{DESCRIPTION}

{Title of Invention} METHOD OF NUCLEAR REPROGRAMMING

{Technical Field}

{0001}

The present invention relates to a method of reprogramming a somatic cell and producing an induced pluripotent stem cell.

{Background Art}

{0002}

Established from human or mouse early embryos, embryonic stem cells (ES cells) are capable of being cultured for a long time while maintaining their potential for differentiating into all types of cells found in a living organism. With this feature, human ES cells are expected to serve for cell transplantation therapies for many diseases, including Parkinson's disease, juvenile diabetes, and leukemia. However, ES cell transplantation poses the problem of causing rejections as with organ transplantation. Additionally, not a few people oppose the use of ES cells established with the destruction of a human embryo, from an ethical viewpoint.

{0003}

If the dedifferentiation of a patient's somatic cells is induced to establish cells possessing pluripotency and proliferating capability similar to those of an ES cell (herein these cells are referred to as "induced pluripotent stem cells" (iPS cells), and sometimes referred to as "embryonic stem cell-like cells" or "ES-like cells"), the established cells will be useful as ideal pluripotent cells that do not pose the problems of rejections and ethical issues. In recent years, it has been reported that iPS cells can be produced from mouse and human differentiated cells, arousing great attention (International Patent Application Publication No. WO2007/69666; Cell, 126, pp.663-676, 2006; Cell, 131, pp.861-872, 2007; Science, 318, pp.1917-1920, 2007; Nature, 451, pp.141-146, 2008).

{0004}

All these methods comprise the step of introducing a plurality of particular nuclear reprogramming factors (e.g., in Cell, 126, pp.1-14, 2006, 4 factors are used: Oct3/4, Sox2, Klf4, and c-Myc) into a somatic cell to achieve reprogramming, which step involves the use of a retrovirus or a lentivirus for the purpose of introducing the genes that encode the nuclear reprogramming factors into a somatic cell efficiently. However, since gene delivery using a viral vector involves safety issues, there is a demand for developing a method of producing iPS cells without using a viral vector.

{Summary of the Invention}

{Technical Problem}

{0005}

It is an object of the present invention to provide a method of producing an iPS cell by reprogramming a somatic cell without using a viral vector such as a retrovirus.

{Solution to Problem}

{0006}

The present inventors extensively investigated to solve the problems described above, and found that an iPS cell can be produced by introducing genes that encode reprogramming factors into a somatic cell by means of a non-viral expression vector such as a plasmid vector, and that a safe iPS cell can be obtained from a somatic cell by the method. The present invention has been developed on the basis of these findings.

{0007}

Accordingly, the present invention provides a method of producing an induced pluripotent stem cell, comprising the step of introducing at least one kind of non-viral expression vector incorporating at least one gene that encodes a reprogramming factor into a somatic cell.

{0008}

In a preferred embodiment, the present invention provides the above-described method wherein the vectors are non-viral expression vectors autonomously replicable outside a

chromosome; and the above-described method wherein the vector is a plasmid vector.

{0009}

In another preferred embodiment, the present invention provides the above-described method wherein the gene that encodes a reprogramming factor is one of genes selected by a method of screening for nuclear reprogramming factors described in WO 2005/80598 or a combination of a plurality of such genes; and the above-described method wherein the gene that encodes a reprogramming factor is one or more kinds of genes selected from the group consisting of an Oct family gene, a Klf family gene, a Sox family gene, a Myc family gene, a Lin family gene, and the Nanog gene, preferably a combination of two kinds of genes, more preferably a combination of three kinds of genes, particularly preferably a combination of four or more kinds of genes.

{0010}

More preferable combinations are (a) a combination of two kinds of genes consisting of an Oct family gene and a Sox family gene; (b) a combination of three kinds of genes consisting of an Oct family gene, a Klf family gene, and a Sox family gene; (c) a combination of four kinds of genes consisting of an Oct family gene, a Klf family gene, a Sox family gene, and a Myc family gene; (d) a combination of four kinds of genes consisting of an Oct family gene, a Sox family gene, a Lin family gene, and the Nanog gene; (e) a combination of six kinds of genes consisting of an Oct family gene, a Klf family gene, a Sox family gene, a Myc family gene, a Lin family gene, and the Nanog gene;and the like. Furthermore, it is also preferable to include the TERT gene and/or the SV40 Large T antigen gene in the combination. As the case may be, it is preferable to exclude Klf family genes.

Particularly preferred combinations thereof are a combination of two kinds of genes consisting of Oct3/4 and Sox2; a combination of three kinds of genes consisting of

Oct3/4, Klf4, and Sox2; a combination of four kinds of genes consisting of Oct3/4, Klf4, Sox2, and c-Myc; a combination of four kinds of genes consisting of Oct3/4, Sox2, Lin28, and Nanog; and a combination of six kinds of genes consisting of Oct3/4, Klf4, Sox2, c-Myc, Lin28, and Nanog. It is also preferable to include the TERT gene and/or the SV40 Large T antigen gene in these combinations. As the case may be, it is preferable to exclude Klf4.

{0011}

In another preferred embodiment, the present invention provides the above-described method wherein the number of kinds of non-viral expression vectors introduced into a somatic cell is 1, 2, 3, or 4; the above-described method wherein the genes that encode reprogramming factors are a combination of three kinds of genes consisting of an Oct family gene, a Klf family gene, and a Sox family gene, and these genes are incorporated in one kind of non-viral expression vector; the above-described method wherein the genes that encode nuclear reprogramming factors are a combination of four kinds of genes consisting of an Oct family gene, a Klf family gene, a Sox family gene, and a Myc family gene, and the Oct family gene, the Klf family gene, and the Sox family gene are incorporated in one kind of non-viral expression vector; the above-described method wherein the Oct family gene, the Klf family gene, and the Sox family gene are incorporated in one kind of non-viral expression vector in this order in the orientation from the 5′ to 3′ end; and the above-described method wherein the Oct family gene, the Klf family gene, and the Sox family gene are incorporated in one kind of non-viral expression vector with an intervening sequence enabling polycistronic expression.

{0012}

In another preferred embodiment, the present invention provides the above-described method wherein two or more kinds of the above-described non-viral expression vectors are concurrently introduced into a somatic cell; the above-

described method wherein the genes that encode reprogramming factors are a combination of four kinds of genes consisting of an Oct family gene, a Klf family gene, a Sox family gene, and a Myc family gene, and a first non-viral expression vector incorporating three or less kinds of genes selected from among the four kinds of genes, and a second non-viral expression vector incorporating the remaining gene(s) out of the four kinds of genes are concurrently introduced into a somatic cell; the above-described method wherein the three or less kinds of genes are an Oct family gene, a Klf family gene, and a Sox family gene, and the remaining gene is a Myc family gene; the above-described method wherein the three or less kinds of genes are Oct3/4, Klf4, and Sox2, and the remaining gene is c-Myc; and the above-described method wherein introduction of the non-viral expression vector into a somatic cell is repeatedly performed twice or more.

In a particularly preferred embodiment, the present invention provides the above-described method wherein a first non-viral expression vector harboring Oct3/4, Klf4, and Sox2, and a second non-viral expression vector harboring c-Myc are introduced into a somatic cell; the above-described method wherein a first non-viral expression vector harboring Oct3/4, Klf4, and Sox2 in this order in the orientation from the 5′ to 3′ end, and a second non-viral expression vector harboring c-Myc are introduced into a somatic cell; the above-described method wherein Oct3/4, Klf4, and Sox2 are ligated in this order in the orientation from the 5′ to 3′ end with an intervening sequence enabling polycistronic expression and inserted into the first non-viral expression vector; the above-described method wherein the first non-viral expression vector and the second non-viral expression vector are concurrently introduced into a somatic cell; and the above-described method wherein the introduction is repeatedly performed twice or more. Also provided is the above-described method wherein whole or prat of the at least one non-viral expression vector introduced is

substantially not integrated in the chromosome.

{0013}

In another preferred embodiment, the present invention provides the above-described method wherein the somatic cell is a somatic cell of a mammal, including a human, preferably a human or mouse somatic cell, particularly preferably a human somatic cell; the above-described method wherein the somatic cell is a fetal human cell or a somatic cell derived from an adult human; and the above-described method wherein the somatic cell is a somatic cell collected from a patient.

{0014}

In another aspect, the present invention provides an induced pluripotent stem cell that can be obtained by the above-described method. In a preferred embodiment, the present invention also provides an induced pluripotent stem cell wherein all or some of the at least one non-viral expression vector introduced is substantially not integrated in the chromosome.

{0015}

Also provided are the above-described induced pluripotent stem cell wherein the somatic cell is a somatic cell of a mammal, including a human, preferably a human or mouse somatic cell, particularly preferably a human somatic cell; the above-described induced pluripotent stem cell wherein the somatic cell is a fetal human cell or a somatic cell derived from an adult human; and the above-described induced pluripotent stem cell wherein the somatic cell is a somatic cell collected from a patient.

{0016}

A non-viral expression vector, preferably a plasmid vector, for use in the above-described method of producing an induced pluripotent stem cell, incorporating at least one gene that encodes a reprogramming factor, is also provided by the present invention.

