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(54) Title: ADULT HUMAN OLFACTORY STEM CELL

(57) Abstract: An isolated human olfactory stem cell can be prepared by culturing human tissue from olfactory neuroepithelium to form neurospheres.

ADULT HUMAN OLFACTORY STEM CELLS

BACKGROUND OF THE INVENTION

Stem cell transplants have broken new ground in disease research. Many believe that stem cells are the keys capable of unlocking treatments for some of the world's most devastating diseases, including cancer, multiple sclerosis, Alzheimer's disease, spinal cord injuries and Parkinson's disease. However, the benefits and successes of stem cell research are often overshadowed by moral and ethical considerations because the most versatile stem cells used in research and treatments originate from human embryos or aborted fetal tissues. These ethical concerns are often weighed against the ability of stem cells to revolutionize the practice of medicine and improve the quality and length of life. The potential answers and treatments stem cells promise have spurred many research efforts, even in the face of moral and ethical concerns.

Initially, pluripotent stem cells were isolated and developed from two sources: directly from the inner cell mass of human embryos at the blastocyst stage and from fetal tissue obtained from terminated pregnancies. However with the significant advantages to be gained from use of stem cells, researchers have been searching for a source of these cells, in adults, that would allow them to avoid the ethical debate associated with the use of stem cells derived from embryos and fetal tissues. Multipotent stem cells have not been found for all types of adult tissue, but discoveries in this area of research are increasing. For example, until recently, it was thought that stem cells were not present in the adult nervous system, but in recent years, neuronal stem cells have been isolated from the adult rat and mouse nervous systems.

While the possibility of deriving stem cells from adult tissue sources holds real promise, there are also some significant limitations. First, adult stem cells are often present in only minute quantities, are difficult to isolate and purify, and their number may decrease with age. Further, although stem cells have been isolated from diverse regions of the adult central nervous system (CNS), they can be removed from none of these locations without serious consequences to the donor (A. Gritti, *et. al.*, 1996; V.G. Kukekov, *et al.*, 1997).

Due to the difficulties associated with deriving stem cells from adult tissues, typically fetal and neonatal olfactory bulbs have been used as a source of cells for transplantation into regions of the nervous system. (See for example, Njenga, M.K and M. Rodriguez, 1998; Rao, M.S., 1999; R. Tennent, and M.I. Chuah, 1996; Li, Y, *et. al.*, 2000). For example, Archer *et al.,* transplanted fetal glial cells into the canine CNS and showed that the transplanted cells caused a large scale remyelination of demyelinated cells and long term survival of these cells. Archer *et al* compared results achieved by transplanting fetal cells with those achieved by transplanting adult cells and found that the fetal cells were more capable of remyelination and survived longer.

Other researchers have avoided the ethical debate of using embryonic and fetal stem cells by using other cells and tissues, and more specifically by using adult olfactory bulb tissue, isolated from the brain, for spinal cord repair. For example, Li *et al.* grafted ensheathment cells from the olfactory bulb into a damaged spinal cord and enabled regeneration of corticospinal tract neurons in the region of the graft (Li, Y., *et. al.*, 2000). Ramón-Cueto *et. al.* have shown that olfactory bulb ensheathment cells, removed from the bulb, help regenerating spinal cord axons cross a gap in the spinal cord (Ramón-Cueto *et. al.*, 1998). Doucette found that ensheathing cells can adopt several different roles as the need arises. Specifically they are able to switch their phenotype from that resembling an astrocyte to that of a myelinating Schwann cell (R. Doucette, 1995).

The unique regenerative capacity of olfactory neuroepithelium (ONe), found in the nasal cavity, has been well documented in numerous reports. The presence of a stem cell population in ONe with the capacity to produce both

neurons and their ensheathment and supporting cells is well known (A.L. Calof, *et. al.*, 1998). Still the difficulty has not been in knowing where adult stem cells are but rather in actually locating and isolating adult stem cells, and maintaining them in a mitotically active state. Others have established cultures of viable stem cells from various sources including embryonic mice (A.L. Calof *et. al.,* 1989, 1998), embryonic rats (A. Kalyani, *et. al.,* 1997; T. Mujaba *et. al.,* 1998; M.S. Rao *et. al.,* 1998; and L.S. Shihabuddin *et al.,* 1997) and neonatal mice and rats (N.K. Mahanthappa *et. al.,* 1993; J.K. McEntire *et. al.,* 2000; S.K. Pixley, 1992, 1994; and M. Satoh and M. Takeuchi, 1995). Cultures from adult mice and rats, (A.L. Calof, *et. al.,* 1998, 1989; F. Feron, *et. al.*, 1999; A. Gritti, *et. al.*, 1996; E.D. Laywell, *et. al.*, 1999; N. Liu, *et. al.*, 1998; K.P.A. Mac Donald, *et. al.*, 1996; and J.S. Sosnowski, *et. al.,* 1995) human embryos, (A.L. Vescovi *et. al.,* 1999) biopsies from patients with Alzheimer's disease (B. Wolozin *et. al.,* 1993) and normal human adults (F. Feron, *et. al.,* 1999; W. Murrel, *et. al.*,1996; and B. Wolozin, *et. al.*, 1992) have produced viable ONe cultures but none have produced stem or neurosphere-forming cells. Instead, each of these cultures contained committed neurons, glia and epithelial cells.

Therefore identifying a source of readily accessible adult autologous neural stem cells that can be obtained without permanent damage to the donor individual would be of great benefit not only because it avoids the ethical concerns associated with using embryonic and fetal stem cells, but also by providing powerful tools for developing treatments, increasing the successes of transplantation techniques, and by providing methods for diagnostic and drug development evaluations.

BRIEF SUMMARY OF THE INVENTION

In a first aspect, the present invention is an isolated human olfactory stem cell.

In a second aspect, the present invention is a cell culture of an isolated human olfactory stem cell.

In a third aspect, the present invention is a method of isolating cells, by culturing human tissue from olfactory neuroepithelium to form neurospheres.

In a fourth aspect, the present invention is a method of forming a cell culture by isolating cells obtained from culturing human tissue from the olfactory neuroepithelium to form neurospheres and then contacting the isolated cells with a differentiation factor.

In a fifth aspect, the present invention is a method of forming a differentiated cell, by contacting an isolated human olfactory stem cell with a differentiation factor.

In a sixth aspect, the present invention is a method of treating a neurological disorder by transplanting a plurality of isolated human olfactory stem cells.

In a seventh aspect, the present invention is a method of treating a neurological disorder by transplanting a plurality of cells differentiated by contacting an isolated human olfactory stem cell with a differentiation factor.

In an eighth aspect, the present invention is a method of treating a neurological disorder by isolating a plurality of cells by culturing human tissue from olfactory neuroepithelium to form neurospheres and transplanting a plurality of these isolated human olfactory stem cells.

In a ninth aspect, the present invention is a method of evaluating a compound for neurological effects by contacting an isolated human stem cell with the compound.

In a tenth aspect, the present invention is a kit with a plurality of human olfactory stem cells.

BRIEF DESCRIPTION OF SEVERAL VIEWS OF THE DRAWINGS

Figure 1. Human ONe neurospheres.

Figure 2a-2b. Neurosphere forming cells immunopositive for β-tubulin isotype III.

Figure 2c. Neurosphere forming cells immunopositive for NCAM.

Figure 2d. Neurosphere forming cells immunopositive for MAP2ab

Figure 3a-3b. Neurosphere cells immunonegative for neuronal markers β-tubulin isotype III, NCAM, and MAP2ab, but immunopositive for A2B5 and GFAP .

Figure 4a-4b. Subculture of neurosphere-forming cells.

Figure 4c-4d. Subculture of neurosphere-forming cells supplemented with 2.5 mM dibutyryl-cAMP.

Figure 5. Localization of Trk receptors on subcultured neurosphere-forming cells.

DETAILED DESCRIPTION OF THE INVENTION

That human ONe can be manipulated *in vitro* to form neurospheres from donors as old as 95 years of age, demonstrates a remarkable degree of neuroplasticity in these cells. Furthermore the direct, minimally invasive surgical accessibility of human ONe, coupled with its pluripotency, makes this a good autologous source of stem cells. These cells can be removed, expanded, and manipulated *ex vivo* prior to return, via transplantation to the donor for regeneration of damaged neural tissue. These pluripotent stem cells can also be used to generate patient-specific genetic diagnostic evaluation and treatment.

ONe provides a source of viable adult pluripotent stem cells, capable of use in research, treatments, drug development, and transplantations, which avoids the ethical concerns associated with use of embryonic and fetal stem cells. Even further, use of ONe avoids ethical concerns associated with the use of animal models and can even be used where there are no animal models. ONe has a life long regenerative capacity; stem cells located within the ONe replace aging and

damaged neurons and their sustentacular cells. The accessibility of ONe and proliferative capacity make it a unique source for progenitor cells. Further the ability to obtain ONe pluripotent stem cells from the nasal cavity eliminates the need to use highly invasive and damaging procedures that are currently available to obtain post-embryonic stem cells. In addition, since one of the greatest problems encountered in transplantations is tissue rejection, providing stem cells for autologous transplantation eliminates the need to wait for a histocompatible donor and thereby greatly reduces both the frequency and severity of rejection. The present invention also can provide a source of stem cells from individuals with unique nervous system disorders such as bi-polar disorder, schizophrenia or amyotrophic lateral sclerosis for use in drug or treatment development. The present invention also has the advantage of generating patient-specific cell populations for immunological, pharmacological and genetic diagnostic evaluations.

II. Definitions

A. Cell Types

A cell that is "totipotent" is one that may differentiate into any type of cell and thus form a new organism or regenerate any part of an organism.

A "pluripotent" cell is one that has an unfixed developmental path, and consequently may differentiate into various differentiated cell types, for example, neurons, oligodendrocytes, astrocytes, ensheathing cells or glial cells. Pluripotent cells resemble totipotent cells in that they are able to develop into other cell types; however, various pluripotent cells may be limited in the number of developmetal pathways they may travel.

A "multipotent cell" is a cell that is derived from a pluripotent pre-cursor and can differentiate into fewer cell types than this pluripotent pre-cursor.

A "stem cell" describes any precursor cell, capable of self-renewal, whose daughter cells may differentiate into other cell types. In general, a stem cell is capable of extensive proliferation, generating more stem cells (self-renewal) as well as more differentiated progeny. Thus, a single stem cell can generate

millions of differentiated cells as well as other stem cells. Stem cells provide a continuous source of tissue precursor cells.

Stem cells may divide asymmetrically, with one daughter cell retaining the stem state and the other expressing some distinct other specific function and phenotype. Alternatively, some of the stem cells in a population can divide symmetrically into two stems, thus maintaining some stem cells in the population as a whole, while other cells in the population give rise only to differentiated progeny. Researchers have noted that cells that begin as stem cells might proceed toward a differentiated phenotype, such as a neuron, but then "reverse" and re-express the stem cell phenotype upon implantation.

