

END-TO-END PLATFORM FOR HUMAN PLURIPOTENT STEM CELL MANUFACTURING

BACKGROUND

[0001] Stem cell technology has revolutionized regenerative medicine, ushering in a new era focused on curative therapies rather than disease management. Over the past decade, efforts toward the development and optimization of cGMP compliant, large-scale manufacturing of cell-based therapies have significantly increased. However, industrialization of stem-cell based therapies requires innovative solutions to close the gap between research and commercialization. For instance, scalable cell production platforms are needed to reliably deliver the cell quantities needed during the various stages of development and commercial supply.

[0002] Human pluripotent stem cells (hPSCs) are a key source material for generating therapeutic cell types, and successful generation of human induced pluripotent stem cells (hiPSCs) by somatic cell reprogramming has opened new avenues in regenerative medicine, disease modeling and drug development. Capable of self-renewal and pluripotency, hiPSCs derived from patients of both normal and aberrant phenotypes provide a theoretically limitless supply of clinically relevant iPSC-derived cells without existing limitations and immune-rejection. For instance, given the heart's limited to no regenerative capacity, new cardiomyocytes can instead be derived from hiPSCs by modulating developmental cues critical in embryonic development in vivo.

[0003] Essential to the successful differentiation of iPSCs to a specific cell lineage, however, includes careful consideration of the microenvironment and method with which iPSCs are maintained. While a wealth of information has been gained through the use of traditional two-dimensional (2D) culture, this system fails to generate the number of cells required in many therapies in a cost-effective manner and does not fully recapitulate in vivo conditions.

[0004] For instance, to replace the number of cells lost during a myocardial infarction, for example, approximately 1×10^9 cells are required per patient dose. Given that 2D-based cell culture platforms are non-scalable with minimal capacity for expansion, achieving high cell densities in a 2D system would involve costly arrangements including extensive manual effort, laboratory space and personnel. These platforms also often do not possess adequate systems to control or monitor

parameters such as the production of key metabolites by hiPSCs in culture. Moreover, iPSC-derived cardiomyocytes remain phenotypically immature despite a number of studies demonstrating enhanced maturation through modulation of existing methodologies.

[0005] A number of studies have demonstrated the feasibility of hPSC expansion in suspension cultures using aggregate and microcarrier (MC)-based three-dimensional (3D) culture systems. Aggregate-based 3D culture provides a more physiologically relevant microenvironment, but has been shown not only to require the small molecule, Y27632, for the survival of hPSCs, but also sequential passaging to achieve high fold expansion. Not without its own advantages, microcarrier-based culture systems facilitate larger surface area to volume ratio for scalability, provide large surface area for adhesion and growth during expansion, flexibility in using defined extracellular matrices, and allow maintenance of homogenous culture conditions.

[0006] Therefore, it would be a benefit to provide a cGMP compliant, commercially viable, scalable process to generate large numbers of high quality hPSCs. Further, it would be beneficial to provide an end-to end platform and process for hPSC expansion that solves one or more of the above problems, and/or that provides a microcarrier based expansion that uses xeno-free culture conditions. Moreover, it would be a benefit to provide an end-to-end platform and process where cells are expanded in a closed, automated and controlled single-use stirred tank bioreactor. Additionally or alternatively, it would be beneficial to provide a closed step of harvest and separation from the MCs, as well as concentrating the cells using a closed, automated centrifugation system, where the cells may be further cryopreserved. It would also be beneficial if the cryopreserved cells may also serve as the starting material, (e.g., cryopreserved hPSCs) that can be either thawed into 2D culture prior to inoculation or thawed directly into a bioreactor. It would be an additional benefit if an end-to-end platform that solved one or more of the above problems while also achieving a high expansion fold of >50 using the platform within 9-14 days of culture. Furthermore, it would be advantageous if the expanded hPSCs demonstrate high quality of self-renewal and pluripotency, and/or are capable of differentiation to all three germ layers. Additionally, it would be beneficial to provide an end-to-end platform that does not require the use of a 2D seed train.

SUMMARY

[0007] In general, the present disclosure is directed to a process for manufacturing pluripotent stem cells. The process includes placing a plurality of microcarriers into a bioreactor, inoculating the bioreactor with pluripotent stem cells, incubating the pluripotent stem cells in the bioreactor for a period of time sufficient to yield a fold expansion of about 50 times or greater to give expanded pluripotent stem cells, concentrating the expanded pluripotent stem cells, and cryopreserving the expanded pluripotent stem cells. Further, the pluripotent stem cells are inoculated at a seeding density of about 0.2×10^6 cells/mL or less, and the process is a closed and/or automated process.

[0008] In one aspect, the pluripotent stem cells are not passaged during incubation. Additionally or alternatively, in an aspect, the pluripotent stem cells used for inoculating the bioreactor are inoculated into the bioreactor as cryopreserved pluripotent stem cells. In a further aspect, the pluripotent stem cells are not incubated in a 2D process prior to inoculating the bioreactor.

[0009] Furthermore, in an aspect, the plurality of microcarriers have a particle size of about 125 μm or greater. Additionally or alternatively, the plurality of microcarriers are coated with a growth matrix prior to being placed in the bioreactor.

[0010] In a further aspect, the method includes a harvesting step after incubation. In an aspect, a non-enzymatic passaging solution is used to separate the microcarriers from the expanded pluripotent stem cells. Additionally or alternatively, in one aspect, after passaging with the non-enzymatic passaging solution, the pluripotent stem cells and plurality of microcarriers are run through a mesh having a mesh size sufficient to allow the pluripotent stem cells to pass through while restricting passage of the microcarriers. In one aspect, the mesh size is about 10 μm to about 100 μm .

[0011] Moreover, in a further aspect, the concentrating is performed by a continuous centrifugation device. In an aspect, a flow rate into the continuous centrifugation device is selected that allows formation of a fluidized bed in about 15 minutes or less. Furthermore, in one aspect, cell retention in the fluidized bed is about 80% or greater.

[0012] Additionally or alternatively, in an aspect, the cell retention after cryopreservation is about 70% or greater.

[0013] In one aspect, during incubation, the microcarriers and pluripotent stem cells are subject to agitation. In a further aspect, the agitation has an initial speed, and the initial speed is increased after about 1 to 5 days to a second speed. Furthermore, in an aspect, the second speed is increased after about 1 to 5 days to a third speed. Additionally or alternatively, in one aspect, the agitation has an initial speed and the initial speed is increased to a second speed when the cell density reaches about 1×10^5 cells/cm² to about 10×10^5 cells/cm². Moreover, in an aspect, during a first 24 hours or less after inoculation, the agitation is discontinuous agitation.

[0014] In yet another aspect, the bioreactor is a perfusion bioreactor.

[0015] Other features and aspects of the present disclosure are discussed in greater detail below.

BRIEF DESCRIPTION OF THE DRAWINGS

[0016] A full and enabling disclosure of the present disclosure is set forth more particularly in the remainder of the specification, including reference to the accompanying figures, in which:

[0017] Fig. 1A shows a schematic representation of an end-to-end platform according to the present disclosure;

FIG. 1B is a cross sectional view of a bioreactor system in accordance with the present disclosure

Fig. 2 shows graphs of RTiPSC3B and RTiPSC4i hiPSCs growth and expansion over time;

Fig. 3 shows graphs of cell growth and expansion using small and large sized microcarriers;

Fig. 4 shows graphs of cell growth and expansion of RTiPSC4i using low cell densities;

Fig. 5 shows graphs of cell growth and expansion of RTiPSC3B using low cell densities;

Fig. 6 shows graphs of cell growth and expansion using uncoated and coated microcarriers;

FIG. 7 shows graphs of cell growth and expansion with and without microcarriers;

FIG. 8 shows graphs of consolidated cell density and fold expansion using 2D cultured cell inoculum;

FIG. 9 is images of cell-microcarrier clusters at 100X magnification;

FIG. 10 shows the monitoring of nutrient and metabolite concentrations and process parameters in 3-liter bioreactor suspension cultures of hiPSCs according to the present disclosure;

FIG. 11 shows phase contrast images of iPSCs expanded in a bioreactor according to the present disclosure at 100X magnification;

FIG. 12 shows immunofluorescence staining of iPSCs expanded in a bioreactor according to the present disclosure;

FIG. 13 is a graph of quantitative analysis of hPSC-associated markers by flow cytometry of cells expanded in a bioreactor according to the present disclosure;

FIG. 14 shows pluripotency of cells expanded in a bioreactor according to the present disclosure by immunofluorescence staining of germ layer-specific markers;

FIG. 15 shows immunofluorescence staining for lineage-specific markers for RTiPSC3B and LiPSC18R cell lines;

FIG. 16 is a graph showing the percentage of viable cells escaping the kSep chamber during fluidized bed formation according to an aspect of the present disclosure;

FIG. 17 is a graph showing the percentage of viable cells escaping the fluidized bed per run versus process time according to an aspect of the present disclosure;

FIG. 18 shows phase contrast images of single cells post concentration at 24 hours and 72 hours post plating;

FIG. 19 shows expression via immunofluorescence staining of cells expanded in a bioreactor and concentrated according to an aspect of the present disclosure;

FIG. 20 is a graph of quantitative analysis of hPSC-associated markers by flow cytometry of cells expanded in a bioreactor and concentrated according to an aspect of the present disclosure;

FIG. 21 shows pluripotency of cells expanded in a bioreactor and concentrated by directed differentiation into endoderm, neural stem cells, and cardiomyocytes, according to an aspect of the present disclosure;

FIG. 22 shows phase contrast images of cryopreserved cells 48-72 hours post thaw at 40X magnification;

FIG. 23 shows cells stained with AP staining kit at three days (vial #2) and five days post-plating;

FIG. 24 shows graphs of cell growth and fold expansion of directly thawed versus freshly inoculated cells in spinner flasks;

FIG. 25 shows graphs of cell growth and fold expansion of cells thawed into a 3-liter bioreactor according to an aspect of the present disclosure;

FIG. 26 show phase contrast images demonstrates cell growth on microcarriers on different days of the bioreactor run at 100X magnification (scale bar: 100 μ m);

FIG. 27 shows iPSCs thawed into suspension and expanded in a bioreactor according to an aspect of the present disclosure have typical iPSC morphology when plated onto 2D, before and after release from the microcarriers;

FIG. 28 shows detection of hPSC-associated markers by immunofluorescence staining in cells post-harvest and concentration according to an aspect of the present disclosure;

FIG. 29 is a graph of quantitative analysis of hPSC-associated markers by flow cytometry of cells post-harvest and cells concentrated after harvest according to an aspect of the present disclosure;

FIG. 30 shows direct differentiation of iPSCs thawed into suspension, expanded in a bioreactor, and concentrated according to an aspect of the present disclosure;

FIG. 31 is a schematic representation of the experimental design for using 3D seed train as inoculum according to an aspect of the present disclosure;

FIG. 32 shows graphs of cell growth and fold expansion of LiPSC18R on microcarriers collected from a spinner flask and inoculated in a 3-liter bioreactor according to an aspect of the present disclosure;

FIG. 33 shows graphs of cell growth and fold expansion of RTiPSC3b released from microcarriers as single cells and inoculated in a 3-liter bioreactor according to an aspect of the present disclosure;

FIG. 34 shows phase contrast images of cells growing on microcarriers on different days in 3D culture at 100X Magnification (scale bar 200 μ m);

FIG. 35 shows phase contrast images of colonies formed by cells expanded in a bioreactor according to an aspect of the present disclosure five days post plating at 40X magnification (Scale bar: 100 μ m);

FIG. 36 shows a quality assessment of hiPSCs expanded through a 3D seed train according to an aspect of the present disclosure by immunofluorescence staining of hPSC-associated markers at 100X magnification;

FIG. 37 is a graph of quantitative analysis of hPSC-associated markers of hiPSCs expanded through a 3D seed train according to an aspect of the present disclosure;

FIG. 38 shows immunofluorescence staining of germ layer-specific markers on embryoid bodies (EBs) of hiPSCs expanded through a 3D seed train according to an aspect of the present disclosure;

FIG. 39 show a chart of a two-week cell expansion in 2D;

FIG. 40 illustrates a dip tube/perfusion line;

FIG. 41 illustrates a media feed line;

FIG. 42 illustrates a harvest line extension assembly;

FIG. 43 illustrates a gas line assembly;

FIG. 44 illustrates a gas line assembly;

FIG. 45 illustrates a 2D agitation speed characterization curve;

FIG. 46 illustrates a harvest scheme; and

FIG. 47 illustrates a flex concepts bag integrated with 65 μ m mesh filter.

[0018] Repeat use of reference characters in the present specification and drawings is intended to represent the same or analogous features or elements of the present invention.

DEFINITIONS AND ABBREVIATIONS

[0019] It is to be understood that the terminology used herein is for the purpose of describing particular embodiments only and is not intended to limit the scope of the present invention. In this specification and in the claims that follow, reference will be made to a number of terms that shall be defined to have the following meanings:

[0020] As used herein, the terms "about," "approximately," or "generally," when used to modify a value, indicates that the value can be raised or lowered by 10% and remain within the disclosed embodiment.

[0021] As used herein, the term “xeno-free” refers to a medium that contains about 5% or less by weight of animal or human derived components, such as about 2% by weight or less, such as about 1% by weight or less animal or human derived components, and in one aspect, may refer to a medium completely free of animal components, human components, or both human and animal components.

[0022] Abbreviations:

hPSCs	Human pluripotent stem cells
hiPSCs	Human induced pluripotent stem cells
MCs	Microcarriers
EBs	Embryoid Bodies
BSC	Bio Safety Cabinet
VVD	Vessel volume per day

DETAILED DESCRIPTION

[0023] It is to be understood by one of ordinary skill in the art that the present discussion is a description of exemplary embodiments only, and is not intended as limiting the broader aspects of the present disclosure.

[0024] In general, the present disclosure is directed to a large scale, closed system, end-to-end platform, and process related thereto, for the manufacture of human pluripotent stem cells (hPSCs) that demonstrates excellent growth, expansion, recovery, and viability. Particularly, the present disclosure has developed a microcarrier-based bioreactor suspension platform to expand hiPSCs to cell densities of $>2 \times 10^9$ cells/L using xeno-free, fully defined hPSC medium with a closed, automated process for hiPSC harvest and concentration, and extensively characterized the expanded hiPSCs. For instance, the present disclosure has found that an end-to-end platform, and related process, according to the present disclosure allows for excellent cell growth and expansion even when using lower seeding densities and/or when using larger microcarriers than previously believed. Furthermore, the present disclosure has found that an end-to-end platform, and related process, according to the present disclosure may exhibit markedly improved cell recovery and viability, even after concentration and cryopreservation. In addition, the present disclosure has unexpectedly found that cells expanded according to the

present disclosure may be used to seed further expansions, allowing for 2D seed train growth to be avoided.

[0025] Referring first to Fig. 1A, an exemplary schematic for an end-to-end hPSC expansion platform 100 and process related thereto, will be discussed. Of course, as noted above, in one aspect, step two (104) and three (106) may be eliminated by using cryopreserved cells expanded according to the end-to-end platform 100 and process as will be described herein.

[0026] Nonetheless, in one aspect, cryopreserved cells are used to inoculate a 2D seed train flask 104. The cryopreserved cells 102 may be cryopreserved cells generally known in the art, such as cells cryopreserved in CryoStor10 and commercially available. However, in one aspect, the cryopreserved cells 102 may be cells cryopreserved 116 according to the end-to-end platform 100 and process described herein. Thus, in one aspect, the cryopreserved cells 102 are cells cryopreserved 116 in a prior batch of expanded cells.

[0027] Regardless of whether the cryopreserved cells 102 were formed according to the present disclosure or were otherwise acquired, in one aspect, the cryopreserved cells 102 can be thawed into a 2D seed train flask 104. The cells may be inoculated at a seed density of about 0.01×10^6 cells/cm² to about 0.1×10^6 cells/cm², such as about 0.015×10^6 cells/cm² to about 0.05×10^6 cells/cm², such as about 0.02×10^6 cells/cm² to about 0.04×10^6 cells/cm².

[0028] In one aspect, a kinase inhibitor, such as rho-associated coiled-coil containing protein kinase inhibitor (ROCKi) may be initially used with the thawed cells in the 2D seed train flask in addition to a nutrient matrix. However, after a period of time, such as about 24 hours or less, such as about 22 hours or less, such as about 20 hours or less, such as about 18 hours or less, such as about 16 hours or less, the kinase and nutrient matrix combination is replaced with an appropriate cell nutrient medium/matrix that is, in one aspect, generally free of kinase inhibitors. As used herein, a nutrient media or matrix refers to any fluid, compound, molecule, or substance that can increase the mass of a bioproduct, such as anything that may be used by an organism to live, grow or otherwise add biomass. For example, a nutrient feed can include a gas, such as oxygen or carbon dioxide that is used for respiration or any type of metabolism. Other nutrient media can include carbohydrate sources. Carbohydrate sources include complex sugars and simple sugars, such as glucose, maltose, fructose, galactose, and mixtures thereof. A nutrient media can also include

an amino acid. The amino acid may comprise, glycine, alanine, valine, leucine, isoleucine, methionine, proline, phenylalanine, tryptophan, serine, threonine, asparagine, glutamine, tyrosine, cysteine, lysine, arginine, histidine, aspartic acid and glutamic acid, single stereoisomers thereof, and racemic mixtures thereof. The term "amino acid" can also refer to the known non-standard amino acids, e.g., 4-hydroxyproline, ϵ -N,N,N-trimethyllysine, 3-methylhistidine, 5-hydroxylysine, O-phosphoserine, γ -carboxyglutamate, γ -N-acetyllysine, ω -N-methylarginine, N-acetylserine, N,N,N-trimethylalanine, N-formylmethionine, γ -aminobutyric acid, histamine, dopamine, thyroxine, citrulline, ornithine, β -cyanoalanine, homocysteine, azaserine, and S-adenosylmethionine. In some embodiments, the amino acid is glutamate, glutamine, lysine, tyrosine or valine.

[0029] The nutrient media can also contain one or more vitamins. Vitamins that may be contained in the nutrient media include group B vitamins, such as B12. Other vitamins include vitamin A, vitamin E, riboflavin, thiamine, biotin, and mixtures thereof. The nutrient media can also contain one or more fatty acids and one or more lipids. For example, a nutrient media feed may include cholesterol, steroids, and mixtures thereof. A nutrient media may also supply proteins and peptides to the bioreactor. Proteins and peptides include, for instance, albumin, transferrin, fibronectin, fetuin, and mixtures thereof. A growth medium within the present disclosure may also include growth factors and growth inhibitors, trace elements, inorganic salts, hydrolysates, and mixtures thereof. Trace elements that may be included in the growth medium include trace metals. Examples of trace metals include cobalt, nickel, and the like. For instance, and for example only, in one aspect, the nutrient medium/matrix may be L7™ hPSC matrix medium sold by Lonza.

[0030] Nonetheless, the thawed cells are seeded for growth in the 2D seed train flask 104 and maintained in the 2D seed train flask 104 until the cells reach a confluence of about 50% to about 100%, such as about 55% to about 95%, such as about 60% to about 90%, such as about 70% to about 85% confluence. For instance, in one aspect, the cells may be maintained in the 2D seed train flask 104 for about 3 days to about 9 days, such as about 4 days to about 8 days, such as about 5 days to about 7 days, in order to achieve the desired confluence and/or cell number.

[0031] After the cells have reached an appropriate confluence, the cells contained in the 2D seed train flask 104 may be passaged to a 2D seed train one-layer cell stack 106. While any passaging may be used as known in the art, in one

aspect, in order to further improve cell viability and retention, a non-enzymatic cell detachment formulation may be used. For instance, in one aspect, the passaging solution may be a sodium citrate based passaging solution, such as a hypertonic sodium citrate solution, which may, in one aspect, be non-animal origin. Furthermore, in one aspect, the sodium citrate passaging solution may also include at least one salt and a liquid, such as, for example only, L7™hPSC Passaging Solution sold by Lonza.

[0032] Regardless of the passaging solution selected, the cells are placed in the 2D seed train cell stack 106 at a seeding density of about 0.01×10^6 cells/cm² to about 0.05×10^6 cells/cm², such as about 0.015×10^6 cells/cm² to about 0.04×10^6 cells/cm², such as about 0.02×10^6 cells/cm² to about 0.03×10^6 cells/cm². Once seeded, the cells are maintained in the 2D seed train cell stack 106 until the cells reach a confluence of about 50% to about 100%, such as about 55% to about 95%, such as about 60% to about 90%, such as about 70% to about 85% confluence. For instance, in one aspect, the cells may be maintained in the 2D seed train trays 106 for about 3 days to about 9 days, such as about 4 days to about 8 days, such as about 5 days to about 7 days, in order to achieve the desired confluence and/or cell number.

[0033] Nonetheless, after the desired cell number and/or confluence is obtained, the cells contained in the 2D seed train cell stack 106 may be harvested using a passaging solution. The passaging solution may be the same as the passaging solution discussed above or may instead use a second passaging solution. Regardless of the passaging solution selected, the harvested cells may be used to inoculate a stirred tank bioreactor 108, which may be referred to as a bioreactor herein, in order to undergo cell expansion.

[0034] In general, any suitable bioreactor may be used. The bioreactor, for instance, may comprise a fermenter, a stirred-tank reactor, an adherent bioreactor, a wave-type bioreactor, a disposable bioreactor, and the like. In the embodiment illustrated in Fig. 1B, the bioreactor 10 comprises a hollow vessel or container that includes a bioreactor volume 12 for receiving a cell culture within a fluid growth medium. As shown in Fig. 1B, the bioreactor system can further include a rotatable shaft 14 coupled to an agitator such as dual impellers 16 and 18.