{0017}

A somatic cell induced and differentiated from the above-described induced pluripotent stem cell is also provided by the present invention.

{0018}

The present invention also provides a stem cell therapy comprising the step of transplanting to a patient a somatic cell obtained by differentiation induction of an induced pluripotent stem cell obtained by the above-described method using a somatic cell separated from the patient.

{0019}

The present invention further provides a method of evaluating the physiological activities and toxicities of compounds, drugs, poisonous substances and the like using various cells obtained by differentiation induction of an induced pluripotent stem cell obtained by the above-described method.

{Advantageous Effects of Invention}

{0020}

Produced without using a vector to be integrated into a chromosome, such as a retrovirus, the induced pluripotent stem cell provided by the present invention is advantageous in that tumorigenesis and other problems do not arise in the somatic cells and tissues obtained by differentiating the induced pluripotent stem cell. In a preferred embodiment of the present invention, in the induced pluripotent stem cell produced by the method of the present invention, all or some of the at least one non-viral expression vector introduced is episomally present, substantially not integrated in the chromosome. Therefore, the method of the present invention makes it possible to prepare a highly safe induced pluripotent stem cell from, for example, a patient's somatic cell, and the cells obtained by differentiating this cell (e.g., myocardial cells, insulin-producing cells, or nerve cells and the like) can be safely used for stem cell transplantation therapies for a broad range of diseases, including heart failure, insulin-

dependent diabetes, Parkinson's disease and spinal injury.

{Brief Description of Drawings}

{0021}

FIG. 1 shows a time course protocol for transfecting a somatic cell (MEF) with Oct3/4, Klf4, Sox2, and c-Myc using plasmids according to the method of the present invention, results of seven independent tests (left photographs, 432A-1 to 432A-7: cell density $1x10^6$ cells/100 mm dish) and results of another test (right photographs, 432B-1: cell density $2x10^5$ cells/100 mm dish). The lowermost panels in the center show control results (no transfection). In FIG. 1, the Phase columns show phase-contrast images, and the GFP columns show GFP-positive colonies.

FIG. 2 shows an expression plasmid for iPS cell production. Three kinds of cDNAs that encode Oct3/4, Klf4, and Sox2 were ligated in this order with sequence encoding the 2A peptide as intervening sequence, and inserted into the pCX plasmid (pCX-2A-mOKS). Furthermore, a cDNA of c-Myc was inserted into pCX (pCX-c-Myc). The bald lines show the amplification regions used in the PCR analysis for detecting plasmid integration in the genome (FIG. 6).

FIG. 3 shows the time schedules for iPS cell induction using plasmids. The solid arrows indicate the time points of transfection of the respective plasmids.

FIG. 4 shows the morphology of non-virus mediated iPS cells established. The upper panels show phase-contrast images, and the lower panels show GFP-positive colonies (scale bar = 200 μm).

FIG. 5 shows results of PCR analysis for the genetic expression of ES cell markers, obtained using total RNAs isolated from ES cells, iPS cells induced using retroviruses (clone 20D-17: Nature, 448, pp.313-317, 2007), iPS cells induced using plasmids (clones 440A-3, 4, 7, 8, 10 and 11; clone 432A-1), and MEF cells.

FIG. 6 shows the detection of plasmid integration by PCR.

Genomic DNAs were extracted from a C57BL/6 mouse, iPS cell induced using retroviruses (clone 20D-17), iPS cells induced with plasmids (clone 432A-1; clones 440A-1 to 11) and MEF cells, and analyzed by PCR using the primers shown in FIGS. 2, 13 and 14. In the PCR for O-1, K and M, the bands derived from endogenous genes are indicated by the outlined arrowheads, and the bands derived from integrated plasmids are indicated by the solid arrowheads. For the Fbx15 reporter, the lower band indicates wild-type alleles, and the upper band indicates knocked-in alleles.

FIG. 7 shows results of teratoma formation. iPS cells without integration of plasmids (clones 440A-3, -4, and -8) were subcutaneously transplanted to nude mice. Four weeks later, tumors were resected and stained with hematoxylin and eosin. Shown from above are the results for gut-like epithelial tissue, epidermal tissue, striated muscles, and nerve tissue, respectively (scale bar = 50 μm).

FIG. 8 shows chimeric mice derived from iPS cells without integration (clones 440A-3 and -8).

FIG. 9 shows the detection of integration of plasmids by PCR. Genomic DNAs were extracted from an ICR mouse, iPS cell (clone 432A-1), and chimeric mice derived from iPS cells induced using plasmids (clone 432A-1; clones 440A-3, 8), and the O-1, K and M regions shown in FIG. 2 were amplified by PCR. The bands derived from endogenous genes are indicated by the outlined arrowheads, and the bands derived from integrated plasmids are indicated by the solid arrowheads. The presence of the Nanog reporter and Fbx15 reporter was also detected by PCR.

FIG. 10 shows the probes used in Southern blot analysis and the positions of the restriction endonuclease recognition sites. E indicates EcoRI, and B indicates BamHI.

FIG. 11 shows results of Southern blot analysis. Genomic DNAs (6 μg) were extracted from RF8 ES cells and iPS cells (clones 440A-3, 4, 7, 8, 10, and 11; clone 432A-1), and cleaved

with BamHI and EcoRI. A mixture of the pCX-2A-mOKS and pCX-c-Myc plasmids (each 20 pg) served for control. The outlined arrowheads indicate the bands derived from endogenous genes, and the solid arrowhead indicates the band derived from the Oct3/4 pseudogene (estimated size 2049 bp) on chromosome 3. The arrows indicate the bands derived from transgenes. Although the identities of the many bands observed in clone 432A-1 are unclear, this may suggest the integration of multiple transgenes. The GFP probe was used to detect Nanog reporter alleles.

FIG. 12 shows results of SSLP analysis. On genomic DNAs (each 50 ng) from C57BL/6 mouse, RF8 ES cell, iPS cells without integration (clones 440A-3 to 11) and MEF cells, SSLP analysis was performed. These iPS cells derive from a mixture of five MEF cell clones (clones 1, 2, 3, 5, and 6).

FIGS. 13 and 14 show the primers used for PCR in Examples 1 to 3.

FIG. 15 shows a time course protocol for transfecting human dental pulp stem cells with Oct3/4, Klf4, Sox2, c-Myc, Lin28, Nanog and the SV40 Large T antigen using plasmids according to the method of the present invention, and 16 independent iPS cell colonies.

FIGS. 16 and 17 show photographs of iPS cells established from fetal HDF (5 clones: 203A-1 to 203A-5, of which 203A-4 was picked up as a negative control) on day 31 after transfection (FIG. 16) and in the 2nd subculture (FIG. 17).

FIG. 18 shows the results of genomic-PCR analysis of 5 iPS cell clones (203A-1 to 203A-5).

FIGS. 19 and 20 show photographs of iPS cells established from human dental pulp stem cells (5 clones: 217A-1 to -4 and -6) on day 35 after transfection (FIG. 19) and in the 2nd subculture (FIG. 20).

FIG. 21 shows the results of genomic-PCR analysis of 5 iPS cell clones (217A-1 to -4 and -6).

FIGS. 22 and 23 show photographs of iPS cells established

from young female HDF (2 clones: 279A-1 and -2) on day 35 after the first electroporation (FIG. 22) and clone 279A-2 after passage culture (FIG. 23; the right panel is a closeup picture of the boxed area in the left panel).

FIG.24 shows the results of genomic-PCR analysis of iPS cell clone 279A-2 demonstrating the integration of the transgenes.

FIG. 25 shows photographs of iPS cells (8 clones: 497A-1 to A-8) after the selection (colonies were selected on day 25 after transfection). The upper panels show phase-contrast images, and the lower panels show GFP-positive colonies.

FIG. 26 shows the results of genomic-PCR analysis of 5 iPS cell clones (497A-1 to A-5). In 497A-2 and 497A-5, no exogenous gene was not integrated into the genome.

{Description of Embodiments}

{0022}

The method of the present invention is intended to produce an induced pluripotent stem cell, comprising the step of introducing at least one kind of non-viral expression vector incorporating at least one gene that encodes a reprogramming factor into a somatic cell. The non-viral expression vector is preferably an expression vector autonomously replicable outside a chromosome, more preferably a plasmid expression vector.

{0023}

As an example of a means for identifying a nuclear reprogramming factor, a nuclear reprogramming factor screening method described in WO 2005/80598 can be utilized. All disclosures therein are incorporated herein by reference. Those skilled in the art are able to screen for nuclear reprogramming factors, and to utilize them for the method of the present invention, by referring to the aforementioned publication. It is also possible to identify nuclear reprogramming factors using a method modified or altered from the above-described screening method.

{0024}

Some examples of combinations of genes that encode reprogramming factors are disclosed in WO2007/69666. All disclosures therein are incorporated herein by reference. Those skilled in the art are able to choose genes that can suitably be used in the method of the present invention as appropriate by referring to the aforementioned publication. Other examples of combinations of genes that encode reprogramming factors are given in Science, 318, pp.1917-1920, 2007, WO2008/118820 and the like. Therefore, those skilled in the art are able to understand the diversity of combinations of genes that encode nuclear reprogramming factors; by utilizing a nuclear reprogramming factor screening method described in WO 2005/80598, appropriate combinations of genes other than the combinations described in WO2007/69666 and Science, 2007 (supra) can be utilized in the method of the present invention.