"Human olfactory stem cell" means a cell which is human, as determined by the chromosome structure or reaction with human specific antibodies, and has at least two of the following characteristics, and preferably has at least three of the following characteristics, more preferably has least four of the following characteristics, still more preferably has at least five of the following characteristics and most preferably has all of the following characteristics:

divides every 18-24 hours for over 200 passages;

immunoreactivity for the marker β-tubulin isotype III is significantly elevated when the cell is grown on various substratum, such as a matrix coated with a mixture of enctanin, laminin and collagen IV (ECL-matrix) alternatively laminin or fibronectin may also be used;

immunoreactivity for β-tubulin isotype III is much higher than other cell types immunoreactivity for this marker;

addition of dibutyryl cAMP to the culture growing on ECL-matrix causes the cells to form processes;

immunopositive for NCAM marker; or

does not require a feeder layer for growth and proliferation.

The human olfactory stem cell may not have all of the aforementioned characteristics, but will have at least two of these characteristics simultaneously.

Preferably human olfactory stem cells will propagate in culture and can differentiate into one or more of the following cell types: neurons, ensheathing cells, epithelial cells or astrocytes.

A "neurosphere" is a cluster of about 20 to 80 mitotically active neuronal or glial pre-cursor cells. Generally neurospheres represent a population of neural cells in different stages of maturation formed by a single, clonally expanding pre-cursor that forms spherical, tightly packed cellular structures.

An "oligosphere" is a cluster of mitotically active oligodendrocyte, pre-cursor cells. Generally oligospheres represent a population of oligodendrocytes in different stages of maturation formed by a single, clonally expanding pre-cursor that forms spherical, tightly packed cellular structures. (V. Avellana-Adalid, *et. al.,* 1996; S.C. Zhang, *et. al.,* 1998).

"Post-embryonic" cells include any cells present in a vertebrate at any stage after birth.

B. Characterization of Cell Types

"Isolated" means outside of the body or *ex vivo* and containing at least 10% of the human olfactory stem cell, including cells that may be frozen individually or are frozen in a clump or cluster.

A "marker" is used to determine the differentiated state of a cell. Markers are characteristic, whether morphological or biochemical (enzymatic), particular to a cell type, or molecules expressed by the cell type. Preferably, such markers are proteins, and more preferably possess an epitope for antibodies or other binding molecules available. However, a marker may comprise any molecule found in a cell, including but not limited to, proteins (peptides and polypeptides), lipids, polysaccharides, gangliosides, nucleic acids, steroids and derivatives thereof.

Markers may be detected by any method available to one of skill in the art. In addition to antibodies (and all antibody derivatives) that recognize and bind to at least one epitope on a marker molecule, markers may be detected using analytical techniques, such as by protein dot blots, sodium dodecyl sulfate polyacrylamide gel electrophoresis (SDS-PAGE), or any other gel system that

separates proteins, with subsequent visualization of the marker (such as Western blots), gel filtration, affinity column purification; morphologically, such as fluorescent-activated cell sorting (FACS), staining with dyes that have a specific reaction with a marker molecule (such as ruthenium red and extracellular matrix molecules), specific morphological characteristics (such as the presence of microvilli in epithelia, or the pseudopodia/filopodia in migrating cells, such as fibroblasts and mesenchyme); and biochemically, such as assaying for an enzymatic product or intermediate, or the overall composition of a cell, such as the ratio of protein to lipid, or lipid to sugar, or even the ratio of two specific lipids to each other, or polysaccharides. In the case of nucleic acid markers, any known method may be used. If such a marker is a nucleic acid, PCR, RT-PCR, *in situ* hybridization, dot-blot hybridization, Northern blots, Southern blots and the like may be used, coupled with suitable detection methods.

A marker or a combination of markers will show specificity to a cell type. Myofibrils, for example, are characteristic solely of muscle cells; axons are only found in nervous tissue, cadherins are typical of epithelia, β2-integrins to white blood cells of the immune system, and a high lipid content characteristic of oligodendrocytes while lipid droplets are unique to adipocytes. See Table 1 below for a list of Markers that may be used in the present invention.

Table 1 Markers for use in identification of cell types

Antibodies and Growth Factor Receptors	**Useful dilutions when the diluent is the described antibody or growth factor**	**Target**	**Source***
Trk A, B, C or pan	1:100	Neurotrophin receptors	Santa Cruz BioTech, Santa Cruz, CA
NGF receptor $p75^{NGFR}$, human	1:50	Neurons and glia	Sigma, St. Louis, MO

monoclonal			
GFAP, polyclonal	no dilution	Ensheathment progenitor	INCSTAR, Stillwater, MN
GFAP, monoclonal	1:40	Ensheathment progenitor, astrocytes, olfactory glia	Boehringer Mannheim, Indianapolis, IN
A2B5, monoclonal	1:100	Glia, some neurons	Boehringer Mannheim, Indianapolis, IN
β-tubulin isotype III	clone	Neurons, progenitor cells	Sigma, St. Louis, MO
Monoclonal MAP2ab	1:250	Neurons	Boehringer Mannheim, Indianapolis, IN
Cytokeratin, CK5/6	1:20	Epithelial	Boehringer Mannheim, Indianapolis, IN
E-NCAM (5A5), monoclonal	dilution undetermined	Neurons	DSHB, University of Iowa, IA
NCAM, monoclonal	1:50	Neurons	Chemicon International, Temecula, CA
Apha-internexin	1:50	Immature neurons	Chemicon International, Temecula, CA
Nestin, monoclonal	1:50	Embryonic stem cells	Chemicon International, Temecula, CA
Nestin, polyclonal	1:40	neuronal stem cells	(R. McKay, 1997)
mAb against actin	1:100	Microfilaments	Boehringer Mannheim, Indianapolis, IN

pAb against tubulin	1:20	Microtubules	ICN Biochemicals, Costa Mesa, CA
mAb against tubulin	1:500	Microtubules	Amersham, Arlington Heights, IL
RIP, polyclonal	1:20	Mature oligodendrocytes	Zymed, San Francisco, CA

*Alternatively if these commercial antibodies are not available, one of skill in the art will know how to make antibodies. For example, an antibody may be made in the following manner.

Polyclonal antibodies can be raised against a mammalian host by one or more injections of an immunogen and, if desired, an adjuvant. Typically, the immunogen (and adjuvant) is injected in the mammal by a subcutaneous or intraperitoneal injection. The immunogen may include molecules such as polypeptides, whole cells or fractions of cells and may be recombinantly produced or non-recombinantly produced. Examples of adjuvants include Freund's complete and monophosphoryl Lipid A synthetic-trehalose dicorynomycolate (MPL-TDM). To improve the immune response, an immunogen may be conjugated to a polypeptide that is immunogenic in the host, such as keyhole limpet hemocyanin (KLH), serum albumin, bovine thyroglobulin, and soybean trypsin inhibitor. Protocols for antibody production are well-known (Harlow and Lane, 1988). Alternatively, pAbs may be made in chickens, producing IgY molecules (Schade *et. al.*, 1996).

Monoclonal antibodies may also be made by immunizing a host, or lymphocytes from a host, harvesting the mAb secreting (or potentially secreting) lymphocytes, fusing the lymphocytes to immortalized cells, and selecting those cells that secrete the desired mAb. The mAbs may be isolated or purified from the culture medium or ascites fluid by conventional procedures such as polypeptide A-Sepharose, hydroxylapatite chromatography, gel electrophoresis, dialysis,

ammonium sulfate precipitation or affinity chromatography (Harlow and Lane, 1988; Harlow and Lane, 1999.)

"Plasticity" describes the ability of a cell to vary in developmental pattern, *i.e.* the ability to be molded or altered. Preferably a cell that demonstrates "plasticity" demonstrates the ability to differentiate into various cell types.

"Differentiation" describes the acquisition or possession of one or more characteristics or functions different from that of the predecessor cell type. A differentiated cell is one that has a different character or function from the surrounding structures or from the precursor of that cell (even the same cell). Differentiation gives rise from a limited set of cells (for example, in vertebrates, the three germ layers of the embryo: ectoderm, mesoderm and endoderm) to cellular diversity, creating all of the many specialized cell types that comprise an individual.

Differentiation is a developmental process whereby cells assume a specialized phenotype, *i.e.* acquire one or more characteristic or functions distinct from other cell types. In most uses, the differentiated phenotype refers to a cell phenotype that is at the mature endpoint in some developmental pathway. In many but not all tissues, the process of differentiation is coupled with exit from the cell cycle; in these cases, the cell loses or is greatly restricted in its capacity to proliferate.

A "differentiation factor" is any chemical or thing that will cause differentiation. This includes, for example, substrates and growth factors.

In general, a "growth factor" is a substance that promotes cell growth and development by directing cell maturation and differentiation. Growth factors may also mediate tissue maintenance and repair. Growth factors are ligated by specific receptors and act at very low concentrations. Many growth factors are mediated, at least partially, by second messengers, such as cyclic AMP (cAMP). Members of the neurotrophin family (NGF, BDNF, NT3 and NT4/5) play a key role in neuronal development, differentiation and survival. Growth factors of the neurotrophin family typically act through tyrosine kinase receptors (Trks).

A "neurological disorder" is any disorder, including psychiatric disorders, affecting a part of the nervous system, such as the nerves, spinal cord, or brain. Some examples of neurological disorders would include Parkinson's disease, Alzheimer's disease, multiple sclerosis, amyotrophic lateral sclerosis, spinal cord injury, schizophrenia, autism and bi-polar disorder.

A "neurotransmitter" is any chemical or substance capable of inhibiting or exciting a postsynaptic cell. Some examples of neurotransmitters includes dopamine, serotonin and acetylcholine. It is well known that improper levels of neurotransmitters are associated with numerous disorders, including neurological disorders as described above.

"Neurotigenesis" is the formation of new processes and extension of existing processes resembling those of neurons.

II. Isolating Human Olfactory Stem Cells

ONe tissue is first removed from the nasal cavity. The skilled artisan will appreciate that the ONe tissue may be removed using a variety of methods. A preferred method of removing the ONe tissue involves the use of an endoscope, having a fiber optic cable with a "pincher" at one end, to take a biopsy. An advantage of using this preferred method is the ability to obtain tissue samples from live donor individuals, with minimal invasiveness and discomfort. A further advantage of removing ONe tissues using an endoscope is the ability to freeze or culture the ONe stem cells obtained in an initial collection and the ability to take multiple collections when needed for *in vitro* culture viability or to reach a desired level of stem cell quantity.

A lateral rhinotomy is another method for removing ONe tissues. A lateral rhinotomy is an operative procedure in which the nose is incised along one side so that it may be turned away to provide full access to the nasal cavity and ONe tissue. However this procedure is highly invasive. In a preferred method, the lateral rhinotomy procedure is utilized to remove ONe tissues from a cadaver. In this method, the cadaver is preferably no more than eighteen hours postmortem

and more preferably is six hours postmortem and most preferably, the cadaver is immediately postmortem.