[0035] The bioreactor 10 can be made from various materials. In one embodiment, for instance, the bioreactor 10 can be made from metal, such as stainless steel. Metal bioreactors are typically designed to be reused.

[0036] Alternatively, the bioreactor 10 may comprise a single use bioreactor made from a rigid polymer or a flexible polymer film. When made from a rigid polymer, for instance, the bioreactor walls can be free standing. Alternatively, the bioreactor can be made from a flexible polymer film or shape conforming material that can be liquid impermeable and can have an interior hydrophilic surface. In one aspect, the bioreactor 10 can be made from a flexible polymer film that is designed to be inserted into a rigid structure, such as a metal container for assuming a desired shape. Polymers that may be used to make the rigid vessel or flexible polymer film include polyolefin polymers, such as polypropylene and polyethylene. Alternatively, the polymer can be a polyamide. In still another embodiment, a flexible polymer film can be formed from multiple layers of different polymer materials. In one embodiment, the flexible polymer film can be gamma irradiated.

[0037] The bioreactor 10 can have any suitable volume. For instance, the volume of the bioreactor 10 can be from 0.1 mL to about 25,000 L or larger. For example, the volume 12 of the bioreactor 10 can be greater than about 0.5 L, such as greater than about 1 L, such as greater than about 2 L, such as greater than about 3 L, such as greater than about 4 L, such as greater than about 5 L, such as greater than about 6 L, such as greater than about 7 L, such as greater than about 8L, such as greater than about 10 L, such as greater than about 12 L, such as greater than about 15 L, such as greater than about 20 L, such as greater than about 25 L, such as greater than about 30 L, such as greater than about 35 L, such as greater than about 40 L, such as greater than about 45 L. The volume of the bioreactor 10 is generally less than about 25,000 L, such as less than about 15,000 L, such as less than about 10,000 L, such as less than about 5,000 L, such as less than about 1,000 L, such as less than about 800 L, such as less than about 600 L, such as less than about 400 L, such as less than about 200 L, such as less than about 100 L, such as less than about 50 L, such as less than about 40 L, such as less than about 30 L, such as less than about 20 L, such as less than about 10 L. In one embodiment, for instance, the volume of the bioreactor can be from about 1 L to about 5L. In an alternative embodiment, the volume of the bioreactor can be from about 25 L to

about 75 L. In still another embodiment, the volume of the bioreactor can be from about 100 L to about 350 L.

[0038] In addition to the impellers 16 and 18, the bioreactor 10 can include various additional equipment, such as baffles, spargers, gas supplies, heat exchangers or thermal circulator ports, and the like which allow for the cultivation and propagation of biological cells. For example, in the embodiment illustrated in Fig. 1B, the bioreactor 10 includes a sparger 20 and a baffle 22. The sparger 20 is in fluid communication with a gas supply 48 for supplying gases to the bioreactor 10, such as carbon dioxide, oxygen and/or air. In addition, the bioreactor system can include various probes for measuring and monitoring pressure, foam, pH, dissolved oxygen, dissolved carbon dioxide, and the like.

[0039] As shown in Fig. 1B, the bioreactor 10 can include a rotatable shaft 14 attached to impellers 16 and 18. The rotatable shaft 14 can be coupled to a motor 24 for rotating the shaft 14 and the impellers 16 and 18. The impellers 16 and 18 can be made from any suitable material, such as a metal or a biocompatible polymer. Examples of impellers suitable for use in the bioreactor system include hydrofoil impellers, high-solidity pitch-blade impellers, high-solidity hydrofoil impellers, Rushton impellers, pitched-blade impellers, gentle marine-blade impellers, and the like. When containing two or more impellers, the impellers can be spaced apart along the rotating shaft 14.

[0040] As shown in Fig. 1B, the bioreactor 10 also includes a plurality of ports. The ports can allow supply lines and feed lines into and out of the bioreactor 10 for adding and removing fluids and other materials. In addition, the one or more ports may be for connecting to one or more probes for monitoring conditions within the bioreactor 10. In addition, the bioreactor 10 can be placed in association with a load cell for measuring the mass of the culture within the bioreactor.

[0041] In the embodiment illustrated in Fig. 1B, the bioreactor 10 includes a bottom port 26 connected to an effluent 28 for withdrawing materials from the bioreactor continuously or periodically, such as, in one aspect, to function as a perfusion bioreactor. Thus, in one aspect, the bottom port may include a system of screens or filters in order to maintain the cells in the bioreactor while removing waste and spent matrix materials. In addition, the bioreactor 10 includes a plurality of top ports, such as ports 30, 32, and 34. Port 30 is in fluid communication with a first fluid feed 36, port 32 is in fluid communication with a second feed 38 and port 34 is in fluid

communication with a third feed 40. The feeds 36, 38 and 40 are for feeding various different materials to the bioreactor 10, such as a nutrient media.

[0042] In addition to ports on the top and bottom of the bioreactor 10, the bioreactor can include ports located along the sidewall. For instance, the bioreactor 10 shown in Fig. 1B includes ports 44 and 46.

[0043] Ports 44 and 46 are in communication with a monitoring and control system that can maintain optimum concentrations of one or more parameters in the bioreactor 10 for propagating cell cultures or otherwise producing a bioproduct. In the embodiment illustrated, for example, port 44 is associated with a pH sensor 52, while port 46 is associated with a dissolved oxygen sensor 54. The pH sensor 52 and the dissolved oxygen sensor 54 are in communication with a controller 60. The system of the present disclosure can be configured to allow for the determination and the measurements of various parameters within a cell culture contained within the bioreactor 10. Some of the measurements can be made in line, such as pH and dissolved oxygen. Alternatively, however, measurements can be taken at line or off line. For example, in one embodiment, the bioreactor 10 can be in communication with a sampling station. Samples of the cell culture can be fed to the sampling station for taking various measurements. In still another embodiment, samples of the cell culture can be removed from the bioreactor and measured off line.

[0044] In accordance with the present disclosure, a plurality of parameters can be measured during growth of a cell culture within the bioreactor 10. In general, the parameter being controlled by the process and system of the present disclosure is measured in conjunction with one or more other parameters that can influence the concentration of the parameter being controlled. For example, in one embodiment, lactate concentration is measured within the cell culture in conjunction with at least one other lactate influencing parameter. The lactate influencing parameter can comprise, for instance, glutamate concentration, glucose concentration, an amino acid concentration such as asparagine concentration, or the like. In one embodiment, at line or off line analysis of the cell culture can be performed using any suitable instruments such as a NOVA Bioprofile 400 analyzer sold by Nova Biomedical. The above analyzer is capable of measuring lactate concentration in conjunction with one or more of the lactate influencing parameters.

[0045] In accordance with the present disclosure, the lactate concentration and the concentration of the one or more lactate influencing parameters in addition to

various other conditions in the bioreactor can be fed to the controller 60. The controller includes a control model that, based on the inputted data, is capable of forecasting lactate concentration in the future as the cell culture continues to propagate. In one embodiment, for instance, the controller can provide an early warning system that produces a percent probability as to whether the lactate concentration at the end of the cell culture incubation period is within preset limits or if the cell culture will end in a lactate accumulating state. The controller 60 can also be configured to accurately predict lactate concentration into the future. For instance, in one embodiment, the controller can forecast a lactate concentration trajectory that predicts lactate concentration through the entire incubation period until the cell culture is harvested. In one embodiment, the controller can also be configured to suggest or automatically implement corrective actions in case lactate concentration is not within preset limits. For example, the controller can be configured to determine nutrient feed changes, or changes in other operating conditions that may be required to drive the lactate concentration to a desired value. In order to determine corrective actions, the controller may run multiple iterations for determining future lactate concentrations based on altering one or more conditions within the bioreactor until an optimized change in one or more conditions is selected.

[0046] The controller 60 may comprise one or more programmable devices or microprocessors. As shown in Fig. 1B, the controller 60 can be in communication with the one or more feeds 36, 38 and 40, with one or more effluents 28, and/or with one or more propellers 16/18. In addition, the controller 60 can be in communication with the pH sensor 52, the dissolved oxygen sensor 54, and the gas supply 48 that feeds gas to the sparger 20. The controller 60 can be configured to increase or decrease the flow of materials into and out of the bioreactor 10 based upon the lactate concentration and the concentration of one or more lactate influencing parameters. In this manner, the controller 60 can maintain lactate concentration within preset limits. The controller 60 can operate in an open loop control system or can operate in a closed loop control system, where adjustments to input and/or output devices are completely automated. In other embodiments, the controller 60 can suggest corrective actions in order to influence lactate concentration and the corrective actions can be done manually.

[0047] Regardless of the bioreactor and/or bioreactor selected, in one aspect, the cells harvested from the 2D seed train cell stack 106 may be inoculated into a

bioreactor containing a nutrient media/medium, which may be the same medium as discussed above. In one aspect the nutrient medium may be pre-placed in the reactor in an amount such that the volume of the nutrient medium has a volume that is about 30% or less of the volume of the bioreactor, such as about 40% or less of the volume of the bioreactor, such as about 50% or less of the volume of the bioreactor, such as about 60% or less of the volume of the bioreactor, such as about 66% or less of the volume of the bioreactor, such as about 70% or less of the volume of the bioreactor, and, in one aspect, a volume of the nutrient medium may be placed in the bioreactor such that the nutrient medium has a volume of about 60% to about 70% of the volume of the bioreactor.

[0048] Nonetheless, in one aspect, microcarriers may also be present in the bioreactor in addition to the nutrient medium prior to inoculating the bioreactor. In one aspect, the microcarriers may be introduced into the bioreactor along with the nutrient medium, or may be added after the nutrient medium but prior to inoculation. In a further aspect, the above discussed volume of nutrient media may be present in the bioreactor, and the microcarriers may be added after the initial volume of nutrient media but may be incorporated as part of a second volume of nutrient media. In such an aspect, the second volume of nutrient media containing the microcarriers may be about 10% or less of the volume of the bioreactor, such as about 15% or less of the volume of the bioreactor, such as about 20% or less of the volume of the bioreactor, such as about 25% or less of the volume of the bioreactor, such as about 30% or less of the volume of the bioreactor, such as about 33% or less of the volume of the bioreactor, such as about 35% or less of the volume of the bioreactor, and, in one aspect, a volume of the nutrient medium may be placed in the bioreactor such that the nutrient medium has a volume of about 30% to about 40% of the volume of the bioreactor.

[0049] Regardless of the manner in which the microcarrier are introduced, in one aspect, microcarriers are added to the bioreactor to promote cell growth. For instance, cells can adhere to the surface of the microcarriers for further growth and propagation. In this manner, the microcarriers can provide greater surface area for cell culture growth within the reactor. In fact, some anchorage-dependent cells, such as certain animal cells, need to attach to a surface in order to grow and divide. In some systems, the microcarriers are suspended within a nutrient medium caused by

general agitation prior to, during, and/or after introduction to the bioreactor, which optimizes and maximizes the growing conditions within the bioreactor system.

[0050] Microcarriers can be made from various different materials, including polymers. The microcarriers can have any suitable shape and, in some applications, comprise round beads. In one aspect, microcarriers can generally have a median particle size of from about 50 μm to about 350 μm , such as from about 75 μm to about 300 μm , such as from about 100 μm to about 250 μm , such as from about 125 μm to about 225 μm , or any ranges or values therebetween. Previously, it was believed that small microcarriers (e.g. about 90-150 μm) were necessary for optimal expansion. However, the present disclosure has unexpectedly found that larger microcarriers (e.g. greater than 125 μm) may be used in combination with the process described herein, and yield expansion results, as good as, or better than results obtained with small microcarriers. Therefore, in one aspect, the microcarriers have a median particle size of about 125 μm or greater, such as about 150 μm or greater, such as about 175 μm or greater, such as about 200 μm or greater, such as about 210 μm or greater, such as about 350 μm or less, such as about 325 μm or less, such as about 300 μm or less, such as about 275 μm or less, such as about 250 μm or less, or any ranges or values therebetween. This provides a further benefit as small microcarriers are difficult to obtain, often requiring specialized equipment, thus larger particle sizes allow greater flexibility in scale-up of end-to-end expansion platforms.

[0051] Furthermore, in one aspect, the microcarriers may also be coated with a nutrient medium prior to introduction to a bioreactor and/or suspension in a nutrient medium. Particularly, the present disclosure has found that iPSCs showed improved growth and expansion when used with coated microcarriers as compared to uncoated microcarriers. Thus, in one aspect, the microcarriers may be coated with a nutrient matrix as discussed, such as a nutrient matrix as discussed above. Furthermore, in one aspect, the microcarriers may be coated in the same medium in which they are (or will be) suspended, or alternatively, may be coated in a different medium than the nutrient medium in which they will be supported. In yet a further aspect, the medium may be largely the same for coating and the support medium, but the coating medium and/or support medium may have one or more different additives.

[0052] Notwithstanding the nutrient medium and microcarriers selected, the bioreactor may be inoculated with cells as discussed above at a seeding density of about 0.01×10^6 cells/cm² to about 0.2×10^6 cells/cm², such as about 0.02×10^6 cells/cm² to about 0.15×10^6 cells/cm², such as about 0.03×10^6 cells/cm² to about 0.1×10^6 cells/cm², such as about 0.04×10^6 cells/cm² to about 0.07×10^6 cells/cm². Particularly, as discussed above, it was previously believed that a high seeding density of 0.2×10^6 cells/cm² was necessary for a 3 L or larger bioreactor to yield good expansion results. However, as will be discussed in greater detail below in regards to Figs. 4 and 5, the present disclosure has found that small seeding densities (e.g. lower than 0.2×10^6 cells/cm²) may be used in conjunction with the present disclosure, and yield excellent expansion results.

[0053] For instance, the present disclosure has found that low seeding densities may actually allow for higher fold expansion than higher seeding densities, such as a fold expansion of about 50 times or greater, such as about 60 times or greater, such as about 70 times or greater, such as about 80 times or greater, such as about 90 times or greater, such as about 100 times or greater, such as, in one aspect, about 50 times to about 120 times, such as about 60 times to about 100 times, such as about 70 times to about 95 times, such as about 80 times to about 90 times, or any ranges or values therebetween. Furthermore, the present disclosure has found that, unexpectedly, the expansion may take less time than an incubation that begins with a higher seeding density. For instance, the above expansions may take place in about 7 to about 18 days, such as about 8 to about 16 such as about 9 to about 14 days, and in one aspect, may reach a desired expansion (or seeding density) at a time less than a platform seeded with a high seeding density.

[0054] As discussed above, in one aspect, after the nutrient media, microcarriers, and inoculum have been introduced to the bioreactor, the contents of the bioreactor may be subjected to agitation. In one aspect, the bioreactor may be subjected to continuous gentle agitation at about 25 rpm to about 125 rpm, such as about 35 rpm to about 110 rpm, such as about 40 rpm to about 100 rpm, such as about 45 rpm to about 95 rpm, such as about 50 rpm to about 90 rpm, or any ranges or values therebetween. However, in a further aspect, the present disclosure has found that cell expansion may be further improved by a stepped agitation based upon cell density. For instance, in one aspect, the agitation may be increased every other day, such as every third day, such as every fourth day, such as every fifth day, by

increasing the rpms by at least about 5 rpms, such as at least about 10 rpms, such as at least about 15 rpms, such as at least about 20 rpms, such as at least about 25 rpms, such as about 30 rpms or less.

[0055] Additionally or alternatively, the increase in rpms may be based upon a cell density measurement. For instance, in one aspect, the initial agitation speed may be set to about 25 rpm to about 75 rpm, such as about 35 rpm to about 65 rpm, such as about 40 rpm to about 60 rpm, such as about 45 rpm to about 55 rpm. Cell density measurements may be conducted, and when a cell density reaches about about 1×10^5 cells/cm² to about 10×10^5 cells/cm², such as about 3×10^5 cells/cm² to about 8×10^5 cells/cm², such as about 5×10^5 cells/cm² to about 7×10^5 cells/cm², an agitation speed may be increased by about 5 rpms, such as at least about 10 rpms, such as at least about 15 rpms, such as at least about 20 rpms, such as at least about 25 rpms, such as about 30 rpms or less.

[0056] Furthermore, in one aspect, after the agitation speed may be increased at least a second time. For instance, cell density measurements may be conducted again (or continuously conducted), and when a cell density reaches about about 4×10^5 cells/cm² to about 5×10^6 cells/cm², such as about 4.5×10^5 cells/cm² to about 4×10^6 cells/cm², such as about 5×10^5 cells/cm² to about 3×10^6 cells/cm², an agitation speed may be increased again by about 5 rpms, such as at least about 10 rpms, such as at least about 15 rpms, such as at least about 20 rpms, such as at least about 25 rpms, such as about 30 rpms or less.

[0057] In one aspect, the present disclosure has also found that discontinuous agitation on seeding day (first 24 hours of incubation) may further improve cell viability and expansion. Furthermore, the present disclosure has found that the discontinuous agitation may also be cascading agitation, such that earlier agitation is shorter, with increasing length of agitation and decreasing rest between agitation as time progresses. For instance, please refer to the characterization curve in 5.20.3 below. In such an aspect, the discontinuous and/or discontinuous cascading agitation may take place for the first 24 hours or less after inoculation, such as about 20 hours or less, such as about 18 hours or less, such as about 14 hours or less, such as about 10 hours or less after inoculation.

[0058] Nonetheless, when a desired cell density is reached, the expanded cells may be harvested 110. Namely, in one aspect, the expanded cells may be passaged and separated from the microcarriers by a non-enzymatic passaging

solution, which may be the same passaging solution as discussed above, or may be a second passaging solution. Additionally, it should be understood that the passaging solution as discussed above may also include a kinase inhibitor. Furthermore, in one aspect, the passaging solution may also be combined with a nutrient media for passaging the cells from the bioreactor to the harvesting bag 110. Regardless, in one aspect, the cells are separated from the microcarriers by using an appropriate passaging solution, and are passed through a mesh having a mesh size selected to catch the microcarriers while allowing the cells to proceed through tubing to the harvest bag. For instance, in one aspect, the harvest bag assembly may have a mesh having a mesh size of about 10 μm to about 100 μm , such as about 25 μm to about 75 μm , such as about 50 μm to about 70 μm , or any ranges or values therebetween.

[0059] After the expanded cells have been harvested, the cells may be concentrated 112, such as by centrifugation. In one aspect, a flow rate through the centrifuge is selected based upon the formation of a fluidized bed. For instance, a flow rate may be optimized in order to minimize the time needed to establish the fluidized bed, maximize cell recover, and maintain cell viability and proliferation. Particularly, the present disclosure has found that cell retention and viability may be increased by establishing a fluidized bed in a short amount of time (such as about 15 minutes or less, such as from about 9 to about 13 minutes, such as about 10 minutes to about 12 minutes, in one aspect), and by minimizing a percentage of cells escaping the fluidized bed. For instance, in one aspect, the optimized fluidized bed may retain about 70% or greater of the cells, such as about 80% or greater, such as about 90% or greater of the cells entering the fluidized bed.

[0060] Nonetheless, after concentration, the cells may be filled and 114 and preserved by cryopreservation as may be known in the art.

[0061] While passaging has been discussed during several steps of Fig. 1, it should be understood and acknowledged that, unexpectedly, no passaging is needed during the incubation time, namely that greater than ten-fold expansion can be achieved in a continuous suspension culture according to the present disclosure.

[0062] Furthermore, as mentioned above, while 2D seed train steps 104 and 106 have been discussed in regards to Fig. 1, it should be understood that the present disclosure has also found that 3D seed train cells formed according to the present disclosure may be used to directly inoculate the bioreactor 108. Thus, in one

aspect, steps 104 and 106 may be eliminated, and instead, cryopreserved cells 116 may be used as cryopreserved cells 102, and placed directly into bioreactor step 108. This finding is important for continued scale up of the platform, as larger end-to-end platforms (such as larger volume platforms) require larger and larger numbers of cells for inoculation. Therefore, a process for producing 3D seed train cells enables continued growth of scale-up, as the number of cells produced via a 3L end-to-end platform far exceed 2D seed train production over the same time period.

[0063] For instance, the present disclosure has found that an end-to-end platform using a process according to the present disclosure may yield about 1 million cells/mL to about 5 million cells/mL, such as about 1.5 million cells/mL to about 4.5 million cells/mL, such as about 2 million cells/mL to about 4 million cells/mL. Additionally, the present disclosure has found that the process and platform according to the present disclosure may exhibit a cell retention after concentration of about 70% or greater, such as about 75% or greater, such as about 80% or greater, such as about 85% or greater, such as about 90% or greater. This finding also provides a further benefit, as 2D seed train provides high risk of contamination in addition to being time consuming and difficult. Therefore, direct inoculation with 3D seed train may also improve a lowered risk of contamination.

[0064] Additionally, the present disclosure has found that the end-to-end platform may be configured to be a closed system, and, in one aspect, may use single use vessels and tubing. Therefore, the end-to-end platform may further lower risk of contamination.

[0065] Furthermore, while the discussion has thus far focused on human pluripotent stem cells, it should be understood that other appropriate cells may be selected to undergo expansion according to the process and platform discussed herein. Additionally, as may be understood by one having skill in the art, the iPSCs discussed herein may be used as intermediates for any number of cells, as, will be discussed in greater detail below, the iPSCs expanded herein show excellent viability and differentiation.

