and methods of the present invention may comprise at least one of FGF-7, FGF-10 or FGF-22 or variants or functional fragments thereof. In specific embodiments, a combination of at least two of FGF-7, FGF-10 and FGF-22, or variants or functional fragments thereof, are present. In another embodiment, all three of FGF-7, FGF-10 and FGF-22, or variants or functional fragments thereof, are present. It is contemplated that if any of FGF-7, FGF-10 or FGF-22 or variants or functional fragments are present, each is initially present at a concentration of approximately 0.1 ng/ml to approximately 100 ng/ml, more specifically from approximately 0.5 ng/ml to approximately 50 ng/ml, more specifically from approximately 1 ng/ml to approximately 25 ng/ml, more specifically from approximately 1 ng/ml to approximately 12 ng/ml, or most specifically at a concentration of approximately 8 ng/ml.

[0086] In additional certain embodiments, the compositions and methods of the present invention comprise serum albumin (SA). In specific embodiments, the SA is either bovine SA (BSA) or human SA (HAS). In still more specific embodiments, the concentration of the SA is more than about 0.2%, volume to volume (v/v), but less than about 10% v/v. In even more specific embodiments, the concentration of SA is more than about 0.3%, 0.4%, 0.5%, 0.6%, 0.7%, 0.8%, 0.9%, 1.0%, 1.2%, 1.4%, 1.6%, 1.8%, 2.0%, 2.2%, 2.4%, 2.6%, 2.8%, 3.0%, 3.2%, 3.4%, 3.6%, 3.8%, 4.0%, 4.2%, 4.4%, 4.6%, 4.8%, 5.0%, 5.2%, 5.4%, 5.6%, 5.8%, 6.0%, 6.2%, 6.4%, 6.6%, 6.8%, 7.0%, 7.2%, 7.4%, 7.6%, 7.8%, 8.0%, 8.2%, 8.4%, 8.6%, 8.8%, 9.0%, 9.2%, 9.4%, 9.6% and 9.8% (v/v).

[0087] In additional embodiments, the compositions and methods comprise at least one insoluble substrate. For example, the differentiable cells may be placed on a cell culture surface that comprises such compounds as, but is not limited to, polystyrene, polypropylene. The surface may, in turn, be coated with an insoluble substrate. In specific embodiments, the insoluble substrate is selected from the group consisting of a collagen, a fibronectin and fragments or variants thereof. Other examples of insoluble substrates include, but are not limited to, fibrin, elastin, fibronectins, laminins and nidogens.

[0088] Accordingly, the cell culture environments and methods of the present invention comprise plating the cells in an adherent culture. As used herein, the terms "plated" and "plating" refer to any process that allows a cell to be grown in adherent culture. As used herein, the term "adherent culture " refers to a cell culture system whereby cells are cultured on a solid surface, which may in turn be coated with an insoluble substrate that may in turn be coated with another surface coat of a substrate, such as those listed below, or any other chemical or biological material that allows the cells to proliferate or be stabilized in culture. The cells may or may not tightly adhere to the solid surface or to the substrate. The substrate for the adherent culture may comprise any one or combination of polyornithine, laminin, poly-lysine, purified collagen, gelatin, fibronectin, tenascin, vitronectin, entactin, heparin sulfate proteoglycans, poly glycolytic acid (PGA), poly lactic acid (PLA), and poly lactic-glycolic acid (PLGA). Furthermore, the substrate for the adherent culture may comprise the matrix laid down by a feeder layer, or laid down by the pluripotent human cell or cell culture. As used herein, the term "extracellular matrix" encompasses solid substrates such as but not limited to those described above, as well as the matrix laid down by a feeder cell layer or by the pluripotent human cell or cell culture. In one embodiment, the cells are plated on MATRIGEL™-coated plates. In another embodiment, the cells are plated on fibronectin-coated plates. In certain embodiments, if the cells are plated on fibronectin, the plates are prepared by coating with 10 μg/ml human plasma fibronectin (Invitrogen, #33016-015), diluted in tissue grade water, for 2-3 hours at room temperature. In another embodiment, serum can be placed in the medium for up to 24 hours to allow cells to plate to the plastic. If using serum to promote the attachment of the cells, the media is then removed and the compositions, which are essentially serum-free, are added to the plated cells.

[0089] The compositions and methods of the present invention contemplate that the differentiable cells are cultured in conditions that are essentially free of a feeder cell or feeder layer. As used herein, a "feeder cell" is a cell that grows *in vitro*, that is co-cultured with a target cell and stabilizes the target cell in its current state of differentiation. As used herein, a "feeder cell layer" can be used interchangeably with the term "feeder cell." As used herein, the term "essentially free of a feeder cell" refers to tissue culture conditions that do not contain feeder cells, or that contain a *de minimus* number of feeder cells. By "*de minimus*", it is meant that number of feeder cells that are carried over to the instant culture conditions from previous culture conditions where the differentiable cells may have been cultured on feeder cells. In one embodiment of the above method, conditioned medium is obtained from a feeder cell that stabilizes the target cell in its current state of differentiation. In another embodiment, the defined medium is a non-conditioned medium, which is a medium that is not obtained from a feeder cell.

[0090] As used herein, the term "stabilize," when used in reference to the differentiation state of a cell or culture of cells, indicates that the cells will continue to proliferate over multiple passages in culture, and preferably indefinitely in culture, where most, if not all, of the cells in the culture are of the same differentiation state. In addition, when the stabilized cells divide, the division typically yield cells of the same cell type or yield cells of the same differentiation state. A stabilized cell or cell population in general, does not further differentiate or de-differentiate if the cell culture conditions are not altered, and the cells continue to be passaged and are not overgrown. In one embodiment, the cell that is stabilized is capable of proliferation in the stable state indefinitely, or for at least more than 2 passages. In a more specific embodiment, the cells are stable for more than 3 passages, 4 passages, 5 passages, 6 passages, 7 passages, 8 passages, 9 passages, more than 10 passages, more than 15 passages, more than 20 passages, more than 25 passages, or more than 30 passages. In one embodiment, the cell is stable for greater than approximately 1 month, 2 months, 3 months, 4 months, 5 months, 6 months, 7 months, 8 months, 9 months, 10 months, or 11 months of continuous passaging. In another embodiment, the cell is stable for greater than approximately 1 year of continuous passaging. In one embodiment, stem cells are maintained in culture in a pluripotent state by routine passage in the defined medium until it is desired that they be differentiated. As used herein, the term "proliferate" refers to an increase in the number cells in a cell culture.

