DESCRIPTION

Title of Invention : Method for Producing Sheet-shaped Cell Culture

Technical Field

[0001]

The present invention relates to a method for producing a sheet-shaped cell culture having a high activity, a sheet-shaped cell culture produced by the production method, a pharmaceutical composition comprising the sheet-shaped cell culture, a method for treating a disease using the sheet-shaped cell culture and the like.

Background Art

[0002]

Recently, attempts to implant various cells have been made in order to repair damaged tissues and the like. For example, in order to repair cardiac muscle tissues damaged by ischemic heart disease such as angina pectoris and myocardial infarction, it has been attempted to use fetal cardiac muscle cells, skeletal myoblasts, mesenchymal stem cells, cardiac stem cells, ES cells and the like (NPL 1).

[0003]

As part of the attempts, a cell structure formed using a scaffold and a sheet-shaped cell culture which is a sheet of cells have been developed (PTL 1).

With respect to therapeutic applications of a sheet-shaped cell culture, use of a cultured epidermal sheet for skin injuries such as a burn, use of a corneal epithelial sheet-shaped cell culture for corneal injuries, use of an oral mucosal sheet-shaped cell culture for endoscopic resection of esophageal cancer and the like have been investigated.

[0004]

In order that a sheet-shaped cell culture engrafts in the recipient tissue and carries out a desired function, it is necessary that oxygen, nutrients and the like are supplied to the culture, and it is known that for this, effects of various cytokines such as HGF (hepatocyte growth factor) and VEGF (vascular endothelial growth factor) which have an angiogenic effect are useful (PTL 1). Therefore, it is believed that the engraftment rate of a sheet-shaped cell culture and its functionality can be improved when the cytokine productivity of the sheet-

shaped cell culture can be improved. Also, it is known that these cytokines are useful for the regeneration of tissues (NPL 2), and it is thus believed that when the cytokines produced by a sheet-shaped cell culture act on the recipient tissue, the regeneration of the tissue would be promoted. However, no low-cost easy method for improving the cytokine productivity of a sheet-shaped cell culture has been known.

Citation List

Patent Literature

[0005]

[PTL 1] JP-T-2007-528755

Non Patent Literature

[0006]

[NPL 1] Haraguchi et al., Stem Cells Transl Med. 2012 Feb; 1(2): 136-41

[NPL 2] Nakagami et al., J Atheroscler Thromb. 2006 Apr; 13(2): 77-81

Summary of Invention

Technical Problem

[0007]

An object of the invention is to provide a sheet-shaped cell culture having a high activity such as high cytokine productivity, a production method thereof, a pharmaceutical composition containing the sheet-shaped cell culture and a method for treating a disease using the sheet-shaped cell culture.

Solution to Problem

[0008]

The present inventors have conducted intensive investigation to achieve the object and have found that the activities of a sheet-shaped cell culture such as cytokine productivity can be improved by conducting steps of freezing and thawing cells during the production of the sheet-shaped cell culture, thereby completing the invention.

[0009]

That is, the invention relates to the following subject matters.

(1) A method for producing a sheet-shaped cell culture, comprising

a step of freezing cells,

a step of thawing the frozen cells, and

a step of forming a sheet-shaped cell culture.

(2) The method as described in the above item (1), wherein the cells are autologous cells or allogeneic cells.

(3) The method as described in the above item (1) or (2), wherein the cells are autologous cells.

(4) The method as described in any one of the above items (1) to (3), wherein the sheet-shaped cell culture is formed after the step of thawing the cells substantially without proliferation of the cells.

(5) The method as described in any one of the above items (1) to (4) which further comprises a step of recovering the sheet-shaped cell culture after the step of forming the sheet-shaped cell culture, wherein the step of thawing the cells is carried out within 48 hours before the step of recovering the sheet-shaped cell culture.

(6) The method as described in any one of the above items (1) to (5) which comprises a step of proliferating the cells before the step of thawing the cells.

[0007]

(7) The method as described in any one of the above items (1) to (6) which comprises a step of washing the cells after the step of thawing the frozen cells and before the step of forming the sheet-shaped cell culture.

(8) The method as described in any one of the above items (1) to (7), wherein the cells are selected from the group consisting of myoblasts, mesenchymal stem cells, cardiac muscle cells, fibroblasts, cardiac stem cells, embryonic stem cells, iPS cells, synoviocytes, chondrocytes, epithelial cells, endothelial cells, hepatocytes, pancreatic cells, nephrocytes, adrenal cells, periodontal ligament cells, gingival cells, periosteal cells and skin cells.

(9) The method as described in any one of the above items (1) to (8), wherein the obtained sheet-shaped cell culture has an activity higher than the activity of a sheet-shaped cell culture produced by a method which does not comprise a step of freezing cells and a step of thawing frozen cells.

(10) The method as described in the above item (9), wherein the activity is selected from the group consisting of cytokine productivity, engrafting ability, angiogenesis ability and tissue regeneration ability.

(11) The method as described in the above item (10), wherein the cytokine is selected from the group consisting of HGF and VEGF.

[0011]

(12) A sheet-shaped cell culture produced by the method as described in any one of the above items (1) to (11).

(13) A pharmaceutical composition comprising the sheet-shaped cell culture as described in the above item (12).

(14) A method for treating a disease associated with an abnormality of a tissue in a subject, comprising administering an effective amount of the sheet-shaped cell culture as described in the above item (12) or the pharmaceutical composition as described in the above item (13) to a subject in need thereof.

(15) The method as described in the above item (14), wherein the tissue is selected from the group consisting of a cardiac muscle, a cornea, a retina, an esophagus, skin, a joint, cartilage, a liver, a pancreas, a gingiva, a kidney, a thyroid gland, a skeletal muscle and a middle ear.

(16) The method as described in the above item (14), wherein the disease is selected from the group consisting of a cardiac disease, a corneal disease, a retinal disease, an esophageal disease, a skin disease, a joint disease, a cartilage disease, a liver disease, a pancreatic disease, a dental disease, a renal disease, a thyroid disease, a muscular disease and a middle ear disease.

Advantageous Effects of Invention

[0012]

Since the sheet-shaped cell culture produced by the method of the invention has a high activity such as high cytokine productivity and is excellent in the engraftment in a tissue, the viability and the functionality after the engraftment, the sustainability of the function and the like, various diseases can be treated efficiently. Moreover, when the cytokines produced by the sheet-shaped cell culture produced by the method of the invention act on the recipient tissue, the regeneration of the tissue can be promoted. In addition, because the freezing and thawing operations in the invention are highly compatible with the conventional methods for producing a sheet-shaped cell culture and do not require much time or high cost, the production method of the invention can be used widely for producing a sheet-shaped cell culture.

Brief Description of Drawings

[0013]

[Fig. 1] A graph showing the concentrations of VEGF and HGF secreted into culture solutions in the sheet-formation cultivation step.

[Fig. 2] A graph showing the concentrations of VEGF secreted by sheet-shaped cell cultures after production into culture solutions.

[Fig. 3] A graph showing the concentrations of HGF secreted by sheet-shaped cell cultures after production into culture solutions.

[Fig. 4] A photographic figure showing the mesenchymal stem sheet-shaped cell cultures produced by the production method of example 9. Sheet-shaped cell cultures are observed in the four successive wells in the middle.

Description of Embodiments

[0014]

Unless otherwise defined in the present description, all of the technical terms and scientific terms used in the description have the same meanings as those generally accepted by one skilled in the art. All of the patents, applications, published applications and other publications that are referred to in the description are entirely cited in the description by reference.

[0015]

An aspect of the invention relates to a method for producing a sheet-shaped cell culture, containing a step of freezing cells, a step of thawing the frozen cells and a step of forming a sheet-shaped cell culture. Although restriction to any specific theory is not desired, it is believed that in the production method of the invention, by subjecting cells to freezing and thawing steps, cells with a low activity are excluded while cells with a high activity remain, resulting in the improvement of the activity of the sheet-shaped cell culture as a whole.

[0016]

The cells used in the production method of the invention are not specifically restricted as long as they can form a sheet-shaped cell culture and include adherent cells (adhesive cells) for example. Examples of the adherent cells include adherent somatic cells (such as cardiac

muscle cells, fibroblasts, epithelial cells, endothelial cells, hepatocytes, pancreatic cells, nephrocytes, adrenal cells, periodontal ligament cells, gingival cells, periosteal cells, skin cells, synoviocytes and chondrocytes), tissue stem cells (such as myoblasts and cardiac stem cells), pluripotent stem cells (such as embryonic stem cells and iPS (induced pluripotent stem) cells), mesenchymal stem cells and the like. Accordingly, examples of the cells used in the production method of the invention include myoblasts (such as skeletal myoblasts), mesenchymal stem cells (such as those derived from bone marrow, adipose tissues, peripheral blood, skin, hair roots, muscle tissues, endometria, placentas and cord blood), cardiac muscle cells, fibroblasts, cardiac stem cells, embryonic stem cells, iPS cells, synoviocytes, chondrocytes, epithelial cells (such as oral mucosal epithelial cells, retinal pigment epithelial cells and nasal mucosal epithelial cells), endothelial cells (such as vascular endothelial cells), hepatocytes (such as hepatic parenchymal cells), pancreatic cells (such as pancreatic islet cells), nephrocytes, adrenal cells, periodontal ligament cells, gingival cells, periosteal cells, skin cells and the like.