{0025}

Preferable genes that encode reprogramming factors include one or more kind of genes selected from the group consisting of an Oct family gene, a Klf family gene, a Sox family gene, a Myc family gene, a Lin family gene, and the Nanog gene, preferably a combination of two kinds of genes, more preferably of three kinds of genes, and particularly preferably of four kinds of genes.

Examples of Oct family genes, Klf family genes, Sox family genes, and Myc family genes are given in WO2007/69666. Likewise, for Lin family genes, those skilled in the art are likewise able to extract a family gene. For example, as examples of Lin family genes, Lin28 and Lin28B may be included.

{0026}

More preferable combinations include, but are not limited to,

(a) a combination of two kinds of genes consisting of an Oct family gene and a Sox family gene;

(b) a combination of three kinds of genes consisting of an Oct family gene, a Klf family gene, and a Sox family gene;

(c) a combination of four kinds of genes consisting of an Oct family gene, a Klf family gene, a Sox family gene, and a Myc family gene;

(d) a combination of four kinds of genes consisting of an Oct family gene, a Sox family gene, a Lin family gene, and the Nanog gene;

(e) a combination of six kinds of genes consisting of an Oct family gene, a Sox family gene, a Klf family gene, a Myc family gene, a Lin family gene, and the Nanog gene;

and the like.

All these genes are present in common in mammals, including humans. Genes derived from optionally chosen mammals (e.g., humans, mice, rats, bovines, sheep, horses, monkeys) can be used in the present invention. In addition to wild-type gene, mutant genes whose translation products have several (e.g., 1 to 10, preferably 1 to 6, more preferably 1 to 4, more preferably 1 to 3, particularly preferably 1 or 2) amino acids substituted, inserted, and/or deleted, and possess a function similar to that of the wild type gene product, can also be utilized. For example, as c-Myc genes, the wild type, a gene encoding stable type mutant (T58A) and the like may be used. The same applies to other gene products.

{0027}

In addition to the aforementioned genes, a gene that encodes a factor that induces cell immortalization may further be combined. As disclosed in WO2007/69666, for example, the TERT gene, and one or more kind of genes selected from the group consisting of the following genes: SV40 Large T antigen, HPV16 E6, HPV16 E7, and Bmil, can be used singly, or in combination as appropriate.

Examples of preferable combinations include:

(f) a combination of five kinds of genes consisting of an Oct family gene, a Klf family gene, a Sox family gene, a Myc family gene, and the TERT gene;

(g) a combination of five kinds of genes consisting of an Oct

family gene, a Klf family gene, a Sox family gene, a Myc family gene, and the SV40 Large T antigen gene;

(h) a combination of six kinds of genes consisting of an Oct family gene, a Klf family gene, a Sox family gene, a Myc family gene, the TERT gene, and the SV40 Large T antigen gene; and

(i) a combination of seven kinds of genes consisting of an Oct family gene, a Klf family gene, a Sox family gene, a Myc family gene, a Lin family gene, the Nanog gene, and the TERT gene or the SV40 Large T antigen gene.

As required, the Klf family gene may be excluded from the aforementioned combinations.

{0028}

Furthermore, in addition to the aforementioned genes, one or more kind of genes selected from the group consisting of Fbx15, ERas, ECAT15-2, Tcl1, and β-catenin may be combined, and/or one or more kind of genes selected from the group consisting of ECAT1, Esg1, Dnmt3L, ECAT8, Gdf3, Sox15, ECAT15-1, Fthl17, Sall4, Rex1, UTF1, Stella, Stat3, and Grb2 may also be combined. These combinations are specifically described in WO2007/69666.

{0029}

If one or more kind of these genes are already expressed in the somatic cell to be reprogrammed, the gene(s) can be excluded from the genes to be introduced. When one or more kind of these genes are introduced into a somatic cell to be reprogrammed using a vector to be integrated into a chromosome, such as a retrovirus, the remaining one or more genes can be introduced using a non-viral expression vector according to the method of the present invention. Alternatively, when one or more kind of the gene products of these genes are introduced into a nucleus by means of fused protein or nuclear microinjection, the remaining one or more genes can be introduced using a non-viral expression vector according to the method of the present invention.

{0030}

Particularly preferable combinations of genes are,

(1) a combination of two kinds of genes consisting of Oct3/4 and Sox2;

(2) a combination of three kinds of genes consisting of Oct3/4, Klf4, and Sox2;

(3) a combination of four kinds of genes consisting of Oct3/4, Klf4, Sox2, and c-Myc;

(4) a combination of four kinds of genes consisting of Oct3/4, Sox2, Lin28, and Nanog;

(5) a combination of five kinds of genes consisting of Oct3/4, Sox2, c-Myc, TERT, and SV40 Large T antigen;

(6) a combination of six kinds of genes consisting of Oct3/4, Klf4, Sox2, c-Myc, TERT, and SV40 Large T antigen;

(7) a combination of six kinds of genes consisting of Oct3/4, Klf4, c-Myc, Sox2, Lin28, and Nanog;

(8) a combination of seven kinds of genes consisting of Oct3/4, Klf4, c-Myc, Sox2, Lin28, Nanog, and TERT or SV40 Large T antigen,

and the like.

In addition to the aforementioned genes, a gene that encodes a factor that induces cell immortalization may further be combined. As disclosed in WO2007/69666, for example, one kind or more of genes selected from the group consisting of the TERT gene, and the following genes: HPV16 E6, HPV16 E7, and Bmil, can be used singly, or in combination as appropriate.

When reprogramming is performed using nerve stem cells endogenously expressing Sox2 and c-Myc, or the like as a somatic cell source, a combination of two kinds of genes consisting of Oct3/4 and Klf4, or a combination of two kinds of genes consisting of Oct3/4 and c-Myc (see Nature, Published online, 29 June 2008, p1-5 (doi:10.1038/nature07061)) can also be mentioned.

In the combinations (3), (5), (6), and (7) above, L-Myc can be used in place of c-Myc.

{0031}

It should be noted that combinations of genes are not limited thereto. Additionally, the scope of the present invention includes a method wherein one or more genes selected from among the above-described genes are introduced into a somatic cell using a non-viral expression vector, and the remaining gene or gene product is introduced into the somatic cell by another means. For example, it is also possible to introduce one or more genes selected from among the above-described genes into a somatic cell using a non-viral expression vector, and to introduce the remaining gene into the somatic cell using a viral vector such as retroviral vector, lentiviral vector, adenoviral vector, adeno-associated viral vector, Sendai viral vector.

{0032}

When two or more kinds of genes that encode reprogramming factors are introduced into a somatic cell using non-viral expression vectors, some of the two or more kinds of genes to be introduced can be introduced into a somatic cell at a time different from that for other genes, or all kinds of genes to be introduced can be concurrently introduced into a somatic cell; however, it is preferable that all genes to be introduced be concurrently introduced into a somatic cell. When two or more kinds of different non-viral expression vectors are used to introduce two or more kinds of genes, all kinds of non-viral expression vectors can be concurrently introduced into a somatic cell; this represents a preferred embodiment of the present invention.

{0033}

In the method of the present invention, as genes that encode reprogramming factors, for example, a combination of four kinds of genes consisting of an Oct family gene, a Klf family gene, a Sox family gene, and a Myc family gene can be used. A combination of three kinds of genes consisting of an Oct family gene, a Klf family gene, and a Sox family gene, or a combination of two kinds of genes selected from among the

aforementioned three kinds of genes can also be used.

In the method of the present invention, it is preferable that the above-described four kinds, three kinds, or two kinds of genes be concurrently introduced into a somatic cell. To introduce the above-described four kinds, three kinds, or two kinds of genes, one kind of non-viral expression vector incorporating all these genes may be used. Altenatively, several kinds of non-viral expression vectors may be used in combination as appropriate, so as to cover all the combinations of these genes. When several kinds of non-viral expression vectors are used, it is preferable that preferably two or three kinds, more preferably two kinds of non-viral expression vectors be used. It is preferable that these non-viral expression vectors be concurrently introduced into a somatic cell.

{0034}

If the number of genes introduced exceeds four kinds, several kinds of non-viral expression vectors may be combined as appropriate, so as to cover all the combinations of these genes. When several kinds of non-viral expression vectors are used, it is preferable that preferably two to five kinds, more preferably two to four kinds, more preferably three or four of non-viral expression vectors be used. These non-viral expression vectors are preferably concurrently introduced into a somatic cell.

{0035}

An example of a preferable method is a method wherein one non-viral expression vector harboring an Oct family gene, a Klf family gene, and a Sox family gene, and one non-viral expression vector harboring a Myc family gene are introduced into a somatic cell concurrently or at different times; in this method, it is preferable that the two kinds of non-viral expression vectors be concurrently introduced into the somatic cell. In another preferred embodiment, it is also possible to use a method wherein one non-viral expression vector harboring

an Oct family gene, a Klf family gene, a Sox family gene, and a Myc family gene is introduced into a somatic cell.