[0091] In certain embodiments, the compositions and methods comprise an inactivator of BMP signaling. As used herein, an "inactivator of BMP signaling" refers to an agent that antagonizes the activity of one or more BMP proteins or any of their upstream or downstream signaling components through any of its possible signaling pathways. The compound(s) used to inactivate BMP signaling can be any compound known in the art, or later discovered. Non-limiting examples of inactivators of BMP signaling include dominant-negative, truncated BMP receptor, soluble BMP receptors, BMP receptor-Fc chimeras, noggin, follistatin, chordin, gremlin, cerberus/DAN family proteins, ventropin, high dose activin, and amnionless.

[0092] In certain embodiments, the compositions and methods can comprise at least one hormone, cytokine, adipokine, growth hormone or variant or functional fragment thereof. It is currently contemplated that in certain embodiments, the growth hormone present in the defined medium will be of the same species as the differentiable cells that are cultured with the defined media. Thus, for example, if a human cell is cultured, the growth hormone is human growth hormone. The use of growth hormone that is from a species different than the cultured cells is also contemplated. Preferably the hormone, cytokine, adipokine and/or growth hormone is present at an initial concentration of approximately 0.001 ng/ml to approximately 1000 ng/ml, more preferably approximately 0.001 ng/ml to approximately 250 ng/ml, or more preferably approximately 0.01 ng/ml to approximately 150 ng/ml.

[0093] Examples of cytokines and adipokines that may be included in the compositions and methods of the present invention include, but are not limited to, the four α-helix bundle family of cytokines, the interleukin -1 (IL-1) family of cytokines, the IL-17 family of cytokines and the chemokine family of cytokines. Of course, the invention contemplates members and subclasses of each of these families of cytokines, such as, but not limited to, the CC chemokines, the CXC chemokines, the C chemokines and the CX_3C chemokines, interferons, interleukins, lymphotoxins, c-kit ligand, granulocyte-macrophage colony-stimulating factor (GM-CSF), monocyte-macrophage colony-stimulating factor (M-CSF), granulocyte colony-stimulating factor (G-CSF), leptin, adiponectin, resistin, plasminogen activator inhibitor-1 (PAI-1), tumor necrosis factor-alpha (TNFα), tumor necrosis factor-beta (TNFβ), leukemia inhibitory factor, visfatin, retinol binding protein 4 (RBP4), erythropoietin (EPO), thrombopoietin (THPO). Of

course, one of skill in the art will understand that the invention contemplates variants or functional fragments of the above-listed factors.

[0094] The present invention relates to methods of culturing differentiable cells, with the methods comprising plating differentiable cells on a cell culture surface, providing a basal salt nutrient solution to the cells and providing a means for stimulating ErbB2-directed tyrosine kinase activity in the cells.

[0095] In one embodiment, differentiable cells are contacted with the at least one of the compositions of the invention in the absence of serum or serum replacement, and in the absence of a feeder cell layer, such that the cells are maintained in an undifferentiated state for at least one month. Pluripotency can be determined through characterization of the cells with respect to surface markers, transcriptional markers, karyotype, and ability to differentiate to cells of the three germ layers. These characteristics are well known to those of ordinary skill in the art.

[0096] It is contemplated that the differentiable cells can be passaged using enzymatic, non-enzymatic, or manual dissociation methods prior to and/or after contact with the defined medium of the invention. Non-limiting examples of enzymatic dissociation methods include the use of proteases such as trypsin, collagenase, dispase, and ACCUTASE™. In one embodiment, ACCUTASE™ is used to passage the contacted cells. When enzymatic passaging methods are used, the resultant culture can comprise a mixture of singlets, doublets, triplets, and clumps of cells that vary in size depending on the enzyme used. A non-limiting example of a non-enzymatic dissociation method is a cell dispersal buffer. Manual passaging techniques have been well described in the art, such as in Schulz *et al.*, 2004 Stem Cells, 22(7):1218-38. The choice of passaging method is influenced by the choice of extracellular matrix, and is easily determined by one of ordinary skill in the art.

[0097] In one specific embodiment, methods of culturing differentiable cells comprise providing a dissociation solution to a layer of stem cells that are contained in a culture chamber prior to dissociation, where the dissociation breaks apart the layer of cells into single cells. After dissociation, the single cells are placed into a new tissue culture chamber with a stem cell culture solution, wherein the stem cell culture solution comprises a basal salt nutrient solution and an

ErbB3 ligand. Once cultured, the single stem cells are placed in conditions that permit growth and division of the single cells.

[0098] The disaggregation solution used in the methods of the present invention can be any disaggregation solution capable of breaking apart or disaggregating the cells into single cells, without causing extensive toxicity to the cells. Examples of disaggregation solutions include, but are not limited to, trypsin, ACCUTASE™, 0.25% Trypsin/EDTA, TrypLE, or VERSENE™ (EDTA) and trypsin. The methods of the present invention need not result in every cell of the confluent layer being disaggregated into single cells, provided that at least a few single cells are disaggregated and capable of being re-cultured.

[0099] Differentiable cells may also be utilized to screen for molecules or factors that influence their plasticity or other characterisitics. For example, differentiable cells could be used to identify agents that induce apoptosis, differentiation or proliferation, as well as similar effects in differentiated lineages that have been generated from the differentiable cells.

[00100] Because the compositions and methods of the present invention allow for single cell passaging, differentiable cells have been successfully cultured in high-throughput settings, such as, but not limited to, 96-well plates and 384-well plates. Figure 16 shows the morphology and alkaline phosphatase staining of BG02 cells that were cultured in DC-HAIF in both a 96-well and 384-well plate, using the methods described herein. Briefly, hESCs cells that were split, using ACCUTASE™, and plated in 96-well and 384-well plates and cultured showed a similar plating efficiency as what is observed using other culture dishes. In addition, the cells formed colonies, and were expanded successfully over 5 days in the smaller environments. These smaller cultures remained morphologically undifferentiated, and stained uniformly positive for alkaline phosphatase, a marker of undifferentiated cells. Furthermore, hESCs could also be grown in 96-well culture devices (not shown) that provide real-time measurements of impedance, which can be used to measure cell proliferation and viability using the RT-CES™ methods from ACEA Biosciences, Inc. (www.aceabio.com). Such an approach would enable a label-free identification and quantitation of subtle or immediate effects on differentiable cells, as well as measurements of proliferation, apoptosis and changes to morphology, in real time.

[00101] The compositions and methods of the invention may contain virtually any combination of the components set out above or described elsewhere herein, provided the compositions and methods comprise a basal salt nutrient solution and a means for stimulating ErbB2 directed tyrosine kinase activity. As one skilled in the art would recognize, the components of the compositions and methods of the invention will vary according to the protocol design. Accordingly, one embodiment of the present invention relates to culturing differentiable cells in 96-well plates and/or 384-well plates. Indeed, using the methods and compositions of the present invention, the cell culture chamber, *i.e.*, the culture dish, is no longer limited to specific dimensions. Thus, the methods of the present invention is not limited to specific culture chamber dimensions.