[0017]

In the invention, the "sheet-shaped cell culture" is a sheet formed with cells connected to each other, and it is typically constituted by one cell layer but also includes those constituted by two or more cell layers. The cells may be connected to each other directly (including those connected via a cellular element such as an adhesion molecule) and/or via a mediator. The mediator is not specifically restricted as long as it is a substance which can connect cells at least physically (mechanically), but examples thereof include extracellular matrix and the like. The mediator is preferably derived from cells, in particular from cells constituting the cell culture. Although the cells are connected to each other at least physically (mechanically), the cells may further be connected functionally, for example chemically or electrically.

[0018]

The sheet-shaped cell culture of the invention preferably does not contain any scaffold (support). A scaffold is sometimes used in the present technical field in order to adhere cells on the surface thereof and/or inside thereof and maintain the physical unity of the cell culture, and a membrane of polyvinylidene difluoride (PVDF) and the like are known for example. The cell culture of the invention can maintain its physical unity without the

scaffold. Also, the cell culture of the invention preferably consists of substances derived from the cells constituting the cell culture and does not contain any other substances.

[0019]

The cells in the invention may be derived from any living thing which can be treated with a sheet-shaped cell culture. Examples of the living thing include, without restriction, human, non-human primates, dogs, cats, pigs, horses, goats, sheep, rodents (such as mice, rats, hamsters and guinea pigs), rabbits and the like. Also, the cells used for forming the sheet-shaped cell culture may be of one kind only, but two or more kinds of cell may be used. In a preferable embodiment of the invention, when two or more kinds of cell form the cell culture, the percentage (purity) of the cells which are the highest in number is 60% or more, preferably 70% or more, more preferably 75% or more, at the time of completion of the cell culture production.

[0020]

The cells may be cells derived from a different species or cells derived from the same species. Here, when the cell culture is used for implantation, the "cells derived from a different species" refer to cells derived from a living thing of a species different from the recipient species. For example, when the recipient is a human, cells derived from a monkey or a pig and the like are cells derived from a different species. Also, the "cells derived from the same species" refer to cells derived from a living thing of the same species as the recipient species. For example, when the recipient is a human, human cells are cells derived from the same species. Cells derived from the same species include self-derived cells (also referred to as self-cells or autologous cells), namely cells derived from the recipient, and cells derived from nonself of the same species (also referred to as allogeneic cells). Self-derived cells do not cause rejection when they are implanted and are thus preferable in the invention. However, it is also possible to use cells derived from a different species or cells derived from nonself of the same species. When cells derived from a different species or cells derived from nonself of the same species are used, immunosuppression treatment is sometimes necessary to inhibit the rejection. In the description, cells other than self-derived cells, namely cells derived from a different species and cells derived from nonself of the same species, are sometimes collectively called nonself-derived cells. In an embodiment of the invention, the cells are autologous cells or allogeneic cells. In an embodiment of the

invention, the cells are autologous cells. In another embodiment of the invention, the cells are allogeneic cells.

[0021]

The step of freezing cells in the production method of the invention can be carried out by any known method. Examples of the method include, without restriction, a method of subjecting cells in a container to freezing means such as a freezer, a deep freezer or a medium at a low temperature (for example, liquid nitrogen and the like) and the like. The temperature of the freezing means is not specifically restricted as long as a part of the cell population in the container, preferably the whole cell population can be frozen but is typically 0°C or lower, preferably -20°C or lower, more preferably -40°C or lower, further preferably -80°C or lower. The cooling rate in the freezing operation is not specifically restricted as long as the survival rate and the function of the cells after freezing and thawing are not seriously impaired, but typically, it is a cooling rate in which cells are cooled from 4°C to -80°C over one to five hours, preferably over two to four hours, particularly over about three hours. Specifically, for example, the cells can be cooled at a rate of 0.46°C/minute. The cooling rate can be achieved by subjecting the container containing the cells to freezing means set at a desired temperature directly or with the container contained in a freezing treatment container. The freezing treatment container may have a function for controlling the rate of the temperature decrease in the container at a certain rate. As the freezing treatment container, any known containers such as BICELL$^{(R)}$ (Nihon Freezer Co., Ltd.) can be used.

[0022]

The freezing operation may be conducted with the cells immersed in a culture solution, a physiological buffer or the like or conducted after treatment of adding a cryoprotectant for protecting the cells during the freezing and thawing operations to the culture solution or replacing the culture solution with a cryopreservation solution containing a cryoprotectant. Accordingly, the production method of the invention may further contain a step of adding a cryoprotectant to the culture solution or a step of replacing the culture solution with a cryopreservation solution. When the culture solution is replaced with a cryopreservation solution, the cryopreservation solution may be added after substantially completely removing the culture solution or the cryopreservation solution may be added with part of the culture solution still remaining, as long as a cryoprotectant is contained at an effective concentration in the solution in which the cells are immersed during freezing. Here,

the "effective concentration" means a concentration at which the cryoprotectant does not exhibit toxicity but exhibits cryoprotective effects such as an effect of preventing the decrease in the survival rate, activity, function or the like of the cells after freezing and thawing as compared with the case where the cryoprotectant is not used. The concentration is known to one skilled in the art or can be suitably determined by a routine experiment or the like.

[0023]

The cryoprotectant used in the production method of the invention is not specifically restricted as long as it has a cryoprotective effect on cells, and examples thereof include dimethyl sulfoxide (DMSO), glycerol, ethylene glycol, propylene glycol, sericin, propanediol, dextran, polyvinylpyrrolidone, polyvinyl alcohol, hydroxyethyl starch, chondroitin sulfate, polyethylene glycol, formamide, acetamide, adonitol, perseitol, raffinose, lactose, trehalose, sucrose, mannitol and the like. One kind of cryoprotectant may be used alone, or two, three or more kinds thereof may be combined and used.

[0024]

The concentration of the cryoprotectant added to the culture solution or the concentration of the cryoprotectant in the cryopreservation solution is not specifically restricted as long as the concentration is the effective concentration defined above but is typically from 2 to 20% (v/v) relative to the total of the culture solution or the cryopreservation solution for example. However, an alternative use concentration which is outside the concentration range but is known for a certain cryoprotectant or is experimentally determined can also be used, and such a concentration is also included in the scope of the invention.

[0025]

The step of thawing the frozen cells in the production method of the invention can be carried out by any known method for thawing cells, and typically for example, the step is achieved by subjecting the frozen cells to thawing means such as a solid, liquid or gas medium (for example, water) at a temperature higher than the freezing temperature, a water bath, an incubator or a thermostat or by immersing the frozen cells in a medium (for example, a culture solution) at a temperature higher than the freezing temperature, although the step is not restricted to these methods. The temperature of the thawing means or the immersion medium is not specifically restricted as long as it is a temperature at which the cells can be thawed within a desired time but is typically from 4 to 50°C, preferably from 30°C to 40°C, more

preferably from 36 to 38°C. Also, the thawing period is not specifically restricted as long as the survival rate and the function of the thawed cells are not seriously impaired but is typically two minutes or shorter, and in particular, the decrease in the survival rate can be prevented significantly when the thawing period is 20 seconds or shorter. The thawing period can be controlled by adjusting the temperature of the thawing means or the immersion medium, the volume or the composition of the culture solution or the cryopreservation solution for freezing or the like.

[0026]

The production method of the invention may contain a step of washing the cells after the step of thawing the frozen cells and before the step of forming the sheet-shaped cell culture. The cells can be washed by any known method and typically for example by suspending the cells in a liquid (such as a culture solution or a physiological buffer containing or not containing serum or a serum component (serum albumin or the like)), centrifuging the suspension, discarding the supernatant and recovering the precipitated cells, although the step is not restricted to this example. In the step of washing the cells, the cycle of suspending, centrifugation and recovery may be conducted once or more than once (for example, two, three, four or five times). In an embodiment of the invention, the step of washing the cells is carried out immediately after the step of thawing the frozen cells.

[0027]

The step of forming a sheet-shaped cell culture in the production method of the invention can be carried out by any known method. Examples of the method include, without restriction, the method described in PTL 1. The step of forming a sheet-shaped cell culture may contain a step of seeding cells on a culture substrate and a step of forming a sheet with the seeded cells.