Once removed, the ONe may be cultured. For example, ONe is cultured in medium containing DMEM (Dulbecco's Modified Eagle Medium) and F12 (1:1) with 10% heat-inactivated fetal bovine serum (FBS) (all media components from GIBCO, Grand Island, NY). Other media may be appropriate, as recognized by the skilled artisan, as well as different animal sources of sera or the use of serum-free media; furthermore, some cultures will require additional supplements, including amino acids (such as glutamine), growth factors, *etc.*. A variety of substrata may be used to culture the cells, for example, plastic or glass, coated or uncoated substrata may be used. For example, the culture plate may be a laminin-fibronectin coated plastic plate. Alternatively the substrata may be coated with extracellular matrix molecules (to encourage adhesion or to control cellular differentiation), collagen or poly-L-lysine (to encourage adhesion free of biological effects). The cell culture substrata may also be treated to be charged. In the case where substratum adhesion is undesired, spinner cultures may be used, wherein cells are kept in suspension. Further the composition of the substrata can play a role in differentiation of ONe stem cells.

The removed ONe not only contains pluripotent stem cells, but it may also contain olfactory receptor neurons (ORNs), olfactory ensheathment or sustentacular cells (OECs), epithelial supporting cells, and fibroblasts. After culturing for several weeks, a population of mitotically active cells emerge, while the ORNs and OECs become vacuolated, retract their processes, and die after approximately three weeks *in vitro*. These mitotically active cells double every day. After 2-3 weeks of additional undisturbed proliferation neurospheres begin to form. However this occurs in only 5-10% of the cultures so multiple cultures are generally needed to form and sustain a collection of cells. The neurosphere cells are collected from the culture. A variety of methods may be used to collect the neurospheres, including enzymatic removal (such as by trypsination), chemical methods, (*e.g.* cation metal chelation using Ethylenediaminetetraacetic Acid (EDTA) or Ethylene,Glycol-bis(β-aminoethyl Ether) N,N,N',N'-Tetraacetic Acid

(EGTA), and mechanically, such as by cell scraping or in the case of suspension cells, by simple centrifugation. After harvest, cells may be washed and separated from unwanted debris by centrifugation with or without a gradient (continuous or step, such as with polyethylene glycol or sucrose), or sorted, if desired by FACS or other binding-based techniques, such as antibodies to a specific cell marker coated on (magnetic) beads. Preferably, all collection methods are performed aseptically. One of skill in the art will know how to properly determine useful parameters, such as incubation times with cell removal agents (chemical or enzymatic), temperatures, centrifugal force, and number and type of washes. After collection, the neurospheres are mechanically dispersed into individual cells, repeatedly washed with an osmotically-appropriate (buffered or unbuffered) solution, usually provided by salt solutions, such as saline's or Ringer's solution and centrifuged to remove cell debris, and then replated at 10^3 cells per mm^2.

The cells may be further isolated from these replated cells and characterized by probing the cells with lineage-specific antibodies, or examined for other useful markers. Initially it is preferred to determine whether neurons are present in the isolated cell cultures. In addition to simple microscopic inspection, neurons may be more sensitively detected by at least the following markers: NCAM, E-NCAM, monoclonal MAP2ab, β-tubulin isotype III, A2B5 and NGF receptor (Table 1). Glial cells may be detected by at least the presence of a glial membrane enriched ganglioside with a monoclonal antibody, such as A2B5. Astrocytes may be detected at least by the presence of glial fibrillary acid protein (GFAP). Table 2 summarizes the immunoreactivity of ONe neurosphere cells which contain human olfactory stem cells.

Table 2 Summary of immunoreactivity of subcultured neurosphere cells from ONe

Antigen Expressed
NCAM+/Nestin+- **
NCAM+/Keratin-
β-tubulin III +/Nestin+-**
β-tubulin III +/GFAP-
GFAP +/β-tubulin III-

GFAP +/RIP-
GFAP +/A2B5+
Trk A +/$p75^{NGFR}$ -
Trk B +/$p75^{NGFR}$ -

** +- means that there are both immunopositive and immunonegative cells wherein at least more than one cell is immunonegative but not all cells are immunonegative.

III. Cell Cultures

Suitable medium and conditions for generating primary cultures and maintaining the above neurosphere cultures are well known in the art and can vary depending on the cell types present. For example, skeletal muscle, bone, neurons, skin, liver and embryonic stem cells are all grown in media differing in their specific contents. Furthermore, media for one cell type may differ significantly from lab to lab and institution to institution. To keep cells dividing, serum, such as fetal calf serum, is added to the medium in relatively large quantities, 1-30% by volume, again depending on cell or tissue type. Specific purified growth factors or cocktails of multiple growth factors can also be added or are sometimes substituted for serum. When differentiation is desired and not proliferation, serum with its mitogens is generally limited to about 0-2% by volume. Specific factors or hormones that promote differentiation and/or promote cell cycle arrest can also be used.

Physiologic oxygen and subatmospheric oxygen conditions can be used at any time during the growth and differentiation of cells in culture, as a critical adjunct to selection of specific cell phenotypes, growth and proliferation of specific cell types, or differentiation of specific cell types. In general, physiologic or low oxygen-level culturing is accompanied by methods that limit acidosis of the cultures, such as addition of strong buffer to medium (such as HEPES), and frequent medium changes and changes in CO_2 concentration.

In addition to oxygen, the other gases for culture typically are about 5% carbon dioxide and the remainder is nitrogen, but optionally may contain varying amounts of nitric oxide (starting as low as 3 ppm), carbon monoxide and other gases, both inert and biologically active. Carbon dioxide concentrations typically range

around 5%, but may vary between 2-10%. Both nitric oxide and carbon monoxide, when necessary, are typically administered in very small amounts (*i.e.* in the ppm range), determined empirically or from the literature.

The medium can be supplemented with a variety of growth factors, cytokines, serum, *etc*. Examples of suitable growth factors are basic fibroblast growth factor (bFGF), neuronal growth factor (NGF), NT3, NT4/5, brain-derived neuronal factor (BDNFs) and colony stimulating factor (CSF). Examples of hormone medium additives are estrogen, progesterone, testosterone or glucocorticoids such as dexamethasone. Examples of cytokine medium additives are interferons, interleukins, or tumor necrosis factor-α (TNFα). One skilled in the art will test additives and culture components in different culture conditions, as these may alter cell response, active lifetime of additives or other features affecting their bioactivity. In addition, the surface on which the cells are grown can be plated with a variety of substrates that contribute to survival, growth and/or differentiation of the cells. These substrates include but are not limited to laminin, ECL-matrix, collagen, poly-L-lysine, poly-D-lysine, polyornithine and fibronectin. In some instances, when 3-dimensional cultures are desired, extracellular matrix gels may be used, such as collagen, ECL-matrix, or gelatin. Cells may be grown on top of such matrices, or may be cast within the gels themselves. For example, the use of an ECL-matrix, promoted the lineage restriction of the ONe derived cells toward maturing neurons as indicated by the level of neuritogenesis.

IV. Transplantation

The stem cells of the present invention may be transplanted into a patient suffering from a neurological disorder, such as spinal cord injury, Alzheimer's disease, Parkinson's disease, amyotrophic lateral sclerosis or multiple sclerosis, as a method of treating the disorder. Methods of transplantation include injection of transformed or cells effective for treating a neurological disorder, via a variety of methods, at the site of injury or a distant site. The cells may be partial or completely differentiated prior to transplantation.

V. Reformation or Formation of CNS structures

The stem cells of the invention may further be used to form or reform damaged or malfunctioning CNS structures, such as axons or encourage regrowth of existing axons. For example, Li *et. al.* have demonstrated that injection of ensheathing cells cultured from adult rat olfactory bulb, at a site of transection of the upper cervical corticospinal tract, induced unbranched, elongative growth of the cut corticospinal axons and restored motor function (Li *et. al.*, 2000). Similarly, the stem cells may be differentiated, and the resulting ensheathing cells selected and transplanted to repair spinal damage.

The differentiation of stem cells can be directed to result in a particular type of daughter cell arising from the parent stem cell. For example when the stem cell of the present invention is exposed to dibutryl cAMP for 24 hours, it differentiates into a progenitor containing a neurofilament precursor. Furthermore, in culture, at least a portion of the stem cells spontaneously differentiate and may be selected. Freezing may be used to store the differentiated cells until enough are collected for an effective transplantation. Therefore by inducing the stem cell of the present invention to form a desired cell type, and injecting this differentiated cell into the site of injury, CNS structures may be treated.

E. Pharmacological Approaches

The cells of the present invention may be used to manufacture pharmaceutically useful compounds, such as dopamine or other neurotransmitters produced by healthy neurons. Therefore by directing the stem cell of the present invention down a differentiation pathway leading to neuron formation, a unique cell culture comprised of differentiated neurons derived from the stem cell of the present invention can provide large cell populations capable of producing large amounts of pharmaceutically useful compounds, such as dopamine. Further, many growth factors, including at least NGF, BDNF, NT3 and NT4/5 may be used to direct the stem cell to differentiate.

Second messengers, such as cAMP may be used to mediate the interaction between the growth factor receptors of the differentiating stem cell and the growth factors themselves. For example, exposure of neurosphere subcultures to media containing 2.5 mM dibutyryl cAMP drastically decreases mitotic activity and increases in the levels of α-internexin, a neuronal marker that appears prior to neurofilament formation in developing neurons.

Additionally, the cells of the invention may be manipulated to express transgenes that encode useful products. An advantage of engineering the cells of the invention, whether differentiated or not, is the possibility of producing polypeptides, such as neuronal polypeptides or stem-cell specific polypeptides that are processed in a manner that they would be in their native context and can thus be cultured in large quantities. Another advantage includes the engineering of such cells prior to transplantation to a subject such that a therapeutically useful molecule is expressed; for example, a patient suffering from Parkinson's disease can have ONe cells harvested to create the stem cells of the invention, but they will not express sufficient dopamine to treat Parkinson's disease. Thus such cells can be engineered with a wild-type dopamine gene (either operably linked to the endogenous dopamine promoters or to an exogenous promoter, depending on the regulation and quantity of secretion that is desired) before implantation

F. Recombinant DNA manipulation of cells

To manipulate DNA *in vitro* so that the cells of the invention are engineered with exogenous nucleic acid sequences, many techniques are availabled to those skilled in the art (Ausubel *et al.*, 1987).

Vectors are tools used to shuttle DNA between host cells or as a means to express a nucleotide sequence. Some vectors function only in prokaryotes, while others function in both prokaryotes and eukaryotes, enabling large-scale DNA preparation from prokaryotes for expression in eukaryotes. Inserting the DNA of interestthe neurological polypeptide is accomplished by ligation techniques and/or mating protocols well known to the skilled artisan. Such DNA is inserted such that its integration does not disrupt any necessary components of the vector. In the case of vectors that are used to express the inserted encoded polypeptide, the introduced DNA

is operably-linked to vector elements that govern its transcription and translation. "Operably-linked" indicates that a nucleotide sequence of interest is linked to regulatory sequences such that expression of the nucleotide sequence is achieved.