[00102] The compositions and methods described herein have several useful features. For example, the compositions and methods described herein are useful for modeling the early stages of human development. Furthermore, the compositions and methods described herein can also serve for therapeutic intervention in disease states, such as neurodegenerative disorders, diabetes mellitus or renal failure, such as by the development of pure tissue or cell type.

[00103] The cell types that differentiate from differentiable cells have several uses in various fields of research and development including but not limited to drug discovery, drug development and testing, toxicology, production of cells for therapeutic purposes as well as basic science research. These cell types express molecules that are of interest in a wide range of research fields. These include the molecules known to be required for the functioning of the various cell types as described in standard reference texts. These molecules include, but are not limited to, cytokines, growth factors, cytokine receptors, extracellular matrix, transcription factors, secreted polypeptides and other molecules, and growth factor receptors.

[00104] It is contemplated that the differentiable cells of the invention can be differentiated through contact with a cell differentiation environment. As used herein, the term "cell differentiation environment" refers to a cell culture condition wherein the differentiable cells are induced to differentiate, or are induced to become a human cell culture enriched in differentiated cells. Preferably, the differentiated cell lineage induced by the growth factor will be homogeneous in nature. The term "homogeneous," refers to a population that contains more

than approximately 50%, 60%, 70%, 80%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, or 99% of the desired cell lineage.

[00105] A cell differentiating medium or environment may be utilized to partially, terminally, or reversibly differentiate the differentiable cells of the present invention. In accordance with the invention the medium of the cell differentiation environment may contain a variety of components including, for example, KODMEM medium (Knockout Dulbecco's Modified Eagle's Medium), DMEM, Ham's F12 medium, FBS (fetal bovine serum), FGF2 (fibroblast growth factor 2), KSR or hLIF (human leukemia inhibitory factor). The cell differentiation environment can also contain supplements such as L-Glutamine, NEAA (non-essential amino acids), P/S (penicillin/streptomycin), N2, B27 and β-mercaptoethanol (β-ME). It is contemplated that additional factors may be added to the cell differentiation environment, including, but not limited to, fibronectin, laminin, heparin, heparin sulfate, retinoic acid, members of the epidermal growth factor family (EGFs), members of the fibroblast growth factor family (FGFs) including FGF2 and/or FGF8, members of the platelet derived growth factor family (PDGFs), transforming growth factor (TGF)/ bone morphogenetic protein (BMP)/ growth and differentiation factor (GDF) factor family antagonists including but not limited to noggin, follistatin, chordin, gremlin, cerberus/DAN family proteins, ventropin, high dose activin, and amnionless or variants or functional fragments thereof. TGF/BMP/GDF antagonists could also be added in the form of TGF/BMP/GDF receptor-Fc chimeras. Other factors that may be added include molecules that can activate or inactivate signaling through Notch receptor family, including but not limited to proteins of the Delta-like and Jagged families as well as inhibitors of Notch processing or cleavage, or variants or functional fragments thereof. Other growth factors may include members of the insulin like growth factor family (IGF), insulin, the wingless related (WNT) factor family, and the hedgehog factor family or variants or functional fragments thereof. Additional factors may be added to promote mesendoderm stem/progenitor, endoderm stem/progenitor, mesoderm stem/progenitor, or definitive endoderm stem/progenitor proliferation and survival as well as survival and differentiation of derivatives of these progenitors.

[00106] The compositions described herein are useful for the screening of test compounds to determine whether a test compound modulates pluripotency, proliferation, and/or

differentiation of differentiable cells. Pluripotency, proliferation and/or differentiation of differentiable cells can be readily ascertained by one of ordinary skill in the art. Non-limiting methods include examining cell morphology, the expression of various markers, teratoma formation, cell counts and measurements of impedance.

[00107] The progression of the differentiable cells to the desired cell lineage, or its maintenance in an undifferentiated state can be monitored by quantitating expression of marker genes characteristic of the desired cell lineage as well as the lack of expression of marker genes characteristic of differentiable cell types. One method of quantitating gene expression of such marker genes is through the use of quantitative PCR (Q-PCR). Methods of performing Q-PCR are well known in the art. Other methods that are known in the art can also be used to quantitate marker gene expression. Marker gene expression can be detected by using antibodies specific for the marker gene of interest.

[00108] In certain embodiments, the screening method encompasses methods of identifying a compound capable of modulating pluripotency, proliferation and/or differentiation of a differentiable cell, comprising (a) providing a differentiable cell; (b) culturing the cell in a composition comprising a basal salt nutrient solution and an ErbB3 ligand, wherein the composition is essentially serum free; (c) contacting the cell with a test compound; and determining whether an increase or decrease in pluripotency, proliferation and/or differentiation occurs in the cell contacted with the compound, said increase being an indication that the compound modulates pluripotency, proliferation and/or differentiation. In certain embodiments, the ErbB3 ligand is HRG-β. In other embodiments, the ErbB3 ligand can be substituted with a test compound, to determine the effects of the test compound. For example, the effects on pluripotency, proliferation and/or differentiation that occurs with the test compound can be compared to the effects on pluripotency, proliferation and/or differentiation that occurs with the ErbB3 ligand to determine the effects of the test compound on the differentiable cells. It is contemplated that any of the compositions described herein can be used in the screening methods of the present invention.

[00109] In yet another embodiment, the cells can be cultured in the absence of an ErbB3 ligand (ErbB2-directed tyrosine kinase activity) to determine the effects of the absence of an ErbB3 ligand (ErbB2-directed tyrosine kinase activity) on the cells.

[00110] Using the methods described herein, compositions comprising the desired cell lineage that are substantially free of other cell types can be produced. Alternatively, compositions comprising mixtures of the differentiable cells and the desired cell lineage can also be produced.

[00111] In some embodiments of the present invention, cells of the desired cell lineage can be isolated by using an affinity tag that is specific for such cells. One example of an affinity tag specific for a target cell is an antibody that is specific to a marker polypeptide that is present on the cell surface of the target cell but which is not substantially present on other cell types that would be found in a cell culture produced by the methods described herein.

[00112] The present invention also relates to kits, wherein the kit comprises a basal salt nutrient solution and at least one compound capable of stimulating ErbB2-directed tyrosine kinase activity. In one embodiment, the kits comprise at least one ErbB3 ligand, as described herein. In another embodiment, the kits comprise more than one ErbB3 ligand. In another embodiment, the kits comprise at least one of TGF-β or a TGF-β family member or a variant or functional fragment thereof as described herein. In yet another embodiment, the kits comprise more than one of TGF-β or a TGF-β family member or a variant or functional fragment thereof. In still another embodiment, the kits comprise at least one fibroblast growth factor or variant or functional fragment thereof. In another embodiment, the kits comprise more than one fibroblast growth factor or variant or functional fragment thereof. In a specific embodiment, the kits comprise at least one of FGF-7, FGF-10, FGF-22 or variants or functional fragments thereof. In another embodiment, the kits comprise serum albumin. In still another embodiment, the kits comprise serum and/or at least one insoluble substrate as described herein and/or at least one disaggregation solution.