{0036}

In a preferred embodiment of the present invention, in a combination of four kinds of genes consisting of an Oct3/4, Klf4, Sox2, and c-Myc, or an optionally chosen combination of three kinds or two kinds selected from among these four kinds of genes, preferably the combination or three kinds or two kinds of genes, wherein said combination does not contain c-Myc, can be used. This preferred embodiment is hereinafter described specifically, to which the scope of the present invention is never limited.

(a1) A method wherein one kind of non-viral expression vector, more preferably a plasmid vector, harboring Oct3/4, Klf4, Sox2 and c-Myc, is introduced into a somatic cell.

(b1) A method wherein a first non-viral expression vector, more preferably a plasmid vector, harboring two kinds of genes selected from among Oct3/4, Klf4, Sox2 and c-Myc, and a second non-viral expression vector, more preferably a plasmid vector, harboring the remaining two kinds of genes selected from among Oct3/4, Klf4, Sox2 and c-Myc, are introduced into a somatic cell. Preferably, the first non-viral expression vector and the second non-viral expression vector can be concurrently introduced into a somatic cell.

(c1) A method wherein a first non-viral expression vector, more preferably a plasmid vector, harboring three kinds of genes selected from among Oct3/4, Klf4, Sox2 and c-Myc, and a second non-viral expression vector, more a preferably a plasmid vector, harboring the remaining one kind of gene selected from among Oct3/4, Klf4, Sox2 and c-Myc, are introduced into a somatic cell. Preferably, the first non-viral expression vector and the second non-viral expression vector can be concurrently introduced into a somatic cell.

(d1) A method wherein a first non-viral expression vector, more preferably a plasmid vector, harboring two kinds of genes

selected from among Oct3/4, Klf4 and Sox2, and a second non-viral expression vector, more preferably a plasmid vector, harboring the remaining one kind of gene selected from among Oct3/4, Klf4 and Sox2, and c-Myc, are introduced into a somatic cell. Preferably, the first non-viral expression vector and the second non-viral expression vector can be concurrently introduced into a somatic cell.

(e1) A method wherein a first non-viral expression vector, more preferably a plasmid vector, harboring Oct3/4, Klf4 and Sox2, and a second non-viral expression vector, more preferably a plasmid vector, harboring c-Myc, are introduced into a somatic cell. Preferably, the first non-viral expression vector and the second non-viral expression vector can be concurrently introduced into a somatic cell.

(f1) A method wherein a first non-viral expression vector, more preferably a plasmid vector, harboring two kinds of genes selected from among Oct3/4, Klf4 and Sox2 in this order in the orientation from the 5′ to 3′ end, and a second non-viral expression vector, more preferably a plasmid vector, harboring c-Myc and any one gene out of Oct3/4, Klf4 and Sox2 not contained in the first non-viral expression vector, are introduced into a somatic cell. More specifically, a first non-viral expression vector, preferably a plasmid vector, harboring (i) Oct3/4 and Klf4, (ii) Klf4 and Sox2, or (iii) Oct3/4 and Sox2 in this order in the orientation from the 5′ to 3′ end can be used; the first non-viral expression vector and the second non-viral expression vector can be concurrently introduced into a somatic cell.

(g1) A method wherein a first non-viral expression vector, more preferably a plasmid vector, harboring Oct3/4, Klf4 and Sox2 in this order in the orientation from the 5′ to 3′ end, and a second non-viral expression vector, more preferably a plasmid vector, harboring c-Myc are introduced into a somatic cell. Preferably, the first non-viral expression vector and the second non-viral expression vector can be concurrently

introduced into a somatic cell.

The method of (f1) or (g1) can be preferably used when the somatic cell is derived from mouse.

{0037}

In (b1) to (f2) above, for either one of the first non-viral expression vector and the second non-viral expression vector, a viral vector (e.g., retroviral vector, lentiviral vector, adenoviral vector, adeno-associated viral vector, Sendai viral vector or the like) can be used in place of the non-viral expression vector.

{0038}

In another preferred embodiment of the present invention, in (a1) to (f2) above, L-Myc can be used in place of c-Myc.

{0039}

In still another preferred embodiment, a combination of three kinds of genes consisting of Oct3/4, Klf4 and Sox2 can be used. This preferred embodiment is hereinafter described specifically, to which the scope of the present invention is never limited.

(a2) A method wherein one kind of non-viral expression vector, more preferably a plasmid vector, harboring Oct3/4, Klf4 and Sox2, is introduced into a somatic cell.

(b2) A method wherein one kind of non-viral expression vector, more preferably a plasmid vector, harboring Oct3/4, Klf4 and Sox2 in this order in the orientation from the 5′ to 3′ end are introduced into a somatic cell.

(c2) A method wherein a first non-viral expression vector, more preferably a plasmid vector, harboring two kinds of genes selected from among Oct3/4, Klf4 and Sox2, and a second non-viral expression vector, more preferably a plasmid vector, harboring the remaining one kind of gene selected from among Oct3/4, Klf4 and Sox2, are introduced into a somatic cell. Preferably, the first non-viral expression vector and the second non-viral expression vector can be concurrently introduced into a somatic cell.

(d2) A method wherein a first non-viral expression vector, more preferably a plasmid vector, harboring two kinds of genes selected from among Oct3/4, Klf4 and Sox2 in this order in the orientation from the 5′ to 3′ end, and a second non-viral expression vector, more preferably a plasmid vector, harboring any one gene out of Oct3/4, Klf4 and Sox2 not contained in the first non-viral expression vector are introduced into a somatic cell. More specifically, a first non-viral expression vector, preferably a plasmid vector, harboring (i) Oct3/4 and Klf4, (ii) Klf4 and Sox2, or (iii) Oct3/4 and Sox2 in this order in the orientation from the 5′ to 3′ end can be used, and the first non-viral expression vector and the second non-viral expression vector can be concurrently introduced into a somatic cell.

The method of (b2) or (d2) can be preferably used when the somatic cell is derived from mouse.

{0040}

In (c2) or (d2) above, for either one of the first non-viral expression vector and the second non-viral expression vector, a viral vector (e.g., retroviral vector, lentiviral vector, adenoviral vector, adeno-associated viral vector, Sendai viral vector or the like) can also be used in place of the non-viral vector.

{0041}

In still another preferred embodiment of the present invention, a combination of two kinds of genes selected from among Oct3/4, Klf4 and Sox2 can be used. This preferred embodiment is hereinafter described specifically, to which the scope of the present invention is never limited.

(a3) A method wherein one kind of non-viral expression vector, more preferably a plasmid vector, harboring two kinds of genes selected from among Oct3/4, Klf4 and Sox2, is introduced into a somatic cell.

(b3) A method wherein one kind of non-viral expression vector, more preferably a plasmid vector, harboring (i) Oct3/4 and Klf4,

(ii) Klf4 and Sox2, or (iii) Oct3/4 and Sox2 in this order in the orientation from the 5′ to 3′ end, is introduced into a somatic cell.

(c3) A method wherein a first non-viral expression vector, more preferably a plasmid vector, harboring one kind of gene selected from among Oct3/4, Klf4 and Sox2, and a second non-viral expression vector, more preferably a plasmid vector, harboring any one gene out of Oct3/4, Klf4 and Sox2 not contained in the first non-viral expression vector, are introduced into a somatic cell. Preferably, the first non-viral expression vector and the second non-viral expression vector can be concurrently introduced into a somatic cell.

The method of (b3) can be preferably used when the somatic cell is derived from mouse.

{0042}

In (c3) above, for either one of the first non-viral expression vector and the second non-viral expression vector, a viral vector (e.g., retroviral vector, lentiviral vector, adenoviral vector, adeno-associated viral vector, Sendai viral vector or the like) can be used in place of the non-viral vector.

{0043}

In still another preferred embodiment of the present invention, a combination of six kinds of genes selected from among Oct3/4, Klf4, Sox2, c-Myc, Lin28 and Nanog can be used. This preferred embodiment is hereinafter described specifically, to which the scope of the present invention is never limited.

(a4) A method wherein a first non-viral expression vector, more preferably a plasmid vector, harboring two kinds of genes selected from among Oct3/4, Klf4 and Sox2, a second non-viral expression vector, more preferably a plasmid vector, harboring the remaining one kind of gene selected from among Oct3/4, Klf4 and Sox2, and a third non-viral expression vector, more preferably a plasmid vector, harboring c-Myc, Lin28 and Nanog genes are introduced into a somatic cell. Preferably, the

first, second and third non-viral expression vectors can be concurrently introduced into a somatic cell.

(b4) A method wherein a first non-viral expression vector, more preferably a plasmid vector, harboring (i) Oct3/4 and Klf4, (ii) Klf4 and Sox2, (iii) Oct3/4 and Sox2 or (iv) Sox2 and Klf4 in this order in the orientation from the 5′ to 3′ end, a second non-viral expression vector, more preferably a plasmid vector, harboring the remaining one kind of gene selected from among Oct3/4, Klf4 and Sox2, and a third non-viral expression vector, more preferably a plasmid vector, harboring c-Myc, Lin28 and Nanog genes in this order in the orientation from the 5′ to 3′ end are introduced into a somatic cell.