[0028]

The culture substrate is not specifically restricted as long as cells can form a cell culture on the culture substrate, and examples include containers made of various materials, a solid or semisolid surface in a container and the like. The structure and material of the container preferably do not allow permeation of a liquid such as a culture solution. Examples of the material include, without restriction, polyethylene, polypropylene, Teflon (registered trademark), polyethylene terephthalate, polymethyl methacrylate, nylon 6,6, polyvinyl alcohol, cellulose, silicon, polystyrene, glass, polyacrylamide, polydimethylacrylamide, metals (such as

iron, stainless, aluminum, copper and brass) and the like. The container preferably has at least one flat surface. Examples of the container include, without restriction, a cell culture dish, a cell culture bottle and the like. In addition, the container may have a solid or semisolid surface in its inside. Examples of the solid surface include a plate, a container and the like made of the various materials above, and examples of the semisolid surface include a gel, a soft polymer matrix and the like. The culture substrate may be produced using the materials, or a commercially available culture substrate may be used. Examples of a preferable culture substrate include, without restriction, a substrate having an adhesive surface suitable for the formation of a sheet-shaped cell culture. Specifically, examples of the culture substrate include: a substrate having a hydrophilic surface, for example a substrate with a surface coated with a hydrophilic compound such as polystyrene, collagen gel and a hydrophilic polymer which has been subjected to corona discharge treatment; a substrate with a surface coated with extracellular matrix such as collagen, fibronectin, laminin, vitronectin, proteoglycan and glycosaminoglycan, a cell adhesion molecule such as those of cadherin family, selectin family and integrin family and the like; and the like. Such a substrate is commercially available (for example, Corning$^{(R)}$ TC-Treated Culture Dish, Corning and the like).

[0029]

The surface of the culture substrate may be covered with a material whose physical properties change in response to a stimulus such as temperature or light. As the material, without restriction, for example known materials such as the following materials can be used: a temperature-responsive material made of a homopolymer or a copolymer of a (meth)acrylamide compound, an N-alkyl-substituted (meth)acrylamide derivative (such as N-ethylacrylamide, N-n-propylacrylamide, N-n-propylmethacrylamide, N-isopropylacrylamide, N-isopropylmethacrylamide, N-cyclopropylacrylamide, N-cyclopropylmethacrylamide, N-ethoxyethylacrylamide, N-ethoxyethylmethacrylamide, N-tetrahydrofurfurylacrylamide and N-tetrahydrofurfurylmethacrylamide), an N,N-dialkyl-substituted (meth)acrylamide derivative (such as N,N-dimethyl(meth)acrylamide, N,N-ethylmethylacrylamide and N,N-diethylacrylamide), a (meth)acrylamide derivative having a cyclic group (such as 1-(1-oxo-2-propenyl)-pyrrolidine, 1-(1-oxo-2-propenyl)-piperidine, 4-(1-oxo-2-propenyl)-morpholine, 1-(1-oxo-2-methyl-2-propenyl)-pyrrolidine, 1-(1-oxo-2-methyl-2-propenyl)-piperidine and 4-(1-oxo-2-methyl-2-propenyl)-morpholine) or a vinyl ether derivative (such as methyl vinyl

ether); a light-absorbing polymer having an azobenzene group; a light-responsive material such as a copolymer of a vinyl derivative of triphenylmethane leuco hydroxide and an acrylamide-based monomer and N-isopropylacrylamide gel containing spirobenzopyran (see for example JP-A-2-211865 and JP-A-2003-33177). By applying a certain stimulus to these materials, the physical properties such as hydrophilicity and hydrophobicity are changed, and the peeling of a cell culture adhered to the materials can be promoted. Culture dishes covered with a temperature-responsive material are commercially available (for example, UpCell(R) of CellSeed Inc.), and the culture dishes can be used for the production method of the invention.

[0030]

The culture substrate may have any shape but is preferably flat. The area thereof is not specifically restricted but is typically from 1 to 200 cm^2, preferably from 2 to 100 cm^2, more preferably from 3 to 50 cm^2.

[0031]

The culture substrate may be coated (covered or coated) with serum. When a culture substrate coated with serum is used, a sheet-shaped cell culture with a higher density can be formed. The term "coated with serum" means the state in which a serum component is adhered to the surface of the culture substrate. The state can be achieved for example by treating the culture substrate with serum, without restriction. The treatment with serum includes bringing serum into contact with the culture substrate and if necessary, incubating for a certain period of time. As the serum, serum of a different species and serum of the same species can be used. When the cell culture is used for implantation, the serum of a different species refers to serum derived from a living thing of a species different from the recipient species. For example, when the recipient is a human, bovine or horse serum such as fetal bovine/calf serum (FBS or FCS), calf serum (CS) and horse serum (HS) is serum of a different species. The "serum of the same species" refers to serum derived from a living thing of the same species as the recipient species. For example, when the recipient is a human, human serum is serum of the same species. Serum of the same species includes self-serum (also called autologous serum), which is serum derived from the recipient, and allogeneic serum, which is derived from an individual which is of the same species but is not the recipient. In the description, serum other than self-serum, namely serum of a different species and allogeneic serum are sometimes collectively referred to as nonself-serum.

[0032]

Serum used for coating the culture substrate is either commercially available or can be prepared from blood collected from a desired living thing by a conventional method. Specifically for example, a method in which collected blood is coagulated by leaving the blood at room temperature for about 20 to 60 minutes and centrifuged at around 1000 to 1200×g and the supernatant is collected and the like are mentioned.

[0033]

When serum is incubated on the culture substrate, an undiluted serum solution may be used, or a diluted serum solution may be used. The serum can be diluted using any medium such as water, physiological saline, various buffers (for example, PBS, HBS and the like) and various liquid media (for example, DMEM, MEM, F12, DME, RPMI1640, MCDB (MCDB102, 104, 107, 120, 131, 153, 199 and the like), L15, SkBM, RITC80-7, DMEM/F12 and the like) without restriction. The dilution ratio is not specifically restricted as long as the serum component can adhere to the culture substrate and is from 0.5 to 100% (v/v) for example, preferably from 1 to 60% (v/v), more preferably from 5 to 40% (v/v).

[0034]

The incubation period is not specifically restricted, either, as long as the serum component can adhere to the culture substrate and is from 1 to 72 hours for example, preferably from 4 to 48 hours, more preferably from 5 to 24 hours, further preferably from 6 to 12 hours. The incubation temperature is not specifically restricted, either, as long as the serum component can adhere to the culture substrate and is from 0 to 60°C for example, preferably from 4 to 45°C, more preferably from room temperature to 40°C.

[0035]

The serum may be discarded after the incubation. As the method for discarding the serum, general methods for discarding a liquid such as suction with a pipette or the like and decantation can be used. In a preferable embodiment of the invention, the culture substrate may be washed with a serum-free washing solution after discarding the serum. The serum-free washing solution is not specifically restricted as long as it is a liquid medium which does not contain serum and which does not adversely affect the serum component adhered to the culture substrate, and include any medium such as water, physiological saline, various buffers (for example, PBS, HBS and the like) and various liquid media (for example, DMEM, MEM, F12, DME, RPMI1640, MCDB (MCDB102, 104, 107, 120, 131, 153, 199 and the

like), L15, SkBM, RITC80-7, DMEM/F12 and the like) without restriction. As the washing method, general methods for washing a culture substrate such as a method in which a serum-free washing solution is added to the culture substrate, stirred for a certain period of time (for example, 5 to 60 seconds) and then discarded can be used without restriction.

[0036]

In the invention, the culture substrate may be coated with a growth factor. The "growth factor" here means a substance which promotes the proliferation of cells as compared to the case without the substance, and examples thereof include epithelial growth factors (EGFs), vascular endothelial growth factors (VEGFs), fibroblast growth factors (FGFs) and the like. The method for coating the culture substrate with a growth factor, the discarding method and the washing method are basically same as those for serum except that the dilution ratio during the incubation is from 0.0001 μg/mL to 1 μg/mL for example, preferably from 0.0005 μg/mL to 0.05 μg/mL, more preferably from 0.001 μg/mL to 0.01 μg/mL.

[0037]

In the invention, the culture substrate may be coated with a steroid. The "steroid" here means a compound having a steroid nucleus which may have adverse effects such as adrenocortical insufficiency and Cushing's syndrome on a living body. Examples of the compound include, without restriction, cortisol, prednisolone, triamcinolone, dexamethasone, betamethasone and the like. The method for coating the culture substrate with a steroid, the discarding method and the washing method are basically same as those for serum except that the dilution ratio during the incubation is, in terms of dexamethasone, from 0.1 μg/mL to 100 μg/mL for example, preferably from 0.4 μg/mL to 40 μg/mL, more preferably from 1 μg/mL to 10 μg/mL.