Vectors can be divided into two general classes: Cloning vectors are replicating plasmid or phage with regions that are non-essential for propagation in an appropriate host cell and into which foreign DNA can be inserted; the foreign DNA is replicated and propagated as if it were a component of the vector. An expression vector (such as a plasmid, yeast, or animal virus genome) is used to introduce foreign genetic material into a host cell or tissue in order to transcribe and translate the foreign DNA. In expression vectors, the introduced DNA is operably-linked to elements, such as promoters, that signal to the host cell to transcribe the inserted DNA. Some promoters are exceptionally useful, such as inducible promoters that control gene transcription in response to specific factors, or tissue-specific promoters. Vectors have many manifestations. A "plasmid" is a circular double stranded DNA molecule that can accept additional DNA fragments. Viral vectors can also accept additional DNA segments into the viral genome. Certain vectors are capable of autonomous replication in a host cell (e.g., bacterial vectors having a bacterial origin of replication and episomal mammalian vectors). Other vectors (*e.g.*, non-episomal mammalian vectors) integrate into the genome of a host cell and replicate as part of the host genome. In general, useful expression vectors are plasmids and viral vectors (*e.g.*, replication defective retroviruses, adenoviruses and adeno-associated viruses); other expression vectors can also be used.

Vectors can be introduced in a variety of organisms and/or cells (Table D). Alternatively, the vectors can be transcribed and translated in vitro, for example using T7 promoter regulatory sequences and T7 polymerase.

Table DExamples of hosts for cloning or expression

Organisms	Examples	Sources and References*
Prokaryotes		
Enterobacteriaceae	*E. coli*	
	K 12 strain MM294	ATCC 31,446
	X1776	ATCC 31,537
	W3110	ATCC 27,325
	K5 772	ATCC 53,635
	Enterobacter	
	Erwinia	
	Klebsiella	
	Proteus	
	Salmonella (*S. tyhpimurium*)	
	Serratia (*S. marcescans*)	
	Shigella	
	Bacilli (B. *subtilis* and *B. licheniformis*)	
	Pseudomonas (P. *aeruginosa*)	
	Streptomyces	
Eukaryotes		
Yeasts	*Saccharomyces cerevisiae*	
	Schizosaccharomyces pombe	
	Kluyveromyces	(Fleer et al., 1991)
	K. lactis MW98-8C, CBS683, CBS4574	(de Louvencourt et al., 1983)

Table DExamples of hosts for cloning or expression

Organisms	Examples	Sources and References*
	K. fragilis	ATCC 12,424
	K. bulgaricus	ATCC 16,045
	K. wickeramii	ATCC 24,178
	K. waltii	ATCC 56,500
	K. drosophilarum	ATCC 36,906
	K. thermotolerans	
	K. marxianus; yarrowia	(EPO 402226, 1990)
	Pichia pastoris	(Sreekrishna et al., 1988)
	Candida	
	Trichoderma reesia	
	Neurospora crassa	(Case et al., 1979)
	Torulopsis	
	Rhodotorula	
	Schwanniomyces (*S. occidentalis*)	
Filamentous Fungi	*Neurospora*	
	Penicillium	
	Tolypocladium	(WO 91/00357, 1991)
	Aspergillus (*A. nidulans* and *A. niger*)	(Kelly and Hynes, 1985; Tilburn et al., 1983; Yelton et al., 1984)
Invertebrate cells	*Drosophila* S2	
	Spodoptera Sf9	
Vertebrate cells	Chinese Hamster Ovary (CHO)	
	simian COS COS-7	ATCC CRL 1651

Table D Examples of hosts for cloning or expression

Organisms	Examples	Sources and References*
	HEK 293	
*Unreferenced cells are generally available from American Type Culture Collection (Manassas, VA).		

Vector choice is dictated by the organism or cells being used, and the desired fate of the vector. Vectors may replicate once in the target cells or may be"suicide" vectors. In general, vectors comprise signal sequences, origins of replication, marker genes, enhancer elements, promoters, and transcription termination sequences. The choice of these elements depends on the organisms in which the vector will be used.

Some of these elements may be conditional, such as an inducible or conditional promoter that is turned"on"when conditions are appropriate. Examples of inducible promoters include those that are tissue-specific, which relegate expression to certain cell types, steroid-responsive, or heat-shock reactive. Some bacterial repression systems, such as the *lac* operon, have been exploited in mammalian cells and transgenic animals (Fieck et al. , 1992; Wyborski et al. , 1996; Wyborski and Short, 1991). Vectors often use a selectable marker to facilitate identifying those cells that have incorporated the vector. Many selectable markers are well known in the art for the use with prokaryotes, usually antibiotic-resistance genes or the use of autotrophy and auxotrophy mutants. Table F summarizes many of the available markers.

Methods of eukaryotic cell transfection and prokaryotic cell transformation are well known in the art. The choice of host cell dictates the preferred technique for introducing the nucleic acid of interest. For mammalian cells, transfection techniques that are exceptionally useful include, *e. g.*, calcium phosphate precipitation-mediated transfection, liposomes, viruses, and electroporation.

Screening assays

The invention provides a method (screening assay) for identifying modalities, *i. e.*, candidate or test compounds or agents (*e.g.*, peptides, peptidomimetics, small molecules or other drugs), foods, combinations thereof, *etc.*, that effect neuronalfunctions, whether stimulatory or inhibitory, including gene expression and translation, gene activity or copies of the gene in cells. Testing for compounds that increase or decrease the neurological polypeptide neurological effect or neuronal activity, such as increasing or decreasing the formation of neurotransmitters (*e. g.*, dopamine, serotonin or acetycholine), neurotransmitter receptors, transmitter binding or even cell death. Differentiation factors may be applied to the cells before contacting the cells with a compound. A compound may modulate neurological effects by affecting: (1) the number of copies of at least one gene in the cell (amplifiers and deamplifiers); (2) increasing or decreasing the transcription of at least one gene (transcription up-regulators and down- regulators); (3) by increasing or decreasing the translation of at least one mRNA into polypeptide (translation up-regulators and down-regulators); or (4) by increasing or decreasing the activity of at least one polypeptide itself (agonists and antagonists).

Genes, mRNAs and polypeptides that are especially useful to observe include those for neurotransmitters and their receptors (such as variations of their expression or activity).

(a) *effects of compounds*

To identify compounds that affect the neurological function the cells of the invention are contacted with a candidate compound, and the corresponding change in the target the neurological polypeptide is assessed (Ausubel et al. , 1987). For DNA amplifiers and deamplifiers, the amount of a target gene, such as one that encodes a neurotransmitter, is measured; for those compounds that are transcription up-regulators and down-regulators, the amount of a target mRNA is determined; for translational up-and down-regulators, the amount of a target polypeptide is measured.

Compounds that are agonists or antagonists may be identified by contacting cells with the compound.

(b) *small molecules*

A"small molecule"refers to a composition that has a molecular weight of less than

about 5 kD and more preferably less than about 4 kD, and most preferably less than 0.6 kD. Small molecules can be nucleic acids, peptides, polypeptides, peptidomimetics, carbohydrates, lipids or other organic or inorganic molecules.

Libraries of chemical and/or biological mixtures, such as fungal, bacterial, or algal extracts, are known in the art and can be screened with any of the assays of the invention. Examples of methods for the synthesis of molecular libraries are described (Carell et al. , 1994a; Carell et al. , 1994b; Cho et al. , 1993; DeWitt et al. , 1993; Gallop et al., 1994; Zuckermann et al., 1994).

Libraries of compounds may be presented in solution (Houghten et al. , 1992) or on beads (Lam et al. , 1991), on chips (Fodor et al. , 1993), bacteria, spores (Ladner et al. , US Patent No. 5,223, 409,1993), plasmids (Cull et al. , 1992) or phage (Cwirla et al. , 1990; Devlin et al. , 1990; Felici et al., 1991 ; Ladner et al. , US Patent No. 5,223, 409,1993 ; Scott and Smith, 1990).

(c) *screens to identify modulators*

Modulators of the expression of a neurologic polypeptide can be identified in a method where a cell is contacted with a candidate compound and the expression of the neurologic polypeptide mRNA or polypeptide in the cell is determined. The expression level of the neurological polypeptide mRNA or polypeptide in the presence of the candidate compound is compared to the neurological polypeptide mRNA or polypeptide levels in the absence of the candidate compound. The candidate compound can then be identified as a modulator of the neurological polypeptide mRNA or polypeptide expression based upon this comparison. For example, when expression of the neurological polypeptide mRNA or polypeptide is greater (*i.e.* , statistically significant) in the presence of the candidate compound than in its absence, the candidate compound is identified as a stimulator of that the neurological polypeptide mRNA or polypeptide expression. Alternatively, when expression of the neurological polypeptide mRNA or polypeptide is less (statistically significant) in the presence of the candidate compound than in its absence, the candidate compound is identified as an inhibitor of the neurological polypeptide mRNA or polypeptide expression. The level of the the neurological polypeptide mRNA or polypeptide expression in cells can be determined by methods described for detecting the neurological polypeptide mRNA or polypeptide.

Identifying markers associated with a neurological disorder

In another aspect, the cells of the invention may be used to identify markers that are associated with a neurological disease or disorder. Such markers include, for example, gene expression difference and genetic lesions. One useful approach would include identifying those genes that are differentially expressed between those stem cells of the invention isolated from a healthy individual and those isolated from an individual afflicted with a neurological disorder. Many methods are available in the art to determine differential gene expression (Ausubel, 1987). Especially useful are those methods that take advantage of high-throughput formats, such as gene chips.

Genetic lesions can be detected by ascertaining: (1) a deletion of one or more nucleotides from a target polypeptide gene; (2) an addition of one or more nucleotides to the target polypeptide gene; (3) a substitution of one or more nucleotides in the target polypeptide gene (4) a chromosomal rearrangement of a the neurological polypeptide gene; (5) an alteration in the level of the neurological polypeptide mRNA transcripts, (6) aberrant modification of the target polypeptide, such as a change genomic DNA methylation, (7) the presence of a non-wild-type splicing pattern of a the target neurological polypeptide mRNA transcript, (8) a non-wild-type level of the target polypeptide gene, (9) allelic loss of the target polypeptide gene, and/or (10) inappropriate post-translational modification of the neurological polypeptide. Mutations in a target neurological polypeptide from a sample can be identified by alterations in restriction enzyme cleavage patterns. For example, sample and control DNA is isolated, amplified (optionally), digested with one or more

restriction endonucleases, and fragment length sizes are determined by gel electrophoresis and compared. Differences in fragment length sizes between sample and control DNA indicates mutations in the sample DNA. Moreover, the use of sequence specific ribozymes can be used to score for the presence of specific mutations by development or loss of a ribozyme cleavage site.

Hybridizing a sample and control nucleic acids, *e.g.*, DNA or RNA, to high-density arrays containing hundreds or thousands of oligonucleotides probes, can identify genetic mutations in a target neurological polypeptide (Cronin et al., 1996; Kozal et al., 1996). For example, genetic mutations in a target neurological polypeptide can be identified in two-dimensional arrays containing light-generated DNA probes (Cronin et al., 1996). Briefly, a first hybridization array of probes can be used to scan through long stretches of DNA in a sample and control to identify base changes between the sequences by making linear arrays of sequential overlapping probes. This step allows the identification of point mutations. A second hybridization array follows that allows the characterization of specific mutations by using smaller, specialized probe arrays complementary to all variants or mutations detected. Each mutation array is composed of parallel probe sets, one complementary to the wild-type gene and the other complementary to the mutant gene.