{0044}

When a gene encoding a factor that induces cell immortalization, such as TERT, SV40 large T antigen, HPV16 E6, HPV16 E7 or Bmil, is further combined with the two, three, four or six genes mentioned above, it can be preferably incorporated into another non-viral expression vector.

{0045}

In the context above, when a plurality of genes (e.g., Oct family gene, Klf family gene, and Sox family gene) are incorporated in one kind of non-viral expression vector, these genes can preferably be inserted into the non-viral expression vector with an intervening sequence enabling polycistronic expression. By using an intervening sequence enabling polycistronic expression, it is possible to more efficiently express a plurality of genes incorporated in one kind of non-viral expression vector. Useful sequences enabling polycistronic expression include, for example, the 2A sequence of foot-and-mouth disease virus (SEQ ID NO:61, sometimes referred to as FMDV 2A-self-processing sequence) (PLoS ONE 3, e2532, 2008; Stem Cells 25, 1707, 2007), IRES sequence and the like, preferably the 2A sequence. More specifically, when a non-viral expression vector harboring (i) Oct3/4, Klf4 and Sox2, (ii) Oct3/4 and Klf4, (iii) Klf4 and Sox2, (iv) Oct3/4 and Sox2,

(v) Sox2 and Klf4 or (vi) c-Myc, Lin28 and Nanog in this order in the orientation from the 5′ to 3′ end is constructed, it is preferable to insert the 2A sequence between these genes. Accordingly, the present invention also provides a use of the 2A sequence for preparing a non-viral expression vector for iPS cell induction, harboring two or more kinds of reprogramming factors.

{0046}

The number of repeats of the manipulation to introduce a non-viral expression vector into a somatic cell is not particularly limited, as far as the effect of the present invention of reprogramming a somatic cell to produce an induced pluripotent stem cell can be accomplished, the transfection can be performed once or more optionally chosen times (e.g., once to 10 times, once to 5 times or the like). When two or more kinds of non-viral expression vectors are introduced into a somatic cell, it is preferable that these all kinds of non-viral expression vectors be concurrently introduced into a somatic cell; however, even in this case, the transfection can be performed once or more optionally chosen times (e.g., once to 10 times, once to 5 times or the like), preferably the transfection can be repeatedly performed twice or more (e.g., 3 times or 4 times).

When the transfection is repeated twice or more, the time interval is exemplified by, but not limited to, 12 hours to 1 week, preferably 12 hours to 4 days, for example, 1 day to 3 days.

{0047}

As used herein, the term "induced pluripotent stem cell (iPS cell)" refers to a cell possessing properties similar to that of ES cells, more specifically including undifferentiated cells reprogrammed from somatic cells possessing pluripotency and proliferating (self-renewal) capability. It should be noted, however, that this term must not be construed as limiting in any sense, and must be construed in the broadest

sense. A method of preparing an induced pluripotent stem cell by means of hypothetical nuclear reprogramming factors is described in WO2005/80598 (in this publication, the term ES-like cell is used), and a method of isolating an induced pluripotent stem cell is also described specifically. WO2007/69666 discloses specific examples of reprogramming factors and methods of somatic cell reprogramming using the same. Therefore, it is desirable that in embodying the present invention, those skilled in the art refer to these publications.

{0048}

In addition to the gene that encodes a reprogramming factor, a regulatory sequence required for transcription (e.g., promoter, enhancer, and/or terminator and the like) is preferably operably linked to the gene in the non-viral expression vector.

As the promoter, a DNA sequence exhibiting transcription activity in somatic cells can be used, and the promoter can be chosen as appropriate according to animal species and kind of somatic cell. Examples of useful promoters that can be expressed in mammalian cells include a promoter of the IE (immediate early) gene of cytomegalovirus (human CMV), initial promoter of SV40, promoter of retrovirus, metallothionein promoter, heat shock promoter, SRα promoter and the like. An enhancer of the IE gene of human CMV may be used along with a promoter. A useful promoter is the CAG promoter (comprising cytomegalovirus enhancer, chicken β-actin promoter and β-globin gene polyA signal site).

{0049}

The non-viral expression vector may incorporate a DNA sequence that allows the autonomous replication of the expression vector in a mammalian somatic cell. An example of the DNA sequence is the SV40 replication origin.

{0050}

The non-viral expression vector is preferably an expression vector autonomously replicable outside the

chromosome, and the non-viral expression vector is preferably one that is not integrated in the chromosome. More preferable examples include plasmid vectors. Examples of the plasmid vector include, but are not limited to, Escherichia coli-derived plasmids (ColE-series plasmids such as pBR322, pUC18, pUC19, pUC118, pUC119, and pBluescript, and the like), Actinomyces-derived plasmids (pIJ486 and the like), Bacillus subtilis-derived plasmids (e.g., pUB110, pSH19 and others), yeast-derived plasmids (YEp13, YEp 24, Ycp50 and the like) and the like, as well as artificial plasmid vectors and the like.

Examples of easily available non-viral expression vectors include, but are not limited to, pCMV6-XL3 (OriGene Technologies Inc.), EGFP-C1 (Clontech), pGBT-9 (Clontech), pcDNAI (FUNAKOSHI), pcDM8 (FUNAKOSHI), pAGE107 (Cytotechnology, 3,133, 1990), pCDM8 (Nature, 329, 840, 1987), pcDNAI/AmP (Invitrogen), pREP4 (Invitrogen), pAGE103 (J. Blochem., 101, 1307, 1987), pAGE210 and the like.

{0051}

The non-viral expression vector may incorporate a selectable marker as required. Examples of the selectable marker include genes that are deficient in the host cell, such as the dihydrofolate reductase (DHFR) gene or the Schizosaccaromyces pombe TPI gene, and genes for resistance to drugs such as ampicillin, kanamycin, tetracycline, chloramphenicol, neomycin, or hygromycin.

{0052}

While a non-viral expression vector such as plasmid vector introduced into a somatic cell is typically not integrated into the genome of the cell, under selection pressure for iPS cell induction, increased integration efficiency of non-viral expression vector may be observed due to the necessity of stable expression of reprogramming factors. Accordingly, when the iPS cells of interest are intended to use for regenerative medicine and the like, the non-viral expression vector can preferably contain a sequence enabling

the excicion of transgenes, such as loxP sequence (Chang et al., STEM CELLS Published Online: 12 Feb 2009 (doi: 10.1002/stem.39)), piggyback transposon (Kaji et al., Nature advance online publication 1 March 2009 (doi:10.1038/nature07864); Woltjen et al., Nature advance online publication 1 March 2009 (doi:10.1038/nature07863)) and tetracycline responsive element in promoter region (Tet-OnR & Tet-Off R Gene Expression Systems, Clontech).

{0053}

A method of ligating a gene that encodes a reprogramming factor, a promoter, an enhancer, and/or a terminator and the like, used in the present invention, in an appropriate order to construct a non-viral expression vector capable of expressing the reprogramming factor in the somatic cell, is obvious to those skilled in the art.

{0054}

When two or more kinds of genes that encode reprogramming factors are used, the genes may be incorporated in one non-viral expression vector. Alternatively, two or more kinds of non-viral expression vectors incorporating different genes may be used. In the latter case, one non-viral expression vector incorporating two or more kinds of genes and a non-viral expression vector incorporating one or more kind genes different therefrom can be combined as appropriate.

{0055}

Any method of expression vector introduction into an animal cell available to those skilled in the art can be used to introduce a non-viral expression vector into a somatic cell. Examples of useful methods include the use of a transfection reagent such as the FuGENE 6 transfection reagent (Roche), the use of a microporator, the electroporation method, the calcium phosphate method, the lipofection method, the DEAE-dextran-mediated transfection method, the transfection method, the microinjection method, the cationic lipid-mediated transfection method, and the like. Nucleofection can also be used to

introduce a gene. These methods may be used in combination.

{0056}

In introducing a non-viral expression vector into a somatic cell, the expression vector may be introduced into the somatic cell being cultured on feeder cells, and may be introduced only into the somatic cell. To increase expression vector introduction efficiency, the latter method is sometimes suitable. The feeder cells used may be those for cultivation of embryonic stem cells; for example, primary culture fibroblasts from a 14- to 15-day mouse embryo, STO (fibroblast-derived cell line) and the like, treated with a chemical agent such as mitomycin C or exposed to radiation, and the like can be used.

{0057}

By culturing a somatic cell incorporating a non-viral expression vector under appropriate conditions, it is possible to allow nuclear reprogramming to progress autonomically, and to produce an induced pluripotent stem cell from the somatic cell. The step of culturing a somatic cell incorporating a non-viral expression vector to obtain an induced pluripotent stem cell can be performed in the same manner as a conventional method using a retrovirus; for example, this can be achieved as described in publications such as Cell, 126, pp.1-14, 2006; Cell, 131, pp.1-12, 2007; and Science, 318, pp.1917-1920, 2007. In producing a human induced pluripotent stem cell, it is sometimes desirable that the cell culture density after expression vector introduction be set at a level lower than that for ordinary animal cell culture. For example, it is preferable to continue the cultivation at a cell density of 10,000 to 100,000 cells, preferably about 50,000 cells per cell culture dish. Any medium can be used for the cultivation, chosen as appropriate by those skilled in the art; for example, in producing a human induced pluripotent stem cell, it is sometimes preferable to use a medium suitable of human ES cell culture. Regarding the choice of medium and culturing

conditions, the aforementioned publications serve for references.