[0038]

The culture substrate may be coated with any one of serum, a growth factor and a steroid or may be coated with any combination thereof, namely combination of serum and a growth factor, of serum and a steroid, of serum, a growth factor and a steroid or of a growth factor and a steroid. When the culture substrate is coated with more than one component, the culture substrate may be coated simultaneously with a mixture of the components or coated in separate steps.

[0039]

Cells may be seeded to the culture substrate immediately after coating the culture substrate with serum or the like, or the culture substrate may be stored after coating and then cells may be seeded. A coated substrate can be stored for a long time by keeping it for example at 4°C or lower, preferably -20°C or lower, more preferably -80°C or lower.

[0040]

Cells can be seeded to the culture substrate by any known method and under any known condition. Cells may be seeded to the culture substrate for example by pouring a cell suspension prepared by suspending cells in a culture solution into the culture substrate (culture container). An instrument suitable for the operation of pouring the cell suspension such as a dropper and a pipette can be used for pouring the cell suspension.

[0041]

In a preferable embodiment of the invention, cells are seeded at a density at which the cells can form a sheet-shaped cell culture substantially without proliferation. The "density at which the cells can form a sheet-shaped cell culture substantially without proliferation" means a cell density at which a sheet-shaped cell culture can be formed when the cells are cultured in a non-proliferating culture solution which contains substantially no growth factor. For example, in the case of skeletal myoblasts, cells are seeded to a culture substrate at a density of about 6,500 cells/cm^2 to form a sheet-shaped cell culture in a method using a culture solution containing a growth factor (for example, see PTL 1), but a sheet-shaped cell culture is not formed when cells at the density are cultured in a culture solution containing no growth factor. Accordingly, the seeding density in the embodiment is higher than the density in a method using a culture solution containing a growth factor. Specifically, the density is typically 1.0×10^5 cells/cm^2 or more for skeletal myoblasts for example. The upper limit of the seeding density is not specifically restricted as long as the formation of the cell culture is not prevented and the cells do not undergo the transition to the differentiation but is less than 3.4×10^6 cells/cm^2 for skeletal myoblasts.

[0042]

Accordingly, the "density at which the cells can form a sheet-shaped cell culture substantially without proliferation" for skeletal myoblasts is from 1.0×10^5 to 3.4×10^6 cells/cm^2 in an embodiment, from 3.0×10^5 to 3.4×10^6 cells/cm^2 in another embodiment, from 3.5×10^5 to 3.4×10^6 cells/cm^2 in still another embodiment, from 1.0×10^6 to 3.4×10^6 cells/cm^2 in still another embodiment, from 3.0×10^5 to 1.7×10^6 cells/cm^2 in still another embodiment, from

3.5×10^5 to 1.7×10^6 cells/cm^2 in another embodiment, and from 1.0×10^6 to 1.7×10^6 cells/cm^2 in further another embodiment. Each of the above ranges may include both of the upper limit and the lower limit or one of the upper limit and the lower limit, as long as the upper limit is less than 3.4×10^6 cells/cm^2. Accordingly, the density may be for example 3.0×10^5 cells/cm^2 or more and less than 3.4×10^6 cells/cm^2 (including the lower limit but not including the upper limit), 3.5×10^5 cells/cm^2 or more and less than 3.4×10^6 cells/cm^2 (including the lower limit but not including the upper limit), 1.0×10^6 cells/cm^2 or more and less than 3.4×10^6 cells/cm^2 (including the lower limit but not including the upper limit), more than 1.0×10^6 cells/cm^2 and less than 3.4×10^6 cells/cm^2 (including neither the lower limit nor the upper limit) or more than 1.0×10^6 cells/cm^2 and 1.7×10^6 cells/cm^2 or less (not including the lower limit but including the upper limit). One skilled in the art can suitably determine the cell density suitable for the invention with respect to cells other than skeletal myoblasts by an experiment according to the disclosure of the description.

[0043]

The step of forming a sheet with the seeded cells can also be carried out by any known method and under any known condition. Unrestricted examples of the method are described for example in PTL 1 and the like. It is believed that a sheet-formation of cells is achieved by the adhesion of cells by the intercellular adhesion mechanism such as an adhesion molecule and extracellular matrix. Accordingly, the step of forming a sheet with the seeded cells can be achieved for example by culturing the cells under a condition under which intercellular adhesion is caused. The condition may be any condition as long as intercellular adhesion can be caused but in general, intercellular adhesion can be caused under a condition similar to the general cell cultivation condition. The condition is for example cultivation at 37°C in 5% CO_2. Also, the cultivation can be carried out at normal pressure (atmospheric pressure). One skilled in the art can select the optimum condition depending on the kind of seeded cells. In the description, the cultivation for forming a sheet with the seeded cells is sometimes called “sheet-formation cultivation”.

[0044]

In an embodiment of the invention, the cultivation of cells is carried out within a certain period, preferably within a period in which the cells do not undergo the transition to the differentiation. Therefore, in the embodiment, the cells are maintained in the undifferentiated state over the cultivation period. The transition of cells to the differentiation can be evaluated

by any method known to one skilled in the art. For example, in the case of skeletal myoblasts, the expression of MHC, the creatine kinase (CK) activity, the multinucleation of cells, the myotube formation and the like can be used as indicators of differentiation. In a preferable embodiment of the invention, the cultivation period is within 48 hours, more preferably within 40 hours, further preferably within 24 hours.

[0045]

The cell culture solution used for the cultivation (sometimes simply referred to as "culture solution" or "culture medium") is not specifically restricted as long as the cells can be kept alive, but typically, a cell culture solution containing an amino acid, a vitamin and an electrolyte as main components can be used. In an embodiment of the invention, the culture solution contains a basal medium for cell cultivation as a base. The basal medium includes DMEM, MEM, F12, DME, RPMI1640, MCDB (MCDB102, 104, 107, 120, 131, 153, 199 and the like), L15, SkBM, RITC80-7, DMEM/F12 and the like) without restriction. Many of the basal media are commercially available, and their compositions have been disclosed.

The basal medium may be used with the standard composition (for example, in the commercially distributed state), or its composition may be suitably changed in accordance with the cell kind or the cell condition. Accordingly, the basal medium used in the invention is not restricted to those having known compositions and includes those in which one or two or more components are added, removed, increased in amount or decreased in amount.

[0046]

Examples of the amino acid contained in the basal medium include, without restriction, L-arginine, L-cystine, L-glutamine, glycine, L-histidine, L-isoleucine, L-leucine, L-lysine, L-methionine, L-phenylalanine, L-serine, L-threonine, L-tryptophan, L-tyrosine, L-valine and the like. Examples of the vitamin include, without restriction, calcium D-pantothenate, choline chloride, folic acid, i-inositol, niacinamide, riboflavin, thiamine, pyridoxine, biotin, lipoic acid, vitamin B12, adenine, thymidine and the like. Examples of the electrolyte include, without restriction, $CaCl_2$, KCl, $MgSO_4$, NaCl, NaH_2PO_4, $NaHCO_3$, $Fe(NO_3)_3$, $FeSO_4$, $CuSO_4$, $MnSO_4$, Na_2SiO_3, $(NH_4)_6Mo_7O_{24}$, $NaVO_3$, $NiCl_2$, $ZnSO_4$ and the like. In addition to these components, the basal medium may contain a saccharide such as D-glucose, sodium pyruvate, a pH indicator such as phenol red, putrescine and the like.

[0047]

In an embodiment of the invention, the concentrations of the amino acids contained in the basal medium are 63.2 to 84 mg/L L-arginine, 35 to 63 mg/L L-cystine, 4.4 to 584 mg/L L-glutamine, 2.3 to 30 mg/L glycine, 42 mg/L L-histidine, 66 to 105 mg/L L-isoleucine, 105 to 131 mg/L L-leucine, 146 to 182 mg/L L-lysine, 15 to 30 mg/L L-methionine, 33 to 66 mg/L L-phenylalanine, 32 to 42 mg/L L-serine, 12 to 95 mg/L L-threonine, 4.1 to 16 mg/L L-tryptophan, 18.1 to 104 mg/L L-tyrosine and 94 to 117 mg/L L-valine.

Also, in an embodiment of the invention, the concentrations of the vitamins contained in the basal medium are 4 to 12 mg/L calcium D-pantothenate, 4 to 14 mg/L choline chloride, 0.6 to 4 mg/L folic acid, 7.2 mg/L i-inositol, 4 to 6.1 mg/L niacinamide, 0.0038 to 0.4 mg/L riboflavin, 3.4 to 4 mg/L thiamine and 2.1 to 4 mg/L pyridoxine.