[0066] Nonetheless, further aspects of the present disclosure will now be discussed in regards to Figs. 2-47 and the exemplary standard operating procedure.

[0067] Unless otherwise noted, Figs. 2-47, and the examples underlying these figures, utilized the following materials and methods:

L7™ hPSC culture system

[0068] Lonza L7™ culture system was developed for culturing hESCs and hiPSCs in feeder-free environment, and allows feeding on an every-other-day media change schedule. The culture system is comprised of recombinant, xeno-free and defined L7™ hPSC Matrix (Lonza, FP-5020) to enable cell attachment, xeno-free L7™ hPSC basal medium, xeno-free L7™ hPSC medium supplement, and non-enzymatic passaging solutions: L7™ hPSC passaging solution (yields cell clumps, Lonza, FP-5013) or F3 hPSC passaging solution (yields single cells). The L7™ hPSC basal medium used in the work described herein was modified by replacing native, animal-based components with respective recombinant components. It is referred to as L7™ TFO2 hPSC basal medium herein.

Human iPSC lines

[0069] The human LiPSC18R iPSC line was generated from CD34+ cord blood cells as previously described (see, e.g. Baghbaderani, B. A. *et al.* Detailed Characterization of Human Induced Pluripotent Stem Cells Manufactured for Therapeutic Applications. *Stem Cell Rev. Reports* (2016) doi:10.1007/s12015-016-9662-8). RTiPSC3B and RTiPSC4i were generated from human peripheral blood mononuclear cells (PBMNCs, Lonza, CC-2702) of two different donors. Cryopreserved PBMNCs were thawed and cultured for six days in a priming medium comprised of an animal-free HPGM™ (Hematopoietic Progenitor Growth Medium, equivalent to Lonza, PT-3926, where native components were replaced with the respective recombinant ones), supplemented with 100 ng/mL recombinant human (rh) stem cell factor (SCF) (PeproTech, AF-300-07), 40 ng/mL insulin-like growth factor (IGF)-1 (PeproTech, AF-100-11), 10 ng/mL Interleukin (IL)-3 (PeproTech, AF-200-03), 1 μM Dexamethasone (Sigma, D1756), 100 μg/mL holo-transferrin (R&D Systems, 2914-HT) and 200 μM 1-Thioglycerol (Sigma, M6145). The PBMNCs were seeded in 6-well plates (Corning, 353046) at a density of $2-4 \times 10^6$ cells/mL. On day 3, cells were collected, counted and seeded in a fresh priming medium at a density of $0.5-1 \times 10^6$ cells/mL. On day 6, cells were collected, and cellular reprogramming was performed.

[0070] To reprogram the cells, 1×10^6 PBMNCs were nucleofected with the episomal plasmids pCE-hOCT3/4, pCE-hSK, pCE-hUL, pCE-mP53DD and pCXB-EBNA-1 [37]. Nucleofection was performed using the 4D-Nucleofector™ System and P3 solution Kit (Lonza, V4XP-3012). After nucleofection, the cells were plated onto 6-well plates pre-coated with L7™ hPSC Matrix, in priming medium containing 0.5mM

Sodium Butyrate (Stemgent, 04-0005) to enhance reprogramming efficiency. Plates were placed in a 37°C humidified incubator (5% CO₂ and 3% O₂). Two days post plating, L7™ hPSC medium was added to the wells without removing the priming media (1:1 ratio). On day 4, the media was aspirated and fresh L7™ hPSC medium, containing 0.5 mM Sodium Butyrate was added. Media change was performed in an every-other-day manner, and cells were incubated in a 37°C humidified incubator (5% CO₂ and 3% O₂) until hiPSC colonies formed and were isolated for further expansion and characterization. These iPSC lines were characterized, showing normal karyotype, expression of key hPSC-associated markers, and demonstrating the potential to differentiate to cells of the three germ layers.

Culturing hiPSCs in 2D

[0071] Human iPSCs were cultured in 2D for the purpose of expanding cells for inoculation in a suspension vessel (spinner flask or stirred tank bioreactor) and characterization following expansion in suspension. hiPSCs were cultured in Lonza L7™ hPSC culture system using the animal-free L7™ TFO2 media and xeno-free L7™ hPSC media supplement. Cells maintained in culture were passaged and harvested either as cell clumps by L7™ hPSC Passaging solution (Lonza, FP-5013) or as single cells with F3 passaging solution to yield single cells and supplemented with 10 µM Y27632 (Stemgent, 04-0012) at plating.

[0072] For the culture of the 2D seed train prior to inoculation in a 3 L bioreactor, human iPSCs were thawed and plated onto L7™ hPSC matrix-coated T-75 culture flask and maintained in L7™ TFO2 media at a cell density of 0.02-0.04 x 10⁶ live cells/cm². When the 2D culture reached 70-80% confluence, iPSC colonies were dissociated into cell clumps using the L7™ hPSC Passaging Solution and plated onto a 1-layer CellStack (Corning, 05-539-094) at a cell density range of 0.02-0.03 x 10⁶ live cells/cm². When the 2D culture reached 70-80% confluence, iPSC colonies were dissociated into cell clumps using the L7™ hPSC Passaging solution and 62-120 x 10⁶ live cells were inoculated in a 3 L bioreactor. The NucleoCounter NC-200 (Chemometec, Denmark) was used to assess the number and viability of the bioreactor cell inoculum.

Microcarrier coating

[0073] Plastic microcarriers (MCs) (SoloHill brand polystyrene 90-150 µm, Pall Corporation, P-215-020 or 125-212 µm, Pall Corporation, P-221-020) were suspended in Dulbecco's Phosphate-Buffered Saline with calcium and magnesium

(DPBS+/, Lonza, 17-513F) and coated with L7™ hPSC Matrix. MCs and L7™ hPSC Matrix were incubated for 2 hours at 37°C. The DPBS+/+ solution was then aspirated, and the MCs were re-suspended in L7™ TFO2 hPSC basal medium and allowed to incubate overnight at room temperature with agitation. For expansion in 125 mL spinner flasks, 600 mg of MCs were incubated with 540 µg of L7™ hPSC Matrix. For expansion in a 3 L stirred tank bioreactor, 20 g of MCs were incubated with 18 mg of L7™ hPSC Matrix.

Culturing hiPSCs in a spinner flask

[0074] Human iPSCs were harvested from 2D as cell clumps or thawed directly as single cells into a 125 mL spinner flask (Corning, 3152) containing 100 mL L7™ media and L7™ hPSC Matrix-coated microcarriers (MCs). hiPSCs cultured in 2D were passaged with either L7™ hPSC Passaging solution to generate cell clumps or F3 passaging solution to dissociate colonies to single cells. The spinner flask was inoculated with either 0.04×10^6 cells/mL of cell clumps or cryopreserved single cells. If single cells were inoculated, media was supplemented with 10 µM Y27632 (Stemgent, 04-0012). Spinner flask cultures were incubated in a 37°C humidified incubator containing 5% CO₂ overnight. After 24 hours, the spinner flask was placed on a magnetic stirring plate with an agitation speed of 25 RPM. The agitation speed was increased as needed to ensure hiPSC-MCs remain in suspension. The maximum agitation speed applied to support cell densities $>2 \times 10^6$ cells/mL was 90 RPM. Media was changed in an every-other-day manner using L7™ TFO2 media with xeno-free L7™ hPSC media supplement. To determine growth of hiPSCs in culture, 5 mL samples were obtained and hiPSCs were dissociated from the microcarriers using the F3 hPSC Passaging solution to generate single cells. The NucleoCounter NC-200 (Chemometec, Denmark) was used to determine cell number and viability.

hPSC expansion in stirred tank bioreactors

[0075] The BioBlu single-use bioreactor vessel was set up according to manufacturer's instructions (Eppendorf, 1386000300). Briefly, the 3 L vessel was equipped with probes required for online monitoring (Mettler Toledo) of key parameters including percentage of dissolved oxygen (DO), pH and temperature. The bioreactor was controlled using a G3 Lab Universal controller (Thermo Fisher Scientific). Prior to inoculation, L7™ hPSC Matrix-coated plastic microcarriers were introduced and the vessel was calibrated as previously described [16] with L7™

TFO2 medium supplemented with L7™ hPSC medium supplement. The 3 L vessel was inoculated at day 0 with either 62-120 x 10⁶ 2D cultured cells in cell clumps (0.02-0.04 x 10⁶ cells/mL) or 204 x 10⁶ cryopreserved single cells at 37°C with initial agitation rate set to 50 RPM. On day 1, perfusion with fresh L7™ TFO2 supplemented medium was initiated at a rate of one Vessel Volume per Day (VVD). Perfusion was performed using a proprietary designed microcarrier retention filter. To monitor the changes in key metabolites, 5 mL samples were taken from the bioreactor at various time points along the run. Offline monitoring to determine changes in parameters such as pH and key nutrients was performed using the BioProfile FLEX Analyzer (Nova Biomedical). To determine cell growth and fold expansion, 15 mL samples were taken in duplicates at various time points along the run and hiPSCs were dissociated from the microcarriers using the F3 hPSC passaging solution to generate single cells. The Nucleocounter NC-200 (Chemometec, Denmark) was used to measure the cell number and viability.

Harvest of hiPSCs from stirred tank bioreactor

[0076] Human iPSCs in the 3 L bioreactor were collected upon reaching approximately >2 x 10⁶ cells/mL. With continuous agitation, the medium was first removed from the vessel. Warm F3 passaging solution was introduced to the vessel with continuous agitation. To verify detachment of hiPSCs from microcarriers, a 5 mL sample was obtained after 25-30 minutes of incubation with F3 passaging solution. The solution containing single cell hiPSCs and microcarrier was then transferred through a 30-65 µm pore sized filtration bag (Flex Concepts, FCC03475.01). The single cells were ultimately transferred into a 3 L bag containing L7™ TFO2 medium supplemented with L7™ hPSC medium supplement. Harvested cells were subjected to various assays including performance evaluation, characterization, downstream processing, and cryopreservation. In bioreactor runs where the intent was to concentrate and cryopreserve the cells for future use, 10 µM Y27632 (Stemgent, 04-0012) was added to the L7™ TFO2 media after treatment with F3 passaging solution.

Downstream processing: flow rate optimization for fluidized bed formation

[0077] A kSep (Sartorius) was fitted with a 400.50 rotor, which functions as a 1/3.5 scale-down model for the kSep400. The associated 400.50 single-use kits (chamber set and valve set) were then installed. A 3 L PSC suspension was harvested from a bioreactor and connected as the feed source. A solution of

PlasmaLyte-A (Baxter) and (0.25%) human serum albumin (Octapharma) was used to prime the system and wash the cells. A static centrifugation speed of 782 g was used. To optimize the formation of the fluidized bed, 3 flow rates (25, 30, 35 mL/min) were tested in increasing order. Prior to each run, the feed source was sampled in triplicate to determine cell density going into the kSep. For the entirety of the concentration process, 5 mL samples were drawn from the stream exiting the kSep chamber and tested using the NucleoCounter NC-200 (Chemometec, Denmark) to monitor the amount of cells escaping the fluidized bed. After 1 L of cell suspension was processed, the kSep was stopped, the chamber was emptied, and the concentrated cells were collected. The kSep was reset, the tubing and chambers were purged, and the process was repeated until all flow rates had been tested and the feed source was depleted.

Downstream processing: hPSC concentration post full harvest

[0078] A bag containing the filtered PSC suspension harvested from the bioreactor was sampled in triplicate, and the viabilities and cell densities were then determined using a NucleoCounter NC-200. The average viable cell density (VCD) was used to calculate the concentrated volume that would be harvested by the kSep using Equation 1.

$$\text{Concentrated Vol} = \frac{(\text{Feed VCD}) * (\text{Feed Vol})}{\text{Target Concentrated VCD}} \quad \text{Equation 1}$$

The kSep400 (Sartorius) was equipped with its respective single-use kits (chamber set and valve set). A 10 L bag of DPBS (-/-) (Lonza) was used to prime the system (no wash step was performed). The feed bag was then welded onto the kSep valve set. The process recipe primed the system, ramped the centrifuge to 1000 g, then pumped cell suspension into 1 chamber at a rate of 120 mL/min (3.5x the value determined in the optimization experiment, rounded down). These settings were maintained until the entirety of the feed was processed by the kSep. Periodically throughout the process, 5 mL samples were drawn from the stream exiting the kSep chamber and were tested using the NucleoCounter NC-200 to monitor the amount of cells escaping the fluidized bed. After the feed bag emptied, the concentrated cells were harvested. The volume of the concentrate was verified, and samples were taken to determine viability and cell density. The remaining concentrate was cryopreserved.

Cryopreservation

[0079] Human iPSCs were suspended in cryopreservation solution (CS10, Biolife Solutions Inc, 210102) containing 10 μ M of Y-27632 (Stemgent, 04-0012). Cryovials were cryopreserved by Cryomed™ Controlled-rate Freezer (Thermo Fisher Scientific, Model 7456) and subsequently stored in liquid nitrogen until use.

Immunofluorescence staining

[0080] Cells cultured in 2D were fixed with 4% paraformaldehyde (Santa Cruz, SC 281692) blocked with blocking solution comprised of 10% donkey serum and 0.1% Triton X-100 in PBS-/- . The cells were incubated with primary antibodies followed by secondary antibody incubation and DAPI staining. Immunofluorescence was observed using Olympus IX73 microscope. The following primary antibodies were used to detect hPSC-associated markers: OCT4/POU5F1 (Abcam, ab19857), NANOG (R&D systems, AF1997), TRA-1-81 (Stemgent, 09-0011), TRA-1-60 (Millipore, MAB4360), SSEA-4 (Millipore, MAB4304). The following primary antibodies were used to detect expression of germ-layer specific markers: SOX17 (R&D systems, AF1924), FOXA2 (Abcam, Ab108422), NESTIN (R&D systems, MAB1259), PAX6 (Biolegend, #901301), α -actinin (Sigma, A7811) and SMA (Millipore, CBL171).

Flow cytometry

[0081] Quantitative detection of hPSC-associated markers was performed using flow cytometry as previously described (see, e.g. Shafa, M., Panchalingam, K. M., Walsh, T., Richardson, T. & Baghbaderani, B. A. Computational fluid dynamics modeling, a novel, and effective approach for developing scalable cell therapy manufacturing processes. *Biotechnol. Bioeng.* (2019) doi:10.1002/bit.27159; Baghbaderani, B. A. *et al.* CGMP-manufactured human induced pluripotent stem cells are available for pre-clinical and clinical applications. *Stem Cell Reports* (2015) doi:10.1016/j.stemcr.2015.08.015; Shafa, M., Yang, F., Fellner, T., Rao, M. S. & Baghbaderani, B. A. Human-induced pluripotent stem cells manufactured using a current good manufacturing practice-compliant process differentiate into clinically relevant cells from three germ layers. *Front. Med.* (2018) doi:10.3389/fmed.2018.00069). Briefly, single cells were live-stained for the cell surface markers: TRA-1-81 (BD Biosciences, #560161), TRA-1-60 (BD Biosciences, #560884) and SSEA-4 (BD Biosciences, #560126). Cells were also fixed, permeabilized and stained for OCT4/POU5F1 (Cell Signaling, #5177S). The samples were processed using either FACSCanto™ II (Becton Dickinson) or the

FACSCelesta™ (Becton Dickinson), and data was acquired using the BD FACSDiva Software followed by analysis using FlowJo v10 software (FlowJo).

Alkaline phosphatase staining

[0082] Alkaline phosphatase staining was performed using StemAb Alkaline Phosphatase Staining Kit II (Stemgent, 00-0055), following manufacturer instructions

Karyotyping

[0083] Live cells were plated onto a T-25 flask, pre-coated with L7™ hPSC Matrix and maintained in L7™ TFO2 hPSC medium. Karyotype analysis (G-banding) was performed at LabCorp (Santa Fe, New Mexico).

Embryoid Body formation

[0084] Embryoid body (EB) formation was performed by plating single cells in AggreWell800 (Stem Cell Technologies, 34811) in medium containing Knockout DMEM F-12 (Gibco, 12660-012), 20% Knockout Serum (Gibco, 10828-028), non-essential amino acids-1x (Gibco, 11140-050) and Glutamax-1x (Gibco, 35050-061). Medium was changed 48 hours later and thereafter till day 7 in an every-other-day mode. On day 7, EB spheres were collected and plated onto plates coated with 0.1% Gelatin (Millipore, ES-006-B) and medium containing DMEM (Gibco 11965-092), 20% FBS (Gibco, SH30071), non-essential amino acids-1x (Gibco, 11140-050) and Glutamax-1x (Gibco, 35050-061). Medium was changed every other day for 7 days. On day 7 post plating, EBs were fixed with 4% paraformaldehyde (Santa Cruz, SC-281692), and stained for detection of cells of the three germ layers with antibodies for the following antigens: SOX17 (R&D Systems, AF1924) for endoderm, PAX6 (BioLegend, PRB-278P) for ectoderm, and SMA (Millipore, CBL171) for mesoderm.

Definitive Endoderm differentiation

[0085] Human iPSCs were differentiated into definitive endoderm (DE) as previously described [39]. Briefly, 0.25×10^6 single cells were seeded onto L7™ hPSC Matrix-coated 24-well plates on day 0 with L7™ TFO2 media containing L7™ hPSC medium supplement and 10 μ M Y27632 (Stemgent, 04-0012). On day 1, the STEMdiff™ Definitive Endoderm Kit (Stem Cell Technologies, 05110) was used to induce DE differentiation according to manufacturer's protocol. The cells were washed, fixed on day 5 and stained for DE-specific markers SOX17 (R&D systems, AF1924) and FOXA2 (Abcam, Ab108422).

Neural stem cell differentiation

[0086] Human iPSCs were differentiated into neural stem cells (NSCs) as previously described [39]. In brief, 0.25×10^6 single cells were seeded onto L7™ hPSC Matrix-coated 6-well plates on day 0 with L7™ TFO2 media containing L7™ hPSC medium supplement and 10 μM Y27632 (Stemgent, 04-0012). On day 1, the culture medium was changed with Neural Induction Medium (NIM) composed of B-27 Plus Neuronal Culture System (Gibco, A3653401) with 1X Glutamax (Gibco, 35050-061), 4 μM CHIR99021 (Stemgent, 04-0004-02), 3 μM SB431542 (Stemgent 04-0010-10) and 10 ng/mL hLIF (Peprotech, 300-00-250). NIM was changed in an every-other-day manner. When the cells reach 95-100% confluence, the cells were passaged as single cells using the F3 passaging solution. 1×10^6 and 0.25×10^6 cells were seeded onto 6- and 24- well plates, respectively (NSC-P1). NIM was replenished the following day and every-other-day till cell were fixed and stained for neural progenitor markers, NESTIN (R&D systems, MAB1259) and PAX6 (Biolegend, 901301). The cell culture plates used for NSC culture were pre-coated by incubating with 20 $\mu\text{g/mL}$ Poly-L-ornithine (Sigma P4957) in sterile cell culture grade water (Lonza 17-524F) for 2 hours at 37°C. The plates were then washed with calcium and magnesium free DPBS (DPBS-/-) (Lonza, 17-512F), followed by a 1-hour incubation at 37°C with 15 $\mu\text{g/mL}$ Laminin (Sigma, 11243217001) re-suspended in DMEM/F12 (Thermo Fisher Scientific, 11330032) or PBS -/- (Lonza, 17-516F).

Cardiac differentiation

[0087] Human iPSCs were differentiated into cardiomyocytes using the Gsk3 inhibitor and Wnt inhibitor (GiWi) protocol as previously described. (see, e.g. Lian, X. *et al.* Directed cardiomyocyte differentiation from human pluripotent stem cells by modulating Wnt/ β -catenin signaling under fully defined conditions. *Nat. Protoc.* (2013) doi:10.1038/nprot.2012.150; Lian, X. *et al.* Robust cardiomyocyte differentiation from human pluripotent stem cells via temporal modulation of canonical Wnt signaling. *Proc. Natl. Acad. Sci. U. S. A.* (2012) doi:10.1073/pnas.1200250109; Zhang, J. *et al.* Functional cardiomyocytes derived from human induced pluripotent stem cells. *Circ. Res.* (2009) doi:10.1161/CIRCRESAHA.108.192237). Briefly, 1×10^6 single cells/mL were seeded onto L7™ hPSC Matrix-coated 6-well plates in the presence of 10 μM Y27632 (Stemgent, 04-0012). Cells were maintained with L7™ TFO2 media containing L7™ hPSC medium supplement until confluence, during which time the cells were treated with 6-12 μM CHIR99021 (Tocris Bioscience, 4423) in RPMI/B27-insulin medium (day 0). After 24 hours, the medium was changed to

fresh RPMI/B27-insulin (day 1). 5-7.5 μ M IWP2 (Tocris Bioscience, 3533) was added on day 3, with fresh medium added on day 5. From day 7, cells were maintained in RPMI/B27 medium with medium changed in an every-other-day manner until spontaneous contraction was observed. Thereafter, iPSC-derived cardiomyocytes were dissociated as single cells using 10X TrypLE™ Select Enzyme (Thermo Fisher Scientific, 12563011) for 5-10 minutes at 37°C. Cells were plated on 24-well plates coated with 0.1% gelatin (Millipore, ES-006-B) in EB20 medium, which is comprised of DMEM/F12 (Thermo Fisher Scientific, 11330032), FBS (GE Healthcare, SH30071.01), MEM Non-Essential Amino Acids (Thermo Fisher Scientific, 11140050), GlutaMAX™ Supplement (Thermo Fisher Scientific, 35050061) and 2-Mercaptoethanol (Thermo Fisher Scientific, 21985023). The cells were fixed and stained for mesoderm-specific markers, α -ACTININ (Sigma, A7811) and smooth muscle actin (SMA) (Millipore, CBL171).