[00113] The kits of the invention may contain virtually any combination of the components set out above or described elsewhere herein. As one skilled in the art would recognize, the components supplied with kits of the invention will vary with the intended use for

the kits. Thus, kits may be designed to perform various functions set out in this application and the components of such kits will vary accordingly.

[00114] Throughout this application, various publications are referenced. The disclosures of all of these publications and those references cited within those publications in their entireties are hereby incorporated by reference into this application in their entirety in order to more fully describe the state of the art to which this invention pertains.

Examples

[00115] The human embryonic stem cell line BG01v (BresaGen, Inc., Athens, GA) was used in some of the experiments described herein. The BG01v hESC line is a karyotypically variant cell line, which exhibits stable karyotype containing specific trisomies (karyotype: 49, XXY,+12,+17). Parent cultures were maintained as described previously (Schulz *et al.*, 2003, BMC Neurosci., 4:27; Schulz *et al.*, 2004, Stem Cells, 22(7):1218-38; Rosler *et al.*, 2004, Dev. Dynamics, 229:259-274; Brimble *et al.*, 2004 Stem Cells Dev., 13:585-596). Briefly, the cells were grown in dishes coated with MATRIGEL™ or fibronectin, in conditioned media from mouse embryonic fibroblasts (MEFs) (MEF-CM) comprising DMEM:F12 with 20% KSR, 8 ng/ml FGF2, 2 mM L-Glutamine, 1x non-essential amino acids, 0.5 U/ml penicillin, 0.5 U/ml streptomycin, 0.1 mM β-mercaptoethanol (Sigma, St. Louis, Missouri, USA), with collagenase passaging.

[00116] The defined culture (DC) media tested herein comprised DMEM/F12, 2 mM Glutamax, 1x non-essential amino acids, 0.5 U/ml penicillin, 0.5 U/ml streptomycin, 10 μg/ml transferrin (all from Invitrogen, Carlsbad, California, USA) 0.1 mM β-mercaptoethanol (Sigma), 0.2% fatty acid-free Cohn's fraction V BSA (Serologicals), 1x Trace Element mixes A, B and C (Cellgro) and 50 μg/ml Ascorbic Acid (Sigma). Variable levels of recombinant growth factors were used, including FGF2 (Sigma), LongR3-IGF1 (JRH Biosciences), Heregulin-β EGF domain (HRGβ, Peprotech), TGFβ (R&D systems), nodal (R&D systems), LIF (R&D systems), EGF (R&D systems), TGFα (R&D systems), HRGα (R&D systems), BMP4 (R&D systems), and Activin A (R&D Systems). LongR3-IGF1 is a modified version of IGF1 that has reduced affinity for IGF1 binding proteins, some of which are expressed in hESCs. DC-HAIF is the defined culture media as above, containing 10 ng/ml HRG-β, 10 ng/ml Activin A, 200 ng/ml LR-

IGF1 and 8 ng/ml FGF2. DC-HAI is defined culture media as above containing 10 ng/ml HRG-β, 10 ng/ml Activin A, and 200 ng/ml LR-IGF1. In both DC-HAIF and DC-HAI, the LR-IGF1 component can, of course be replaced with IFG1.

[00117] MATRIGEL™ coated dishes were prepared by diluting Growth Factor Reduced BD MATRIGEL™ matrix (BD Biosciences, Franklin Lakes, New Jersey, USA) to a final concentration range of about 1:30 to about 1:1000 in cold DMEM/F-12. In one embodiment, the concentration of MATRIGEL™ is about 1:200. 1 ml/35 mm dish was used to coat dishes for 1-2 hours at room temperature or at least overnight at 4°C. Plates were stored up to one week at 4°C. MATRIGEL™ solution was removed immediately before use.

[00118] For the tested conditions, parent cultures were plated into 6-well dishes for comparison of multiple conditions. Cultures were typically plated directly into the test conditions. The cultures were assessed every day and graded based on morphological criteria 4 to 5 days after plating. The grading scale of 1 to 5 involved examining the whole culture and assessing overall proportion of undifferentiated colonies, their relative size, and proportion of colonies or parts of colonies exhibiting obvious differentiation. Grade 5 indicates "ideal" cultures, with large undifferentiated colonies and negligible differentiation. Grade 4 indicates a very good culture, but with some obvious differentiation. Grade 3 indicates an acceptable culture, but with around half the colonies exhibiting obvious differentiation. Grade 2 cultures are predominantly differentiated, with occasional putative undifferentiated cells. Grade 1 cultures contain differentiated colonies or the cultures did not adhere or did not survive. Cultures that exhibited good expansion of undifferentiated cells were passaged to assess longer-term culture in these conditions.

[00119] *Example 1 - Expression of ErbB1-3, Nrg1 and ADAM19 in BG01v cells*

[00120] Real time RT-PCR was used to demonstrate expression of ErbB1-3, Neuregulin and ADAM-19 in BG01v cells (Figure 1). BG01v cells cultured in DC media as described above, containing 100 ng/ml LongR3-IGF1 (LR-IGF1), 8 ng/ml FGF2 and 1 ng/ml Activin A were harvested and RNA was prepared using the RNeasy mini kit (Qiagen) according to the manufacturer's instructions. First strand cDNA was prepared using the iScript kit (Biorad) and real time PCR was carried out using a MJ Research Opticon thermal cycler.

[00121] TaqMan assays on demand (Applied Biosystems) for ADAM19 (Hs00224960_m1), EGFR (Hs00193306_m1), ErbB2 (Hs00170433_m1), ErbB3 (Hs00176538_m1), NRG1 (Hs00247620_m1), OCT4 (Hs00742896_s1) and control GAPDH were used with TaqMan universal PCR (Applied Biosystems). The real time amplification plots are shown in Figure 1, demonstrating expression of these transcripts in undifferentiated BG01v cells.

[00122] *Example 2 - Inhibition of ErbB2 Slows Proliferation of BG01v Cells*

[00123] The EGF domain family of ligands bind to the ErbB family of receptor tyrosine kinases. To examine the effect of known inhibitors of ErbB tyrosine kinases in hESCs, BG01v cells were plated in 6 well trays on MATRIGEL™ diluted at 1:1000, in defined culture medium (DC) containing 100 ng/ml LongR3-IGF1, 8 ng/ml FGF2 and 1 ng/ml Activin A. On the next day, DMSO (carrier control), 50 nM-20 μM AG1478 (an ErbB1 inhibitor), or 100 nM-20 μM AG879 (an ErbB2 inhibitor) was added with fresh medium. The cells were cultured for an additional 5 days, with daily media changes. The cultures were then fixed and stained for alkaline phosphatase activity.