{0058}

The resulting induced pluripotent stem cells can be identified using various markers characteristic of undifferentiated cells; means for this identification are also described in the aforementioned publications specifically and in detail. Various media allowing the maintenance of undifferentiated state and pluripotency of ES cells or media not allowing the maintenance of these properties are known in the art; by using appropriate media in combination, an induced pluripotent stem cell can be isolated efficiently. The differentiation potential and proliferation potential of the isolated induced pluripotent stem cells are easily confirmable for those skilled in the art by utilizing a method of identification in common use for ES cells. When the resulting induced pluripotent stem cell is proliferated under appropriate conditions, a colony of induced pluripotent stem cells is obtained; it is possible to identify the presence of an induced pluripotent stem cell on the basis of the shape of the colony. For example, it is known that mouse induced pluripotent stem cells form raised colonies, whereas human induced pluripotent stem cells form flat colonies, and the shapes of these colonies are extremely similar to those of mouse ES cell and human ES cell colonies, respectively; therefore, it is possible for those skilled in the art to identify the resulting induced pluripotent stem cell on the basis of the shape of the colony. When reprogramming is performed using a somatic cell having a gene incorporating a marker gene such as GFP downstream of a promoter of gene specifically expressing in ES cells, it is possible to identify an induced pluripotent stem cell if the cell becomes positive for the marker (GFP).

{0059}

"Somatic cells" to be reprogrammed by the method of the present invention refers to any cells except totipotent and

pluripotent cells such as early embryos and ES cells, and the choice thereof is not limited. For example, as well as somatic cells in the fetal stage, neonatal somatic cells and mature somatic cells may be used. Preferably, somatic cells derived from mammals, including humans, are used; more preferably human- or mouse-derived somatic cells are used. Specifically, (1) tissue stem cells (somatic stem cells) such as nerve stem cells, hematopoietic stem cells, mesenchymal stem cells, and dental pulp stem cells, (2) tissue progenitor cells, or (3) differentiated cells such as lymphocytes, epithelial cells, muscle cells, fibroblasts (dermal cells and the like), hair cells, liver cells, and gastromucosal cells can be mentioned. When an induced pluripotent stem cell is used to treat a disease, it is desirable to use somatic cells separated from a patient to be treated or from another person sharing the same type of HLA as that of the patient; for example, somatic cells involved in disease and somatic cells involved in disease treatment and the like can be used.

{0060}

In the present invention, to increase the efficiency of induced pluripotent stem cell establishment, in addition to the introduction of a non-viral expression vector of the present invention, various establishment efficiency improvers may be introduced or added. Examples of iPS cell establishment efficiency improvers include, but are not limited to, histone deacetylase (HDAC) inhibitors [e.g., valproic acid (VPA) (Nat. Biotechnol., 26(7): 795-797 (2008)), low-molecular inhibitors such as trichostatin A, sodium butyrate, MC 1293, and M344, nucleic acid-based expression inhibitors such as siRNA and shRNA against HDAC (e.g., HDAC1 siRNA Smartpool® (Millipore), HuSH 29mer shRNA Constructs against HDAC1 (OriGene) and the like), and the like], G9a histone methyltransferase inhibitors [e.g., low-molecular inhibitors such as BIX-01294 (Cell Stem Cell, 2: 525-528 (2008)), nucleic acid-based expression inhibitors such as siRNA and shRNA against G9a (e.g., G9a siRNA

(human) (Santa Cruz Biotechnology) and the like) and the like], L-channel calcium agonist (e.g., Bayk8644) (Cell Stem Cell, 3, 568-574 (2008)), UTF1 (Cell Stem Cell, 3, 475-479 (2008)), Wnt Signaling (e.g., soluble Wnt3a) (Cell Stem Cell, 3, 132-135 (2008)), 2i/LIF (2i is an inhibitor of mitogen-activated protein kinase signaling and glycogen synthase kinase-3; PloS Biology, 6(10), 2237-2247 (2008)), p53 inhibitors (e.g., siRNA and shRNA against p53 (Cell Stem Cell, 3, 475-479 (2008)) and the like. The nucleic acid-based expression inhibitors may be in the form of expression vectors harboring a DNA that encodes siRNA or shRNA. In this case, the DNA that encodes siRNA or shRNA may be inserted into a non-viral expression vector of the present invention, together with reprogramming factors.

{0061}

The induced pluripotent stem cell produced by the method of the present invention is not subject to limitations concerning the use thereof, and can be used for all types of studies and investigations with the use of ES cells and for the treatment of diseases using ES cells, in place of ES cells. For example, by treating an induced pluripotent stem cell obtained from a somatic cell collected from a patient by the method of the present invention with retinoic acid, a growth factor such as EGF, or glucocorticoid and the like, desired differentiated cells (e.g., nerve cells, myocardial cells, blood cells and the like) can be induced to form an appropriate tissue. By returning the differentiated cell or tissue thus obtained to the patient, stem cell therapy by autologous cell transplantation can be accomplished. It should be noted that the use of an induced pluripotent stem cell of the present invention is not limited to the above-described particular embodiment.

{0062}

The present invention also provides a non-viral expression vector for use in the above-described method of producing an induced pluripotent stem cell, i.e., a non-viral

expression vector (preferably a plasmid vector) incorporating at least one gene that encodes a reprogramming factor. The structure of the vector is as described in detail in the section of a method of producing an induced pluripotent stem cell of the present invention.

An example is a non-viral expression vector incorporating an Oct family gene, a Klf family gene, and a Sox family gene, preferably incorporated in this order in the orientation from the 5′ to 3′ end. A more preferable example is a non-viral expression vector incorporating these genes with an intervening sequence enabling polycistronic expression, particularly preferably a non-viral expression vector wherein OCT3/4, Klf4 and Sox 2 are incorporated with an intervening sequence enabling polycistronic expression, preferably FMDV 2A-self-processing sequence, in this order in the orientation from the 5′ to 3′ end.

{0063}

Since a non-viral expression vector such as plasmid vector introduced into a somatic cell is typically not integrated into the genome of the cell, in a preferred embodiment, the present invention provides an induced pluripotent stem cell wherein transgenes are not integrated into the genome. Since such iPS cell reduces a risk causing tumorigenesis in tissues or organs differentiated therefrom and/or disturbance (e.g., disruption or activation) of an endogenous gene, it can preferably be used for regenerative medicine such as cell transplantation therapy.

{0064}

However, under selection pressure for iPS cell induction, increased integration efficiency of non-viral expression vector can be observed due to the necessity of stable expression of reprogramming factors. Therefore, in another preferred embodiment, the present invention provides an induced pluripotent stem cell wherein transgenes are integrated into the genome in the form of plasmid. Such iPS cell can reduce a

risk causing tumorigenesis in tissues or organs differentiated therefrom as compared to an iPS cell induced by retroviral infection. In addition, the transgenes can be excised from the genome as necessary using a Cre/loxP system (Chang et al., 2009 (supra)) or a piggyback transposon vector and piggyback transposon (Kaji et al., 2009 (supra); Woltjen et al., 2009 (supra)) or tetracycline dependent gene induction. A Cre recombinase or transposase for the excision can be introduced into and expressed in the iPS cell using a plasmid vector or adenoviral vector. In the case of using tetracycline dependent gene induction, Tet-repressor protein or mutated Tet-repressor protein is concomitantly expressed.

{Examples}

{0065}

The present invention is hereinafter described in more detail by means of the following Examples, which, however, are not to be construed as limiting the scope of the invention.

{Example 1}

{0066}

Mice having a Nanog reporter were used as an experimental system (Okita et al. Nature, Vol.448, pp.313-317, 2007). These mice were prepared by incorporating EGFP and a puromycin resistance gene into the Nanog gene locus of a BAC (bacterial artificial chromosome) purchased from BACPAC Resources. The mouse Nanog gene is expressed specifically in pluripotent cells such as ES cells and early embryos. Mouse iPS cells positive for this reporter have been shown to possess a differentiation potential nearly equivalent to that of ES cells. These Nanog reporter mice were mated with Fbx15 reporter mice (Tokuzawa et al. Mol Cell Biol, Vol.23, 2699-2708 (2003)), whereby mutant mice having both the Nanog reporter and the Fbx15 reporter were generated.

{0067}

The plasmid used for reprogramming was prepared by treating pCX-EGFP (a plasmid supplied by Dr. Masaru Okabe at

Osaka University: FEBS Letters, 407, 313-319, 1997) with EcoRI, and inserting a construct wherein the coding regions of Oct3/4, Sox2, and Klf4 (all mouse-derived genes) are ligated via the 2A sequence of foot-and-mouth disease virus in the order of Oct3/4, Klf4, and Sox2, in place of EGFP (pCX-2A-mOKS; FIG. 2). Likewise, a plasmid with the coding region of c-Myc inserted thereinto was prepared (pCX-c-Myc; FIG. 2).