Figures and Examples

[0088] Referring first to Fig. 2, and as discussed above, it is shown that the process according to the present disclosure yields fold expansion of greater than 10 over a seventeen-day period. For instance, the hPSC culture system discussed herein, which, in this example, includes the L7™ TFO2 hPSC medium and matrix, supported the expansion of the hiPSCs tested in manually operated, open, spinner flasks and in automated, closed, stirred tank bioreactors. Particularly, RTiPSC4i and RTiPSC3B cells cultured in a xeno-free nutrient media supplemented with growth factors and cytokines optimized for long-term growth, were shown to exhibit excellent growth and expansion. Thus, in this example, L7™ TFO2 hPSC medium supported human iPSC generation from somatic cells such as fibroblast and PBMNCs. Furthermore, while the data is not shown, maintenance of various hESC and hiPSC lines in conventional 2D cell culture platforms, which utilize cell culture vessels coated with L7™ hPSC Matrix to support cell attachment, was also supported. To assess the ability of L7™ TFO2 hPSC media to support growth of hPSCs in suspension, 2D cultured RTiPSC3B and RTiPSC4i cells were harvested as cell clumps and inoculated in L7™ TFO2 hPSC medium at a cell density of 0.2×10^6 cells/mL, with microcarriers 90-150 μ m in diameter coated with L7™ hPSC Matrix. As indicated in Figure 2A and 2B, an initial decrease in cell number was observed during the first days in suspension followed by an increase in cell number, which reached $>2 \times 10^6$ cells/mL on day 17 (>10 -fold expansion). The results indicate that L7™ TFO2

media supports MC-based expansion of hPSCs in suspension and that that 10-fold expansion could be achieved in a continuous suspension culture over 17 days without the need for cell passaging.

[0089] As shown in Fig. 3, the present disclosure has found that, contrary to prior teaching, larger diameter microcarriers (MCs) support expansion of HPSCs as well as, if not better, than small diameter microcarriers. Spinner flasks were inoculated with 0.2×10^6 cells/mL of RTiPSC3B in the presence of 90-150 μ M (small) or 125-212 μ M (large) sized MCs coated with L7™ hPSC Matrix. Similar cell growth and expansion over 17 days was observed when using small and large sized MCs. In both conditions, cells reached $>2 \times 10^6$ cells/mL and >10 -fold expansion on a similar day during culture. These results validate the use of larger sized MCs for cell expansion.

[0090] In Figs. 4 and 5, the present disclosure has shown that, contrary to prior teaching, lower inoculation density does not compromise cell yield, and instead leads to higher fold expansion. To generate high cell numbers in suspension systems such as a 3 L bioreactor with an inoculum cell density of 0.2×10^6 cells/mL, would require 600×10^6 cells at inoculation. Spinner flasks were inoculated with RTiPSC4i cells at two different cell densities: 0.2×10^6 cells/mL and 0.04×10^6 cells/mL. The cells were cultured in suspension for 17 days and cell counts determined at various time points during the expansion period. Fig. 4 shows that comparable cell densities were achieved at both inoculum cell densities. The spinner flasks inoculated with a higher cell density resulted in 3×10^6 cells/mL, while inoculating with a lower cell density resulted in 2.5×10^6 cells/mL on day 17. Comparison of expansion fold results demonstrates that the higher density seeding resulted in ~ 15 -fold expansion by day 17, which is comparable to expansion fold described above in Fig. 2. However, the lower seeding density inoculum, which used five times fewer hiPSCs at inoculation, resulted in 90-fold expansion on day 17. This fold expansion is ~ 6 times higher than that obtained using the higher seeding density.

[0091] To confirm these findings with a different hiPSC line, the present disclosure inoculated RTiPSC3B cells at a cell density of 0.04×10^6 cells/mL with either small or large sized coated MCs. Fig. 5 demonstrated cell growth and fold expansion over 16 days. Cell yield reached $>1.6 \times 10^6$ cells/mL with expansion fold of >40 on either small or large sized MCs. Thus, the present disclosure has found that hiPSCs inoculated at lower cell densities are capable of achieving higher-fold

expansion, easing the burden of large-scale expansion in 2D cell culture platforms prior to inoculation in 3D suspension culture.

[0092] Referring next to Figs. 6 and 7, as discussed above the present disclosure has found that coating microcarriers in nutrient matrix may further enable hPSC attachment to the microcarriers. Cells were harvested from 2D cell culture using L7™ Passaging solution and seeded as cell clumps in spinner flasks at a density of 0.2×10^6 cells/mL. Both flasks contained microcarriers, where in one flask the microcarriers were coated with L7™ hPSC Matrix and in the other, the microcarriers were not coated. While cell viability on day 0 (inoculation day) was determined to be 85%, a cell count performed on day 3 revealed a decrease in cell number. This observation matches previous results for reduced cell density in the first days in suspension (Figs. 2 and 3). On day 7, however, cells that were seeded with L7™ hPSC Matrix-coated MCs showed both high viability (90%) and 2-fold expansion. Cells that were seeded with uncoated MCs failed to show growth and expansion. The results show that coating the MCs improves cell expansion. The experiment was repeated with a lower seeding cell density of 0.04×10^6 cells/mL. LiPSC18R cells were inoculated in a spinner flask with either coated or uncoated MCs. Monitoring cell growth over 7 days showed that expansion was minimal in the spinner flask where cells were incubated with uncoated MCs, compared to 10-fold expansion on day 7 in the spinner flask where cells were incubated with coated MCs.

[0093] To rule out the possibility that the cells expanded without MCs, RTiPSC4i cells were inoculated in spinner flasks with and without large sized MCs coated with L7™ hPSC Matrix as shown in Fig. 7. In the flask that had MCs, cell reached 70-fold expansion in 10 days, while no expansion was detected in the flask that did not have MCs.

[0094] Referring next to Figs. 8 and 9, the present disclosure has further found that the process described herein is scalable to larger bioreactors. The spinner flask experiments demonstrated that hiPSCs expanded in L7™ TFO2 media using L7™ hPSC Matrix-coated MCs resulted in high-fold expansion. To demonstrate scalability, a 3D expansion system in 1 L (data not shown) and 3 L stirred tank bioreactors were conducted. Ten 3 L bioreactor runs were performed using three different hiPSC lines harvested from 2D culture as cell clumps. Cells were inoculated at a cell density range of 0.02 - 0.04×10^6 cells/mL with L7™ hPSC Matrix-coated MCs (125-212 μ M) and maintained in L7™ TFO2 media, perfused at 1 vessel volume per day (VVD).

Cell counts performed on single cells released from the MCs revealed an expansion of 5 to 20-fold in the first 5-9 days, and additional >10 fold expansion onward, resulting in $>2 \times 10^6$ cells/mL (Fig. 8). An average 93-fold expansion within 9-16 days of culture across all three hiPSC cell lines was achieved in these culture conditions. Notably, although RTiPSC4i Run 2 used only 0.027×10^6 cells/mL at inoculation, approximately 80-fold expansion was still achieved in 11 days. This result supports the findings in the spinner flasks experiments, demonstrating that lower inoculum cell density does not compromise cell yield, supporting platform robustness. Cell viability along the various days of the bioreactors run was determined to be high (>85%, data not shown). Images of cell-MC samples taken from the bioreactor at various time points show cell expansion over time (Fig. 9).

[0095] Furthermore, referring to Fig. 10, various metabolites were monitored during incubation. Surprisingly, the present disclosure has found that iPSC cells may have excellent growth and expansion with lower than previously believed levels of dissolved oxygen. Nonetheless, key nutrients, such as glucose, and metabolites, such as lactate, were monitored during run. Figure 10 shows a decrease in glucose levels, corresponding to increased glucose consumption as the cells expand in culture. Glucose concentrations did not drop below 2.4 g/L, even when cell density in the bioreactor reached 3.05×10^6 cells/mL (LiPSC18R Run 2). Conversely, lactate production increased with a maximum concentration of 1.79 g/L seen (LiPSC18R Run 2). For the other cells lines, lactate levels did not exceed 1.6 g/L even for high cell densities of 5.6×10^6 cells/mL (RTiPSC3B) or 5.1×10^6 cells/mL (RTiPSC4i). Additionally, pH and dissolved oxygen (DO) were closely monitored in real-time using the TruBio DV Software from Finesse Solutions. Similarly to the nutrient levels, pH levels were affected by cell expansion. While the set point was 7.2, as cells expanded, pH levels dropped to ~6.8. Dissolved oxygen was set to 50% and maintained for the first few days of the run. As cell expanded, however, DO levels dropped and the Finesse controller could not maintain the set target. DO levels dropped to 30% for cell densities close to 2×10^6 cells/mL. For higher cell densities of $>4 \times 10^6$ cells/mL, DO levels were below 10%.

[0096] Previous studies have demonstrated that O₂ levels regulate hPSCs metabolic flux, but the expression of pluripotency and differentiation markers in hPSCs cultured in either 20% or 5% O₂ was unaltered. Moreover as will be discussed in greater detail below, no differences in proliferation were observed, suggesting that

low O₂ improves hPSC stemness. Others have also shown that 30% DO is the optimal condition to support hPSC expansion. In line with this study, we did not observe an adverse impact on the quality of cells harvested at cell densities of $\sim 2.5 \times 10^6$ cells/mL where DO levels remained >30 . Moreover, characterization of cells harvested from a 3 L bioreactor at a cell density of $>5 \times 10^6$ cells/mL, with corresponding DO levels of 10%, showed that the cells had normal karyotype, expressed hPSC-associated markers and were capable of differentiating into cells of the three germ layers. These findings suggest minimal impact of O₂ levels on the quality of cells expanded in the end-to-end platform discussed herein.

[0097] Furthermore, referring to Figs. 11-13, the present disclosure has found that the hPSCs formed according to the present disclosure exhibited excellent morphology and expression of hPSC-associated markers. Namely, cell harvest from the bioreactor was performed in a closed manner inside the bioreactor. Medium was pumped out, and F3 non-enzymatic passaging solution was pumped in to release the cells from the microcarriers. As a result of F3 passaging solution treatment, cells were released from the microcarriers as single cells. The resulting solution of single cells and microcarriers in F3 passaging solution were then transferred in a closed manner through a separation bag to separate the cells from the microcarriers. The cells passed through the filter bag directly into a collection bag containing L7™ TFO2 hPSC media. In order to assess the quality of expanded hiPSCs post-harvest from a bioreactor, the cells were characterized for morphology, hPSC-associated markers, validated their karyotype, and determined their pluripotency.

[0098] To assess morphology, hiPSCs on MCs or MC-released hiPSCs were plated onto 2D cell culture plates coated with L7™ hPSC Matrix. Fig. 11 shows that RTiPSC3B and LiPSC18R cells, cultured in 2D culture plates after harvest from a 3 L bioreactor, had a typical hPSC colony morphology, including defined edges and tightly packed cells with large nuclei and scant cytoplasm. Moreover, immunofluorescence staining of both cell lines shows qualitative expression of hPSC-associated markers (Figure 12), while flow cytometry results further validated that $>85\%$ of the iPSCs expanded in the bioreactor expressed hPSC-associated markers post-harvest (Figure 13). Karyotype analysis, reflected in Table 1 below, showed no genome abnormality in cells harvested from a bioreactor and cultured for one or more passages in 2D.

Table 1

Cell line	Passage number at inoculation	Bioreactor size	# of 2D passages post harvest	Cell processing before karyotyping	Karyotype
RTiPSC3B	P16	1L	P1	Expansion & harvest	Normal
RTiPSC3B	P16	1L	P1	Expansion & harvest	Normal
RTiPSC4i	P28	1L	P1	Expansion & harvest	Normal
RTiPSC3B	P211	1L	P30	Expansion, harvest, culture in 2D	Normal
RTiPSC3B	P22	3L	P2	Expansion & harvest	Normal
RTiPSC3B	P28	3L	P1	Expansion & harvest	Normal
RTiPSC4i	P31	3L	P1	Expansion & harvest	Normal
RTiPSC3B	P28	3L	P1	Expansion & harvest	Normal
RTiPSC3B	P26	3L	P1	Expansion & harvest	Normal
LiPSC18R	P26	3L	P1	Expansion & harvest	Normal
LiPSC3B1	P29	3L	P1	Expansion, harvest, concentration	Normal
LiPSC18R	P34	3L	P1	Expansion, harvest, concentration	Normal

[0099] Furthermore, as shown in Figs. 14 and 15, the potential of the expanded hiPSCs to differentiate into cells of the three germ layers was assessed either by embryoid body (EB) formation or by directed differentiation. Fig. 14 shows immunofluorescence staining images of plated EBs formed from RTiPSC3B cells expanded in a 3 L bioreactor. Positive detection of germ layer-specific markers demonstrates that cells expanded in a bioreactor retain their potential to give rise to cells of the three germ layers post-harvest. Directed differentiation of hiPSCs to definitive endoderm (DE, endoderm germ layer), neural stem cells (NSCs, ectoderm germ layer) and cardiomyocytes (CMs, mesoderm germ layer) was performed on RTiPSC3B and LiPSC18R cells after harvest from 3 L bioreactors. As shown in Fig. 15, immunostaining for germ-layer specific markers confirmed that the expanded cells retained pluripotency and capability to be directly differentiated to DE, NCSs and CMs. As described in Material and Methods section, immunostaining for CM-specific markers was performed after observing spontaneous contraction.

[00100] Referring next to Figs. 16 and 17, as the manufacture of cell therapies advances towards larger scale cultures in bioreactors, more cells will be used for inoculation and more cells will need to be processed after harvesting. Common existing treatment of iPSCs after a bioreactor harvest is to have an operator wash out the culture media, concentrate the cells via benchtop centrifugation, and then re-suspend in cryoprotectant. Moving towards larger scale GMP production, this open step is a critical contamination risk to the product and ultimately to the patient who would receive it, and is difficult to scale. One solution is to make use of continuous centrifugation devices, for example a kSep400 continuous centrifugation system.

[00101] Optimization of the flow rate during fluidized bed formation was defined as (1) minimizing the time needed to establish the fluidized bed, (2) maximizing cell recovery, and (3) maintaining cell viability and proliferation capabilities. The establishment of the fluidized bed is achieved when the majority of cells coming into the kSep chamber are retained, and thus the percent of escaping cells reaches a minimum. Quantitatively, this can be defined as the escape percent dropping below 10%, meaning the fluidized bed captures 90% or more of the incoming cells.

[00102] The 30 mL/min and 35 mL/min established the fluidized bed in 10-11 minutes, and the 25 mL/min flow rate established the bed after 13-14 minutes (Figure 6A). The cells from the 30 and 35 mL/min tests were taken for cell counts and culturing. The cell counts revealed that the cell viability was not negatively affected by the concentration process and that both protocols had recoveries $\geq 80\%$ (see Table 2 below). The flow rate of 35 mL/min was selected for concentration of iPSCs in the kSep 400.50. This flow rate was scaled up to 120 mL/min when moving into the kSep400.

Table 2

Flow Rate {mL/min}	Before kSep				After kSep				Total Cells Harvested	Recovery (%)
	Harvest volume (mL)	Viable cells into kSep (c)	Viable Cell Density (c/mL)	Viability (%)	Viable cells harvested (c)	Viable Cell Density (c/mL)	Viability (%)			
30	25	3.20E+09	2.94E+06	87.60	2.55E+09	1.02E+08	90%	2.84E+09	80%	
35	30	3.19E+09	3.11E+06	88.33	2.69E+09	8.95E+07	89%	3.02E+09	84%	

[00103] After establishing a possible flow rate (120 mL/min) for both the fluidized bed setting and the concentration steps, five bioreactor harvests were concentrated using the kSep400. For four of these runs, the waste stream exiting the kSep chamber was regularly sampled to monitor the formation and stability of the fluidized bed (Fig. 17). A fifth run was performed, but the formation of the fluidized bed was not monitored. In all four monitored runs, the fluidized bed formed within about 8 minutes (Fig. 17). Across all 5 runs, cell recovery was $> 90\%$ and any loss in viability was $\leq 1.3\%$ (see Table 3 below). It was possible to concentrate the cells up to 2.26×10^8 viable cells/mL. After concentration, the cells from each run were plated onto 2D and were subjected to quality testing (see discussion of Figs. 18-21 below). In all of the kSep400 runs, at the very end of continuous concentration, a slight uptick was observed in the percent of viable cells escaping the fluidized bed (up to an

additional 5%). It is unlikely that this uptick was due to exceeding chamber capacity; the same pattern observed in run 3 ($\sim 12 \times 10^9$ hiPSCs in the chamber) was observed in run 1 ($\sim 3 \times 10^9$ hiPSCs in the chamber). Without wishing to be bound by theory, it could have been due to cell settling in the feed bag, resulting in a sudden influx of concentrated cells (or cell clumps) that disturbed the fluidized bed.

Table 3

	Unit	Run 1	Run 2	Run 3	Run 4	Run 5
Pre-kSep VCD	v c/mL	9.27E+05	1.86E+06	3.40E+06	3.30E+06	1.88E+06
Pre-kSep Viability	%	78.3	90.3	92.5	88.3	88.1
Viable Cells into kSep	c	3.01E+09	6.07E+09	1.19E+10	9.12E+09	4.42E+09
Volume Processed	mL	3250	3265	3500	2760	2353
Post-kSep VCD	v c/mL	9.79E+07	7.88E+07	8.52E+07	2.26E+08	1.04E+08
Post-kSep Viability	%	86.6	89.9	91.3	93.0	86.8
Viable Cells Harvested	c	2.94E+09	5.51E+09	1.08E+10	9.05E+09	4.14E+09
Concentrated Volume	mL	30	70	127	40	40
Recovery	%	97%	91%	91%	99%	94%

[00104] Referring to Figs. 18-21, quality assessments of the expanded hiPSCs post kSep included cell attachment, morphology, hPSC-associated marker expression, karyotype and pluripotency. Post kSep, single cell hiPSCs (RTiPSC3B and LiPSC18R cell line) were plated in two different cell densities on 2D cell culture plates coated with L7™ hPSC Matrix. The cells, cultured in L7™ TFO2 medium, attached well and exhibited typical hPSC morphology (Fig. 18). Likewise, the cells expressed the hPSC markers as determined qualitatively by immunofluorescence staining and quantitatively by flow cytometry (Figs. 19 and 29, respectively).

[00105] To determine whether cells concentrated by kSep are also capable of giving rise to all three germ layers, directed differentiation of RTiPSC3B and LiPSC18R cells post kSep was performed. As shown in Fig. 21, cells post expansion in a bioreactor, harvested as single cells and concentrated by kSep were capable of directly differentiating into neural stem cells, as seen by positive staining for PAX6 and NESTIN; definitive endoderm, as shown by positive staining for FOXA2 and SOX17; and cardiomyocytes, as seen by positive staining for SMA and α -ACTININ, post contraction. The karyotype of LiPSC18R from two independent bioreactor runs, followed by kSep concentration, was determined to be normal (see Table 1 above).

[00106] Referring next to Figs. 22 and 23, cryopreservation of cell-based therapeutic products is a critical aspect of cell therapy. Master and working cell banks

of iPSCs could be readily used for subsequent rounds of expansion and differentiation into the desired cell therapy product. A key hurdle, however, is maintaining the viability and performance of cryopreserved cells.

[00107] Human iPSCs expanded in a 3 L bioreactor and concentrated via kSep were cryopreserved in 1 mL of cryopreservation solution as described above. Cells at high viability of >85% were cryopreserved in various cell densities. The cryopreserved cells were thawed approximately two weeks after cryopreservation, and cell viability and vitality were determined. The viability of the thawed cells was similar across the various cryopreservation cell densities, however, lower than that before cryopreservation (see Table 4 below). Upon plating onto 2D cell culture plates, cells attached, expanded, had hPSC typical morphology and were positive for alkaline phosphatase staining (Figs. 22 and 23). This data also shows the feasibility to cryopreserve hiPSCs to a high cell density of 120 and 240 x 10⁶ cells/ml. This will shorten a 2D seed train for further processes involving cell expansion and differentiation.

[00108] Thus, Figs. 22 and 23 demonstrate that hiPSCs cryopreserved at high cell densities after harvest and subsequent concentration by kSep can be recovered successfully. The cells retain hPSC characteristics as shown by morphology upon plating in 2D and expression of the hPSC-associated marker, alkaline phosphatase.

Table 4

Vial #	Cell line	Cells/vial	Cell viability (%) before cryopreservation	Cell viability (%) post thaw
1	RTiPSC3B	4 x 10 ⁶	90	86
2	LiPSC18R	4 x 10 ⁶	87.3	78.2
3	LiPSC18R	40 x 10 ⁶	87.3	80.4
4	LiPSC18R	120 x 10 ⁶	87.3	79.4
5	LiPSC18R	240 x 10 ⁶	87.3	77.1

[00109] Next, it was examined whether the cryopreserved cells could be used to inoculate a 3 L bioreactor vessel (eliminating the need for a 2D seed train), while retaining their capability of self-renewal and differentiation. Generating sufficient cells in a 2D seed train required in order to provide adequate inoculum for a larger bioreactor is time consuming, highly manual and involves a process vulnerable to contamination. Moreover, given the variability typically observed between cell lines, culture of hPSCs by a 2D seed train depends on subjective decision making and

often requires highly-trained personnel, capable of monitoring for culture irregularities, which could adversely impact subsequent cell expansion in a bioreactor. In order to overcome these challenges, the present disclosure has tested whether a 2D seed train could be avoided by thawing cryopreserved cells into a suspension culture.