Other methods for detecting mutations in a target neurological polypeptide include those in which protection from cleavage agents is used to detect mismatched bases in RNA/RNA or RNA/DNA heteroduplexes (Myers et al., 1985). In general, the technique of "mismatch cleavage" starts by providing heteroduplexes formed by hybridizing (labeled) RNA or DNA containing the wild-type target neurological polypeptide sequence with potentially mutant RNA or DNA obtained from a sample. The double-stranded duplexes are treated with an agent that cleaves single-stranded regions of the duplex such as those that arise from base pair mismatches between the control and sample strands. For instance, RNA/DNA duplexes can be treated with RNase and DNA/DNA hybrids treated with S_1 nuclease to enzymatically digest the mismatched regions. In other embodiments, either DNA/DNA or RNA/DNA duplexes can be treated with hydroxylamine or osmium tetroxide and with piperidine in order to digest mismatched regions. The digested material is then separated by size on denaturing polyacrylamide gels to determine the mutation site (Grompe et al.,

1989; Saleeba and Cotton, 1993). The control DNA or RNA can be labeled for detection.

Mismatch cleavage reactions may employ one or more polypeptides that recognize mismatched base pairs in double-stranded DNA (DNA mismatch repair) in defined systems for detecting and mapping point mutations in a target neurological polypeptide cDNA obtained from samples of cells. For example, the mutY enzyme of *E. coli* cleaves A at G/A mismatches and the thymidine DNA glycosylase from HeLa cells cleaves T at G/T mismatches (Hsu et al., 1994). The duplex is treated with a DNA mismatch repair enzyme, and the cleavage products, if any, can be detected from electrophoresis protocols or the like (Modrich et al., US Patent No. 5,459,039, 1995).

Electrophoretic mobility alterations can be used to identify mutations in a target neurological gene. For example, single strand conformation polymorphism (SSCP) may be used to detect differences in electrophoretic mobility between mutant and wild type nucleic acids (Cotton, 1993; Hayashi, 1992; Orita et al., 1989). Single-stranded DNA fragments of sample and control a target neurological polypeptide nucleic acids are denatured and then renatured. The secondary structure of single-stranded nucleic acids varies according to sequence; the resulting alteration in electrophoretic mobility allows detection of even a single base change. The DNA fragments may be labeled or detected with labeled probes. Assay sensitivity can be enhanced by using RNA (rather than DNA), in which the secondary structure is more sensitive to a sequence changes. The method may use heteroduplex analysis to separate double stranded heteroduplex molecules on the basis of changes in electrophoretic mobility (Keen et al., 1991).

The migration of mutant or wild-type fragments can be assayed using denaturing gradient gel electrophoresis (DGGE; (Myers et al., 1985). In DGGE, DNA is modified to prevent complete denaturation, for example by adding a GC clamp of approximately 40 bp of high-melting point, GC-rich DNA by PCR. A temperature gradient may also be used in place of a denaturing gradient to identify differences in the mobility of control and sample DNA (Rossiter and Caskey, 1990).

Examples of other techniques for detecting point mutations include selective oligonucleotide hybridization, selective amplification, or selective primer extension.

For example, oligonucleotide primers can be prepared in which the known mutation is placed centrally and then hybridized to target DNA under conditions that permit hybridization only if a perfect match is found (Saiki et al., 1986; Saiki et al., 1989). Such allele-specific oligonucleotides are hybridized to PCR-amplified target DNA or a number of different mutations when the oligonucleotides are attached to the hybridizing membrane and hybridized with labeled target DNA.

Alternatively, allele specific amplification technology that depends on selective PCR amplification may be used. Oligonucleotide primers for specific amplifications may carry the mutation of interest in the center of the molecule (so that amplification depends on differential hybridization (Gibbs et al., 1989)) or at the extreme 3'-terminus of one primer where, under appropriate conditions, mismatch can prevent, or reduce polymerase extension (Prosser, 1993). Novel restriction sites in the region of the mutation may be introduced to create cleavage-based detection (Gasparini et al., 1992). Amplification may also be performed using *Taq* ligase (Barany, 1991). In such cases, ligation occurs only if there is a perfect match at the 3'-terminus of the 5' sequence, allowing detection of a known mutation by scoring for amplification.

Another aspect of the invention provides methods for determining a a neurological polypeptide activity or nucleic acid expression in an individual to select appropriate therapeutic or prophylactic agents specifically for that individual (pharmacogenomics). The invention provides an exceptionally powerful tool in that large numbers of cells from patients can be grown *in vitro* and then, if desired, induced to differentiate into the cell type in which the disease or disorder is manifested. Pharmacogenomics allows for the selection of modalities (*e.g.*, drugs, foods) for therapeutic or prophylactic treatment of an individual based on the individual's genotype (*e.g.*, the individual's genotype to determine the individual's ability to respond to a particular agent). Another aspect of the invention pertains to monitoring the influence of modalities (*e.g.*, drugs, foods) on the expression or activity of the neurological polypeptidethe neurological polypeptide in clinical trials.

Diagnostic assays

An exemplary method for detecting the presence or absence of a target neurological polypeptide in a biological sample involves obtaining a biological

sample from a subject and contacting the biological sample with a compound or an agent capable of detecting the neurological polypeptide or nucleic acid such that the presence of the neurological polypeptide is confirmed in the sample. An agent for detecting a neurological polypeptide message or DNA is a labeled nucleic acid probe that specifically hybridizes the target mRNA or genomic DNA. An agent for detecting a neurological polypeptide may be an antibody, preferably an antibody with a detectable label. Abs can be polyclonal, or more preferably, monoclonal. An intact antibody, or a fragment (e.g., F_{ab} or $F(ab')_2$) can be used.

Prognostic assays

Diagnostic methods can furthermore be used to identify subjects having, or at risk of developing, a disease or disorder associated with aberrant expression or activity, such as obesity or obesity-related complications. Prognostic assays can be used to identify a subject having or at risk for developing a disease or disorder. A method for identifying a disease or disorder associated with aberrant polypeptide expression or activity would include a test sample obtained from a subject and detecting a polypeptide or nucleic acid (e.g., mRNA, genomic DNA). A test sample is a biological sample obtained from a subject. For example, a test sample can be a biological fluid (e.g., serum), cell sample, or tissue.

Prognostic assays can be used to determine whether a subject can be administered a modality (e.g., an agonist, antagonist, peptidomimetic, polypeptide, peptide, nucleic acid, small molecule, food, etc.) to treat a disease or disorder associated with aberrant neurological polypeptide expression or activity. Such methods can be used to determine whether a subject can be effectively treated with an agent for a disorder, such as Parkinson's disease. Methods for determining whether a subject can be effectively treated with an agent include obtaining olfactory stem cells from a patient and detecting a target neurological polypeptide or nucleic acid (e.g., where the presence of the neurological polypeptide or nucleic acid is diagnostic for a subject that can be administered the agent to treat a disorder associated with the aberrant neurological polypeptide expression or activity). The isolated stem cells may be treated with one or more differentiation factors before assaying for the neurological polypeptide or nucleic acid presence or activity.

Genetic lesions in a target neurological polypeptide can be used to determine if a subject is at risk for a disorder, such as Parkinson's disease. Methods include detecting, in olfactory stem cells (or differentiated cells arising from the olfactory stem cells) from the subject, the presence or absence of a genetic lesion characterized by at an alteration affecting the integrity of a gene encoding the target neurological polypeptide polypeptide or the mis-expression of the target polypeptide.

F. Cultures and Kits for Testing Pharmaceutical Compounds

The stem cell of the present invention may be obtained from donors with unique neurodegenerative disorders, such as bi-polar disorder, multiple sclerosis or amyotrophic lateral sclerosis. An ONe stem cell may be isolated from a donor, including a cadaver, or from a donor with a unique neurodegenerative disorder. Neurological stem cells of the donor can be maintained in culture, and can give rise to a population of either differentiated or undifferentiated cells that would be useful in testing and developing pharmaceutical compounds as treatments for any diseases or that unique disease of the donor. These cells can be included in a kit, container, pack or dispenser together with instructions for use. When the invention is sold as a kit, the ONe stem cells may also be frozen and then thawed immediately before use. Freezing may permit long-term storage without losing the stem cell function.

Potential drug candidates may be contacted with the stem cell or the differentiated progeny and then the cell examined for changes such as increased or decreased expression of proteins.

a) Containers or vessels

Standard cell freezing conditions may be determined based on the cell type. A common method is 0.5%- 20% Dimethyl Sulfoxide (DMSO), and preferably 10% DMSO and more preferably 5% DMSO (or some other salt capable of inhibiting ice crystal formation) in either 100% serum, cell media or cell media without serum. Cells are carefully collected, washed, concentrated to a suitable density(generally a high density), and then placed in vials. Cells are then placed in an insulated container (e.g. a Styrofoam box) and placed at -20°C in a freezer for 3 hours to a week, or even longer, when necessary or desirable. Next, the cells are transferred to liquid nitrogen for permanent storage. Cells may be shipped on dry ice.

To re-initiate the culture, the cells are usually defrosted rapidly and placed immediately into pre-warmed culture media.

b) Instructional Materials

Kits may also be supplied with instructional materials. Instructions may be printed on paper or other substrate, and/or may be supplied as an electronic-readable medium, such as a floppy disc, CD-ROM, DVD-ROM, Zip disc, videotape, audiotape, etc. Detailed instructions may not be physically associated with the kit; instead, a user may be directed to an internet web site specified by the manufacturer or distributor of the kit, or supplied as electronic mail.

EXAMPLES

It should be appreciated by those of skill in the art that the techniques disclosed in the examples that follow represent the techniques discovered by the inventors to function well in the practice of the invention, and thus can be considered to constitute possible modes for its practice. However, those of skill in the art should, in light of the present disclosure, appreciate that many changes can be made in the specific embodiments that are disclosed and still obtain a like or similar result. The scope of the claims should not be limited by the preferred embodiments set forth in the examples, but should be given the broadest interpretation consistent with the description as a whole.

A. Primary Cell Cultures from Human Cadavers

A lateral rhinotomy approach was employed to remove the olfactory mucosa from underlying tissues from 4 to 18 hour postmortem cadavers. The tissue was then harvested into a cold solution of 0.05% trypsin in Ca^{2+} and Mg^{2+} free Hank's balanced salt solution (HBSS; GIBCO, Grand Island, NY). ONe was removed from its supporting tissues by micro-dissection in cold HBSS, minced into 1 mm^3 pieces, and washed repeatedly with several changes of fresh HBSS. After resuspension in HBSS containing 0.05% trypsin followed by 4 washes with 0.01% deoxyribonuclease in Ca^{2+} and Mg^{2+} free HBSS, cells were incubated for

90 minutes at 37°C with gentle O_2 bubbling to allow dissociation. The tissue and individual cells were centrifuged; the pellet was dispersed by trituration through a fire polished Pasteur pipette and resuspended in growth medium consisting of DMEM and F12 (1:1) and 10% heat-inactivate fetal bovine serum (FBS) (all media components from GIBCO, Grand Island, NY). The cells were plated on laminin-fibronectin coated plastic plates, incubated in an atmosphere of 5% CO_2 in air, and fed every 3-4 days.