[00124] Subconfluent colonies of AP+ BG01v cells observed (Figures 2A, and B) in control and AG1478 cultured cells, indicating that neither DMSO nor AG1478 (50 nM-20 μM) had an apparent affect on cell proliferation. AG879, however, substantially inhibited cell growth at 5 μM (Figure 2C) and caused cell death at 20 μM (not shown). The cultures grown in AG879 did not appear to differentiate and appeared to maintain a pluripotent morphology and alkaline phosphatase activity, indicating that AG879 appeared to inhibit proliferation without inducing differentiation, suggesting that BG01v cells are reliant on ErbB2 signaling for cell survival. Conversely, BG01v cells grown in similar conditions as above do not appear to be reliant on ErbB1 signal for proliferation.

[00125] *Example 3 - BG01v cells are Maintained in Defined Media Containing Heregulin*

[00126] Expression of ErbB2 and ErbB3 and the inhibition of proliferation with AG879 suggested that BG01v cells have active endogenous ErbB signaling and that they may also respond to exogenous HRG-β. BG01v cells were grown in DC medium containing 10 ng/ml

HRG-β, 200 ng/ml LongR3-IGF1, 8 ng/ml FGF2 and 10 ng/ml Activin A, on MATRIGEL™ diluted 1:1000 (Figures 3A and B). These cells were grown for 4 passages, or >20 days, exhibited undifferentiated morphology and did not show elevated spontaneous differentiation.

[00127] Furthermore, BG01v cells were also maintained for 2 passages, or >13 days, in DC medium comprising 10 ng/ml HRGβ, 200 ng/ml LongR3-IGF1, and 10 ng/ml Activin A. These cultures proliferated normally and exhibited very low spontaneous differentiation, demonstrating that BG01v cells could be maintained in defined conditions with HRGβ in the absence of FGF2.

[00128] *Example 4 –The Role of ErbB2-Directed Tyrosine Kinase in ES Cells*

[00129] RT-PCR demonstrated that mESCs express ADAM19, Neuregulin1 (Nrg1), and ErbB1-4 (Figures 4A). In mESCs, ErbB2 and 3 appeared to be expressed at higher levels than ErbB1, with low levels of ErbB4 being detected. These data suggest that endogenous HRG-β could be involved in driving mESC self-renewal.

[00130] The expression of the ErbB receptor transcripts in mouse embryonic fibroblasts (MEFs) was also examined (Figure 4B). MEFs are a heterogenous population of cells derived from E12.5-13.5 viscera that have been used historically to maintain mouse and human EC cells and ES cells. Expression of Nrg1 and Adam19 in this population suggests that the HRG-β ectodomain is also present in MEF-conditioned media and may exert significant effects upon pluripotency.

[00131] AG1478 and AG879 were used to examine the role of HRG/ErbB signaling in mouse ES cells. R1 mouse ES cells were maintained in standard conditions in DMEM, 10% FBS, 10% KSR, 0.5 U/ml penicillin, 0.5 U/ml streptomycin, 1xNEAA, 1 mM sodium pyruvate, 1000 U/ml LIF (ESGRO), 0.1 mM β-ME, and were passaged with 0.5% trypsin/EDTA. $2x10^5$ cells/well were plated in 6 well trays on MATRIGEL™ diluted at 1:1000. The day after plating, DMSO (carrier control), 1-50 μM AG1478, or 1-50 μM AG879 was added with fresh medium. The cells were cultured an additional 8 days, with daily media changes. The cultures were then fixed and stained for alkaline phosphatase activity.

[00132] DMSO and 1-50 μM AG1478 had no apparent affect on cell proliferation, with subconfluent colonies of alkaline phosphatase positive mESCs observed (Figures 5A-C). However, AG879 substantially inhibited cell growth at 50 μM (compare Figures 5D and 5F) and may have slowed proliferation at 20 μM (Figure 5E). mESCs grown in AG879 did not appear to differentiate and maintained a pluripotent morphology, and alkaline phosphatase activity.

[00133] The results indicate that AG879 appeared to inhibit proliferation, without inducing differentiation, of mESCs, suggesting that mESCs require ErbB2 signaling for proliferation. Conversely, mESCs do not appear to be reliant on an ErbB1 signal for proliferation. The concentration of AG879 required to inhibit proliferation was ~10x higher for mESCs than that for BG01v cells grown in defined conditions, indicating that either the serum used in the mESC conditions may have interfered with the activity of the drug, that AG879 has a lower affinity for the mouse ErbB2 tyrosine kinase than for human ErbB2 tyrosine kinase, or that ErbB2 may play slightly different roles with the different species of ES cells.

[00134] Another highly selective inhibitor of the ErbB2 tyrosine kinase, tyrphostin AG825 (Murillo, et al. 2001 Cancer Res 61, 7408-7412), was used to investigate the role of ErbB2 in human ESCs. AG825 significantly inhibited proliferation of hESCs growing in conditioned medium (CM) (Fig. 6A). AG825 inhibited proliferation without widespread cell death, and viable hESCs could be maintained for >5 days (not shown). Western blotting showed that AG825 inhibited autophosphorylation of ErbB2 at tyrosine-1248 in starved/heregulin (HRG) pulsed hESCs growing in DC-HAIF (Fig. 6B). Thus, disruption of ErbB2 signaling severely inhibited hESC proliferation. To establish hESCs in defined growth conditions, cultures could be passaged directly from CM conditions into DC-HAIF and exhibited minimal spontaneous differentiation (Fig. 6C). Colony and cell-counting assays confirmed that LongR3-IGF1 and HRG played the major roles in self-renewal and proliferation in the context of one of the embodiments of the present invention (Fig. 6D, 6E). Phosphorylation of IGF1R, IR, FGF2α, ErbB2, and ErbB3 was also observed in both steady-state DC-HAIF cultures, and in starved cultures that were pulsed with DC-HAIF (Fig. 6F).

[00135] *Example 5 - Culture of Mouse ES Cells in Defined Conditions*

[00136] To further examine the role of HRG/ErbB2 signaling in mouse ES cells, the proliferation of R1 ES cells was examined in DC medium using a combination of growth factors. $1x10^5$ cells/well were plated in 6-well trays, coated with 0.2% gelatin, in DC containing combinations of 10 ng/ml HRG-β, 100 ng/ml LongR3-IGF1, 1 ng/ml Activin A, 1000 U/ml mouse LIF or 10 ng/ml BMP4 (Table 1, below). Proliferation was observed over 8 days.

[00137] Viable colonies only grew in conditions containing at least LIF/HRG-β or LIF/BMP4 (Table 1). No additional obvious benefit was observed when LongR3-IGF1 or Activin were added to these combinations. Normal proliferation was observed in a control parental culture, and no viable colonies were observed in defined media without any growth factors.