[00110] LiPSC18R, cryopreserved as single cells, were thawed and inoculated into a spinner flask at a cell density of 0.04×10^6 cells/mL. In parallel, 2D cultured LiPSC18R cells were dissociated and inoculated as single cells into another spinner flask at the same cell density. Growth and expansion graphs demonstrate that cryopreserved and fresh single cell inoculum reach comparable cell density and fold expansion on day 9 (Fig. 24). To demonstrate scalability of these findings, a 3 L bioreactor was inoculated with LiPSC18R cells previously expanded in a 3 L bioreactor, concentrated by kSep400 and cryopreserved (0.068×10^6 cells/mL seeding density). Nine days after inoculation, cell density of 3.5×10^6 live cells/mL and total expansion >50-fold were achieved (Fig. 25). Representative phase contrast images show continued expansion of LiPSC18R on L7™ hPSC Matrix-coated MCs over time in suspension culture (Fig. 26). Following harvest, concentration and cryopreservation of these cells, the quality of expanded cells was assessed. Fig. 27 shows the formation of colonies with typical morphology from single cells or cell clusters expanded on MCs. Moreover, representative immunofluorescence images and flow cytometry analyses confirmed expression of hPSC-associated markers (Figs. 28, 29, respectively). Directed differentiation of these cells to the three germ layers was also confirmed by immunostaining for cell lineage-specific markers (Fig. 30). These results demonstrate that cryopreserved hiPSC inoculum are capable of expanding in a MC-based suspension system, resulting in a large number of high-quality hiPSCs.

[00111] Particularly, cell densities of $>2 \times 10^6$ hiPSCs/mL were achieved upon inoculation of 0.02 - 0.07×10^6 cells/mL in a stirred tanked bioreactor (see Table 5). As the volume of the bioreactor increases, the amount of inoculum needs to increase proportionally. Generating this inoculum in a traditional manual and open 2D process is non-ideal with increased risk of execution failures.

Table 5

Cell line	Passage number at inoculation	Bioreactor size	Inoculum information	Inoculum cell density cells/mL	Harvest day	Expansion fold
RTiPSC3B	P16	3L	Cells clumps harvested from 2D	0.04×10^6	17	56
RTiPSC3B	P24	1L	Cells clumps harvested from 2D	0.04×10^6	16	45
RTiPSC4i	P28	3L	Cells clumps harvested from 2D	0.04×10^6	17	75
RTiPSC3B	P22	3L	Cells clumps harvested from 2D	0.04×10^6	13	166
RTiPSC3B	P28	3L	Cells clumps harvested from 2D	0.04×10^6	16	127
RTiPSC4i	P31	3L	Cells clumps harvested from 2D	0.04×10^6	12	127
RTiPSC3B	P28	3L	Cells clumps harvested from 2D	0.04×10^6	9	55
RTiPSC3B	P28	3L	Cells clumps harvested from 2D	0.04×10^6	12	66
LiPSC18R	P26	3L	Cells clumps harvested from 2D	0.04×10^6	9	64
LiPSC18R	P29	3L	Cells clumps harvested from 2D	0.04×10^6	11	64
LiPSC18R	P34	3L	Cells clumps harvested from 2D	0.025×10^6	12	112
RTiPSC3B	P29	3L	Cells clumps harvested from 2D	0.04×10^6	15	82
RTiPSC4i	P30	3L	Cells clumps harvested from 2D	0.025×10^6	11	72
LiPSC18R	P34	3L	Cryopreserved single cells	0.04×10^6	17	47
LiPSC18R	P30	3L	Cryopreserved single cells	0.008×10^6	9	53

[00112] However, the present disclosure demonstrates the feasibility of inoculating 3 L bioreactors with cryopreserved cells and achieving approximately 50-fold expansion, showing that a 2D seed train could be completely replaced by a closed 3D seed train. Nevertheless, to meet the required cell number for inoculation of 50 L or larger bioreactors, a considerably sized working cell bank derived from 2D cell culture or suspension culture system is still required. To circumvent this obstacle and mitigate challenges involved with large scale manufacturing of hPSCs, the present disclosure demonstrates the feasibility of a 3D seed train. Particularly, referring to Fig. 31, two conditions were tested: re-inoculation of cell-MC clusters from a spinner flask to a 3 L bioreactor (ConLiPSC18R cells) and transfer of single cells harvested from a spinner flask to a 3 L bioreactor (RTiPSC3B cells). In both conditions, cell density at inoculation was 0.04×10^6 cells/mL and cells were expanded with L7™ hPSC Matrix-coated MCs. The cell-MC clusters from a spinner flask resulted in a maximum cell density of 2.92×10^6 LiPSC18R cells/mL, corresponding to >70-fold expansion in 12 days (Fig. 32), which is comparable to the results shown in Fig. 10 above. The single cells harvested from a spinner flask resulted in ~70-fold expansion of RTiPSC3B cells on day 15, as determined by cell counts from a full harvest (Fig. 33), but, interestingly, exhibited a longer 'lag phase' that may be attributable to inoculating as single cells rather than cell clumps. Representative phase images of cell-MC clusters sampled from the bioreactor on day

2 and day 12 of the run, showing cell expansion (Fig. 34). Fig. 35 shows formation of colonies with typical morphology from single cells or cell clusters expanded on MCs, five days after harvest and plating onto 2D culture plates.

[00113] Additionally, representative immunofluorescence images (Fig. 36) showed the expression of hPSC-associated markers by RTiPSC3B cells expanded in a 3 L bioreactor through a 3D seed train (single cells harvested from a spinner flask). Flow cytometry experiments confirmed that >90% of cells expressed OCT3/4, SSEA-4, TRA-1-81 and Tra-1-60 (Fig. 37). Embryoid body formation assay showed that these cells have retained hPSC differentiation potential (Fig. 38). Based on the results described above, were able to successfully demonstrate that a 3D seed train could lead to high fold expansion of high quality cells, paving the way to commercial scale manufacturing of hPSCs.

[00114] Thus, the present disclosure has shown a microcarrier-based bioreactor suspension platform to expand hiPSCs to cell densities of $>2 \times 10^9$ cells/L using xeno-free, fully defined hPSC medium with a closed, automated process for hiPSC harvest and concentration, and extensively characterized the expanded hiPSCs. The end-to-end platform hPSC culture system, which includes the L7™ TFO2 hPSC medium and matrix, supported expansion of the hiPSCs tested in manually operated, open, spinner flasks and in automated, closed, stirred tank bioreactors. Feasibility experiments performed in spinner flasks inoculated with 0.2×10^6 cells/mL and microcarriers resulted in 10-fold expansion within 17 days without the need for cell passaging. Results were comparable to those previously published when assessing hESC growth on laminin-coated MCs. However, as discussed herein the cells did not require adaptation to suspension culture by pre-conditioning with the MCs in static culture conditions; rather, they could be inoculated directly.

[00115] In addition to the composition of the medium in which hPSCs are expanded, optimizing cell inoculum density is a factor in hiPSC expansion in suspension systems. Particularly, when lower and higher inoculum cell densities are compared, it shows that higher fold expansion can be achieved using lower seeding densities. Moreover, seeding density not only impacts the rate and quality of expansion, but also the cost, labor and expenditure of time associated with achieving the necessary cell density at inoculation.

[00116] Furthermore, the process described herein demonstrated scalability in 1 L or 3 L bioreactor vessels. Particularly, 6-15 $\times 10^9$ cells per 3 L bioreactor run were

successfully produced, (cell line and harvest day-dependent) meeting the number of cells required for a number of clinical indications. Furthermore, over 90-fold expansion was achieved within 9-16 days when using 2D cultured cells as bioreactor inoculum, which is a higher fold expansion than those achieved in spinner flask cultures. Without wishing to be bound by theory, this is likely attributable to better control of key parameters, which influence the rate of hiPSC expansion. The continuous media change, achieved through perfusion, facilitates control of key nutrients and metabolites such as glucose and lactate. pH was controlled via a one-sided control regime in which CO₂ was used to reduce pH when it drifted above the set point of 7.2. Fig 10 shows that this prevented pH from rising more than 0.1 units above set point. However, there was no active control to raise pH (such as base addition), only the passive gradual increase in pH brought about by off-gassing of CO₂. Therefore, as cells expanded, pH dropped gradually to ~6.8'.

[00117] Upon increase in cell expansion, however, a reduction in DO levels was observed, which could not be maintained at the set target of 50% and reached 10% at cell densities $>3 \times 10^6$ cells/mL. Previous studies have demonstrated that O₂ levels regulate hPSCs metabolic flux, but the expression of pluripotency and differentiation markers in hPSCs cultured in either 20% or 5% O₂ was unaltered. Moreover, no differences in proliferation were observed, suggesting that low O₂ improves hPSC stemness. Others have also shown that 30% DO is the optimal condition to support hPSC expansion. In line with the present disclosure, an adverse impact on the quality of cells harvested at cell densities of $\sim 2.5 \times 10^6$ cells/mL where DO levels remained >30 was not observed. Moreover, characterization of cells harvested from a 3 L bioreactor at a cell density of $>5 \times 10^6$ cells/mL, with corresponding DO levels of 10%, showed that the cells had normal karyotype, expressed hPSC-associated markers and were capable of differentiating into cells of the three germ layers. These findings suggest minimal impact of O₂ levels on the quality of cells expanded in the platform according to the present disclosure.

[00118] To increase cGMP process compliance, the present disclosure demonstrated that cells expanded in stirred tank bioreactors could be harvested and concentrated in a closed and automated manner. To date, only one other report exists of concentrating hPSCs using kSep, concentrating $\sim 1.2 \times 10^9$ hPSCs tenfold, with 65% recovery of viable cells. In the process described herein, on average, the kSep process retained 94% of all harvested cells, and was able to process a 3L

bioreactor in under 30 minutes, concentrating cells up to 105-fold. Thus, the data herein shows that at least 48×10^9 hPSCs can be harvested per kSep 400 cycle (12×10^9 cells per chamber x four chambers), though further experiments would be needed to find the maximum capacity. This maximum capacity will be the main scale up constraint: while the 120 mL/min flow rate could reasonably process a 50 L bioreactor in 125 minutes, the total cells harvested from such a bioreactor (100×10^9) could potentially exceed the kSep 400 capacity. This could be overcome by processing two kSep units in parallel, or by harvesting the cells from one unit over two sequential cycles.

[00119] The seamless implementation of a closed, automated concentration step using the kSep400, and subsequent recovery of high-quality hiPSCs, demonstrate the adaptability of the platform according to the present disclosure. The development of a robust, flexible and adaptable process is needed given the continued evolution of cGMP policies and innovations in large-scale manufacturing. Therefore, the MC-based and downstream processing compatible platform discussed herein allow large-scale production of hiPSCs without compromising the quality of expanded hiPSCs.

[00120] Another key element in large-scale manufacturing of cell-based therapies is maintaining the viability of cryopreserved cells such that the therapeutic potential of these cells remains intact. As shown above the cryopreserved hiPSCs produced according to the present disclosure, upon thaw, exhibited confirmed quality and viability.

[00121] In the interest of cost effectiveness and mitigation of risks such as contamination, the present disclosure has demonstrated the ability to directly inoculate cryopreserved cells into 3D. Cryopreserved cells used for the inoculum showed high fold expansion and quality, as was confirmed by cell morphology, expression of hPSC-associated markers and the ability to directly differentiate. Further development of the platform shows feasibility of a 3D seed train such that cells expanded in a 3 L bioreactor, for example, can be re-inoculated in larger bioreactor vessels. Assuming a conservative cell number of 2×10^9 cells/L, cells from one 3 L bioreactor could be potentially serve as the inoculum for 3 x 50 L bioreactors. Assuming an even higher cell yield, achievable by a longer culture period in the bioreactor, one 3L bioreactor could serve as an inoculum for several 50 L bioreactors or even one 250 L bioreactor. Together, this makes possible an expansion process

which is completely 2D-free, closed, automated and requires minimal labor. This will enable commercialization of clinical indications that require large cell numbers, consequently increasing the availability of cell-based therapies.

[00122] Nonetheless, the following references an exemplary Standard Operating Procedure for the process/end-to-end platform described herein.

Eppendorf BioBlu 3C Bioreactor Setup and Operation

1.0 Purpose:

This document outlines the procedure for the setup and operation of the Eppendorf BioBlu 3c Bioreactor using the Finesse controller with respect to iPSC expansion and downstream processing using the kSep® System.

2.0 References:

- 2.1. NOVA manual for operation of the NOVA BioProfile FLEX
- 2.2. pH probe calibration Draft SOP
- 2.3. Optical DO probe calibration Draft SOP

3.0 Materials and Equipment:

3.1. Materials

- 3.1.1. hPSC line
- 3.1.2. L7-TFO2 (L7-NAO) in bags, custom made by Pilot Operations
 - 3.1.2.1. 2 x 13 L bags
 - 3.1.2.2. 2 x 10 L bags
 - 3.1.2.3. 1 x 4 L bag
 - 3.1.2.4. 1 x 2 L bag
 - 3.1.2.5. 1 x 1.5 L bag (For harvest)
- 3.1.3. L7-TFO2 (L7-NAO) in 500 mL bottles, custom made by Pilot operations
 - 3.1.3.1. 6 x 500 mL bottles
- 3.1.4. L7-hPSC Supplement™, Lonza, P/N FP-5020 (10 mL per/L of media)
 - 3.1.4.1. 2 x 100 mL aliquots (for 2 x 10 L bags)
 - 3.1.4.2. 2 x 130 mL aliquots (for 2 x 13 L bags)
 - 3.1.4.3. 1 x 20 mL aliquot (for 1 x 2 L bag)
 - 3.1.4.4. 1 x 40 mL aliquot (for 1 x 4 L bag)
 - 3.1.4.5. 1 x 30 mL aliquot (for 1 x 3 L bag: Harvest bag 1.5 L F3 solution + 1.5 L L7 TFO2)
 - 3.1.4.6. 6 x 5 mL aliquots (for 6 x 500 mL bottles)
- 3.1.5. 1 x 1.5 L F3 solution (For harvest day)
- 3.1.6. 1 x 500 mL F3 solution bottle (For samplings)
- 3.1.7. Tubing:
 - 3.1.7.1. Clear C-flex tubing (1/8" ID x 1/4" OD), Cole Parmer, P/N 06422-05
 - 3.1.7.2. Silicone tubing (1/8" ID x 1/4" OD), Cole Parmer, P/N 06411-67
 - 3.1.7.3. Masterflex PharmMed BPT L/S #16 tubing (3.1" ID), Cole Parmer, P/N EW-06508-16
- 3.1.8. Connectors (or hosebarbs):
 - 3.1.8.1. Straight Through Tube Fitting with Classic Series Barbs 1/8" ID to 1/8" ID, Value Plastics, P/N CC-6005
 - 3.1.8.2. Reduction coupler with 1/8" ID X 1/16" ID, Cole Parmer, P/N EW-40703-41
 - 3.1.8.3. Connector 1/8" ID x 1/4" ID, Cole Parmer, P/N EW-30703-50

- 3.1.8.4. Male Luer Integral Lock Ring to 500 Series Barb, 1/8" ID tubing, Cole Parmer, P/N 30800-18
- 3.1.8.5. Female Luer Thread Style Cap, Cole Parmer, P/N 30800-12
- 3.1.9. Cable ties 5.5", Lonza, P/N 03210 or equivalent (autoclavable)
- 3.1.10. Cable Ties Nylon 4", Cole Parmer, P/N EW-06830-52 or equivalent (autoclavable)
- 3.1.11. Whatman filter, GE Life Sciences, P/N 6713-0425
- 3.1.12. Sartofluor Filter, Sartorius, P/N 518507T7-HH-A 0.2 µm PTFE membrane P/N 4251
- 3.1.13. 50 mL Conical tubes, Lonza, P/N 04621 or equivalent
- 3.1.14. Extension sets, Lonza, P/N CS6226
- 3.1.15. Irradiated Solohill Plastic Microcarriers (125 – 212 µM) for cell culture, Pall Solohill, catalog number PIR-221-020, product code PS102-1521
- 3.1.16. DPBS with Calcium and Magnesium (+/+), Lonza, P/N 17-513F or equivalent
- 3.1.17. DPBS without Calcium and Magnesium (-/-), Lonza, P/N 17-512Q or equivalent
- 3.1.18. 500 mL sterile bottle, Lonza, P/N 00525120 or equivalent
- 3.1.19. 600 mL Transfer pack, Lonza, P/N 03833 or equivalent
- 3.1.20. 1 L Nalgene Cap, Lonza, P/N 05102951 or equivalent
- 3.1.21. Water for cell culture applications, Lonza, P/N 17-724Q or equivalent
- 3.1.22. ROCK inhibitor, Peprotech, Cat#1293823-10 mg
- 3.1.23. Clamps and/or Hemostats
- 3.1.24. Sterilization pouches, 10" x 15", Fisher Scientific, P/N 01-812-57 or equivalent
- 3.1.25. 100 mm dishes (or 6-well plates)
- 3.1.26. Assorted serological pipettes
- 3.1.27. Aspirating pipette, Lonza, P/N CS0075 or equivalent
- 3.1.28. 30 mL Luer lock syringe, Lonza, P/N 08095 or equivalent
- 3.1.29. 60 mL Luer lock syringe, Lonza, P/N 06009 or equivalent
- 3.1.30. 20 L empty media bags
- 3.1.31. 12-well Tissue Culture Plate, Lonza, P/N 04692 or equivalent
- 3.1.32. Cell Liberator – ASI TCS-378, ASI P/N TCS-378 Rev C
- 3.1.33. Via-1 Cassettes, Lonza, P/N 00527228
- 3.1.34. 12-well Tissue Culture Plate, Lonza, P/N 04692 or equivalent
- 3.1.35. 70% Isopropanol
- 3.1.36. Parafilm
- 3.1.37. Foil
- 3.1.38. Lab Tape
- 3.1.39. Filter paper for autoclaving filters
- 3.1.40. Rubber bands
- 3.2. Equipment
 - 3.2.1. Finesse Controllers and Equipment
 - 3.2.2. Scales, Sartorius or equivalent
 - 3.2.3. DO probe, Mettler Toledo
 - 3.2.4. pH probe, Mettler Toledo
 - 3.2.5. Temperature probe (RTD)
 - 3.2.6. Heating jacket, Finesse
 - 3.2.7. Class II Type A/B3 Laminar Flow Biosafety Cabinet (BSC)

- 3.2.8. NucleoCounter NC-200 or equivalent
- 3.2.9. TSCD Sterile Tubing Welder or equivalent
- 3.2.10. Sartorius Bio-welder TC or equivalent
- 3.2.11. Disposable welder blades, Sartorius, P/N 16389-012
- 3.2.12. Nikon Eclipse Ti-S microscope, or equivalent
- 3.2.13. IV stand
- 3.2.14. Masterflex L/S Peristaltic Pump w/ stacked pump accommodating LS25 tubing, or equivalent
- 3.2.15. Pressure Relief Valve, 6.4 psi
- 3.2.16. Tension Tool, Cole Parmer, or equivalent
- 3.2.17. EISCO Retort Base w/ Rod, Fisher, P/N 12-000-103, or equivalent
- 3.2.18. Fisherbrand Castaloy Three-Prong Extension Clamps, 27 cm, Fisher, P/N 05-769-8Q or equivalent
- 3.2.19. Troemner Talboys Labjaws Regular Clamp Holder, Fisher, P/N 02-217-121
- 3.2.20. Sartorius kSep®400 system
- 3.2.21. PlasmaLyte-A Injection pH 7.4, Baxter, P/N 2B2544X
- 3.2.22. Human serum albumin, Lonza, P/N 01459
- 3.2.23. kSep400 Concentration-Wash-Harvest kit, Sartorius, KSEP400-SET-CWH
- 3.2.24. Valve disposable set, Sartorius, P/N KSEP400-TS-CWHRV
- 3.2.25. kSep chamber set, Sartorius, P/N KSEP400.50-CS

4.0 Authority and Responsibility:

- 4.1. Department supervisor or designee will be responsible for training personnel for this procedure.
- 4.2. Technicians will be responsible for reading and following this SOP while performing this procedure.

5.0 Procedure:

~2 weeks cell expansion in 2D from first thaw as shown in Fig. 39

5.1. **Start of 2D seed train**

Note: 2D seed train can be avoided by inoculating cryopreserved cells.

- 5.1.1. For a 3 L bioreactor with cell seeding density of 0.04×10^6 cells/mL, total of 120×10^6 cells are needed on inoculation day. Previous experience showed that cell yield of $>2 \times 10^9$ cells/L could be achieved with a cell density of 0.02 - 0.04×10^6 cells/mL, total of 60 - 120×10^6 cells inoculated in a 3 L bioreactor.
- 5.1.1.1. From thaw: thaw cells into 1 x T-75 to have 0.02 to 0.04×10^6 cells/cm² (2 - 3×10^6 cells/T-75 flask). Add ROCKi when thawing and replace with new 15 mL of complete L7-TFO2 media without ROCKi the day after. When cells reach a confluence of 70-80% (typically within 5 to 7 days), passage the cells from the T-75 to 1 x 1 layer CellStack using L7 passaging solution. Seeding density should be between 0.02 to 0.03×10^6 cells/cm², which corresponds to seeding 15 - 20×10^6 cells into 1 x 1 layer CellStack. When cells reach a confluence of 70-80% (typically within 5 to 7 days) there should be about 100 - 150×10^6 cells in the 1 x 1 layer CellStack.
- 5.1.1.2. Procedure for harvesting cells from a T-75 flask to 1 layer CellStack
 - Remove media.
 - Wash once with DPBS-/-.