B. **Subcultures for Immunofluorescense**

Cells were plated at a concentration of 4 x 10^4 cells /well on 22 mm diameter, prewashed, uncoated coverslips in olfactory epithelial medium (OEM) which consists of 90% Minimal Essential Medium with Hanks' salts with L-glutamine, 10% FBS, and 1 ml of 10 mg/dl gentamycin and incubated for a minimum of 2 days at 37°C in an atmosphere of humidified 5% CO_2 in air to allow attachment prior to immunolocalization.

C. **Immunofluorescent Localization**

Cultures were rinsed with cytoskeletal buffer (CB): MES (2-[*N*-Morpholino]ethane sulfonic acid), 1.95 mg/ml; NaCl, 8.76 mg/ml; 5mM EGTA; 5 mM $MgCl_2$; glucose, 0.9 mg/ml, pH 6.1) and fixed for 10 min at room temperature with 3% paraformaldehyde in CB. Cells were permeabilized with 0.2% Triton X-100 (SIGMA, St. Louis, MO) or cold acetone (preferably about 4°C), for 10 minutes at room temperature. Nonspecific binding sites were blocked by a 1 hour treatment with 1% bovine serum albumin (BSA) in Tris-Buffered Saline (TBS): Tris, 2.42 mg/ml; NaCl, 8.9 mg/ml; 2 mM EGTA; 2 mM MgCl; pH 7.5. To facilitate identification of unreactive cells, 4'6-diaminidino-2-phenylindole dihydrochloride (DAPI): 1:500; 2 mg/ml (Molecular Probes, Eugene, OR) was used to vitally stain DNA in each cell, after which the cells were incubated overnight at 4°C with the primary antibodies listed in Table 1.

After extensive washing with TBS, the cells on the coverslips were incubated for 1 hour at 37°C with the following secondary antibodies: fluorescein-

conjugated goat anti-mouse IgG, fluorescein-conjugated goat anti-rabbit IgG, Texas-red-conjugated goat anti-mouse IgG, Texas-red-conjugated goat anti-rabbit IgG (all diluted 1:40, FITC from Cappel, West Chester, PA; Texas Red from Molecular Probes, Eugene, OR). The immunohistochemical procedures were established in our laboratory. Preabsorbed and secondary antibody only (omission) controls insured the specificity of the reaction. The rat NGF-responsive pheochromocytoma cell line (PC12; American Type Tissue Culture Collection; Manassas, OH) was used as the positive control for the low affinity receptor $p75^{NGFr}$ and Trk antibodies. The 3T3 fibroblast line was used as a negative control. Coverslips were mounted with Mowiol 4-88 (HOECHST CELANESE, Sommerville, NJ) and observed with fluorescence optics using the Leica 4d confocal microscope equipped with argon/krypton and UV lasers. To facilitate direct comparison of treatments, all photomultiplier voltages were kept constant during individual experiments. Confocal images representing 1 μm optical sections were digitized to 1024 x 1024 pixels and presented as maximum density projections.

D. **Electron Microscopy**

Tissue sections were washed with pH 7.4 cacodylate buffer, fixed for 1 hour in 2.5% glutaraldehyde in 0.1 M cacodylate buffer, postfixed for 30 minutes in 1% osmium tetroxide in cacodylate buffer, dehydrated through a graded series of ethanols followed by propylene oxide, and embedded in LX-112 (ELECTRON MICROSCOPY SCIENCES, Ft. Washington, PA). The blocks were trimmed and thick and thin sections were cut and stained with uranyl acetate and lead citrate prior to examination in a Philips CM10 or CM12 transmission electron microscope.

E. **cAMP**

An analysis of the effects of cAMP on neurosphere subcultures increases the understanding of what trophic agents might be involved. Cell cultures were plated at identical densities (4×10^4 cells / well) and maintained in olfactory

epithelial medium (OEM; 90% Minimal Essential Meduim with Hanks' salts with L-glutamine, 10% FBS, and 1 ml of 10 mg/dl gentamycin) for 72 hours and in OEM supplemented with 2.5 mM dibutyrl-cAMP. Cultures were processed for immunofluorescence using antibodies against actin, β-tubulin isotype III, and α-internexin. Within 24 hours of cAMP addition to the cultures, fewer mitotic figures were seen per field and process formation occurred. CAMP reduced cell division and increased process formation. The lineage restriction and differentiation produced by 24 hour exposure to dibutyrl-cAMP demonstrates that some ONe neurosphere forming cells retain the ability to form neuroblasts.

F. MTT Assay

A commercial assay (SIGMA, St. Louis, MO) was used to evaluate cell viability by assessing the reduction of MTT (3-[4,5-dimethylthiazol-2-yl]-2,5-diphenyl tetrazoluim bromide) by mitochondrial dehydrogenase present in viable cells. An increase in the value of the MTT corresponded to an increase in the cell number. Cells were plated at a density of 1 x 10^5 cells / well. After incubation at 37°C for 24 hours, MTT equal to 10% of the culture volume was added to each well. Plates were incubated at 37° C for an additional 4 hours and processed as directed by the manufacturer. The MTT assay of cell viability was used to determine if viability remained constant through various passages. No significant differences (significance was set at $P<0.05$ using ANOVA) were detected.

G. **Results**

ONe harvested 4-18 hours postmortem exhibited a high level of ultrastructural integrity. The olfactory vesicles (OV) with intact non-motile kinocilia were seen. Adjacent cells with motile (9+2) cilia were packed with apical mitochondria and formed tight junctions with ORNs, reflecting their common epithelial origin. Within the first week of culture, most of the viable cells attached to the surface and assumed bipolar, fusiform, stellate or spherical shapes. The heterogeneous population included ORNs, OECs, epithelial supporting cells, fibroblasts and pluripotent cells. The presence of four specific cell types was

confirmed by immunolocalization of lineage-specific antigens and by ultrastructural analysis. ORNs were identified by their neurofilaments and microtubules composed of β-tubulin isotype III that extended throughout their processes as well as the presence of MAP2ab.

Keratin-negative OECs were frequently so closely associated with the ORNs that at times their cell boundaries could be detected only by electron microscopy boundaries. The epithelial supportive population consisted of highly flattened, contact inhibited keratin-positive cells that formed monolayer nests.

ORNs and OECs became vacuolated, retracted their processes and died after the third week *in vitro*. In approximately 5-10% of the cultures, a population of mitotically active cells emerged. These cells doubled every day, were poorly adherent, and appeared to grow in semi-suspension. They were allowed to proliferate undisturbed for an additional 2 weeks during which they formed spheres composed of approximately 20-80 cells (Fig. 1). The initial plating density did not alter the time *in vitro* required for sphere formation. The few cells not associated directly with a specific sphere usually appeared in pairs. The spheres were collected and mechanically dispersed into individual cells, repeatedly washed and centrifuged to remove cell debris. These cultures have been maintained for approximately twenty months and have been through approximately 200 passages.

Cells were probed with lineage-specific antibodies after several passages (Fig. 2). The majority of the cells were positive for one or more of the following neuronal makers: β-tubulin isotype III, NCAM and MAP2ab (Fig. 2). A complex neuron-specific microtubular network was evident even in mitotically active cells. NCAM-positive fluorescence was detected on spinous projections along the processes of cells that assumed bipolar or multipolar shapes (Fig. 2). MAP2ab was localized in doughnut-like structures and short linear segments (Fig. 2).

Approximately 10% of the cells were negative for all of the neuronal markers evaluated. Some of the neuronal negative cells were immunoreactive with A2B5 (mAb reacted with an FITC component), an antibody against a ganglioside-enriched in glial membranes, and/or GFAP (pAb which was reacted

with Texas red) as demonstrated by double labeled experiments. (Fig. 3 a) Most of these cells appeared to be in mitosis. The fluorescent material was punctate and distributed on the cell surface and in the perikaryal cytoplasm. Occasionally in well-spread cells, highly concentrated GFAP reactivity was observed arranged in a perinuclear circular array of globular fluorescence (Fig. 3b). No cells were found positive for RIP. Furthermore cells subcultured from neurospheres were unreactive with either a polyclonal antibody against keratin or a monoclonal antibody against cytokeratins 5/6. All immunological results remained similar for more than 200 passages.

Approximately 24 hours after exposure to dibutyryl cAMP, fewer mitotic neurospheres were seen and process formation occurred. The addition of dibutyryl cAMP reduced cell division and increased process formation. Figures 4a and 4c were taken with Nomarski optics. Bipolar and multipolar cells with 40t?M long ß-tubulin III positive processes formed after 72 hours. (Fig. 4). Alpha-internexin, a neuronal marker that appears prior to neurofilament formation in developing neurons was localized in an occasional process bearing cell. In contrast, cultures maintained in the absence of the nucleotide or sodium butyrate (5mM) remained highly mitotic, had minimal neuritogenesis, and were negative for α-internexin.

The MTT assay of cell viability was used to determine if viability remained constant through various passages. No significant differences ($P<0.05$) were detected.

The nature of neurosphere forming cells was characterized further by determining the presence and distribution of a family of neurotrophin receptor kinases (Trk A, B, C, and pan). The majority of the cells were reactive for Trk A and B, but negative for Trk C. Trk A is restricted to a small population of basal cells until its acceleration by bulbectomy. Trk B is widely distributed in immature neurons and becomes more abundant as the neurons mature following target innervation. Trk C is present only in highly differentiated ORNs. Occasionally, cells were observed that were positive solely for Trk A or B, while a smaller population remained immunonegative for all Trks, including a monoclonal antibody that recognized all three. Trk A had the most intense immunoreactivity.

Under conditions of low serum (<2%), Trk A immunoreactivity occurred in patches which in some cells aggregated to form polar caps (Fig. 5). In contrast, punctate Trk B immunoreactivity was distributed over the entire surface and extended to the distal regions of the processes (Fig. 5). The neurosphere forming population was further probed with antibody for the human low affinity NGF receptor $p75^{NGFr}$ (Fig. 5). No positive cells were observed. Double-labeling demonstrated the absence of $p75^{NGFr}$ immunoreactivity even in Trk A positive cells (Fig 5). The 3T3 fibroblasts served as a negative control for Trk A.

Further, though the default phenotype of the human olfactory stem cell is typically neuronal, the cells also occasionally exhibited glial and epithelial expression. B104 cells (BCM) are known to promote oligoprogenitors and produce "oligospheres" (V. Avellana-Adalid, *et. al.*, 1996), in non-human cells (*i.e.* it has been shown to have this property in mice) and was therefore added to the ONe neurosphere culture media. BCM exposure resulted in oligosphere-like formation within 72 hours and the effect was dose dependent. The cells were oligosphere-like because they showed an increased level of cells immunopositive for A2B5, a glial and oligodendrocyte marker.

J. Prophetic Examples

1. Treatment of Parkinson's Disease

Initially, obtain ONe tissue from either the patient suffering from Parkinson's disease, or from a histocompatible donor. Preferably the donor is related to the patient, and more preferably the donor is an immediate relative of the patient. Preferably the ONe tissue is obtained through an endoscopic bioposy.

Next grow the ONe tissue in culture and isolate neurospheres from the culture. Optionally, dibutyryl cAMP, various substrata, and neurotrophic growth factors may be added to initiate differentiation of the neurosphere cells.