[0048]

The cell culture solution may contain one or two or more kinds of additive such as serum, a growth factor, a steroid component and a selenium component, in addition to the above components. However, these components are impurities introduced during the production steps and may cause side effects such as anaphylactic shock on the recipient in clinical practice, and it is desirable to exclude these components in the application to a clinical use. Accordingly, in a preferable embodiment of the invention, the cell culture solution does not contain an effective amount of at least one kind of these additives. In a more preferable embodiment of the invention, the cell culture solution does not substantially contain at least one kind of these additives. Moreover, in a particularly preferable embodiment of the invention, the cell culture solution contains substantially no additive. Therefore, the cell culture solution may contain a basal medium only.

[0049]

In an embodiment of the invention, the cell culture solution contains substantially no serum. In the description, a cell culture solution that contains substantially no serum is sometimes referred to as a "serum-free culture medium". Here, the expression "contains substantially no serum" means that the serum content in the culture solution is at a level which does not cause any adverse effect when the cell culture is applied to a living body (for example, an amount at which the serum albumin content in the cell culture is less than 50 ng) and preferably means that these substances are not actively added to the culture solution. In the invention, in order to prevent a side effect of the implantation, the cell culture solution

preferably contains substantially no serum of a different species and further preferably contains substantially no nonself-serum.

[0050]

In an embodiment of the invention, the cell culture solution does not contain an effective amount of a growth factor. Here, "an effective amount of a growth factor" means an amount of a growth factor which promotes the proliferation of cells with significance as compared to the case without the growth factor or for convenience an amount which is generally added for the purpose of proliferating cells in the technical field. The significance of promotion of the cell proliferation can be suitably evaluated for example by any statistical method known in the technical field such as t test, and the generally added amount can be known from various publications in the technical field. Specifically, the effective amount of EGF for the cultivation of skeletal myoblasts is for example 0.005 μg/mL or more.

[0051]

Accordingly, the expression "does not contain an effective amount of a growth factor" means that the concentration of the growth factor in the culture solution in the invention is lower than the effective amount. For example, the concentration of EGF in the culture solution for the cultivation of skeletal myoblasts is preferably less than 0.005 μg/mL, more preferably less than 0.001 μg/mL. In a preferable embodiment of the invention, the concentration of a growth factor in the culture solution is lower than the general concentration in a living body. In the embodiment, for example, the concentration of EGF in the culture solution for the cultivation of skeletal myoblasts is preferably less than 5.5 ng/mL, more preferably less than 1.3 ng/mL, further preferably less than 0.5 ng/mL. In a further preferable embodiment, the culture solution in the invention contains substantially no growth factor. Here, that the culture solution contains substantially no growth factor means that the growth factor content in the culture solution is at a level which does not cause any adverse effect when the cell culture is applied to a living body and preferably means that a growth factor is not actively added to the culture solution. Accordingly, in the embodiment, the culture solution does not contain a growth factor in a concentration same as or more than the concentration contained in the other components such as serum.

[0052]

In an embodiment of the invention, the cell culture solution contains substantially no steroid component. Here, the "steroid component" means, among compounds having a

steroid nucleus, a compound which may have adverse effects such as adrenocortical insufficiency and Cushing's syndrome on a living body. Examples of the compound include, without restriction, cortisol, prednisolone, triamcinolone, dexamethasone, betamethasone and the like. Accordingly, the expression "contains substantially no steroid component" means that the content of the compounds in the culture solution is at a level which does not cause any adverse effect when the cell culture is applied to a living body and preferably means that the compounds are not actively added to the culture solution, which means that the culture solution does not contain any steroid component in a concentration same as or more than the concentration contained in the other components such as serum.

[0053]

In an embodiment of the invention, the cell culture solution contains substantially no selenium component. Here, the "selenium component" includes a selenium molecule and a selenium-containing compound, in particular, a selenium-containing compound capable of releasing a selenium molecule in a living body, such as selenous acid. Accordingly, the expression "contains substantially no selenium component" means that the content of the substances in the culture solution is at a level which does not cause any adverse effect when the cell culture is applied to a living body and preferably means that the substances are not actively added to the culture solution, which means that the culture solution does not contain any selenium component in a concentration same as or more than the concentration contained in the other components such as serum. Specifically, for example, in the case of human, the selenium concentration in the culture solution is lower than a value derived by multiplying the normal value in human serum (for example, 10.6 to 17.4 μg/dL) by the ratio of human serum contained in the culture medium (that is, when the human serum content is 10%, the selenium concentration is less than 1.0 to 1.7 μg/dL for example).

[0054]

In the preferable embodiment of the invention, a step of removing impurities introduced during the production steps such as a growth factor, a steroid component and a serum component of a different species by washing or the like, which has been necessary for producing a cell culture to be applied to a living body, is not necessary. Accordingly, an embodiment of the method of the invention does not contain a step of removing the impurities introduced during the production steps.

Here, the "impurities introduced during the production steps" typically include the following substances introduced in the respective production steps. That is, the impurities are those derived from the cell substrate (for example, proteins derived from the host cells and DNA derived from the host cells), those derived from the cell culture solution (for example, inducers, antibiotics and medium components), those introduced during the steps of extracting, separating, processing and purifying the target substance, which are conducted after the cell cultivation and the like (for example, see Notification No. 571 issued by Pharmaceutical and Food Safety Bureau).

[0055]

The cultivation of cells can be carried out under a condition which is generally employed in the technical field. For example, a typical cultivation condition is cultivation at 37°C in 5% CO_2. Also, the cultivation can be carried out at normal pressure (atmospheric pressure). From the viewpoints of sufficiently forming a cell culture and of preventing the cell differentiation, the cultivation period is preferably within 48 hours, more preferably within 40 hours, further preferably within 24 hours. The cultivation can be carried out in a container of any size and shape. The size and shape of a cell culture can be adjusted by adjusting the size/shape of the cell-adhesion surface of the culture container or by providing a form with desired size/shape on the cell-adhesion surface of the culture container and culturing the cells in the form.

[0056]

In an embodiment of the production method of the invention, the sheet-shaped cell culture is formed after the step of thawing the cells substantially without proliferation of the cells. This procedure can further increase the activity of the sheet-shaped cell culture.

The expression "substantially without proliferation" of the cells means that the cells are not proliferated to an extent going beyond the measurement error, and whether the cells have proliferated or not can be evaluated for example by comparing the number of seeded cells and the number of cells after forming the cell culture. In the invention, the number of cells after forming the sheet-shaped cell culture is typically 300% or less, preferably 200% or less, more preferably 150% or less, further preferably 125% or less, particularly preferably 100% or less based on the number of seeded cells.

[0057]

Because the proliferation of cells depends on various conditions such as the number of seeded cells (density of seeded cells), the cultivation environment (for example, cultivation period, cultivation temperature and the like) and the composition of the culture medium, it is possible not to substantially proliferate the cells by adjusting the conditions. Among the conditions, by increasing the density of seeded cells, the sheet-shaped cell culture can be obtained in a relatively short time while the proliferation of the cells is prevented, and thus it is preferable in the invention to control the proliferation with the density of seeded cells. The density at which the sheet-shaped cell culture can be formed substantially without proliferation of the cells has already been described above.

[0058]

Accordingly, in the embodiment, the sheet-formation cultivation is carried out after the step of thawing the cells without any further step of proliferating the cells, under a condition under which the cells are not substantially proliferated. In addition, in the embodiment, a step which does not involve cell proliferation such as a step of washing the cells can be carried out after the step of thawing the cells and before the sheet-formation cultivation.

[0059]

The production method of the invention may further contain a step of recovering the formed sheet-shaped cell culture after the step of forming the sheet-shaped cell culture. The recovery of the sheet-shaped cell culture is not specifically restricted as long as the sheet-shaped cell culture can be released (peeled) from the culture substrate as the scaffold while keeping its sheet structure at least partially, and for example, the sheet-shaped cell culture can be recovered by enzyme treatment using a protease (for example, trypsin and the like) and/or by mechanical treatment such as pipetting. Also, when the cells are cultured on a culture substrate with a surface covered with a material whose physical properties change in response to a stimulus such as temperature or light and the cell culture is thus formed, the sheet-shaped cell culture can be released nonenzymatically by applying a certain stimulus.

[0060]

An embodiment of the production method of the invention further contains a step of recovering the sheet-shaped cell culture after the step of forming the sheet-shaped cell culture, and the step of thawing the cells is carried out within 48 hours before the step of recovering the sheet-shaped cell culture. By controlling the interval between the step of thawing the

cells and the step of recovering the sheet-shaped cell culture to be 48 hours or shorter, preferably 36 hours or shorter, more preferably 24 hours or shorter, the activity of the sheet-shaped cell culture can be further increased.

[0061]

The production method of the invention may further contain a step of proliferating the cells before the step of thawing the cells. The step of proliferating the cells may be carried out by any known method, and one skilled in the art is familiar with the cultivation conditions suitable for the proliferation of respective cell kinds. In the production method of the invention, when the sheet-shaped cell culture is formed after the step of thawing the cells substantially without proliferation of the cells or when the step of thawing the cells is carried out within 48 hours before the step of recovering the sheet-shaped cell culture, it is useful to carry out the step of proliferating the cells before the step of thawing the cells in order to obtain a desired number of cells.