Add 12 mL of L7 passaging solution. Incubate at 37°C and watch closely for forming holes. in the culture every 5 min. Wait until 10 mins.

Tap the T-75 flask to detach the cells from the flask.

Transfer L7 passaging solution into sterile 50 mL conical tube.

Add 12 mL of complete L7-TFO2 media to the flask.

Perform cell count.

5.1.1.3. Procedure for harvesting cells from a 1 layer CellStack:

Remove media.

Wash once with DPBS-/-.

Add 75 mL of warm L7 passaging solution. Incubate at 37°C and watch closely for forming holes in the culture every 5 min. Wait until 15 mins.

Once holes are formed, tap the 1 x 1 layer CellStack to release the cells.

Tap the flask multiple times to detach the cells from the bottom.

Collect cells in a 250 mL conical tube and add 75 mL of complete L7-TFO2 media to the flask.

Perform cell count.

Seeding density of 0.04×10^6 cells/mL is required for Solohill Microcarriers. For a 3 L working volume experiment, this totals to 120×10^6 viable cells.

5.1.2. In ~5-7 days of iPSC culture in 2D, one can expect about $100\text{-}150 \times 10^6$ cells per 1 x 1 layer CellStack, depending on the hPSC line.

5.1.3. Media should be changed every other day with complete L7-TFO2 media.

5.1.4. Cells should be harvested at 70-80% confluence; higher confluence can lead to lower cell vitality and can, therefore, affect attachment.

Few days prior to Bioreactor set up (set up occurs on a Tuesday, Inoculation on a Wednesday, preparations begin few days before, between Thursday-Friday)

5.2. Coat 1 x 6-well plate and 8 wells of a 24-well plate and a T-25 flask with L7-Matrix for 2D control.

5.3. Coat more plates if required for 2D differentiation, Karyotyping etc.

5.4. Tubing Assembly

5.4.1. Tubing assemblies should be done in advance.

5.4.2. General notes for all assemblies:

5.4.3. Use silicone gloves and paper towels while assembling the tubes to prevent formation of sores on fingers.

5.4.3.1. Secure tubing to hosebarb/connectors using cable ties and a Tension tool. Setting should be set to 3.

5.4.3.2. Cover all filters with blue paper and secure with rubber bands – this is to keep the filters dry.

5.4.4. Assemble dip tube/perfusion out line:

5.4.4.1. Assemble dip tube/perfusion out line as shown in Fig. 40

5.4.4.2. Test the height of the headplate adapter/screw in a spare vessel – make sure that the mesh is close to, but not touching the vessel bottom.

5.4.4.3. Gently roll the tubes into a loop and loosely (without the use of tension tool) secure with 5" cable ties. Using a tension tool over the looped tubes could lead to either closure of the tubes thereby blocking them during autoclaving or tear the tubes making the assembly unfit for use.

5.4.4.4. Gently put dip tube into a large autoclave bag (12" x 18"), with the top at end pointing to the end that is normally opened so that it can be pulled out aseptically easily. Double-wrap with a second bag in case the mesh tears through the first bag.

5.4.5. Media feed line

5.4.5.1. Assemble media feed line as shown in Fig. 41.

5.4.5.2. Tie up gently and place in autoclave bag (10" x 15").

5.4.6. Harvest line extension assembly (If full harvest is intended):

(→ means connect)

(1) Whatman filter → (2) 3" long silicone tubing → (3) 1/8 MPC coupling body → (4) 1/4 MPC coupling insert → (5) 10" long cflex 1/4" – 3/8" tubing → (6) 1/4" to 3/16" reducer → (7) 25" long PharMed L/S #16 tubing → (8) 3/16" to 3/16" connector → (9) 20" long cflex 1/8" – 1/4" tubing → (10) Whatman filter. Both sides of each connection is secured by a zip tie as shown in Fig 42

The Eppendorf BioBlu 3c bioreactor has a MPC coupling body at the end of its harvest line to which the 1/4 MPC coupling insert of the above extension assembly will be attached inside the BSC in a sterile condition.

5.4.6.1. Tie up gently and place in autoclave bag.

5.4.7. Autoclave all assemblies on dry autoclave cycle:

Put the paper side facing up (plastic side of the bag facing the surface of the autoclave).



5.4.8. After completion of the autoclave cycle, allow the bags to cool slightly before carefully removing the autoclaved bags, spraying with 70% alcohol and placing inside the BSC. Allow the bags to dry completely before use (especially perfusion dipstick that tends to easily tear the wet bag).

5.5. Coating and preparing irradiated microcarriers: 4 days before inoculation day

5.5.1. Aseptically place 20 g (2 of 10 g bottles) of Solohill Plastic microcarriers in a 1 L sterile Nalgene bottle.

5.5.2. Add 300 mL (pre-warmed for 30 mins, if cold) DPBS with Calcium and Magnesium (DPBS+/+) to the bottle.

5.5.3. Add L7 matrix so that there is 1 mg/mL of L7 matrix per 225 mg of microcarriers.

5.5.3.1. For 20 g of large MCs, this would be ~18 mL of L7 matrix at concentration of 1 mg/mL (total 18 mg of L7-matrix). Please see reconstitution protocol at the end of the document.

5.5.4. Allow carriers to incubate at 37°C for at least 2 hours.

5.5.5. Let MCs settle and aspirate as much of the DPBS+/+ solution as possible.

- 5.5.6. Add ~300 mL of incomplete L7-TFO2 and incubate overnight on shaker at speed of 30 RPM, wrap the bottle with aluminum foil.
- 5.5.7. The next day, add 700 mL of incomplete L7-TFO2 media to the same bottle to make it 1 L.
- 5.5.8. Store in 4°C if not being used immediately.
- 5.5.8.1. Coated microcarriers have been stored in 4°C for up to 1.5 weeks before being used. Longer storage period has not been tested.

5.6. Inoculation Media and Perfusion Media Preparation

Preparation of media for perfusion

(This does not necessarily have to be done on Day -4, as long as a media bag is ready on Day 1 for perfusion initiation.)

- 5.6.1. Have Pilot Ops prepare media in bags and bottles in the following way:
 - 5.6.1.1. 1 x 7 L bag for D-1 (2 L will be mixed with the 1 L L7 matrix coated microcarriers. The remainder will be saved for the harvest day when media bag is changed on Day 2).
 - 5.6.1.2. 2 x 7 L bag for perfusion on Day 2
 - 5.6.1.3. 2 x 7 L bags for media bag changes on Day 6
 - 5.6.1.4. 1 x 7 L bags for media bag change on Day 9
 - 5.6.1.5. 1 or 2 x 7 L bag on Day 12 if necessary
 - 5.6.1.6.
- 5.6.2. Bags should be supplemented with appropriate amount of L7-supplement (10 mL supplement per liter of media) the day before media bag change or on the same day.
- 5.6.3. On harvest day, ROCKi (10 μ M final concentration) should be added in 1.5 L L7 media that will be used for quenching 1.5 L of F3 solution. This will increase single cells survival.

Day -2: Monday

5.7. pH probe calibration

- 5.7.1. For electrochemical (standard) pH probe:
 - 5.7.1.1. Calibrate using the SOP: *pH probe calibration Draft SOP*
 - 5.7.1.2. Autoclave pH probe. Make sure that capped end of the probe is on the side of the bag that is easily opened.
 - 5.7.1.3. Make sure that the electronics end of the probe is capped and the probe double wrapped in autoclave bags. Autoclave on liquid setting.
 - 5.7.1.4. Allow to cool before proceeding: ~ 30-60 min.
 - 5.7.1.5. After cooling, transfer probes to the BSC.

Day -1: Tuesday

5.8. Bioreactor vessel preparation in BSC

- 5.8.1. Start the day by placing the 2 L L7-Media bag in the reach-in incubator to warm up to facilitate the saturation of the media with oxygen.
- 5.8.2. Spray the following with 70% IPA and bring into the BSC:
 - BioBLU 3c vessel (S/N: _____), Exp:
 - pH probe (S/N: _____)
 - Tubing sets (dip tube/perfusion out, media in, harvest line)
 - 2x extension sets

- DO probe (S/N: _____)
- 5.8.3. Remove the plastic wrapping from the bioreactor. Make sure that everything is attached and closed. Note the two white caps on PG13.5 ports of the vessel for insertion of probes. **Check the vessel for any cracks or broken parts and discard any cracked or broken vessel.**
- 5.8.4. Insert pH probe:
 - 5.8.4.1. Gently swing pH probe downward to make sure there are no bubbles at the sensing end.
 - 5.8.4.2. Loosen the red cap labeled pH without removing it.
 - 5.8.4.3. Open autoclave bag containing the pH probe. Only hold the probe with the cap and slide the probe out of the bag aseptically.
 - 5.8.4.4. Remove the red cap from the port on the bioreactor. Tilt the bioreactor so that the opening can be observed.
 - 5.8.4.5. Carefully and aseptically guide the pH probe through the opening without touching any external portion of the bioreactor. Only hold the pH probe using the cap. It may be necessary to hold back the bioreactor tubing to prevent them from touching the probe. Screw the probe into the port.
- 5.8.5. Insert dip tube:
 - 5.8.5.1. Loosen the white cap labeled "Spare 1" without removing it.
 - 5.8.5.2. Open the autoclave bag containing the perfusion dipstick and tubing. Only part of the dipstick/tubing above the screw can be touched.
 - 5.8.5.3. Insert the mesh end of the perfusion dipstick into the third bioreactor port aseptically. Care is needed to ensure that the tubing does not touch the portion of the perfusion stick to be housed within the reactor and that the mesh of the dipstick does not get bent.
 - 5.8.5.4. **Take care not to bend the mesh against the bottom of the vessel, this could break it.**
 - 5.8.5.5. Screw the perfusion tubing into the port, ensuring that the perfusion tubing does not become tangled. Point top part of the perfusion dipstick away from the impeller of bioreactor.
- 5.8.6. Ensure pH probe and perfusion dipstick are screwed tightly in the bioreactor and wrap parafilm around all screw ports.
- 5.8.7. On the "Harvest" line on the bioreactor, remove the male MPC connection, leaving the female connection exposed.
- 5.8.8. Attach the harvest line assembly by aseptically removing the MPC coupling body part and inserting the male type connection on the assembly line into the female connection on the bioreactor
- 5.8.9. Attach extension sets onto two luer lock female type connections on the bioreactor using the male type luer connection on the extension set. The two luer lock ports needing extension set connections are labeled as LA2 (Liquid addition, to be used for sampling) and Sample (to be used as a "back up" to LA2 line).
- 5.8.10. Close every tubing line in two places: at the headplate (using the Roberts clamp built onto the vessel) and at the far end of the line (using a hemostat).
- 5.8.11. Double check that everything is securely attached and that all ports are closed to open air. Then remove the reactor from the BSC.
- 5.8.12. Weld the Media-In line to the LA1 line (this can also be done during perfusion set up).

5.9. Bioreactor setup on Finesse controller

- 5.9.1. Reset the Finesse controller:

- 5.9.1.1. Click the CONTROLLERS OFF button.
- 5.9.1.2. Click the "RESET ALL TOTAL AND TIMERS" (Gas MFCs and pump modules).
- 5.9.2. Bring assembled bioreactor to the Finesse controller.
- 5.9.3. Tare the scale using the physical tare button, and place bioreactor on the pre-tared scale next to the appropriate controller tower.
- 5.9.4. Record the weight as "bioreactor vessel weight before connecting to controller" Bioreactor vessel weight before connecting to controller:
- 5.9.5. Create the setup and default files on the Finesse controller if it is the first time the bioreactor is setup on the Finesse controller. Otherwise, load the existing files.

DO probe

- 5.9.6. Insert the DO probe (first you need to unscrew the DO well entrance on the headplate for a 220 mm probe). Make sure that the probe tip is tightly pressed against the membrane at the bottom.
- 5.9.7. Connect the DO probe to the J-box. Verify that the J-box has power and is connected to the DO input on the G3.

pH probe (electrochemical/standard)

- 5.9.8. Remove the cap from the pH probe and connect to Finesse controller using the wire labeled pH.

RTD (temperature probe)

- 5.9.9. Insert the RTD probe and connect to the Finesse controller.
- 5.9.9.1. If using a wire RTD, make sure to tape it down.

Motor

- 5.9.10. Attach the motor to the center of the bioreactor top:
 - 5.9.10.1. The motor should fit in the groove on the headplate of the bioreactor. The motor may impinge on the DO probe and some adjustment may be needed.
 - 5.9.10.2. Test that the motor is securely placed by testing agitation at 50 RPM. If impeller does not rotate smoothly or if the Process Value is more than ± 5 RPM of the set point, stop the agitation and readjust the motor.

Heating jacket

- 5.9.11. Affix the heating jacket around the bioreactor. Ensure that the electric wire travels from the top of the blanket to the controller (in order to ensure the weight does not fluctuate every time the heating jacket is removed to check for clumps in the bioreactor). Make sure the heating jacket does not touch the scale, offsetting the vessel-weight reading.

Gas line

- 5.9.12. Connect the gas line (which has silicone tubing attached to it with a male luer connector) from the MFC labeled HS (headspace) to the gas inlet line with a female type luer connector filter.
 - 5.9.12.1. Make sure that a Pressure Relief valve has been attached to line coming from the MFC. If not, attach a relief valve in the silicone line coming from the HS port, by cutting it and sliding the tubing from either end onto the relief valve.

This relief valve prevents over-pressurizing of the vessel in the event of primary or secondary exhaust failures due to clogging.

- 5.9.13. Secure the exhaust and gas in lines to the motor with Zip ties, as shown in FIG. 43.
- 5.9.14. Tape the Media-In and Media Out lines down to the table, as shown in FIG. 44.
- 5.9.15. At this point, the bioreactor is ready to be filled with media. Record the weight as “added weight of bioreactor probes and accessories”:
_____.
- 5.9.16. Tare the scale. From this point on, the weight of the scale should correspond to the liquid mass inside the bioreactor.
- 5.9.16.1. If “vessel weight” in TruBio is not reading zero, manually tare it using the magnifying glass icon on the bottom left of the vessel weight faceplate window choosing 1pt standardize and enter zero.
- 5.9.17. Enter a batch ID in TruBio (as per the experiment), and click **BATCH START**.

5.10. Fill bioreactor with media

- 5.10.1. Weld the 7 L L7 supplemented media bag to the LA2 extension set tubing.
- 5.10.2. Set Agitation to AUTO mode with a set point of 50 RPM.
- 5.10.3. Remove the clamps from the tubing between the bag and the bioreactor. Elevate the bag using the IV pole to create a pressure gradient and allow media to enter the bioreactor. Ensure that only 2 L of media are added based on changes in bioreactor weight.
- 5.10.4. Place the 1 L bottle with coated MCs+media in the BSC and aseptically replace the Nalgene bottle cap with a Nalgene bottle cap with tubing. Transfer the content of the 1 L bottle to the bioreactor by welding using a PVC welder. While transferring the MCs+media to the bag, gently shake the bottle frequently to avoid MC settlement.
- 5.10.5. Open the clamps on the gas inlet line and the exhaust. All others should be closed.
- 5.10.6. Clamp and sterilely seal the tubing retaining enough tubing length so that with a hemostat attached it rests on the bench without tension on the tubing. It is important to maintain some length on the tubing for future sterile welding and sampling. Leave enough length to be able to reach a welder.

5.11. Air equilibration

- 5.11.1. Click Config > Vessel Settings Management > Vessel Load
- 5.11.2. Load “3L BioBLU air equilibration set up”. Once loaded, name the file according to the experiment and note the name here: _____.
- 5.11.3. Load “3L BioBLU air equilibration default”. Once loaded, name the file according to the experiment and note the name here: _____.
- 5.11.4. Check to make sure air is flowing smoothly through the system by dipping the exhaust filter in a cap of water and ensuring that there is bubbling.
- 5.11.5. Verify the following critical control parameters:

Temperature SP	37°C
Agitation	100 RPM

Air flow rate*	2 LPM
All other gases	Off

* You must use the right-most air module to achieve a rate greater than 0.5 LPM for the equilibration process. Make sure to turn off the air control on the left side that is reading 0.5 LPM as the default set up (set it to "0", change to Manual).

5.11.6. The complete details of the "3L BioBLU air equilibration setup" load file can be found in Appendix A.

5.11.7. Leave the reactor incubating to become saturated with air. This should take several hours. Track the DO level using the process history view. Saturation is reached when the DO level plateaus.

5.12. Calibrate DO to 100% saturation after system is saturated with air

5.12.1.1. Complete a two-point calibration for the optical DO probe using the *Optical DO probe calibration SOP for 3L vessel*.

5.13. pH correction (electrochemical/standard)

5.13.1. Take a 5 mL sample through the LA(S) line via syringe.

5.13.2. Read the sample on the NOVA.

5.13.3. If the NOVA reading deviates 0.05 or more units from the TruBio reading, correct the pH by clicking the pH faceplate > details > 1-point standardize.

5.14. Prepare bioreactor set points for inoculation

5.14.1. Click Config>Vessel Settings Management>Load file (Refer to step 5.7.5 for how to create the files).

5.14.2. Load "3L BioBLU pre-inoculation setup" and name it "PSC 3L Run # PreInoc setup". Without exiting the window, click on vessel load again.

5.14.3. Load "3L BioBLU pre-inoculation default" and name it "PSC 3L Run # PreInoc default".

5.14.4. Verify the following critical control parameters:

Temperature SP	35°C
pH SP	7.2
DO SP	50%
N2, CO2, O2	Cascade
Air	Auto, 0.1 LPM
Agitation	55 RPM

5.14.5. The complete details of the "3L BioBLU pre-inoculation setup" load file can be found in Appendix A.

5.14.6. Fill out the following in the Daily Bioreactor Checklist (the rest are N/A):

- Bubble test
- Check gas tank levels

5.14.7. Leave system overnight. If possible, check in on the system before leaving for the day.

Day 0 (Inoculation): Wednesday

- 5.15. Fill out Daily Bioreactor Checklist. Verify that pH/DO/temperature have stabilized.
- 5.16. Supplement bioreactor with 30 mL of L7 hPSC supplement:
 - 5.16.1. Spray a 2 mL aspirating pipette, an appropriate sized syringe with a luer lock, and an extension set with 70% IPA and set in the BSC.
 - 5.16.2. Aseptically connect the syringe to the aspirating pipette.
 - 5.16.3. Make sure to also intake 10 mL air to gather the solution within the syringe in its entirety and for clearing the line after injection.
 - 5.16.4. Using the syringe, collect L7-supplement
 - 5.16.5. Turn the syringe over
 - 5.16.6. Remove the aspirating pipette
 - 5.16.7. Connect the female type end of the extension set to the luer lock on the syringe.
 - 5.16.8. The syringe-extension set containing the L7-supplement can now be removed from the BSC and welded to the bioreactor by a PVC welder transferring the L7-supplement to the bioreactor.
- 5.17. **Check pH**
 - 5.17.1. Take a 5 mL sample through the LA(S) line via syringe.
 - 5.17.2. Read the sample on the NOVA.
 - 5.17.3. If the NOVA reading deviates 0.05 or more units from the TruBio reading, correct the pH by clicking the faceplate > details > 1-point standardize.
- 5.18. **Harvest cells from 2D, transfer to closed syringe**
 - 5.18.1. Harvest cells from 2D culture using L7-passaging solution per Lonza L7-passaging protocol. Record the start time for harvest and time of inoculation:
 - 5.18.1.1. Aspirate media from Cell Stack
 - 5.18.1.2. Wash cell stack with 75 mL of DPBS +/-
 - 5.18.1.3. Add 75 mL of L7 passaging solution
 - 5.18.1.4. Incubate cells for 5-15 minutes (monitor for holes, per L7-passaging protocol).
 - 5.18.1.5. When cells are ready for harvest, tap the 1 x 1 layer CellStack few times.
 - 5.18.1.6. Collect cells into a sterile 250 mL conical tube.
 - 5.18.1.7. Add 75 mL of completed L7-TFO2 media into the 1 x 1 layer CellStack.
 - 5.18.1.8. Centrifuge the conical tubes at 200 g/5 mins.
 - 5.18.1.9. Discard the supernatant and re-suspend the pellet in 30 mL complete L7-TFO2 medium.
 - 5.18.1.10. Count cells using NC-200 and solution 10, "Aggregate Cell Assay."
 - 5.18.1.10.1. Place 100 µL and 200 µL of cell solution in two separate Eppendorf tubes.
 - 5.18.1.10.2. Label tube 1 "Cells with Solution 10" and tube 2 "Cells."
 - 5.18.1.10.3. Remove Solution 10 from 4°C .
 - 5.18.1.10.4. Go to the NC-200 and add 100 µL of Solution 10 to the tube labeled "Cells with Solution 10."
 - 5.18.1.10.5. Only vortex the tube with Solution 10 to mix. For the tube containing only cells only tap and swirl the tube since vortex may affect the viability of the cells.
 - 5.18.1.10.6. Set the program on the NC-200 to "**Viability and Cell Count-Aggregated Cell Assay**" per manufacturer's protocol.
 - 5.18.1.10.7. Press run. The system will prompt you to add a cassette with cells plus addition of solution 10. Using Via – 1 cassette take cells from tube with solution

10 and insert into NC-200. The machine will take a reading and then prompt you to put a new cassette without solution. This is where you would take cells from the tube labeled "cells" (no solution 10).