The cells may then be transplanted, for example, by injecting them into the Substantia Nigra of the brain. Once the neurons are present in the brain of the afflicted individual, they will produce dopamine, and thereby help treat the disease. One advantage of this method is that it may be repeated, as needed, and

thereby alleviate some of the suffering of the patient. Optionally, cells may be selected for the excretion of dopamine before transplantation. Optionally, cells may be differentiated prior to transplantation.

2. Treatment of Multiple Sclerosis

Initially, obtain ONe tissue from either the patient suffering from multiple sclerosis, or from a histocompatible donor. Preferably the donor is related to the patient, and more preferably the donor is an immediate relative of the patient. Preferably the ONe tissue is obtained through an endoscopic biopsy.

Next grow the ONe tissue in culture and isolate oligosphere-like cells from the culture. Optionally, dibutyryl cAMP and growth factors may be added to initiate differentiation of the oligosphere-like cells.

The cells may then be transplanted , for example, by injecting them into the spinal cord, brain or other such area having a patch of sclerosis. Once the transplanted cells are present in the afflicted individual, they will produce myelin, and thereby help treat the disease. One advantage of this method is that it may be repeated, as needed, and thereby alleviate some of the suffering of the patient. Optionally, cells may be selected for the production of myelin before transplantation. Optionally, cells may be differentiated prior to transplantation.

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CLAIMS:

1. A method of preparing cultured cells from olfactory neuroepithelium, comprising:

dispersing adult human tissue comprising olfactory neuroepithelium collected from a live donor to form a cell population comprising separated cells;

culturing said cell population in a culture medium as an adherent cell population to induce formation of a suspended cell population, wherein said suspended cell population comprises neurospheres, wherein said suspended cell population comprises one or more cells that are each immunoreactive for both nestin and beta-tubulin isotype III;

subculturing said suspended cell population, wherein said subculturing comprises collecting said suspended cell population comprising neurospheres; dispersing said neurospheres into separated cells; and culturing said separated cells; and

detecting the presence of cells in the suspended cell population that are each immunoreactive for both nestin and beta-tubulin isotype III with antibodies, or antigen-binding fragments thereof, that bind nestin and beta-tubulin isotype III.

2. The method of claim 1, wherein said suspended cell population doubles every 18-24 hours in Olfactory Epithelial Medium (OEM) at 37°C in an atmosphere of humidified 5% CO2, wherein said OEM consists of 90% Minimal Essential Medium with Hanks' salts with L-glutamine and 10% FBS.

3. The method of claim 1, wherein said living donor is a patient having a neurological disorder.

4. The method of claim 3, wherein the neurological disorder is selected from the group consisting of spinal cord injury, Parkinson's disease, amyotrophic lateral sclerosis and multiple sclerosis.

5. A method of forming a differentiated cell selected from the group consisting of neurons, glia, and neurons and glia, comprising:

contacting the cultured cells made by the method of claim 1 with a differentiation factor.

6. The method of claim 5, wherein the differentiation factor is at least one growth factor.

7. The method of claim 5, wherein the differentiation factor is a substrate.

8. A method of evaluating a compound for neurological effects, comprising:
contacting the cultured cells made by the method of claim 1 with the compound.

9. The method of claim 8, further comprising examining the culture for cell death.

10. The method of claim 8, further comprising, prior to the contacting with the compound, contacting the culture with a differentiation factor.

11. The method of claim 10, further comprising examining the stem cells that are immunoreactive for both nestin and beta-tubulin isotype III for increased or decreased neurotransmitter binding.

12. The method of claim 10, further comprising examining the stem cells that are immunoreactive for both nestin and beta-tubulin isotype III for increased or decreased neurotransmitter formation.

13. The method of claim 11, wherein the neurotransmitter is selected from the group consisting of dopamine, serotonin and acetylcholine.

14. The method of claim 12, wherein the neurotransmitter is selected from the group consisting of dopamine, serotonin and acetylcholine.