[0062]

In an embodiment, the production method of the invention does not contain a step of introducing a gene into the cells. In another embodiment, the production method of the invention contains a step of introducing a gene into the cells. The gene to be introduced is not specifically restricted as long as it is useful for treating the target disease, and the gene may be a cytokine such as HGF and VEGF for example. The gene can be introduced by any known method such as calcium phosphate transfection, lipofection, ultrasonic transfection, electroporation, particle gun method, a method using a virus vector such as an adenovirus vector or a retrovirus vector and microinjection. The gene can be introduced into the cells for example before the step of thawing the cells without restriction.

[0063]

The sheet-shaped cell culture obtained by the production method of the invention has an activity higher than that of a sheet-shaped cell culture produced by the same method as the production method of the invention except that the method does not contain a step of freezing the cells and a step of thawing the frozen cells (hereinafter, sometimes referred to as the control sheet-shaped cell culture). Examples of the activity include, without restriction, cytokine productivity, engrafting ability, angiogenesis ability, tissue regeneration ability and the like. Here, that the activity is higher means that the activity is higher than the activity of the control sheet-shaped cell culture, without restriction, for example by 5% or more, 10% or

more, 20% or more, 30% or more, 40% or more, 50% or more, 60% or more, 70% or more, 80% or more, 90% or more or 100% or more.

[0064]

In the invention, the cytokine means a proteinaceous factor which is released from a cell and mediates various intercellular interactions. Accordingly, the cytokine in the invention is not restricted to those released from immune cells. In an embodiment of the invention, the cytokine is useful for the engraftment of the sheet-shaped cell culture in the recipient tissue. In an embodiment of the invention, the cytokine is useful for the angiogenesis. In an embodiment of the invention, the cytokine is useful for the regeneration of a tissue. Such a cytokine is known in the technical field, and one skilled in the art can determine an appropriate cytokine based on known information. In an embodiment of the invention, the cytokine includes a growth factor. In an embodiment of the invention, the cytokine is selected from the group consisting of HGF and VEGF. Accordingly, in an embodiment of the invention, the cytokine productivity is the growth factor productivity. Also, in an embodiment of the invention, the cytokine productivity is the productivity of a growth factor selected from the group consisting of HGF and VEGF.

[0065]

The activity of the sheet-shaped cell culture can be quantified by various methods. When the activity is cytokine productivity, for example, the cytokine productivity can be quantified by culturing the sheet-shaped cell culture in a culture solution for a certain period of time and measuring the amount of a cytokine secreted into the culture solution or measuring the amount of a cytokine gene expressed in the sheet-shaped cell culture. Methods for measuring the amount of a certain protein or the level of gene expression are known in the technical field. Examples of the method for measuring the amount of a protein include, without restriction, electrophoresis, Western blotting, mass spectrometry, EIA, ELISA, RIA, immunohistochemical method, immunocytochemical method and the like; and examples of the method for measuring the level of gene expression include, without restriction, Northern blotting, Southern blotting, DNA microarray analysis, RNase protection assay, PCR methods such as RT-PCR and real-time PCR, *in situ* hybridization and the like.

[0066]

When the activity is engrafting ability, the engrafting ability can be quantified by applying the sheet-shaped cell culture to a tissue, observing the state of the applied sheet-

shaped cell culture, for example the adhesion to the tissue, the size, color and form of the remaining culture and the like, after a certain period of time and giving scores to them. When the activity is angiogenesis ability, the angiogenesis ability can be quantified by applying the sheet-shaped cell culture to a tissue, observing the states of the applied sheet-shaped cell culture and the part of the tissue to which the sheet-shaped cell culture was applied, for example the presence or absence of angiogenesis and the like, after a certain period of time and giving scores to the states. When the activity is tissue regeneration ability, the tissue regeneration ability can be quantified by applying the sheet-shaped cell culture to a tissue, observing the state of the part of the tissue to which the sheet-shaped cell culture was applied (recipient), for example the tissue size, the microstructure of the tissue, the ratios of the damaged tissue and the normal tissue, the function of the tissue and the like, after a certain period of time and giving scores to them.

[0067]

In an embodiment, all of the steps of the production method of the invention are carried out *in vitro*. In another embodiment, the production method of the invention contains a step carried out *in vivo*, for example, without restriction, a step of collecting cells or a tissue serving as a source of cells from the subject. In an embodiment, all of the steps of the production method of the invention are carried out under a sterile condition. In an embodiment, the production method of the invention is carried out in such a manner that the sheet-shaped cell culture obtained in the end becomes substantially sterile. In an embodiment, the production method of the invention is carried out in such a manner that the sheet-shaped cell culture obtained in the end becomes sterile.

[0068]

Another aspect of the invention relates to a sheet-shaped cell culture produced by the production method of the invention. The sheet-shaped cell culture of the invention is characterized by having an activity higher than that of the control sheet-shaped cell culture. Details of the degree of the high activity are as described above. In an embodiment, an activity of the sheet-shaped cell culture of the invention selected from the group consisting of cytokine productivity, engrafting ability, angiogenesis ability and tissue regeneration ability is higher than that of the control sheet-shaped cell culture. Also, in an embodiment, the productivity of a cytokine selected from the group consisting of HGF and VEGF of the sheet-shaped cell culture of the invention is higher than that of the control sheet-shaped cell culture.

Because the sheet-shaped cell culture of the invention has a high activity, it exhibits better effects than the control sheet-shaped cell culture in various therapeutic applications. In particular, when the HGF and/or VEGF productivity is high, engraftment in the tissue, angiogenesis and tissue regeneration are promoted, and the sheet-shaped cell culture functions continuously over a long period, resulting in the enhancement of the therapeutic effects.

[0069]

The sheet-shaped cell culture of the invention is useful for treating various diseases associated with abnormalities of tissues. Accordingly, in an embodiment, the sheet-shaped cell culture of the invention is for use in treating a disease associated with an abnormality of a tissue. Because the sheet-shaped cell culture of the invention has properties inherent in the constituent cells which are similar to those of a conventional sheet-shaped cell culture except that it has a higher activity, the sheet-shaped cell culture of the invention can be applied at least to a tissue or a disease which can be treated with a conventional sheet-shaped cell culture. Examples of the tissue to be treated include, without restriction, a cardiac muscle, a cornea, a retina, an esophagus, skin, a joint, cartilage, a liver, a pancreas, a gingiva, a kidney, a thyroid gland, a skeletal muscle, a middle ear and the like. Also, examples of the disease to be treated include, without restriction, cardiac diseases (for example, myocardiopathy (myocardial infarction and cardiac injury), cardiomyopathy and the like), corneal diseases (for example, corneal epithelial stem cell deficiency, corneal injury (thermal/chemical corrosion), corneal ulcer, corneal opacity, corneal perforation, corneal scar, Stevens-Johnson syndrome, ocular pemphigoid and the like), retinal diseases (for example, retinitis pigmentosa, age-related macular degeneration and the like), esophageal diseases (for example, prevention of esophageal inflammation/stricture after esophageal surgery (removal of esophageal cancer) and the like), skin diseases (for example, skin injury (external injury and burn) and the like), joint diseases (for example, osteoarthritis and the like), cartilage diseases (for example, cartilage damage and the like), liver diseases (for example, chronic liver disease and the like), pancreatic diseases (for example, diabetes and the like), dental diseases (for example, periodontal disease and the like), renal diseases (for example, renal failure, renal anemia, renal osteodystrophy and the like), thyroid diseases (for example, hypothyroidism and the like), muscular diseases (for example, muscle damage, muscle inflammation and the like) and middle ear diseases (for example, otitis media and the like).

[0070]

That the sheet-shaped cell culture of the invention is effective against the above diseases is described for example in PTL 1, NPL 1, Arauchi et al., Tissue Eng Part A. 2009 Dec;15(12):3943-9; Ito et al., Tissue Eng. 2005 Mar-Apr;11(3-4):489-96; Yaji et al., Biomaterials. 2009 Feb;30(5):797-803; Yaguchi et al., Acta Otolaryngol. 2007 Oct;127(10):1038-44; Watanabe et al., Transplantation. 2011 Apr 15;91(7):700-6; Shimizu et al., Biomaterials. 2009 Oct;30(30):5943-9; Ebihara et al., Biomaterials. 2012 May;33(15):3846-51; Takagi et al., World J Gastroenterol. 2012 Oct 7;18(37):5145-50 and the like.