{0068}

In preparing the construct of the 2A sequence and Oct3/4, Klf4, and Sox2 ligated together, first, sense and antisense oligonucleotides comprising the 2A sequence of foot-and-mouth disease virus (SEQ ID NO:61), upstream restriction endonuclease sites (XbaI and BglII), and downstream restriction endonuclease sites (BspHI, MfeI and PstI), were annealed and inserted into pBluescript II KS (-) vector digested with the XbaI and PstI (pBS-2A). Subsequently, a mouse cDNA that encodes Oct3/4 or Klf4 was amplified by PCR, the translation termination codon was replaced with a BamHI site, and each cDNA was cloned into pCR2.1. Subsequently, the cDNAs of Oct3/4 and Klf4 were ligated with pBS-2A using an appropriate restriction endonuclease to yield pBS-Oct3/4-2A and pBS-Klf4-2A. Subsequently, Klf4-2A was inserted into pBS-Oct3/4-2A in frame using an appropriate restriction endonuclease, whereby pBS-Oct3/4-2A-Klf4-2A was produced. Subsequently, the resulting Oct3/4-2A-Klf4-2A construct was ligated with a cDNA of Sox2 having a translation termination codon in frame, using an appropriate restriction endonuclease. Finally, the resulting Oct3/4-2A-Klf4-2A-Sox2-STOP construct, wherein the 2A sequences and Oct3/4, Klf4, and Sox2 were ligated together, was inserted into the EcoRI site of pCX-EGFP, whereby pCX-2A-mOKS was prepared.

{0069}

Fibroblasts (MEF) were isolated from the aforementioned mutant mouse fetus (13.5 days after fertilization). Not expressing the Nanog gene, MEF does not express EGFP producing

green fluorescence. As such, the MEFs were sown to a 6-well culture plate (Falcon), previously coated with 0.1% gelatin (Sigma), at 1.3 x 10^5 cells per well. The culture medium used being DMEM/10% FCS (DMEM (Nacalai Tesque) supplemented with 10% fetal calf serum), the MEFs were cultured at 37°C, 5%CO_2. The following day, 4.5 μL of the FuGene6 transfection reagent (Roche) was added in 100 μL of Opti-MEM I Reduced-Serum Medium (Invitrogen), and the medium was allowed to stand at room temperature for 5 minutes. Thereafter, 1.5 μg of an expression vector (pCX-2A-mOKS) was added, and the medium was allowed to stand at room temperature for 15 minutes, after which the medium was added to a MEF culture medium. The following day, the medium was removed, and 1.5 μg of another expression vector (pCX-c-Myc) was introduced with the FuGene6 transfection reagent as described above.

{0070}

The following day, the culture medium was replaced with a fresh supply (DMEM/10% FCS) and an expression vector (pCX-2A-mOKS) was introduced as described above; the day after, the culture medium was replaced with an ES cell culture medium (DMEM (Nacalai Tesque) supplemented with 15% fetal calf serum, 2 mM L-glutamine (Invitrogen), 100 μM non-essential amino acids (Invitrogen), 100 μM 2-mercaptoethanol (Invitrogen), 50 U/mL penicillin (Invitrogen) and 50 mg/mL streptomycin (Invitrogen)), and an expression vector (pCX-c-Myc) was introduced using the FuGene6 transfection reagent as described above.

{0071}

The following day, the medium was replaced with an ES cell culture medium. On day 9 after sowing, the MEF culture medium was removed, and the cells were washed by the addition of PBS 2 mL. After the PBS was removed, 0.25% Trypsin/1 mM EDTA (Invitrogen) was added, and the reaction was carried out at 37°C for about 5 minutes. After cells rose, an ES cell culture medium was added, the cells were suspended, and 1x10^6(Exp432A) or 2x10^5(Exp432B) cells were sown onto a 100 mm

dish with feeder cells sown thereto previously. The feeder cells used were SNL cells that had been treated with mitomycin C to terminate their cell division.

{0072}

Subsequently, the ES cell culture medium was replaced with a fresh supply every two days until a visible colony emerged; colonization began around day 17, and complete colonization was observed around day 24 (FIG.1). The time schedule above is summarized in Exp432 in FIGS. 1 and 3.

{0073}

The cells obtained became GFP-positive gradually, exhibited a morphology indistinguishable from that of mouse ES cells (432A-1 in FIG. 4), tested positive for various ES cell markers at similar levels as with ES cells (iPS-432A-1 in FIG. 5), and produced adult chimeric mice. Based on the colony shape characteristic of mouse iPS cells and GFP-positive results and results positive for other non-differentiation markers, it was concluded that by introducing the above-described expression vector into MEF cells, nuclear reprogramming was completely advanced to produce an iPS cell, and the iPS cell proliferated and formed the visible colony. Hence, these results showed that an iPS cell could be prepared without using a retrovirus or a lentivirus. PCR analysis detected the integration of the above-described expression vector into the host genome (iPS-432A-1 in FIG. 6).

{Example 2}

{0073}

To avoid the integration of pCX-2A-mOKS and pCX-c-Myc into the host genome, the transfection protocol was modified.

On days 1, 3, 5, and 7 after the start of the experiment, pCX-2A-mOKS and pCX-c-Myc were transfected together (Exp440 in FIG. 3). As a result, many GFP-positive colonies were obtained, and cells morphologically indistinguishable from ES cells were produced (440A-3 in FIG. 4). The cells obtained expressed the ES cell markers at the same level as with ES cells (iPS-440A in

FIG. 5). To examine for the integration of the plasmid DNA into the genome, 16 sets of PCR primers capable of amplifying each portion of the plasmid were designed (FIGS 2, 13 and 14). In 9 of the 11 GFP-positive clones obtained by the modified protocol, no amplification of an exogenous DNA was observed (FIG. 6). Furthermore, in Southern blot analysis, no integration of an exogenous gene was detected in these clones (FIG. 11). Although the possible presence of a small plasmid fragment cannot be ruled out definitely, the above results showed that these iPS cells did not have the pCX-2A-mOKS and pCX-c-Myc plasmids integrated into the host genome.

{0074}

To rule out the possibility that the iPS cells without integration are derived from possibly contaminating Nanog-GFP ES cells, SSLP analysis was performed. In Exp440 in FIG. 3, MEF cells from five fetuses were used. In the SSLP analysis, these five fetuses were distinguishable, and the derivations of the iPS cells without integration were identified (FIG. 12). This analysis also showed that the iPS cells without integration differed from the ES cells derived from the 129S4 strain (FIG. 12).

{Example 3}

{0075}

To confirm the pluripotency of iPS cells without integration, iPS cells obtained as described in Example 2 were subcutaneously transplanted to nude mice. All clones tested (440A-3, -4, -8 and -10) produced tumors, which included a broad range of cell types, including cells derived from all the three germ layers (FIG. 7). Furthermore, iPS cells without integration were injected into ICR mouse blastocysts. Judging from the coat colors, adult chimeras were obtained from all clones injected (440A-3, -4, -6, -8, -9 and -10) (FIG. 8). In these chimeric mice, PCR analysis did not detect the integration of any of the transgenes (FIG. 9). The PCR analysis detected both the Nanog and Fbx15 reporters in the

chimeras (FIG. 9). Combined with the fact that iPS cells without integration emerged from the double reporter mice, and that the inventor's laboratory does not keep double reporter ES cells, these results showed that the chimeras were derived from iPS cells without integration, rather than from contaminating ES cells. Hence, these results confirmed that the iPS cells without integration possessed pluripotency.

Long-term examination of 71 chimeric mice obtained and offspring thereof showed that in the chimeric mice derived from an iPS cell prepared by introducing 4 genes (Oct3/4, Klf4, Sox2, c-Myc) using a retrovirus, and offspring thereof, compared with normal mice, the mortality rate began to rise earlier, whereas the chimeric mice derived from an iPS cell without integration of the 4 genes and offspring thereof exhibited a survival curve similar to that of normal mice.

When chimeric mice obtained and wild mice were mated, F1 mice were obtained; therefore, it was confirmed that iPS cells without integration contributed to the germline (germline-transmission).

{Example 4}

{0076}

Human dental pulp stem cells (clone name; DP31, PCT/JP2008/068320, J.Dent.Res., 87(7):676-681 (2008)) were used as an experimental system. The DP31 was allowed to express the mouse ecotropic virus receptor Slc7a1 gene using a lentivirus as described in Cell, 131, 861-872 (2007). These cells were cultured using the MSCGM bullet kit (Lonza).

The plasmids used for reprogramming were prepared from pCX-EGFP (supplied by Dr. Masaru Okabe at Osaka University, FEBS Letters, 407, 313-319, 1997) in the same manner as Example 1. Specifically, the pCX-EGFP was treated with EcoRI, and a construct with the coding regions of SOX2 and KLF4 ligated via the 2A sequence of foot-and-mouth disease virus therein was inserted in place of EGFP, whereby the plasmid pCX-hSK was prepared. Likewise, a plasmid with c-Myc, Lin28, and Nanog

ligated via the 2A sequence (pCX-hMLN) therein, a plasmid with the OCT3/4 coding region inserted therein (pCX-hOCT3/4), and a plasmid with the SV40 Large T antigen inserted therein (pCX-SV40LT) were prepared.