Cell line and passage	
Viability (%)	
Live cells/mL	
Dead cells/mL	
Total cells/mL	
Cell Diameter	
Seeding density: 0.04×10^6 cells/mL	
For 3 L bioreactor	120×10^6 cells, which are _____ mL
For 1 well in a 6-well plate (total volume of 2 mL)	0.08×10^6 cells, which are _____ μ l
For 1 x T-25	5×10^5 cells, which are _____ μ l
For 8 wells in a 24-well plate	0.16×10^6 cells, which are _____ μ l

- 5.18.2. Transfer 120×10^6 cells into the 3 L bioreactor.
- 5.18.3. **Note:** if inoculating single cells or cells directly from cryovials, add ROCKi to the bioreactor. A 10 mg bottle of ROCKi dissolved in 3 mL DMSO (10 μ M final concentration) is required.
- 5.18.4. Spray a 2 mL aspirating pipette, an appropriate sized syringe with a luer lock, and an extension set with 70% IPA and set in the BSC.
- 5.18.5. Aseptically connect the syringe to the aspirating pipette.
- 5.18.6. Using the syringe, collect the separated cell volume needed for inoculation. Make sure to also intake some air to gather the solution within the syringe in its entirety.
- 5.18.7. Remove the aspirating pipette.
- 5.18.8. Connect the female type end of the extension set to the luer lock on the syringe.
- 5.18.9. The syringe-extension set containing the cells can now be removed from the BSC.

5.19. Inoculate bioreactor via syringe

- 5.19.1. Sterile weld the syringe's extension set tubing to the LA(S) line (same one used to add media and microcarriers).
- 5.19.2. Unclamp the tubing.
- 5.19.3. Holding the syringe downward so that the plunger is pushed toward the ground, push out the cell solution until the cell and media solution are out of the syringe.
- 5.19.4. Invert the syringe, so that the plunger is facing upwards and push the cell + media solution out of the tubing and into the bioreactor. It is possible to observe the solution moving as air is pushed through the tubing.
- 5.19.5. Clamp near the end of the tubing near the top of the bioreactor.
- 5.19.6. Sterile seal off the line.

5.19.7. Record time of inoculation:

5.20. Post-inoculation setup

5.20.1. Click Config > Vessel Settings Management > Load file.

5.20.1.1. Load “3L BioBLU post-inoculation setup” and name it “PSC 3L Run # PostInoc setup.”

5.20.1.2. Without exiting the window, load “3L BioBLU post-inoculation default” and name it “PSC 3L Run # PostInoc default.”

5.20.2. Exit the window and verify the following critical control parameters:

Temperature SP	Cascaded to Characterizing curve 2
pH SP	7.2
DO SP	50%
N ₂ , CO ₂ , O ₂	Cascade
Air	Auto, 0.1 LPM
Agitation	Cascaded to Characterizing curve 1 (see below for seeding day agitation protocol)
Timers 1,2	Reset to zero, then started immediately after inoculation

5.20.3. Verify the agitation speed under characterization curve 1 under the configuration window

Seeding day agitation protocol (characterization curve 1):

Minute	RPM
0	0
9	50
10	0
70	0
75	50
80	0
140	0
145	50
150	0
210	0
215	50
220	0
280	0
285	50
290	0
350	0
355	50
360	0
420	0
425	50
430	50

5.21. Culture 2D control

In 1 well of an L7-matrix coated 6-well plate, seed cells at a density of 0.04×10^6 cells/mL and culture as 2D control cells for the bioreactor and FACS analysis. Seed cells in a T-25 flask for karyotyping and in 8 wells of a 24-well plate for IF, at cell density of 0.04×10^6 cells/mL.

Add ROCKi (10 μ M final concentration) to the wells when single cells are seeded and replace with fresh medium post 24 hrs.

Day 1

5.22. Setting agitation speed

5.22.1. Click Config > Vessel Settings Management > Vessel Load.

5.22.2. Load "PSC 3L BioBlu Day 1 to 16 Default". After the file is loaded the controller will ask you to name the file. The file should be named to reflect the experiment. Note the name here: _____.

5.22.3. Note: Agitation speed will be dependent on growth pattern and expansion rate of a given cell line. Agitation rates through end of culture will be set manually in "agitation" faceplate according to cell density per the table below. If not counting cells every day and cells+MC failed to mix and settled on the bottom of the vessel, then the agitation speed needs to be increased accordingly.

RPM	Cell Density Range (cells/mL)
50	Day 1 to 6×10^5
70	5×10^5 to 2×10^6
90	$>2 \times 10^6$

5.22.4. Reset Timer 1 by clicking on Timer 1, click on pause, click on reset, and then click on start. Make sure agitation speed is cascaded.

5.22.5. Verify that Characterizing Curve #1 has the values per FIG. 45. Otherwise, make a correction and click "apply values".

6.0 Prepare media feed for perfusion initiation on Day 1

6.1. Supplement two 7 L bag of L7-TFO2 media with 70 mL of L7 supplement each as described in section 5.14.

6.2. Connect waste and feed bags

Waste bag:

6.2.1. Prepare a 20 L empty bag (with a 1/8x1/4" C-flex line) to use as a waste bag by closing all the clamps.

6.2.2. Sterilely weld the bag's 1/8x1/4" C-flex to the C-flex at the end of the perfusion out line. Keep the line long enough for the waste bag to reach the scale on the floor.

6.2.3. Place a scale on the ground near the bioreactor; place a large plastic container to hold the waste bag onto it.

6.2.4. Place the bag inside of this container and tare the scale.

6.2.5. Insert the Pharmed tubing, part of the perfusion-out line, into the perfusion out pump (#4) on the Finesse controller.

6.2.6. Examine the tubing from the bioreactor to the waste bag and remove any clamps and unkink any kinks in the tubing.

Media feed bag:

6.2.7. Make sure all clamps on the media feed bag are closed.

6.2.8. Sterilely weld the 1/8 x 1/4 C-flex on the Media-In Line to the LA (1) line.

- 6.2.9. Sterilely weld the 1/8x1/4" C-flex on the feed bag to the C-flex tubing at the far end of the Media-In line.
- 6.2.10. Hang the media feed bag on an IV stand or equivalent. If there is bench space, the media feed bag can lay in a bin.
- 6.2.11. Insert the Pharmed portion of the Media-In line into the pump controller pump #3, Media In.
- 6.2.12. Make sure to protect media bag from light by covering it.

6.3. Prime Lines

- 6.3.1. Notes:
 - 6.3.1.1. Before pumping liquid, always make sure entire path is unclamped and free of kinks.
 - 6.3.1.2. Check the direction of the pumps based on the flow direction needed. This can be done by pressing on the button next to each pump. The pump designated as perfusion-out must have a clockwise motion taking media from bioreactor and directing it to the waste bag. The pump designated as Media-In must have a counter clockwise motion to bring the fresh media to the bioreactor.
 - 6.3.1.3. To troubleshoot pump-related issues, make sure they are configured properly by referring to Appendix A. This configuration should not vary from run to run.
- 6.3.2. Unclamp the path from perfusion dip tube to waste bag.
- 6.3.3. Prime the waste line by advancing media from the bioreactor vessel until you see it enter the waste bag.
- 6.3.4. Unclamp the path from feed bag to bioreactor.
- 6.3.5. Prime the feed line by advancing media from the feed bag until you see it dripping into the bioreactor vessel.

6.4. Calibrate perfusion out pump

- 6.4.1. Place a scale on the ground near the bioreactor; place a large plastic container to hold the waste bag onto it.
- 6.4.2. Place the bag inside of this container and tare the scale.
- 6.4.3. Place the Pharmed LS 16 tubing, part of the tubing on the perfusion dipstick, into the perfusion out pump (#4) on the Finesse controller.
- 6.4.4. Examine the tubing from the bioreactor to the waste bag and remove any clamps and unkink any kinks in the tubing.
- 6.4.5. Click on Config near the bottom left of the main finesse controller screen.
- 6.4.6. Identify the category of Pumps on the right side of the screen.
- 6.4.7. The fourth pump is the perfusion out pump and it is labeled Perfusion Out.
- 6.4.8. Click on the pump module and a window, Pump #4 Config, will appear.
- 6.4.9. Verify that Flow Control is selected under the Speed/Flow box on the left side of this window.
- 6.4.10. Identify the direction of flow from the bioreactor to the waste bag (Direction can be changed on this window between CW & CCW). Make sure that the correct direction is selected.
- 6.4.11. In the Control mode box on the right side of this window, make sure that Standard (remote set point) is selected.
- 6.4.12. Click **Apply Values**.
- 6.4.13. Click on Main to return to the main Finesse controller screen.
- 6.4.14. To test if the pump is working, double check that the tubing line is free of kinks and clamps and start pressing on the button next to the pump to test the

pump. Examine fluid movement in the line. When visible moving at a consistent pace, continue until the media is entering the waste bag. Alternatively, instead of continuously pressing the button next to the pump, the Output Value of the perfusion out pump can be set to 50-80% for this priming step. Examine carefully for any leaks in the tubing. In case of any leak, immediately stop the pump, clamp the tubing on the bioreactor, close the clamp on the waste bag and call the supervisor to determine further course of action.

Calibrate the Pump

- 6.4.15. Click on the Perfusion out pump faceplate, select the magnifying glass and select calibrate. This loads the TruBio calibration module.
- 6.4.16. Adjust pump speed 1,2 and 3 to 5%, 10% and 15%, respectively.
- 6.4.17. Set activation time to 120 seconds and click start.
- 6.4.18. Choose "Automatic, attached scale."
- 6.4.19. Click start.
- 6.4.20. Choose "pump liquid from the scale" (measures decrease in vessel weight).
- 6.4.21. Click start.
- 6.4.22. Select prime. Since you have already primed the line, click STOP as soon as it starts (or if you haven't primed the line, do so now).
- 6.4.23. Click start, do not touch the scale.
- 6.4.24. At the end of calibration, enter username: administrator password: deltav. Click on apply then exit.
- 6.4.25. In the main screen, click the pump 4 faceplate and check the 100% output value in g/min, record in batch record.

6.5. Initiate perfusion

- 6.5.1. Click on the vessel weight faceplate on the upper right corner of the screen.
- 6.5.2. Set to Auto and enter the current vessel weight as the SP based on the scale next to the bioreactor setup.
- 6.5.3. Tare the scale holding the waste bag.
- 6.5.4. Set the media-in pump (pump 3) to cascade on "vessel weight output".
- 6.5.5. Set the perfusion-out pump (pump 4) to auto, set value to 1VVD (2.08 g/min for 3000 mL, adjust accordingly).
- 6.5.6. Record the perfusion start time in the batch record.
- 6.5.7. Record the following in the "perfusion check" portion of the Daily Bioreactor Checklist:
 - 6.5.7.1. Waste weight (g) (either AM or PM, choose accordingly)
 - 6.5.7.2. Perfusion out rate, target
Note: From this step onwards, if the vessel needs to be touched, the perfusion-out and media-in need to be set on auto and zero.
 - 6.5.7.3. 2 hours after perfusion initiation, check:
 1. For any leaks due to improper welds
 2. Waste and media bags
 3. The vessel weight on the SP reflects the value entered in 6.5.2.

6.6. Media bag is changed on: Fridays and Tuesdays until end of run

- 6.6.1. It is recommended to prepare media the day before or on the same day as scheduled media bag switch. Completed media should not be kept longer than 2 weeks at 4°C or 4 days at room temperature.

- 6.6.2. Before or on Fridays of media bag changes, prepare 2 bags of 7 L L7 complete media with 70 mL of L7 supplement each.
- 6.6.2.1. This is enough for 4 days of 1 VVD perfusion (4 x 3 L) plus 2 L extra.
- 6.6.3. Before or on Tuesdays of media bag changes, prepare 2 bags of 7 L complete media with 70 mL of L7 supplement each.
- 6.6.3.1. This is enough for 3 days of 1 VVD perfusion (3 x 3 L) plus 2 L extra.

7.0 OPTIONAL: DAPI staining (usually after 24 hours)

- 7.1. Invert the syringe to suspend carriers and deposit a sample of carriers into a well of a 12-well plate. A single layer of carriers is desired.
- 7.2. Allow carriers to settle, remove media carefully to not disturb carriers.
- 7.3. Add 1 mL DPBS+/-, swirl and allow carriers to settle.
- 7.4. Remove DPBS carefully as to not disturb the carriers.
- 7.5. Add 1 mL of the Cytofix/Cytoperm.
- 7.6. Incubate in a cell culture incubator for 20 min.
- 7.7. Remove the Cytofix/Cytoperm solution without disturbing the carriers.
- 7.8. Add 1 mL DPBS+/-, swirl and allow carriers to settle.
- 7.9. Remove DPBS carefully as to not disturb the carriers.
- 7.10. Add 1 mL 1X-DAPI and let the sample sit in the dark for 5min.
- 7.10.1. Note: A 100X working solution from a stock of 5 mg/mL DAPI solution can be prepared at the beginning of the run, stored frozen at -20°C. This 100X solution can be used to prepare 1X DAPI solution with DPBS (with Calcium and Magnesium) for daily staining.
- 7.11. Image - Take images of each sample using a fluorescent microscope.

Day 1 to day before harvest

8.0 Daily Activities

- 8.1. **Fill out the daily reactor checklist provided at the end of this document.**
- 8.2. **Sampling days**
Although there are no strict sampling requirements (we generally sample 3 times a week), the following guidelines are recommended:

If inoculation occurs on a Wednesday:

Cell count sampling	2, 5, 7, 9, 12, 15, 16
pH/NOVA sampling,	same as cell count

If inoculation occurs on a Thursday:

Cell count sampling	4, 6, 8, 10, 13, 15, 16
pH/NOVA sampling,	same as cell count

Cell count information can be found in under 8.4.

- 8.3. **Fill out the NOVA data table provided at the end of this document for samples taken.** Note: If the NOVA instrument is malfunctioning or requires repair, freeze NOVA 5 mL sampling in -20°C for later analysis of metabolites.
- 8.4. **Sampling once perfusion has begun**
- 8.4.1. Refer to section 8.1 for recommended sampling schedule.

- 8.4.2. Record the pre-sampling vessel weight in the Daily Bioreactor Checklist.
- 8.4.2.1. Stop perfusion before sampling (see above, "Replacing media feed and/or waste bags")
- 8.4.2.2. Set agitation to Auto and temporarily increase agitation speed by 10 RPM. Wait 2 minutes.
- 8.4.2.3. Sample as usual (2 x 15 mL for VCD, 1 x 5 mL for NOVA) Place 0.5 mL of NOVA sample in a 24-well plate and record images under microscope.
- 8.4.2.3.1. Make sure all syringes have extra air space.
- 8.4.2.3.2. Remove about 10 mL of cells via LA(S) line, then push the cells back through the line, keep pushing until bubbles are seen coming out of the LA(s) line in the reactor.
- 8.4.2.3.3. Draw 15 mL sample.
- 8.4.2.3.4. Repeat the same method for the next sample and so forth.
- 8.4.2.4. Return agitation speed to its previous set point.
- 8.4.2.5. Record new (reduced) vessel weight, and set the vessel weight faceplate to this new weight as its set point (do not "dilute" the system back to original weight before taking samples, readjust weight so to reflect no changes in media addition or perfusion out).
- 8.4.2.6. Set the agitation to cascade. Restart perfusion (see above, "Replacing media feed and/or waste bags").

F3 Release cell counts: Sample ~3 times a week, every other day on weekday

F3 Release: 2 x 15 mL samples should be taken for cell count and microcarriers and cells are to be treated with 2 x 7.5 mL of F3 (15 mM Sodium Citrate).

- ☐ Aliquot 15 mL F3 solution into a 50 mL conical tube and place it in the incubator for 10 min. to bring it to 37°C.
- ☐ Take 2 x 15 mL sample per Bioreactor SOP.
- ☐ Inject samples in to two separate labeled 50 mL tubes ("Sample 1" and "Sample 2", sample 1 should be the first sample taken from the bioreactor, and sample 2 should be the second).
- ☐ Let MC-cells settle (~5-8 minutes).
- ☐ Remove ~1 mL of supernatant and place in Eppendorf tube for supernatant cell count using NC-200.

Supernatant Cell Count

DAY				
Viability %				
Live cells/mL				
Dead cells/mL				
Total cells/mL				

DAY				
Viability %				
Live cells/mL				
Dead cells/mL				
Total cells/mL				

- ☐ Remove as much as supernatant possible from the sample without aspirating MC+cells.
- ☐ Re-suspend in 7.5 mL F3 solution (1/2 of initial sample volume to F3 solution).
- ☐ Invert tube a couple of times.
- ☐ Incubate at 37°C for 15-20 minutes, invert tube every ~5 minutes.
- ☐ After 15-20 minutes, cells can be checked under the microscope (while in tube) to ensure that majority of cells have detached from carriers.
- ☐ **Note: As aggregates get larger (i.e. later in culture), an incubation time of 20-25 minutes may be required**
- ☐ During incubation, prepare two 50 mL tube with 7.5 mL (1/2 x original F3 volume) of warmed L7-TFO2 media (**it can be complete or incomplete media**).
- ☐ After incubation is complete, pipette MC+cell solution 2-3 times (do not over-pipette as this affects viability).
- ☐ Making single cells suspension: Strain MC+cells through 70 µm cell strainer to remove free carriers into the 50 mL tube with 15 mL of L7-TFO2 to neutralize.
- ☐ Spin cells at 200 x g for 5 minutes.
- ☐ Re-suspend cell pellet in 1 mL of media between days 1 to 10 and 15 mL of media between days 10 to 16 (specify 1 mL or 15 mL next to the indicated day in the table below).
- ☐ In earlier cell culture days there are not a lot of cells, so in order to obtain a detectable cell count with the NC-200 it is best to re-suspend the cell pellet in a small volume.
- ☐ Remember to take into account dilution factor on samples which were re-suspended in 1 mL of media (they will be 15 times less than original sample volume, and therefore cell counts will be 15 times less).
- ☐ Count by NC-200 to identify cell number and viability.

Cell count method: Cell aggregate protocol (2 cassettes method)

Sample ID:								
Date and Initials:								
Viability (%)								
Live cells (cells/mL)								

Dead cells (cells/mL)								
Total cells (cells/mL)								
Cell diameter (µM)								
Cells in aggregates (%)								

Record results in bioreactor data excel sheet.

8.5. Measuring Perfusion Accuracy

8.5.1. Measure the perfusion accuracy as follows (record this information in the "Perfusion Check" section of the Bioreactor Daily Checklist):

8.5.1.1. Check the waste in the morning, record the weight and time.

8.5.1.2. Calculate the actual perfusion rate as follows:

$$\frac{[t2 \text{ weight (g)} - t1 \text{ weight (g)}]}{[t2 - t1] (\text{min})}$$

8.5.1.3. If the actual perfusion rate deviates from the target (2.08 for 1VVD) by more than 10%, adjust the set point of Pump 4 as follows:

$$\text{new set point} = \frac{[\text{old set point}] * [2.08]}{[\text{actual perfusion rate}]}$$

8.5.1.4. If the perfusion is stable and on-target, there is no need for an afternoon check.

8.5.1.5. If the perfusion is deviating more than usual, an afternoon check is recommended.

8.6. OPTIONAL/ONLY IF APPLICABLE: Increasing agitation rate

8.6.1. If values appear insufficient, (microcarriers are settling), see 5.22.3. Speeds above 150 RPM are not recommended.

8.7. Replacing media feed and/or waste bags

8.7.1. Only 3-4 days' worth of media should be out at a time, so every 3-4 days, the bag needs to be replaced (it can be replaced more frequently as well, if desired).

8.7.2. Waste bag is replaced at the same time as the media bag change.

8.7.2.1. Don't forget to tare the scale after a new bag is replaced.

8.7.2.2. Never allow the waste bag to fill up all the way as it is a safety hazard to lift it off the floor, and there needs to be enough room in the bag for bleach.

8.7.2.3. To dispose of the bag:

8.7.2.3.1. Transfer bag to the sink, stand the bag so it does not tip over.

8.7.2.3.2. Cut open the bag from the top.

8.7.2.3.3. Add ~10% bleach.

8.7.2.3.4. Wait for ~20 minutes.

8.7.2.3.5. Disposed of bleached waste down the drain.

- 8.7.3. If the feed and/or waste bag needs to be replaced:
- 8.7.3.1.1. Prepare the new waste bag or feed bag in advance.
 - 8.7.3.1.2. Record the set point of the perfusion out pump in the batch record.
 - 8.7.3.1.3. Stop perfusion by setting the output on Pump 4 to zero, and setting Pump 3 to Manual, and then zero.
 - 8.7.3.1.4. Seal the C-flex line with a Hot Lips sealer (seal as close as possible to the feed/waste bag).
 - 8.7.3.1.5. Cut the seal.
 - 8.7.3.1.6. Weld on the new feed or waste bag using the 1/8x1/4" C-flex line.
 - 8.7.3.1.7. Set up the new feed bag where the old one was, or set the waste bag on the scale on the floor (and tare the scale again).
 - 8.7.3.1.8. Resume perfusion by setting the perfusion out pump to its previous set point, and setting the media in pump to CAS.