[0071]

The sheet-shaped cell culture of the invention can be applied to the tissue to be treated and used for repairing or regenerating the tissue, but the sheet-shaped cell culture can also be implanted to a part other than the tissue to be treated (for example, subcutaneous tissues and the like) as a source of a bioactive substance such as a hormone (for example, Arauchi *et al.*, Tissue Eng Part A. 2009 Dec;15(12):3943-9, Shimizu *et al.*, Biomaterials. 2009 Oct;30(30):5943-9 and the like). Also, by fragmenting the sheet-shaped cell culture into a size which can be administered by injection and injecting the fragments to a part which should be treated, an effect higher than that of the injection of a single-cell suspension can be obtained (Wang *et al.*, Cardiovasc Res. 2008 Feb 1;77(3):515-24). Accordingly, such a use method can be applied also with respect to the sheet-shaped cell culture of the invention.

[0072]

In an embodiment, the sheet-shaped cell culture of the invention is substantially sterile. In an embodiment, the sheet-shaped cell culture of the invention is sterile. In an embodiment, the sheet-shaped cell culture of the invention is not genetically manipulated. In another embodiment, the sheet-shaped cell culture of the invention is genetically manipulated. The genetic manipulation includes, without restriction, for example, introduction of a gene which enhances the viability of the sheet-shaped cell culture, its engrafting ability, function and the like and/or a gene which is useful for treating a disease. Examples of the gene to be introduced include, without restriction, cytokine genes such as HGF gene and VEGF gene.

[0073]

Another aspect of the invention relates to a pharmaceutical composition containing the sheet-shaped cell culture of the invention.

The pharmaceutical composition of the invention may contain various additional components such as a pharmaceutically acceptable carrier, a component which enhances the viability of the sheet-shaped cell culture, its engrafting property, function and/or the like and another effective component which is useful for treating the target disease, in addition to the sheet-shaped cell culture of the invention. As the additional components, any known components can be used, and one skilled in the art is familiar with the additional components. Moreover, the pharmaceutical composition of the invention can be combined with a component which enhances the viability of the sheet-shaped cell culture, its engrafting property, function and/or the like, another effective component which is useful for treating the target disease or the like. In an embodiment, the pharmaceutical composition of the invention is for use in treating a disease associated with an abnormality of a tissue. The tissues and diseases to be treated are as described for the sheet-shaped cell culture of the invention.

[0074]

Another aspect of the invention relates to a method for treating a disease associated with an abnormality of a tissue in a subject, containing administering an effective amount of the sheet-shaped cell culture of the invention or the pharmaceutical composition to a subject in need thereof. The tissues and the diseases to be treated by the treatment method of the invention are as described for the sheet-shaped cell culture of the invention. Also, in the treatment method of the invention, a component which enhances the viability of the sheet-shaped cell culture, its engrafting property, function and/or the like, another effective component which is useful for treating the target disease or the like can be combined with the sheet-shaped cell culture of the invention or the pharmaceutical composition.

[0075]

The treatment method of the invention may further contain a step of producing a sheet-shaped cell culture according to the production method of the invention. The treatment method of the invention may further contain a step of collecting cells or a tissue serving as a source of cells for producing the sheet-shaped cell culture from a subject, before the step of producing the sheet-shaped cell culture. In an embodiment, the subject from which the cells or the tissue serving as a source of the cells is collected is the same individual as the subject treated by administration of the sheet-shaped cell culture or the pharmaceutical composition. In another embodiment, the subject from which the cells or the tissue serving as a source of

the cells is collected is a different individual of the same species as the subject treated by administration of the sheet-shaped cell culture or the pharmaceutical composition. In another embodiment, the subject from which the cells or the tissue serving as a source of the cells is collected is an individual of a different species from that of the subject treated by administration of the sheet-shaped cell culture or the pharmaceutical composition.

[0076]

In the invention, the term "subject" means any individual of a living thing, preferably an animal, further preferably a mammal, further preferably a human individual. In the invention, the subject may be healthy or may have any disease, but in case where the treatment of a disease associated with an abnormality of a tissue is planned, the subject typically means a subject having the disease or having the risk of developing the disease.

[0077]

The term "treatment" includes all kinds of medically acceptable preventive and/or therapeutic intervention for the purpose of healing, remission, prevention or the like of a disease. For example, the term "treatment" includes medically acceptable intervention with various purposes including delaying or stopping of the progress of a disease associated with an abnormality of a tissue, regression or elimination of a lesion, prevention of the onset of the disease, prevention of the recurrence and the like.

[0078]

In the invention, the effective amount is for example an amount which can prevent the onset or recurrence of a disease, reduce a symptom or delay or stop the progress (for example, the size or weight of the sheet-shaped cell culture) and is preferably an amount which prevents the onset and recurrence of the disease or cures the disease. Also, an amount which does not cause any adverse effect exceeding the advantages of the administration is preferable. The amount can be suitably determined for example through a test using an experimental animal such as a mouse, a rat, a dog or a pig or a disease model animal or the like, and such a test method is well known to one skilled in the art. Also, the size of the tissue lesion to be treated may be an important index for determining the effective amount.

[0079]

The administration method is typically direct application to a tissue, but when fragments of the sheet-shaped cell culture are used, the sheet-shaped cell culture may be administered through various routes through which administration by injection is possible,

such as intravenous, intramuscular, subcutaneous, local, intraarterial, intraportal, intraventricular and intraperitoneal routes.

The frequency of administration is typically once per treatment, but several administrations are also possible when the desired effect is not obtained.

[Examples]

[0080]

The invention is explained in more detail referring to the following examples, but the examples are specific examples of the invention and the invention should not be restricted to the examples.

Example 1

Cryopreserved human skeletal myoblasts (derived from a human skeletal muscle sample) were thawed at 37°C and washed twice using a buffer containing 0.5% serum albumin. In a culture medium containing 20% serum, 5×10^6 to 5×10^7 cells were suspended, and the cells were seeded to a flask and then cultured for two to three days.

A culture medium containing 20% serum was added to UpCell$^{(R)}$ (3.5 cm dish or 24-well multiwell, CellSeed Inc.) until the culture surface was completely covered, and the UpCell$^{(R)}$ was treated in an environment at 37°C of 5% CO_2 for three hours to three days. After the treatment, the culture medium added was discarded.

The cultured cells were recovered, suspended in a culture medium containing 20% serum and seeded to the treated UpCell$^{(R)}$ at a density of 2 to 20×10^5 cells/cm^2, and sheet-formation cultivation was carried out in an environment at 37°C of 5% CO_2 for about a day.

[0081]

Example 2

In a culture medium containing 20% serum, 5×10^6 to 5×10^7 human skeletal myoblasts (derived from a human skeletal muscle sample) were suspended, and the cells were seeded to a flask and then cultured for two to three days. After recovering the cultured cells, the cells were suspended in a storage solution for freezing cells (a basal medium containing 10% DMSO) at a concentration of 1 to 5×10^7 cells/mL and cryopreserved in a liquid nitrogen tank.

A culture medium containing 20% serum was added to UpCell$^{(R)}$ (3.5 cm dish or 24-well multiwell, CellSeed Inc.) until the culture surface was completely covered, and the

UpCell(R) was treated in an environment at 37°C of 5% CO_2 for three hours to three days. After the treatment, the culture medium added was discarded.

The cryopreserved skeletal myoblasts were thawed at 37°C and washed twice using a buffer containing 0.5% serum albumin. The cells washed were suspended in a culture medium containing 20% serum and seeded to the treated UpCell(R) at a density of 2 to 20×10^5 cells/cm^2, and sheet-formation cultivation was carried out in an environment at 37°C of 5% CO_2 for about a day.

[0082]

Example 3

After the sheet-formation cultivation in example 1 or example 2, all of the culture supernatants were recovered, and the concentrations of the cytokines (VEGF and HGF) produced in the culture supernatants were measured by ELISA (n=3). The measurement was carried out using Human VEGF Quantikine ELISA Kit (R&D systems, catalogue No. DVE00) and RayBio(R) Human HGF ELISA Kit (RayBiotech, Inc., catalogue No. ELH-HGF-001) in accordance with the manuals of the manufacturers. From the results shown in Fig. 1, it can be seen that VEGF and HGF are produced during the sheet-formation cultivation in both of the production methods of Example 1 and Example 2. The production amounts were higher in the production method of Example 2.

[0083]

Example 4

Sheet-shaped cell cultures formed in UpCell(R) (24-well multiwell, CellSeed Inc.) in accordance with the method of example 1 or example 2 were peeled off by thermal treatment and washed with HBSS(+). Then, 400 μL of an MCDB medium containing 2.5% FBS was added to each well, followed by cultivation in a CO_2 incubator for about 24 hours. After the cultivation, all of the supernatants were recovered, and the concentrations of the cytokines (VEGF and HGF) produced in the culture supernatants were measured by ELISA as in example 3. To the wells from which the supernatants were recovered, 400 μL of an MCDB medium containing 2.5% FBS was added again, followed by cultivation in a CO_2 incubator for 48 hours. After the cultivation, all of the supernatants were recovered, and the concentrations of the cytokines (VEGF and HGF) produced in the culture supernatants were measured by ELISA as in example 3. From the results shown in Figs. 2 and 3, it can be seen that the sheet-shaped cell cultures produced by both of the production methods of Examples 1 and 2

produce VEGF and HGF and that the production continues for as long as 96 hours. Also, the production amounts were higher with the sheet-shaped cell culture produced by the production method of Example 2.