Table 1

HRG	IGF	Activin	LIF	BMP4	Growth
+					No
+			+		Yes
+	+				No
+	+		+		Yes
+	+	+			No
+	+	+	+		Yes
+		+			No
+		+	+		Yes
			+	+	Yes
+			+	+	Yes

[00138] A quantitative assay was performed by plating $2x10^5$ cells/well in 6-well trays on 1:1000 MATRIGEL™, in selected combinations of 10 or 50 ng/ml HRG-β, 10 ng/ml EGF, 1000 U/ml LIF or 10 ng/ml BMP4. The cultures were grown for 8 days, fixed, and the number of

alkaline phosphatase colonies was counted (Figure 7A). No colonies were observed in defined conditions without growth factors, and <45 colonies were observed with HRG-β, HRG-β/EGF and HRG-β/BMP combinations. While 1358 colonies were observed in LIF alone, 4114 and 3734 colonies were observed in the 10 ng/ml HRG-β/LIF and 50 ng/ml HRG-β/LIF combinations, respectively. This indicated that in defined conditions, LIF alone provided a substantial pluripotency signal, and HRG-β exhibited a large synergistic effect with LIF, more than doubling the number of proliferating mESC colonies in this assay. Low magnification images of this assay also indicate this synergistic proliferative effect (Figures 7B-G).

[00139] *Example 6 – Characterization of Pluripotency of Human Embryonic Stem Cells (hESCs) maintained in DC-HAIF*

[00140] Multiple approaches were used to confirm the maintenance of plasticity of hESCs in DC-HAIF. BG02 cells cultured in DC-HAIF for 6 months (25 passages) maintained the potential to form complex teratomas (Fig. 8A) and representatives of the three germ layers *in vitro* (Fig. 8B). Transcriptional analyses were used to compare global expression in hESCs cells (Liu et al 2006, BMC Dev Biol 6, 20) maintained in CM and DC-HAIF. Greater than 11,600 transcripts were detected in BG02 cells grown in DC-HAIF for 10 and 32 passages, and BG02 cells grown in CM for 64 passages. There were about 10364 transcripts common to all populations (Fig. 8C), including known hESC markers such as CD9, DNMT3, NANOG, OCT4, TERT and UTF1 (not shown). High correlation coefficients were observed in comparisons of CM and DC-HAIF cultures (R^2select=0.928), as well as in early and late passage cells (R^2select=0.959) (Fig. 8D). Hierarchical clustering analysis demonstrated that BG02 cells maintained in DC-HAIF grouped tightly and retained a close similarity to BG02 and BG03 cells maintained in CM (Fig. 8E). These data are consistent with previous analyses showing that undifferentiated hESCs clustered tightly compared to embryoid bodies or fibroblasts (Liu et al 2006, BMC Dev Biol 6, 20). Thus, cells maintained in the compositions of the present invention are able to maintain key markers of pluirpotency. Accordingly, the compositions of the present invention can be used as a simple medium for supporting self-renewal of differentiable cells.

[00141] *Example 7 – Maintenance of Human Embryonic Stem Cells (hESCs) on Humanized Extracellular Matrices (ECMs) in DC-HAIF*

[00142] To investigate the role of ErbB2 signaling and develop a defined media for hESCs, DC-HAIF cultures were initially expanded on culture dished coated with growth factor-reduced MATRIGEL ™1:30, but could also be maintained successfully long-term on this substrate diluted 1:200 (Fig. 9A), or 1:1000. BG02 and CyT49 hESCs could also be maintained for >5 passages on tissue culture dishes coated with human serum (Fig. 9B); human fibronectin (Fig. 9C); or VITROGRO™ (Fig. 9D), which is a proprietary humanized ECM.

[00143] *Example 8 – Single Cell Passaging of Human Embryonic Stem Cells (hESCs)*

[00144] Multiple research groups have demonstrated that certain triplodies, notably of hChr12 and 17, are accumulated in hESCs under certain sub-optimal culture conditions (Baker et al., 2007 Nat. Biotech.25(2):207-215). The appearance of triploidies seems to be most directly related to poor cell survival when cultures are split to single cells at passaging, providing a presumed strong selective growth advantage for cells harboring these aneuploidies. Conversely, hESCs growing in one embodiment of the present invention, DC-HAIF, maintained high viability at plating after being split to single cells (Fig. 10A-D). BG01 and BG02 cells maintained a normal karyotype (Fig. 10E) after being passaged with ACCUTASE™ for > 18 and 19 passages respectively. The maintenance of normal karyotype in cells demonstrated that disaggregation of hESC cultures to single cells did not inherently lead to the accumulation of these trisomies in hESCs maintained in DC-HAIF. BG01 and BG02 cultures were also passaged by disaggregation to single cells with multiple passaging agents (Fig. 11). Cultures were split with ACCUTASE™, 0.25% Trypsin/EDTA, TrypLE, or VERSENE™ (EDTA) for 5 passages and karyotyped. The data demonstrate that culturing and passaging hESCs in the compositions of the present invention maintained a normal karyotype in at least two human embryonic cell lines, using a variety of cell disaggregation reagents.

[00145] Large-scale expansion of undifferentiated hESCs is also possible, using the compositions of the present invention. A starting confluent culture of BG02 cells in a 60 mm plate was expanded in DC-HAIF through 4 passages to generate >1.12 x10^{10} cells in 20 days in a single experiment. The cultures remained undifferentiated, as demonstrated by >85% of the cells

in the batch maintaining expression of markers of pluirpotency such as OCT4, CD9, SSEA-4, TRA-1-81 when examined by flow cytometry (Fig. 12A). Expression of other markers of pluripotency was also observed by RT-PCR analysis, while markers of differentiated lineages α-fetoprotein, MSX1 and HAND1 were not detected (Fig. 12B). Fluorescence *in situ* hybridization analysis demonstrated that the cells cultured and passaged in DC-HAIF maintained expected copy numbers for hChr12 (98% 2-copy), hChr17 (98% 2-copy), hChrX (95% 1-copy) and hChrY (98% 1-copy) (Fig. 12C). Karyotyping analysis also demonstrated that a normal euploid chromosome content and banding profile was maintained in these cells

[00146] *Example 9 – Insulin and IGF1 Exert Different Effects on hESCs When Applied at Physiological Concentrations*

[00147] Essentially all of the reported culture conditions for hESCs to date include supraphysiological levels of insulin, which can stimulate both IR and IGF1R. To distinguish the activities that insulin and insulin-substitutes exert, compared to IGF1, hESCs are cultured in defined media conditions in physiological levels of these growth factors. The concentrations of insulin and IGF1 are titrated from about 0.2 to about 200 ng/ml and cell proliferation is monitored by counting cells after 5 days. Cultures that expand successfully are serially passaged 5 times. Physiological levels of IGF1 support the expansion of hESC cultures, whereas physiological levels of insulin do not, indicating that the activity of insulin or insulin-substitutes cannot replace IGF1, and that IGF1 and insulin (or insulin substitutes) represent separate classes of biological activities with regard to action on hESCs.