FIGURE 1

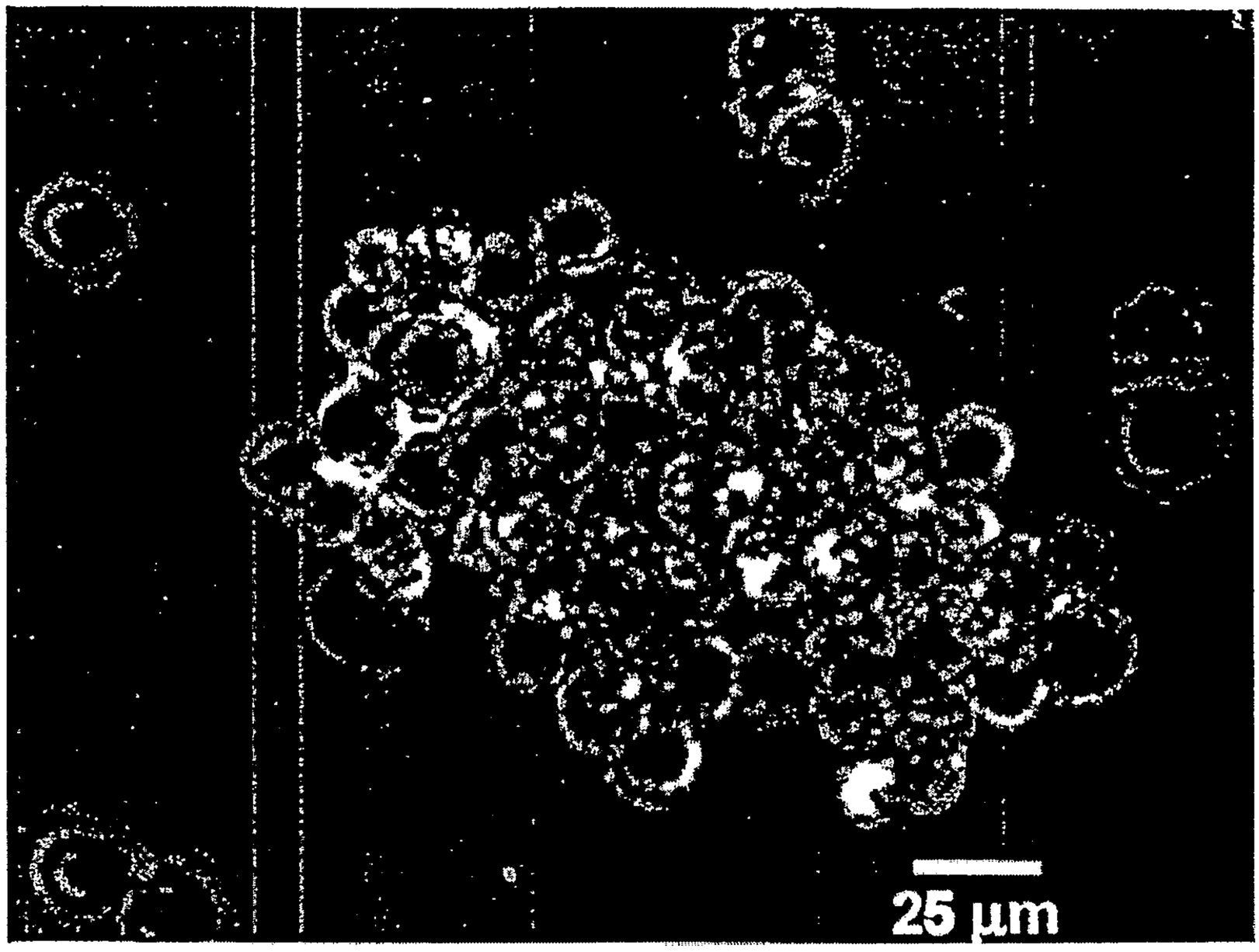

FIGURE 2

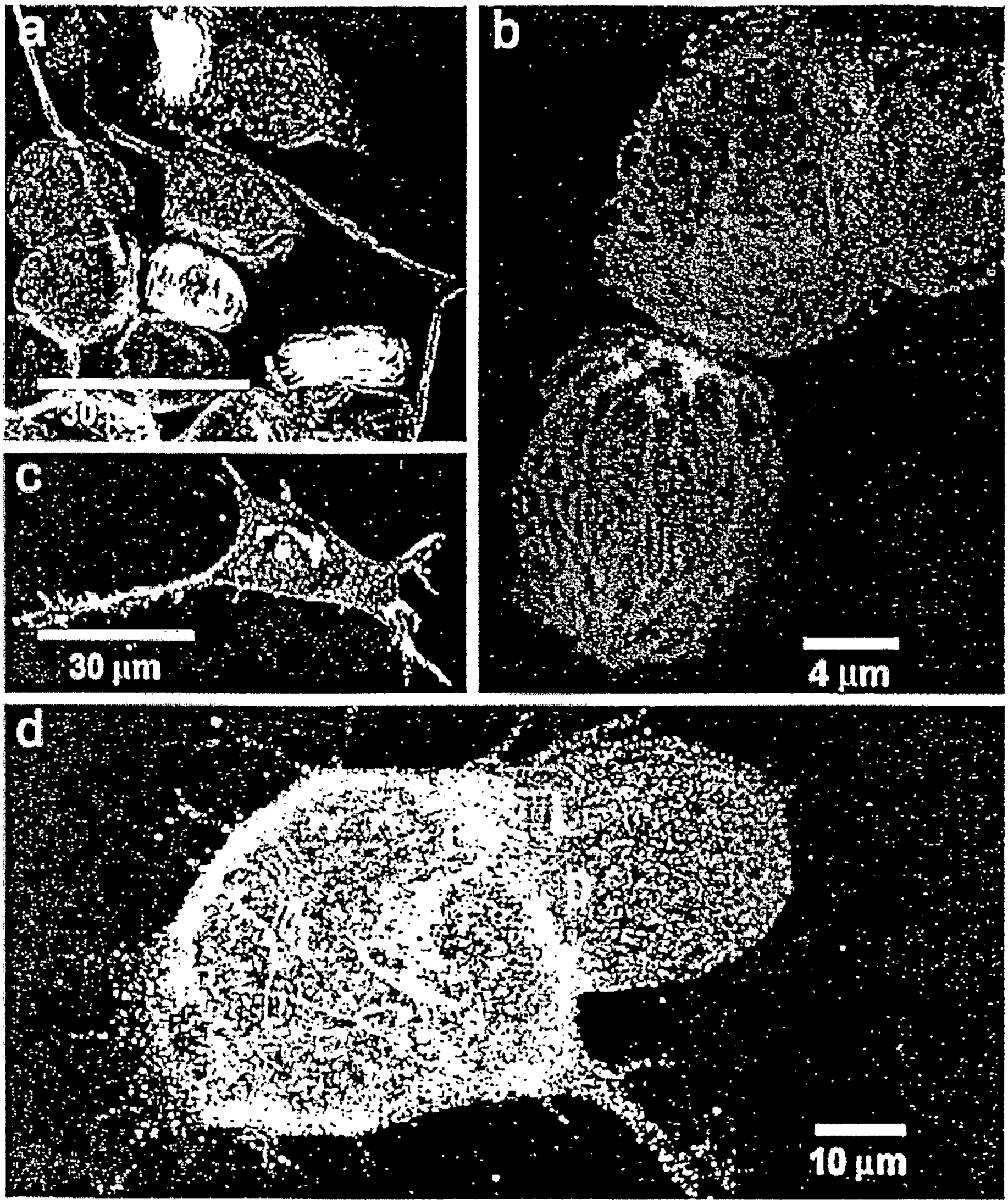

FIGURE 3

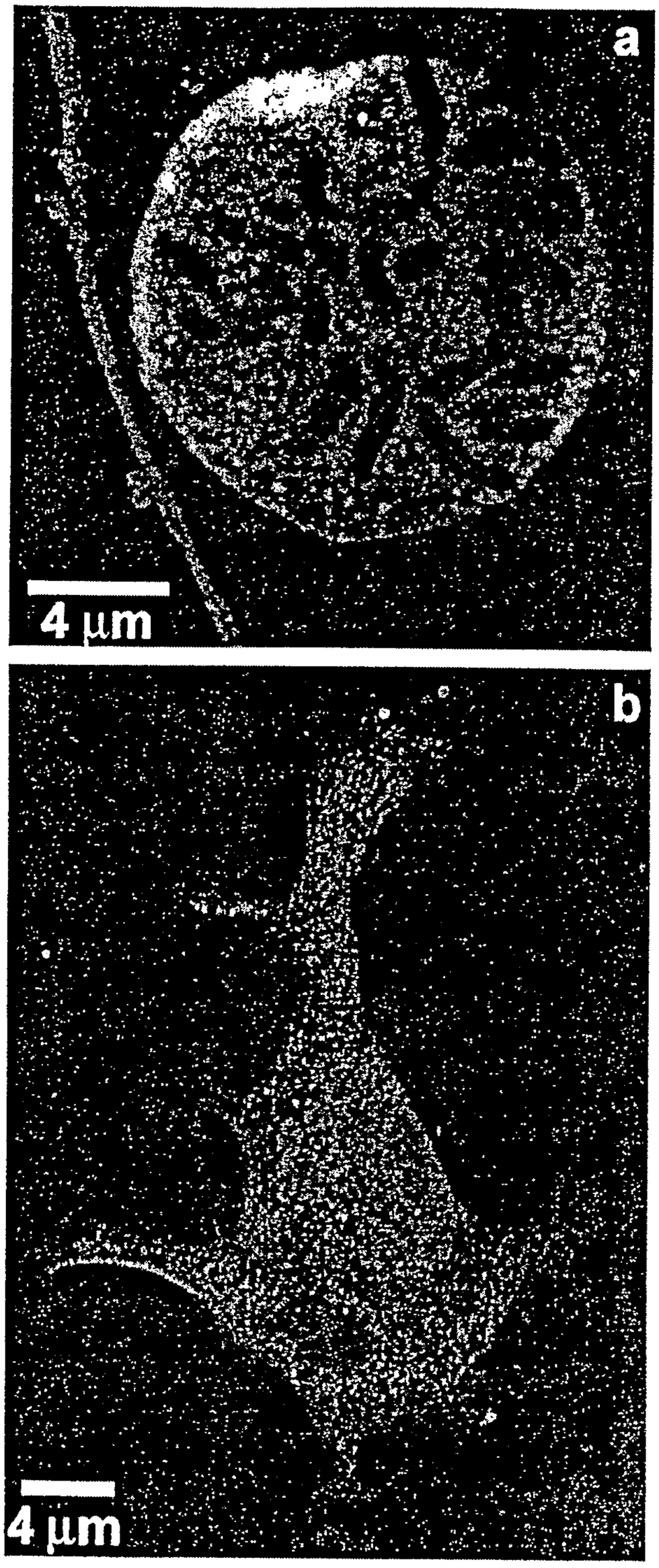

FIGURE 4

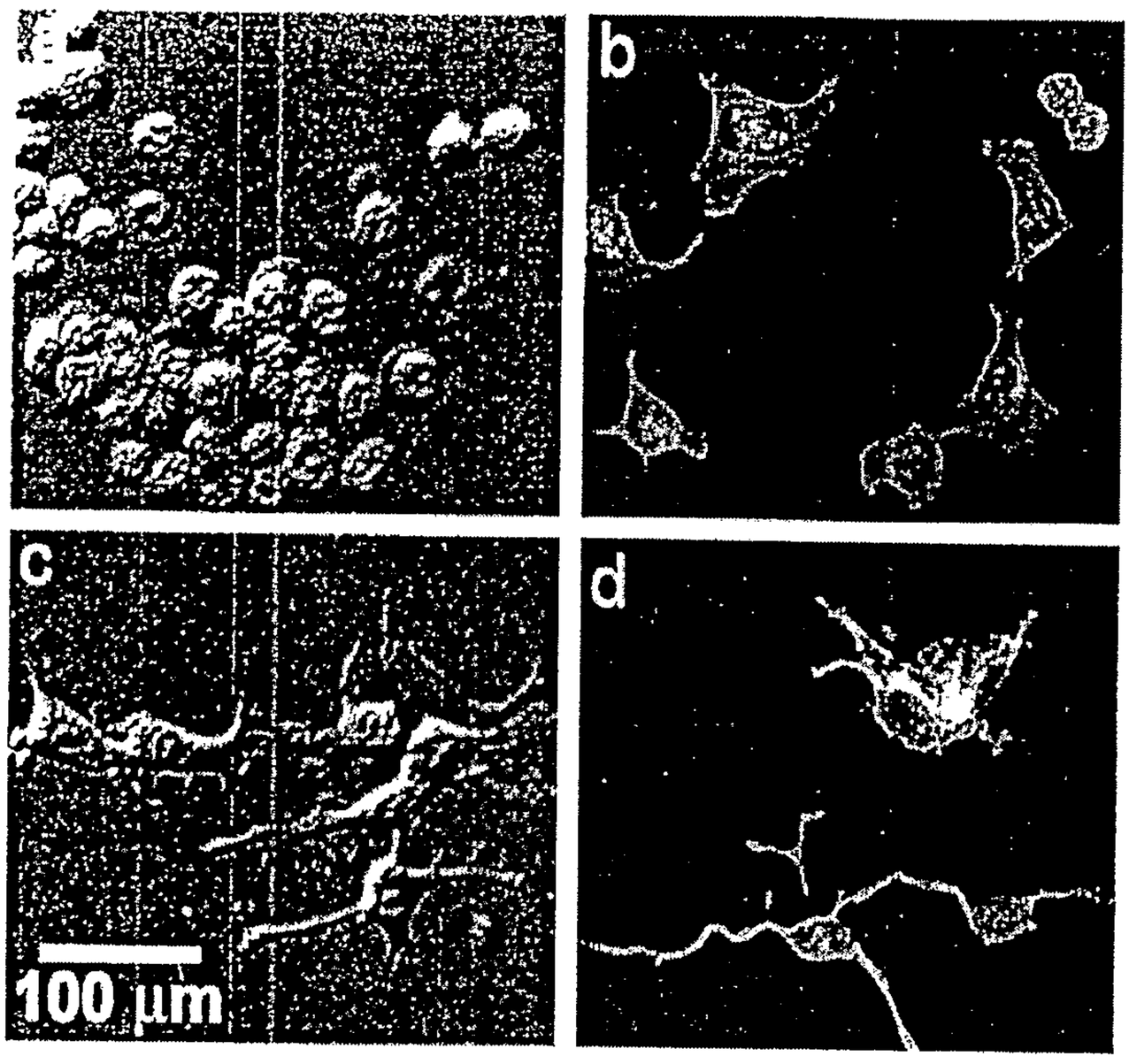
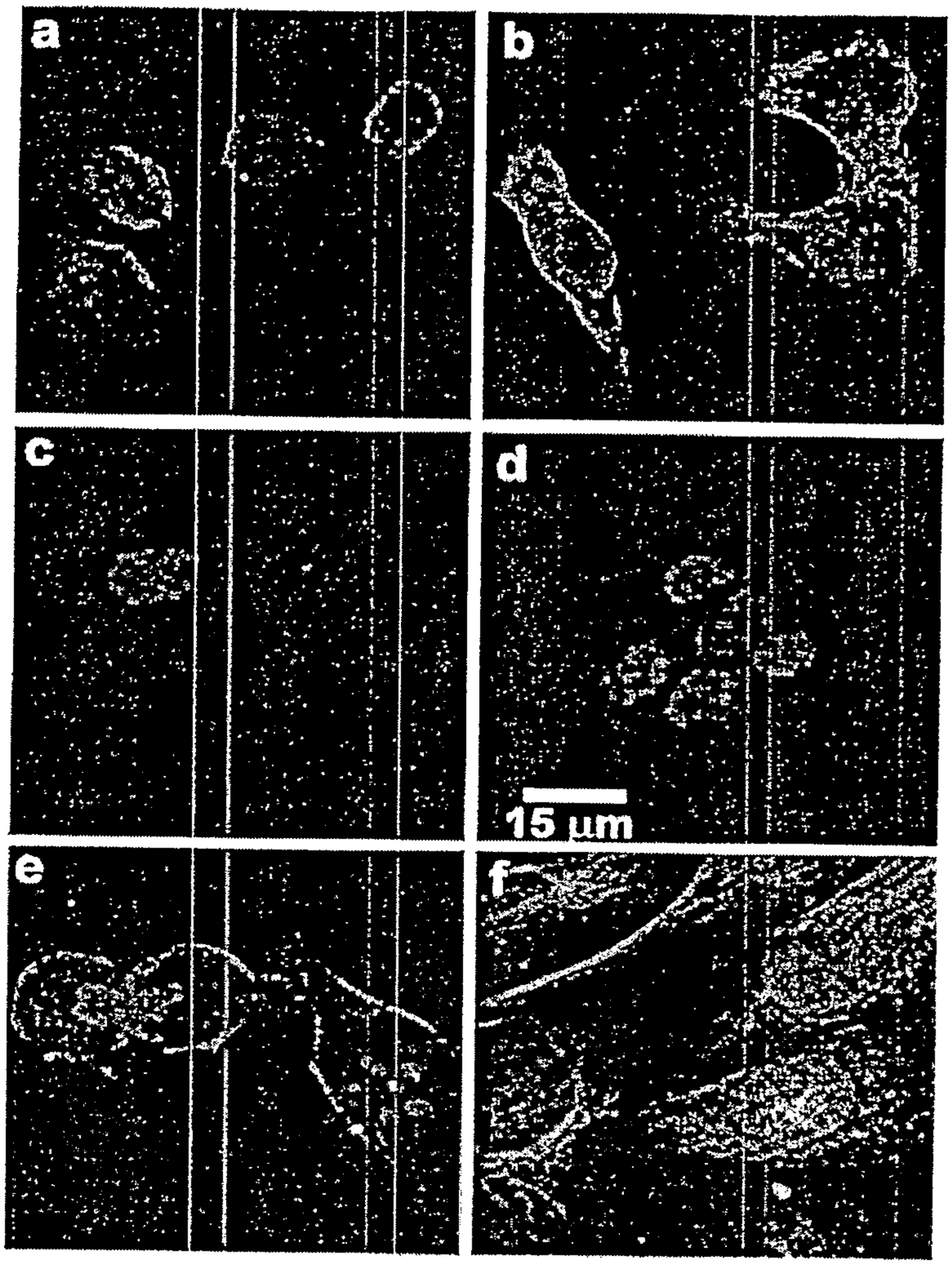
FIGURE 5