Pre-harvest and harvest day activity checklist

- ☐ Coat with L7-Matrix
 - 4 x 6-well plate (for 2D control- cells-MCs and single cells)
 - 4 x 24-well plate (For IF)
 - 1 x T-25 flask (For karyotyping)
 - 1 x 6-well plate (for ectoderm, endoderm and mesoderm directed differentiation)
- ☐ Prepare 100 mL Incomplete WiCell media for EB formation (if EBs formation assay is planned)
 - Knockout DMEM F-12 (1x) → 78 mL
 - 20% Knockout serum → 20 mL
 - NEAA (non-essential amino acids) (1x) → 1000 µL
 - Glutamax (1x) → 1000 µL
- ☐ ROCKi (10 mM) solution
- ☐ 1 x 500 mL F3 solution
- ☐ Complete L7 media
- ☐ Prepare differentiation media if directed differentiations are planned.
 - StemDiff endoderm differentiation medium and instructions
 - Neurobasal medium and supplements for Ectoderm differentiation
 - Medium for Mesoderm differentiation
- ☐ Samples to take from the bioreactor:
 - 3 x 15 mL sample for cell count

- 1 x 5 mL sample for NOVA and images
- 1 x 5 mL sample for plating on 2D in 24 well plate
- ☐ Perform cell count on 15 mL samples
- ☐ Use the cells from the 15 mL samples for the following:
 - ☐ Plate ~200,000 cells into L7M coated 3 wells in 6 well plate
 - ☐ Plate ~500,000 cells in L7M coated T25 flask
 - ☐ Follow Aggrewell protocol for EB generation
 - ☐ Cryopreserve 4 x 10⁶, 10 x 10⁶, 40 x 10⁶, 120 x 10⁶, 240 x 10⁶, and 320 x 10⁶ cells/vial.
 - ☐ 4-5 x 10⁶ cells for FACS.
 - ☐ Collect 2D cells for FACS.

Take negative control cells from LN₂ for FACS and plate them

Pre-harvest day and harvest day of a 3 L bioreactor

Activities:

For flow activity:

- i. A week before touch base with FACS machine responsible person to make sure it works.
- ii. Run CST the day before flow, or early morning on flow day.

Sampling and imaging on pre-harvest day:

- a. **2 x 32 mL samples for cell and viability count. 15 mL F3 and then 15 mL L7 media to quench**
 - b. **NOVA sample- 5 mL**
 - c. **From cell sample before cell release:**
 - i. Plating on 2D: 1 mL/well in a 6-well plate, two wells. Total of 2 mL. Total cell #: N/A
 - ii. Plating on 2D: 1 mL/4 wells in a 24-well plate, eight wells. Need 2 mL. Total cell #: N/A
 - d. **From cell sample after cell release:**
 - i. Plating on 2D: 200,000 cells/well in a 6-well plate, two wells. With ROCKi. Total cell #: 0.4 x 10⁶ cells
 - ii. Plating on 2D: 50,000 cells/well in a 24-well plate, eight wells. ROCKi. Total cell #: 0.4 x 10⁶ cells
- iii. **Directed differentiation:**

Ectoderm: Low density is needed. Plate 250,000 cells/well in a 6-well plate. One well. 500,000 cells/well. One well. Total cell # 0.75 x 10⁶ cells. Images should be taken.

Endoderm: Confluent culture is needed. 1 x 10⁶/well in a 6-well plate. One well. 2 x 10⁶/well in a 6-well plate. One well. Total of 3 x 10⁶ cells. For IF: 1 x 10⁶/4

wells in a 24-well plate and 2 x 10⁶/4 wells in a 24-well plate. Total of 3 x 10⁶ cells. Total: 6 x 10⁶ cells.

Mesoderm: 1 x 10⁶ cells/well in a 6-well plate. Two wells. Total of 2 x 10⁶ cells.

iv. **Karyotyping:** 500,000 cells/T-25. Total of 0.5 x 10⁶ cells.

v. **EBs formation assay:** 1.2 x 10⁶ cells/well. Four wells. Total of 4.8 x 10⁶ cells.

vi. **Cryopreserve:** 4 x 10⁶ cells/mL x 10 vial = 40 x 10⁶ cells. Cryopreserve: 20 x 10⁶ cells/mL x 3 vials. If cell count is higher than 2 x 10⁶ cells/mL, cryopreserve more using Mr.Frosty/cool-cell.

Sampling and imaging on harvest day:

If FACS machine is having issues, then fix cells: 300,000 cells/tube x 15 tubes.

a. 2 x 18 mL samples for cell and viability count. 9 mL F3 and then 9 mL L7 media

e. **NOVA sample - 5 mL**

f. From cell sample before cell release:

i. Plating on 2D: 1 mL/well in a 6-well plate, two wells. Total of 2 mL. Total cell #: N/A

ii. Plating on 2D: 1 mL/4 wells in a 24-well plate, eight wells. Need 2 mL. Total cell #: N/A

g. From cell sample after cell release:

i. Plating on 2D: 200,000 cells/well in a 6-well plate, two wells. With ROCKi. Total cell #: 0.4 x 10⁶ cells

ii. Plating on 2D: 50,000 cells/well in a 24-well plate, eight wells. ROCKi. Total cell #: 0.4 x 10⁶ cells

iii. Directed differentiation:

Ectoderm: Low density is needed. Plate 250,000 cells/well in a 6-well plate. One well. 500,000 cells/well. One well. Total cell # 0.75 x 10⁶ cells. Images should be taken.

Endoderm: Confluent culture is needed. 1 x 10⁶/well in a 6-well plate. One well. 2 x 10⁶/well in a 6-well plate. One well. Total of 3 x 10⁶ cells. For IF: 1 x 10⁶/4 wells in a 24-well plate and 2 x 10⁶/4 wells in a 24-well plate. Total of 3 x 10⁶ cells. Total: 6 x 10⁶ cells

Mesoderm: 1 x 10⁶ cells/well in a 6-well plate. Two wells. Total of 2 x 10⁶ cells

iv. **Karyotyping:** 500,000 cells/T-25. Total of 0.5 x 10⁶ cells

v. **EBs formation assay:** 1.2 x 10⁶ cells/well. Four wells. Total of 4.8 x 10⁶ cells

vi. **Cryopreservation:** 4 x 10⁶ cells/mL, 10 x 10⁶ cells/mL, 20 x 10⁶ cells/mL, 40 x 10⁶ cells/mL, 120 x 10⁶ cells/mL, and 240 x 10⁶ cells/mL. CRF model 7456 and program below:

1. Wait at 4.0°C.
2. Wait at Chamber = 4.0°C until sample = 5.0°C.
3. Ramp 1°C/min until sample = -6°C.
4. Ramp 25.0°C/min until chamber = -47.0°C.
5. Ramp 15.0°C/min until chamber = -14.0°C.
6. Ramp 1.0°C/min until chamber = -40.0°C.

7. Ramp 10.0°C/min until chamber = -90°C.
8. End

9.0 Harvest Day

Note: Feasible to use these expanded cells to inoculate another stirred tank bioreactor (3D seed train).

9.1. Section 10 contains a harvest day “checklist” sample

9.2. Warm 1.5 L bag of F3 solution to 37°C

9.3. Warm 1.5 L bag of L7-TFO2 basal media to 37°C

9.3.1. Record the weight of the bioreactor:

9.3.2. Weld cfex tubing on the 1.5 L bag of L7-TFO2 media to the cfex tubing on the mesh filter bag (used for harvest separate the microcarriers). Designate this side of the bag as the “cell” side and keep face down.

9.3.3. Transfer 1.5 L of media to a new 5 L media bag.

9.3.4. Transfer 3 mL of 10 mM ROCKi solution to the media bag using a 30 mL syringe too. (To make the volume larger to transfer all the ROCKi in the bag, add 15 mL of L7 medium + 3 mL ROCKi and transfer all into the media bag).

9.3.5. Attach the other cfex tubing on the mesh filter bag to the cfex tubing end of the harvest line.

9.4. Attach a new 5 L empty bag (seal all tubing ports) to the perfusion line via the cfex tubing ends, this bag will be the “waste” bag used when removing the media via the perfusion line.

9.5. While the cells are agitating, begin removing the media from the bioreactor via the perfusion out line and into the waste bag. This can be done using the pump on the finesse system (using the pump-able tubing, such as the pharmed tubing) or using a separate pump at 200 g/min.

9.5.1. The microcarriers might “stick” to the mesh filter end of the perfusion line. This is normal, just bang/tap the vessel or perfusion dipstick to knock some of the carriers off.

9.5.2. **Remove the heating jacket when half the volume (~1.5 L) is removed.**

9.5.3. **Every 1/3 of volume decrease, lower the agitation speed by 10 RPM, once the top of the impeller is visible, stop agitation.**

9.5.4. A small amount of media will be left (along with the microcarriers), 10% of original volume is appropriate.

9.6. Connect the bag of F3 solution (1.5 L) to the harvest line to avoid direct drops on the cells.

9.7. Be sure to keep the pharmed tubing so that you can pump the solution in faster if needed at 400 g/min.

9.8. Pump or use gravity to fill the bioreactor with F3 solution while there is no agitation.

9.9. Once the bioreactor is half-full, put on the heating jacket and center the bioreactor on the scale.

- 9.10. Once the bioreactor is full of F3 solution, do continuous agitation at 90 RPM for 30 minutes.
- 9.10.1. A 5 mL sample can be taken via the sampling line(s) to see how the cells look under a microscope (place in a vessel- i.e 10 cm dish or 6 w plate) post 15-20 mins F3 treatment.
- 9.10.2. If majority of cells look to be detached from the MCs (25-30 mins) then begin the filtration process, otherwise keep incubating in F3 until cells have successfully detached (Note: since F3 is non enzymatic, longer incubations will not harm the cells, certain kinds of mechanical stress will such as over pipetting).
- 9.11. Make sure cells are agitating at 90 RPM and begin removing the cells via the harvest line into the mesh filter – you can use the finesse pumps or a separate pump (separate pump will go faster).
- 9.11.1. When the top of the impeller is visible, decrease agitation to 30 RPM.
- 9.11.2. Towards the end, you can tilt the bioreactor towards the harvest line withdraw area to get as much of the cells out as possible.
- 9.12. The cells are now separated from the microcarriers and in a total of 3 L of solution.
- 9.13. To take a sample from the filter bag, attach the Harvest Line Sampler to the cflex end of the mesh filter bag designated “cell” side and take 3 x 5 mL samples.
- 9.14. Perform cell count.

Date			
Day			
Viability %			
Live cells/mL			
Dead cells/mL			
Total cells/mL			
Cell diameter (µM)			
% aggregates 5 or more			

- ☐ Full or Partial Harvest (see **Harvest Scheme**)
- ☐ Disassemble reactor: bleach
- ☐ Get rid of waste bag: bleach

- 9.15. On the main window of the Finesse screen, click on “RESET ALL TIMERS AND TOTALS” and “CONTROLLERS OFF” buttons then click on “Batch Stop”. Remove all connections between the vessel and the control tower – DO, pH connections, heating blanket, remove RTD from thermo well. Dispose of all biological materials in biohazard containers. Cleanse and store all other components like DO, pH probes and perfusion dipstick.

10. Data Export:

- a. Switch to the Historian PC.
- b. On the desktop, open the folder "use this folder."
- c. In this folder, click on the file titled "Copy of Finesse_Historian_Template_v01.20b_tot.xlsx"
- d. The Historian should be AP01.
- e. Click on the vessel number (e.g. V1). It will become a dropdown menu. Select the vessel number to be accessed.
- f. Select an interval for the data to be extracted.
- g. Type appropriate start date and time (e.g. start of intermittent agitation).
- h. Type appropriate stop date and time (e.g. before removal of media for harvest).
- i. Verify that the number of days calculated corresponds to the bioreactor run data to be exported and verify that the Date Time Format is in US.
- j. Click export.
- k. Save as the data that is exported into the new excel file that appears.
- l. Use a USB drive to transfer the data from the CPU.
- m. Close Excel
- n. Return the Keyboard, mouse and monitor connections to the tower controller CPU.

11. Downstream Processing: kSep400

12.1 Harvested cells can be further concentrated using the kSep400 as per USWW-20415.

- i. Flow rate optimization for fluidized bed formation
 1. Fit the kSep with a 400.50 rotor.
 2. Install the associated 400.50 single-use kits (chamber set and valve set).
 3. Connect the 3 L PSC suspension harvested from the bioreactor to the feed source.
 4. Prime the system and wash the cells with a solution of PlasmaLyte-A and 0.25% human serum albumin.
 5. Use a static centrifuge speed of 782 g.
 6. To optimize the formation of the fluidized bed, test 3 flow rates in increasing order (25, 30 and 35 mL/min).
 7. Prior to each run, sample the feed source in triplicate to determine the cell density going into the kSep.
 8. For the entirety of the concentration process, draw 5 mL samples from the stream exiting the kSep chamber and monitor the amount of cells escaping the fluidized bed using the NucleoCounter NC-200.
 9. Stop the kSep, empty the chamber and collect the concentrated cells after 1 L of cell suspension was processed.
 10. Reset the kSep, purge the tubing and chambers and repeat the process until all flow rates have been tested and the feed source depleted.

ii. hPSC concentration post full harvest

1. Sample the bag containing the filtered PSC suspension harvested from the bioreactor in triplicates.
2. Determine the cell viability and density using the NucleoCounter NC-200.
3. Calculate the concentrated volume that would be harvested by the kSep by using the average viable cell density (VCD). See Equation 1.

Equation 1:

$$\text{Concentrated Vol} = \frac{(\text{Feed VCD}) * (\text{Feed Vol})}{\text{Target Concentrated VCD}}$$

4. Equip the kSep400 with its respective single-use kits (chamber set and valve set).
5. Use a 10 L bag of DPBS-/- to prime the system.
6. Weld the bag onto the kSep valve set.
7. Use the process recipe (Appendix B-C) to prime the system, ramp the centrifuge to 1000 g and pump the cell suspension into 1 chamber at a rate of 120 mL/min.
8. Maintain the settings until the entirety of the feed was processed by the kSep.
9. Periodically draw 5 mL samples from the stream exiting the kSep chamber and use the NucleoCounter NC-200 to monitor the amount of cells escaping the fluidized bed.
10. After emptying the feed bag, harvest the concentrated cells.
11. Verify the volume of the concentrated cells by taking samples to determine viability and cell density using the NucleoCounter NC-200.
12. Cryopreserve the remaining concentrate as described above.

Appendix B: Recipe parameters for kSep400.50.

Parameter	Value	Unit
Active Vessels	A	n/a
Speed	782	g
Bioreactor Volume	50	L
Bioreactor Prime Volume	30	mL
Cycle Volume	Disabled (3.33)	L/Ch
Establish Bed (Bed-setting flow rate)	30	mL/min
Establish bed time	600	min

Flow Rate Ramp Time	0	min
Normal Flow Rate	25, 30, or 35	mL/min/Ch
Recirc. Wash	0	mL
Recirc. duration	0	Min
Recirc. Cycles	0	cycles
Wash flow rate	0	mL/min
# washes	0	#/Ch
2 nd Wash flow rate	0	mL/min/Ch
# washes	0	#/Ch
Mix and Harvest Speed	782	g
Mix Bed flow rate	0	mL/min/Ch
Mix bed duration	0	Sec
Mix Bed cycles	0	Cycles
Harvest Flow Rate	50	mL/min/Ch
Initial Dump Volume	33	mL
Harvest Volume	40	mL

Appendix C: Recipe parameters for kSep400.

Parameter	Value	Unit
Active Vessels	A	n/a
Speed	1000	g
Bioreactor Volume	1	L
Bioreactor Prime Volume	20	mL
Cycle Volume	Disabled (99.0)	L/Ch
Establish Bed (Bed-setting flow rate)	120	mL/min
Establish bed time	60	min
Flow Rate Ramp Time	0	min
Normal Flow Rate	120	mL/min/Ch
Recirc. Wash	0	mL

Recirc. duration	0	Min
Recirc. Cycles	0	cycles
Wash flow rate	204	mL/min
# washes	0	#/Ch
2 nd Wash flow rate	204	mL/min/Ch
# washes	0	#/Ch
Mix and Harvest Speed	1000	g
Mix Bed flow rate	204	mL/min/Ch
Mix bed duration	0	Sec
Mix Bed cycles	0	Cycles
Harvest Flow Rate	120	mL/min/Ch
Initial Dump Volume	Variable – Depends on length of tubing after welding	mL
Harvest Volume	Variable - Depends on cell concentration in harvest bag	mL

12. Recommendations:

- ☐ Reduce L7 matrix quantity during MC coating.
- ☐ Reduce open steps for MC coating.
- ☐ Reduce media consumption by using 1/2 VVD until expansion of approximately 1.3×10^6 cells.
- ☐ Thaw cryopreserved cells directly into 3 L bioreactor (avoiding 2D seed train).
- ☐ Transfer expanded cells from one suspension vessel to another (enabling 3D seed train).

Harvest Scheme

b. Sample Harvest Activity Checklist:

Harvest Day Activity Checklist
 29Mar2018
 PSC 3L Run 2

- ☐ Obtain the following materials
 - ☐ 3L of F3
 - ☐ 6L of Basal L7TFO2
 - ☐ Warm the following materials:
 - ☐ Basal L7TFO2 media
 - ☐ Completed L7TFO2
 - ☐ Thaw knockout serum (-20C)
 - ☐ Knockout DMEM
 - ☐ Coat the following:
 - ☐ 8 wells in a 24 well plate with L7 matrix
- Experiment: PSC 3L Run ____ Vessel Number: ____

	Date					
	Culture Day					
Stability of Bioreactor Environment	Check for stability of pH, DO, temperature in the last 12 hours					
	Check for stability of vessel weight, $\pm 10\%$ of set point					
	Bubble test on exhaust filter					
	Check O₂, N₂ and CO₂ tank pressure and levels					
	Clumping – Y/N? Shake vessel, elaborate in comments					
	Online DO %					
	Vessel Temperature (°C)					
	Agitation Rate (RPM)					
	Pre-sample vessel weight (g)					

Perfusion check	Sample Time (NOVA)					
	Online pH					
	Offline pH					
	1-point pH correction needed? (Y/N)					
	Sample Time (VCD)					
	Post-Sample vessel weight (g)					
	New vessel weight set point (g)					
	Perfusion out rate set point (g/min)					
	AM waste weight check time					
	AM waste weight (g)					
	Perfusion out rate, target (g/min)					
	Perfusion out rate, actual (g/min)					
	Correction needed to perfusion out SP? (Y/N)					
	PM waste weight check time					
	PM waste weight (g)					
	Perfusion out rate, target (g/min)					
	Perfusion out rate,					

	actual (g/min)					
	Correction needed to perfusion out SP? (Y/N)					
	Initials					

	Date					
	Culture Day					
Stability of Bioreactor Environment	Check for stability of pH, DO, temperature in the last 12 hours					
	Check for stability of vessel weight, ±10% of set point					
	Bubble test on exhaust filter					
	Check O₂, N₂ and CO₂ tank pressure and levels					
	Clumping – Y/N? Shake vessel, elaborate in comments					
	Online DO %					
	Vessel Temperature (°C)					
	Agitation Rate (RPM)					
	Pre-sample vessel weight (g)					
Sampling	Sample Time (NOVA)					
	Online pH					

Perfusion check	Offline pH					
	1-point pH correction needed? (Y/N)					
	Sample Time (VCD)					
	Post-Sample vessel weight (g)					
	New vessel weight set point (g)					
	Perfusion out rate set point (g/min)					
	AM waste weight check time					
	AM waste weight (g)					
	Perfusion out rate, target (g/min)					
	Perfusion out rate, actual (g/min)					
	Correction needed to perfusion out SP? (Y/N)					
	PM waste weight check time					
	PM waste weight (g)					
	Perfusion out rate, target (g/min)					
	Perfusion out rate, actual (g/min)					
	Correction needed to perfusion					

	out SP? (Y/N)					
	Initials					

[illegible]

**Preparing 1 mg/mL L7-matrix solution, with total of 18mg
(To be used in step 5.3.3 of the BioBlu 3C bioreactor set up SOP)**

Reagents:

Tissue Culture grade water

L7-Matrix, 3 vials of 5 mg

L7-matrix, 3 vials of 1mg

Step 1: Reconstituting 3 vials of 5 mg lyophilized L7-Matrix to have a 1 mg/mL solution.

- ☐ Put 12 mL of cell culture water in a 50 mL conical tube.
- ☐ Reconstitute each vial in 1 mL of water and swirl gently. Do not vortex.
- ☐ Leave the vial for 5 min to dissolve
- ☐ Transfer the content of each vial to the 50 mL conical tube containing 12 mL cell culture water

Step 2: Reconstituting 3 vials of 1mg lyophilized L7-Matrix, and adding to solution made in step 1, to have 18 mg in 1 mg/mL solution.

- ☐ Reconstitute each vial in 1 mL of water and swirl gently. Do not vortex.
- ☐ Leave the vial for 5 min to dissolve.

Step 3: Coating MCs

- ☐ Adding the 18 mL solution of L7-Matrix (1mg/mL) to 300 mL of DPBS +/+, as indicated in step 5.3.3 of the BioBlu 3C bioreactor set up SOP.

The deviations during a Run should be mentioned in the table below:

Run name	Deviation Event	Cause	Mitigation

[00123] These and other modifications and variations to the present invention may be practiced by those of ordinary skill in the art, without departing from the spirit and scope of the present invention, which is more particularly set forth in the

appended claims. In addition, it should be understood that aspects of the various embodiments may be interchanged both in whole or in part. Furthermore, those of ordinary skill in the art will appreciate that the foregoing description is by way of example only, and is not intended to limit the invention so further described in such appended claims.