[00148] *Example 10 – Methods for Screening the Effects of Supplements*

[00149] To initially examine the effects of Vitamin B_{12} and Vitamin B_6 on the growth or differentiation hESCs growing at an intermediate density, BG02 cells are split using ACCUTASE™ and 1 x 10^5 cells/well are plated in 6-well trays in defined culture (DC) media. The DC media contains 10 ng/ml HRG-β, 200 ng/ml LongR3-IGF1, and 10 ng/ml FGF10. Vitamin B_6 (0.5 μM) and/or Vitamin B_{12} (0.5 μM) are added to experimental wells. Cell numbers in each condition are counted after 7 days. Cell counting and colony counting of both experimental and control wells will provide insight on the effects of Vitamin B_6 and Vitamin B_{12} on cell growth.

[00150] In addition, markers of differentiation, such as OCT4 can be assayed in the experimental well to determine the effects of the additives and supplements to the differentiation state of the differentiable cells.

[00151] *Example 11 – Culturing of hESCs in the Absence of FGF2*

[00152] BG02 cells were maintained long term in DC-HAI, for 20 passages (Fig. 13A), and BG01 cells were also serially passaged in DC-HAI, both in the absence of FGF2. The cultures did not deteriorate or exhibit overt differentiation, and exhibited normal expansion of undifferentiated colonies throughout the culture period. The maintenance of a normal male karyotype in a BG02 culture was demonstrated after 6 passages in DC-HAI (Fig. 13B, 20/20 normal metaphase spreads).

[00153] Transcriptional analyses were used to compare global expression in hESCs cells maintained in DC-HAIF and DC-HAI. Total cellular RNA was isolated from hESCs using Trizol (Invitrogen) and was treated with DNase I (Invitrogen) according to the manufacturer's suggested protocol. Sample amplification was performed with 100 ng of total RNA using the Illumina RNA Amplification kit and labeling was achieved by incorporation of biotin-16-UTP (Perkin Elmer Life and Analytical Sciences) at a ratio of 1:1 with unlabeled UTP. Labeled, amplified material (700 ng per array) was hybridized to Illumina Sentrix Human-6 Expression Beadchips containing 47,296 transcript probes according to the manufacturer's instructions (Illumina, Inc.). Arrays were scanned with an Illumina Bead Array Reader confocal scanner and primary data processing, background subtraction, and data analysis were performed using Illumina BeadStudio software according to the manufacturer's instructions. A minimum detection confidence score of 0.99 (a computed cutoff indicating the target sequence signal was distinguishable from the negative controls) was used to discriminate the presence or absence of transcript expression. Data analysis was performed using parallel approaches described for other hESC samples (Liu et al 2006, BMC Dev Biol 6:20). Hierarchical clustering was performed as described previously (Liu et al 2005, BMC Dev Biol 6:20), and was based on average linkage and Euclidean distances as the similarity metric using differentially expressed genes identified by ANOVA ($p<0.05$). Detailed descriptions of the sensitivity and quality control tests used in array manufacture and algorithms used in the Bead studio software are available from Illumina, Inc

(San Diego, CA). The majority of transcripts detected were expressed in both DC-HAIF and DC-HAI BG02 cultures, including known hESC markers such as CD9, DNMT3, NANOG, OCT4, TERT and UTF1 (not shown). High correlation coefficients were observed in comparisons of DC-HAIF and DC-HAI cultures (R^2 select=0.961) (Fig. 14). Hierarchical clustering analysis demonstrated that BG02 cells maintained in DC-HAI grouped tightly and retained a close similarity to cells maintained in DC-HAIF, as well as BG02 and other hESC lines in multiple culture formats (Fig. 15). These data are consistent with previous analyses showing that undifferentiated hESCs clustered tightly compared to embryoid bodies or fibroblasts (Liu et al 2006, BMC Dev Biol 6:20).

[00154] Furthermore, BG02 cells maintained in DC-HAI differentiated to representatives of mesoderm, endoderm and ectoderm in complex teratomas formed in SCID-beige mice (not shown), formally demonstrating the maintenance of pluripotency in cultures grown in the absence of exogenous FGF2.

[00155] To examine if exogenous FGF2 was required in the context of single cell passaging, BG01 cells were passaged with ACCUTASE™ and grown in defined conditions containing only 10 ng/ml HRG-β and 200 ng/ml LongR3-IGF1 (DC-HI). These DC-HI cultures were maintained for 10 passages, and did not exhibit overt differentiation or a slowing of proliferation.

[00156] These studies clearly demonstrated that the provision of exogenous FGF2 is not required when hESCs are maintained in defined media minimally containing heregulin and IGF1. Furthermore cultures absent FGF2 retained key properties of pluripotency, including transcriptional profile and differentiation to mesoderm, endoderm and ectoderm *in vivo*.

CLAIMS

1. A method of expanding pluripotent stem cell number, the method comprising culturing pluripotent stem cells in a culture medium comprising a basal salt nutrient solution and an ErbB3 ligand, wherein the cell medium is essentially free of serum, wherein the pluripotent stem cells expand in number and do not differentiate, wherein:

(i) the pluripotent stem cells are of human origin and the culture medium further comprises an activator of insulin like growth factor 1 receptor (IGF1R), wherein the activator of insulin like growth factor 1 receptor (IGF1R) comprises IGF-1, IGF-2, or an IGF-1 analog, wherein the IGF-1 analog comprises LongR3-IGFI, Des(1-3)IGF-1, [Arg^3]IGF-l, [Ala^{31}]IFG-1, Des(2,3)[Ala^{31}]IGF-l, [Leu^{24}]IGF-1, Des(2,3)[Leu^{24}]IGF-1, [Leu^{60}]IGF-l, [Ala^{31}][Leu^{60}]IGF-l, or [Leu^{24}][Ala^{31}]IGF-l, or

(ii) the pluripotent stem cells are of mouse origin and the culture medium further comprises leukemia inhibitory factor (LIF).

2. The method of claim 1, wherein the culture medium is free of exogenous insulin and insulin substitutes.

3. The method of any one of claims 1 or 2, wherein the ErbB3 ligand in the culture medium is selected from the group consisting of Neuregulin-β, Heregulin-β(HRG-β), Heregulin-α (HRG-α), Neu differentiation factor (NDF), acetylcholine receptor-inducing activity (ARIA), glial growth factor 2 (GGF2), motor-neuron derived factor (SMDF), Neuregulin-2, Neuregulin-2β (NRG2-β), Epiregulin, Biregulin and functional fragments thereof.