[0084]

Example 5

Cryopreserved human mesenchymal stem cells are thawed at 37°C and washed twice using a buffer containing 0.5% serum albumin. In a culture medium containing serum, 5×10^6 to 5×10^7 cells are suspended, and the cells are seeded to a flask and then cultured for two to three days.

A culture medium containing serum is added to UpCell(R) (3.5 cm dish or 24-well multiwell, CellSeed Inc.) until the culture surface is completely covered, and the UpCell(R) is treated in an environment at 37°C of 5% CO_2 for three hours to three days. After the treatment, the culture medium added is discarded.

The cultured cells are recovered, suspended in a culture medium containing serum and seeded to the treated UpCell(R) at a density of 2 to 20×10^5 cells/cm^2, and sheet-formation cultivation is carried out in an environment at 37°C of 5% CO_2 for about a day.

[0085]

Example 6

In a culture medium containing serum, 5×10^6 to 3×10^7 human mesenchymal stem cells are suspended, and the cells are seeded to a flask and then cultured for two to three days. After recovering the cultured cells, the cells are suspended in a storage solution for freezing cells (a basal medium containing 10% DMSO) at a concentration of 1 to 5×10^7 cells/mL and cryopreserved in a liquid nitrogen tank.

A culture medium containing serum is added to UpCell(R) (3.5 cm dish or 24-well multiwell, CellSeed Inc.) until the culture surface is completely covered, and the UpCell(R) is treated in an environment at 37°C of 5% CO_2 for three hours to three days. After the treatment, the culture medium added is discarded.

The cryopreserved cells are thawed at 37°C and washed twice using a buffer containing 0.5% serum albumin. The cells washed are suspended in a culture medium containing serum and seeded to the treated UpCell(R) at a density of 2 to 10×20^5 cells/cm^2, and sheet-formation cultivation is carried out in an environment at 37°C of 5% CO_2 for about a day.

[0086]

Example 7

Cryopreserved human cardiac muscle cells are thawed at 37°C and washed twice using a buffer containing 0.5% serum albumin. In a culture medium containing serum, 5×10^6 to 3×10^7 cells are suspended, and the cells are seeded to a flask and then cultured for two to three days.

A culture medium containing serum is added to UpCell(R) (3.5 cm dish or 24-well multiwell, CellSeed Inc.) until the culture surface is completely covered, and the UpCell(R) is treated in an environment at 37°C of 5% CO_2 for three hours to three days. After the treatment, the culture medium added is discarded.

The cultured cells are recovered, suspended in a culture medium containing serum and seeded to the treated UpCell(R) at a density of 2 to 20×10^5 cells/cm^2, and sheet-formation cultivation is carried out in an environment at 37°C of 5% CO_2 for about a day.

[0087]

Example 8

In a culture medium containing serum, 5×10^6 to 3×10^7 human cardiac muscle cells are suspended, and the cells are seeded to a flask and then cultured for two to three days. After recovering the cultured cells, the cells are suspended in a storage solution for freezing cells (a basal medium containing 10% DMSO) at a concentration of 1 to 5×10^7 cells/mL and cryopreserved in a liquid nitrogen tank.

A culture medium containing serum is added to UpCell(R) (3.5 cm dish or 24-well multiwell, CellSeed Inc.) until the culture surface is completely covered, and the UpCell(R) is treated in an environment at 37°C of 5% CO_2 for three hours to three days. After the treatment, the culture medium added is discarded.

The cryopreserved cardiac muscle cells are thawed at 37°C and washed twice using a buffer containing 0.5% serum albumin. The cells washed are suspended in a culture medium containing serum and seeded to the treated UpCell(R) at a density of 2 to 20×10^5 cells/cm^2, and sheet-formation cultivation is carried out in an environment at 37°C of 5% CO_2 for about a day.

[0088]

Example 9

In a culture medium containing serum, 1×10^6 to 3×10^7 human mesenchymal stem cells were suspended, and the cells were seeded to a flask and then cultured for two to three days. After recovering the cultured cells, the cells were suspended in a storage solution for freezing cells (a basal medium containing 10% DMSO) at a concentration of 1 to 5×10^6 cells/mL and cryopreserved in a liquid nitrogen tank.

A culture medium containing serum was added to UpCell(R) (48-well multiwell, CellSeed Inc.) until the culture surface was completely covered, and the UpCell(R) was treated in an environment at 37°C of 5% CO_2 at normal pressure (atmospheric pressure) for three hours to three days as in Examples 1, 2 and 5 to 8. After the treatment, the culture medium added was discarded.

The cryopreserved cells were thawed at 37°C and washed twice using a buffer containing 0.5% serum albumin. The cells washed were suspended in a culture medium containing serum and seeded to the treated UpCell(R) at a density of 2 to 20×10^5 cells/cm^2, and sheet-formation cultivation was carried out in an environment at 37°C of 5% CO_2 at normal pressure (atmospheric pressure) for about a day as in Examples 1, 2 and 5 to 8. As shown in Fig. 4, the sheet-shaped cell cultures produced had homogeneous white color, and no defect was observed in an appearance test.

[0089]

One skilled in the art understands that a large number of various modifications are possible without departing from the spirit of the invention. Accordingly, it should be understood that the embodiments described in the description are only examples and that the embodiments have not been described with the intention of restricting the scope of the invention.

CLAIMS

[Claim 1]

A method for producing a sheet-shaped cell culture, comprising

a step of freezing cells,

a step of thawing the frozen cells, and

a step of forming a sheet-shaped cell culture.

[Claim 2]

The method according to claim 1, wherein the cells are autologous cells or allogeneic cells.

[Claim 3]

The method according to claim 1 or 2, wherein the cells are autologous cells.

[Claim 4]

The method according to any one of claims 1 to 3, wherein the sheet-shaped cell culture is formed after the step of thawing the cells substantially without proliferation of the cells.

[Claim 5]

The method according to any one of claims 1 to 4 which further comprises a step of recovering the sheet-shaped cell culture after the step of forming the sheet-shaped cell culture, wherein the step of thawing the cells is carried out within 48 hours before the step of recovering the sheet-shaped cell culture.

[Claim 6]

The method according to any one of claims 1 to 5 which comprises a step of proliferating the cells before the step of thawing the cells.

[Claim 7]

The method according to any one of claims 1 to 6 which comprises a step of washing the cells after the step of thawing the frozen cells and before the step of forming the sheet-shaped cell culture.

[Claim 8]

The method according to any one of claims 1 to 7, wherein the cells are selected from the group consisting of myoblasts, mesenchymal stem cells, cardiac muscle cells, fibroblasts, cardiac stem cells, embryonic stem cells, iPS cells, synoviocytes, chondrocytes, epithelial

cells, endothelial cells, hepatocytes, pancreatic cells, nephrocytes, adrenal cells, periodontal ligament cells, gingival cells, periosteal cells and skin cells.

[Claim 9]

The method according to any one of claims 1 to 8, wherein the obtained sheet-shaped cell culture has an activity higher than the activity of a sheet-shaped cell culture produced by a method which does not comprise a step of freezing cells and a step of thawing frozen cells.

[Claim 10]

The method according to claim 9, wherein the activity is selected from the group consisting of cytokine productivity, engrafting ability, angiogenesis ability and tissue regeneration ability.

[Claim 11]

The method according to claim 10, wherein the cytokine is selected from the group consisting of HGF and VEGF.

[Claim 12]

A sheet-shaped cell culture produced by the method according to any one of claims 1 to 11.

[Claim 13]

A pharmaceutical composition comprising the sheet-shaped cell culture according to claim 12.

[Claim 14]

A method for treating a disease associated with an abnormality of a tissue in a subject, comprising administering an effective amount of the sheet-shaped cell culture according to claim 12 or the pharmaceutical composition according to claim 13 to a subject in need thereof.

[Claim 15]

The method according to claim 14, wherein the tissue is selected from the group consisting of a cardiac muscle, a cornea, a retina, an esophagus, skin, a joint, cartilage, a liver, a pancreas, a gingiva, a kidney, a thyroid gland, a skeletal muscle and a middle ear.

[Claim 16]

The method according to claim 14, wherein the disease is selected from the group consisting of a cardiac disease, a corneal disease, a retinal disease, an esophageal disease, a skin disease, a joint disease, a cartilage disease, a liver disease, a pancreatic disease, a dental disease, a renal disease, a thyroid disease, a muscular disease and a middle ear disease.