{0077}

The DP31 cultured in a 100 mm dish was washed with PBS, 0.25% Trypsin/1 mM EDTA (Invitrogen) was added, and the reaction was carried out at 37°C for about 5 minutes. After cells rose, MSCGM was added, the cells were suspended, and $6x10^5$ cells were recovered in a 15 mL tube. The cells were centrifuged at 800 rpm for 5 minutes; after the supernatant was removed, and the expression plasmids were introduced using the Human Dermal Fibroblast Nucleofector Kit (Amaxa). The amounts of plasmids used were 0.5 μg for pCX-hOCT3/4, 1.0 μg for pCX-hSK, 1.5 μg for pCX-hMLN, and 0.5 μg for pCX-SV40LT. After the treatment, the cells were sown to a 6-well plate. After being cultured with MSCGM for 10 days, the cells were again washed with PBS, 0.25% Trypsin/1 mM EDTA (Invitrogen) was added, and the reaction was carried out at 37°C for about 5 minutes. After cells rose, MSCGM was added, the cells were suspended, and $1x10^6$ cells were sown onto a 100 mm dish with feeder cells sown thereto previously. The feeder cells used were SNL cells that had been treated with mitomycin C to terminate their cell division. Thereafter, until a colony began to be observed, the medium was replaced with a fresh supply every two days. The medium used was prepared by mixing equal volumes of a primate ES cell culture medium (ReproCELL) supplemented with MSCGM and bFGF (4 ng/mL), respectively. Colonization began around day 19, confirming the establishment of human iPS cell (FIG. 15).

{0078}

Next, fetal human HDF (Cell applications, INC) was transfected with the same seven kinds of genes as described above. After the transfection, the cells were cultured using a primate ES cell culture medium (ReproCELL) supplemented with 4 ng/ml recombinant human bFGF (WAKO). MSTO cells served as

feeder cells. Photographs of cells on day 31 after transfection (5 clones: 203A-1 to 203A-5, of which 203A-4 was picked up as a negative control) are shown in FIG. 16, and photographs of cells in the 2nd subculture are shown in FIG. 17. The 203A-1 to 203A-3 and 203A-5 clones exhibited a typical ES cell-like morphology, confirming the establishment of human iPS cells.

These cells were subjected to genomic-PCR analysis, and examined for the integration of the transgenes into the genome. The results are shown in FIG. 18. In all clones, the integration of Oct3/4 (pCX-hOCT3/4) and c-Myc (pCX-hMLN) was detected. The integration of Klf4 (pCX-hSK) was detected in the clones other than 203A-4. The integration of SV40LT (pCX-SV40LT) was not detected in any of the clones.

{Example 5}

{0079}

Dental pulp stem cells DP31, used in Example 4, were transfected with six kinds of genes, excluding the SV40 Large T antigen (pCX-hSK, pCX-hMLN, pCX-hOCT3/4), in the same manner as Example 4. Photographs of cells on day 35 after the transfection (5 clones: 217A-1 to -4 and -6) are shown in FIG. 19. Photographs of cells in the 2nd subculture are shown in FIG. 20. All clones exhibited a typical ES cell-like morphology, confirming the establishment of human iPS cells.

These human iPS cell clones established (217A-1 to 217A-4, 217A-6) were subjected to genomic-PCR analysis. The results are shown in FIG. 21. In all these clones, the integration of the transgenes was demonstrated.

{Example 6}

{0080}

An HDF cell line derived from a 6-year-old Japanese female (HDF-120; JCRB) was allowed to express the Slc7a1 gene. The resulting cells (HDF-120-Slc) were transfected with the aforementioned six kinds of genes and an shRNA against p53 (shRNA2: SEQ ID NO:62) (vectors introduced: pCX-hOCT3/4, pCX-

hSK, pCX-hMLN-shp53).

Each of pCX-hOCT3/4 (0.5 μg), pCX-hSK (1.0 μg), and pCX-hMLN-shp53 (1.5 μg) was electrically introduced into 6.0 $x10^5$ cells of HDF-120-Slc using Microporator (100 μL tip, 1600 V, 10 ms, 3 times). Ten days later, each vector was once again electrically introduced under the same conditions, and the cells were sown onto MSTO (100 mm dish). These cells were cultured using DMEM/10% FCS until day 10, thereafter using a primate ES cell culture medium (ReproCELL) supplemented with 4 ng/ml recombinant human bFGF (WAKO). Photographs of cells on day 35 after the first electroporation are shown in FIG. 22. Photographs of cells after passage culture are shown in FIG. 23. A typical ES cell-like morphology was exhibited, confirming the establishment of human iPS cells. Genomic-PCR analysis demonstrated the integration of the transgenes (lane 279A-2 in FIG. 24).

{Example 7}

{0081}

Expression vectors separately incorporating the four kinds of genes Oct3/4, Klf4, Sox2 and c-Myc (pCX-Oct4, pCX-Sox2, pCX-Klf4, pCX-c-Myc) were introduced into MEF cells derived from a Nanog reporter mouse (Okita et al. Nature, Vol.448, pp.313-317, 2007) per the protocol in Example 2.

First, the Nanog reporter MEF cells were sown onto a gelatin-coated 6-well plate ($1.3x10^5$ cells/well), and transfected with each of pCX-Oct4 (0.37 μg), pCX-Sox2 (0.36 μg), pCX-Klf4 (0.39 μg), and pCX-c-Myc (0.38 μg) using FuGene6 on days 1, 3, 5, and 7. On day 9, $1x10^6$ cells (1.0) or $0.2x10^6$ cells (0.2) were sown onto MSTO-PH or gelatin (100-mm dish), and colonies were selected on day 25. Photographs of cells after the selection are shown in FIG. 25. A colony shape characteristic of mouse iPS cells and GFP-positive results were obtained, confirming the establishment of mouse iPS cells. The mouse iPS cell clones established (497A-1 to A-5) were subjected to genomic-PCR analysis. The results are shown in

FIG. 26. Both 497A-2 and 497A-5 were shown to be iPS cells without integration of any of the exogenous genes.

{Industrial Applicability}

{0082}

According to the method of the present invention, it is possible to prepare a highly safe induced pluripotent stem cell from, for example, a patient's somatic cell. The cells obtained by differentiating the induced pluripotent stem cell (e.g., myocardial cells, insulin-producing cells, nerve cells and the like) can be safely used for stem cell transplantation therapy for a broad range of diseases, including heart failure, insulin-dependent diabetes, Parkinson's disease and spinal injury.

{0083}

While the present invention has been described with emphasis on preferred embodiments, it is obvious to those skilled in the art that the preferred embodiments can be modified. The present invention intends that the present invention can be embodied by methods other than those described in detail in the present specification. Accordingly, the present invention encompasses all modifications encompassed in the gist and scope of the appended "Claims".

The contents disclosed in any publication cited here, including patents and patent applications, are hereby incorporated in their entireties by reference, to the extent that they have been disclosed herein.

This application is based on U.S. provisional patent application Nos. 61/071,508, 61/136,246, 61/136,615 and 61/193,363, the contents of which are hereby incorporated by reference.

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What is claimed is:

1. A method of producing an induced pluripotent stem cell, comprising the steps of: concurrently introducing two or more plasmids into a mammalian somatic cell in vitro, wherein the two or more plasmids encode the following reprogramming factors: Oct 3/4, Sox 2, Klf4, and a Myc family member selected from the group consisting of c-Myc, N-Myc, L-Myc and T58A mutant of c-Myc, wherein at least one plasmid vector encodes two or more of the reprogramming factors via an intervening sequence enabling polycistronic expression, and culturing the mammalian somatic cell in a medium that supports pluripotent stem cells such that iPS cells are obtained, wherein at least a portion of the one or more plasmids are not integrated into a chromosome of the somatic cell.

2. The method of claim 1, wherein the reprogramming factors further comprise one or more factors selected from the group consisting of Lin28, Lin28B, Nanog, TERT, SV40 Large T antigen, HPV16 E6, HPV16 E7, and Bmi1.

3. The method of claim 1, wherein the genes that encode Klf4 and Sox 2 are incorporated in one plasmid with an intervening sequence enabling polycistronic expression.

4. The method of claim 3, wherein the intervening sequence is a 2A sequence derived from foot-and-mouth disease virus.

5. The method of claim 3, wherein the plasmid comprising the genes that encode Klf4 and Sox 2 further comprise the Oct 3/4 gene.

6. The method of claim 1, wherein the genes that encode Sox 2 and Klf4 are incorporated in a first plasmid vector with an intervening sequence enabling polycistronic expression, and the Myc family gene is incorporated in a second plasmid vector.

7. The method of claim 1, wherein the mammalian somatic cell is a human somatic cell.

8. The method of claim 1, wherein the intervening sequence is a 2A sequence derived from foot-and-mouth disease virus.

9. The method of claim 6, wherein the intervening sequence is a 2A sequence derived from foot-and-mouth disease virus.