4. The method of claim 3, wherein the ErbB3 ligand is HRG-β.

5. The method of any one of claims 1-4, wherein the culture medium further comprises transforming growth factor beta (TGF-β) or a TGF-β family member.

6. The method of claim 5, wherein the TGF-β family member is selected from the group consisting of Nodal, Activin A, Activin B, bone morphogenetic protein-2 (BMP2), and bone morphogenetic protein-4 (BMP4).

7. The method of claim 6, wherein the TGF-β family member is Activin A.

8. The method of any one of claims 1-7, wherein the cell medium is free of exogenous fibroblast growth factor.

9. The method of any one of claims 1-7, wherein the cell medium further comprises at least one fibroblast growth factor (FGF) selected from the group consisting of FGF-2, FGF-7, FGF-10, and FGF-22.

10. The method of claim 9, wherein the at least one FGF is FGF-7, FGF-10 and FGF-22.

11. The method of any one of claims 1-10, wherein the culture medium comprises a serum albumin (SA).

12. The method of claim 11, wherein the SA is bovine SA (BSA) or human SA (HSA).

13. The method of claim 11, wherein the concentration of the SA is more than about 0.2%, volume to volume (v/v).

14. The method of claim 11, wherein the concentration of SA is less than about 5% v/v.

15. The method of any one of claims 1-14, wherein the pluripotent stem cells are selected from the group consisting of embryonic stem (ES) cells, early primitive ectoderm-like (EPL) cells, inner cell mass (ICM)/epiblast cells, embryonic germ (EG) cells, and pluripotent cells derived by dedifferentiation or nuclear transfer.

16. The method of claim 15, wherein the pluripotent stem cells are (ES) cells.

17. The method of any one of claims 1-16, wherein the pluripotent stem cells are of human origin and wherein the culture medium further comprises an activator of insulin like growth factor 1 receptor (IGF1R).

18. The method of claim 17, wherein the activator of IGF1R comprises insulin-like growth factor 1 (IGF1) or longR3-IGF1.

19. The method of any one of claims 1-16, wherein the pluripotent stem cells are of mouse origin and the culture medium further comprises leukemia inhibitory factor (LIF).

20. The method of any one of claims 1-19, wherein the culturing comprises culturing the pluripotent stem cells on a solid surface in an adherent culture.

21. The method of any one of claims 1-19, wherein the culturing comprises culturing the pluripotent stem cells in a suspension culture.

22. A method of identifying a compound that modulates proliferation and/or differentiation of pluripotent stem cells, the method comprising:

culturing the pluripotent stem cells in a culture medium comprising a basal salt nutrient solution, an ErbB3 ligand, and a candidate compound, wherein the cell medium is essentially free of serum;

determining whether an increase or decrease in proliferation and/or differentiation occurs in the pluripotent stem cells cultured with the compound relative to a control, wherein the increase or decrease indicates that the compound modulates proliferation and/or differentiation of the pluripotent stem cells, wherein:

(i) the pluripotent stem cells are of human origin and the culture medium further comprises an activator of insulin like growth factor 1 receptor (IGF1R), wherein the activator of insulin like growth factor 1 receptor (IGF1R) comprises IGF-1, IGF-2, or an IGF-1 analog, wherein the IGF-1 analog comprises LongR3-IGFI, Des(1-3)IGF-1, [Arg^3]IGF-l, [Ala^{31}]IFG-1, Des(2,3)[Ala^{31}]IGF-l, [Leu^{24}]IGF-1, Des(2,3)[Leu^{24}]IGF-1, [Leu^{60}]IGF-l, [Ala^{31}][Leu^{60}]IGF-l, or [Leu^{24}][Ala^{31}]IGF-l, or

(ii) the pluripotent stem cells are of mouse origin and the culture medium further comprises leukemia inhibitory factor (LIF).

23. The method of claim 22, wherein the culturing comprises culturing the pluripotent stem cells on a solid surface in an adherent culture.

24. The method of claim 22, wherein the culturing comprises culturing the pluripotent stem cells in a suspension culture.

25. The method of claim any one of claims 22-24, wherein the culture medium is free of exogenous insulin and insulin substitutes.

26. The method of any one of claims 22-25, wherein the ErbB3 ligand in the culture medium is selected from the group consisting of Neuregulin-β, Heregulin-β(HRG-β), Heregulin-α (HRG-α), Neu differentiation factor (NDF), acetylcholine receptor-inducing activity (ARIA), glial growth factor 2 (GGF2), motor-neuron derived factor (SMDF), Neuregulin-2, Neuregulin-2β (NRG2-β), Epiregulin, Biregulin and functional fragments thereof.

27. The method of claim 26, wherein the ErbB3 ligand is HRG-β.

28. The method of any one of claims 22-27, wherein the culture medium further comprises transforming growth factor beta (TGF-β) or a TGF-β family member.

29. The method of claim 28, wherein the TGF-β family member is selected from the group consisting of Nodal, Activin A, Activin B, bone morphogenetic protein-2 (BMP2), and bone morphogenetic protein-4 (BMP4).

30. The method of claim 29, wherein the TGF-β family member is Activin A.

31. The method of any one of claims 22-30, wherein the cell medium is free of exogenous fibroblast growth factor.

32. The method of any one of claims 22-30, wherein the cell medium further comprises at least one fibroblast growth factor (FGF) selected from the group consisting of FGF-2, FGF-7, FGF-10, and FGF-22.

33. The method of claim 32, wherein the at least one FGF is FGF-7, FGF-10 and FGF-22.

34. The method of any one of claims 22-33, wherein the culture medium comprises a serum albumin (SA).

35. The method of claim 34, wherein the SA is bovine SA (BSA) or human SA (HSA).

36. The method of claim 34, wherein the concentration of the SA is more than about 0.2%, volume to volume (v/v).

37. The method of claim 34, wherein the concentration of SA is less than about 5% v/v.

38. The method of any one of claims 22-37, wherein the pluripotent stem cells are selected from the group consisting of embryonic stem (ES) cells, early primitive ectoderm-like (EPL) cells, inner cell mass (ICM)/epiblast cells, embryonic germ (EG) cells, and pluripotent cells derived by dedifferentiation or nuclear transfer.

39. The method of claim 38, wherein the pluripotent stem cells are (ES) cells.

40. The method of any one of claims 22-39, wherein the pluripotent stem cells are of human origin and wherein the culture medium further comprises an activator of insulin like growth factor 1 receptor (IGF1R).

41. The method of claim 40, wherein the activator of IGF1R comprises insulin-like growth factor 1 (IGF1) or longR3-IGF1.

42. The method of any one of claims 22-39, wherein the pluripotent stem cells are of mouse origin and the culture medium further comprises leukemia inhibitory factor (LIF).