

SPECIFICATION

METHOD FOR EVALUATING QUALITY OF HUMAN MESENCHYMAL STEM CELL, AND MONOCLONAL ANTIBODY FOR USE IN SAID METHOD

TECHNICAL FIELD

[0001] The present invention relates to a method for quality evaluation of human mesenchymal stem cells, a method for isolation, selection and culture of human mesenchymal stem cells, a cell population of rapidly proliferating human mesenchymal stem cells, as well as monoclonal antibodies that specifically recognize rapidly proliferating human mesenchymal stem cells.

BACKGROUND ART

[0002] Mesenchymal stem cells (MSCs) are a kind of somatic stem cells which are increasingly used for clinical applications, after hematopoietic stem cells, because they have fewer ethical problems associated with cell collection and have differentiation potency into various types of tissues such as bone, cartilage, fat, etc. Mesenchymal stem cells can be isolated through relatively simple manipulations as described later, and therefore are widely used as materials for biomaterials, for example, by being induced to differentiate into cartilage, bone and others mainly in test tubes and then used for local transplantation.

As a method for isolation and culture of human mesenchymal stem cells, the culture method reported in Non-patent Document 1 is commonly used. However, a cell population obtained by such a conventional method contains many contaminant cells of less quality (which have lost their differentiation, proliferation and migration potency), and these contaminant cells serve as a factor causing further loss of quality because they affect the cells which should have inherently had potential.

Under these conventional circumstances, there has been established a method for isolation and culture of human mesenchymal stem cells, which achieves higher proliferation potency, differentiation potency and migration potency than those in conventional methods (Non-patent Documents 2 and 3 and Patent Document 1). According to these Non-patent Documents 2 and 3 and Patent Document 1, antibodies

against CD271 (LNGFR) and CD90 (Thy1) are used to select LNGFR⁺ Thy1⁺ cells from human bone marrow, placental chorion, fat tissue, peripheral blood, dental pulp and so on, whereby human mesenchymal stem cells can be enriched.

[0003] Moreover, the selected LNGFR⁺ Thy1⁺ cells are subjected to single cell (clone) culture to select a rapidly expanding lot (REC: Rapidly Expanding Clone), whereby human mesenchymal stem cells excellent in proliferation potency, differentiation potency and migration potency can be obtained in high purity.

The high purity human mesenchymal stem cells (RECs) thus obtained were found to have proliferation potency, differentiation potency and migration potency which were all 1000-fold or more higher than those of mesenchymal stem cells obtained by conventional methods.

According to the features of the above method for isolation and culture of human mesenchymal stem cells, single cell culture allows the formation of conditions free from contaminant cells and thus enables expansion culture while maintaining cell quality. In particular, because of retaining migration potency, the resulting cells can be administered via the intravenous route, and therefore can be expected for use in serious systemic diseases such as bone and cartilage hypoplasia.

Prior Art Documents

Patent Documents

[0004] Patent Document 1: JP 2009-60840 A

Non-patent Documents

[0005] Non-patent Document 1: Pittenger, M.F., Mackay, A.M., Beck, S.C., Jaiswal, R.K., Douglas, R., Mosca, J.D., Moorman, M.A., Simonetti, D.W., Craig, S., and Marshak, D.R. (1999). Multilineage potential of adult human mesenchymal stem cells. *Science* 284, 143-147.

Non-patent Document 2: Mabuchi Y, Morikawa S, Harada S, Niibe K, Suzuki S, Renault-Mihara F, Houlihan DD, Akazawa C, Okano H, Matsuzaki Y. (2013). LNGFR+THY-1+VCAM-1hi+ Cells Reveal Functionally Distinct Subpopulations in Mesenchymal Stem Cells. *Stem Cell Reports* 1, 152-165.

Non-patent Document 3: CGH array data, Gene Expression Omnibus (GEO) (accession number: GSE34484)

SUMMARY OF THE INVENTION

PROBLEM TO BE SOLVED BY THE INVENTION

[0006] Unlike immortalized cell lines, even RECs cannot avoid the loss of cell quality when repeatedly subcultured over a long period of time. However, at present, there is no accurate indicator for the loss of quality.

[0007] The present invention aims to provide a method for quality evaluation of human mesenchymal stem cells, a method for isolation, selection and culture of human mesenchymal stem cells, a cell population of rapidly proliferating human mesenchymal stem cells, as well as monoclonal antibodies that specifically recognize rapidly proliferating human mesenchymal stem cells.

[0008] In addition, gene expression analysis was performed between RECs and the other clones of less quality (MEC: Moderately Expanding Clone, SEC: Slowly Expanding Clone) to thereby select REC-specific genes. The present invention further aims to prepare novel monoclonal antibodies that recognize proteins expressed from the specific genes.

MEANS TO SOLVE THE PROBLEM

[0009] To achieve the above aim, the method for quality evaluation of human mesenchymal stem cells according to the present invention is characterized in that from a cell population containing human mesenchymal stem cells, rapidly proliferating human mesenchymal stem cells are isolated, selected and cultured, and cells expressing Ror2 or Fzd5 (or the abundance ratio thereof) in the cell population thus isolated, selected and cultured are quantified to determine whether or not each cell population is acceptable. According to this constitution, Ror2 or Fzd5 when expressed alone allows determination of whether or not a cell population is composed of RECs, and the determination can be made in a simpler manner because cultured cells may also be used for this purpose. It should be noted that LNGFR is not expressed in cultured cells even when they are RECs, and Thy1 when expressed alone does not allow determination of whether or not a cell population is composed of RECs.

[0010] In the above constitution, cells expressing Ror2 or Fzd5 may be quantified by using anti-Ror2 monoclonal antibody or anti-Fzd5 monoclonal antibody. In this case, mRNA expression of Ror2 may be quantified by quantitative PCR, or alternatively, cells

expressing Ror2 or Fzd5 may be quantified by immunostaining. However, it should be noted that Ror2 is expressed extracellularly and hence analyzed by flow cytometry (hereinafter referred to as “FCM”) is easily applicable for the above purpose, whereas Fzd5 is expressed intracellularly and visual evaluation such as immunostaining is therefore suitable for the above purpose.

[0011] On the other hand, to achieve the above aim, the method for isolation, selection and culture of human mesenchymal stem cells is characterized in that from a cell population containing human mesenchymal stem cells, rapidly proliferating human mesenchymal stem cells are isolated, selected and cultured, and cells expressing Ror2 or Fzd5 (or the abundance ratio thereof) in the cell population thus isolated, selected and cultured are quantified to determine whether or not each cell population is acceptable, thus selecting only the cell population(s) determined to be acceptable.

[0012] In this constitution, cells expressing Ror2 or Fzd5 may be quantified by using anti-Ror2 monoclonal antibody or anti-Fzd5 monoclonal antibody. In this case, cells expressing mRNA of Ror2 may be quantified by quantitative PCR, or alternatively, cells expressing Ror2 or Fzd5 may be quantified by immunostaining.

[0013] Moreover, the above step where rapidly proliferating human mesenchymal stem cells are isolated, selected and cultured may comprise a step where the cell population containing human mesenchymal stem cells is analyzed by FCM for cells stained simultaneously with anti-LNGFR monoclonal antibody and anti-Thy1 monoclonal antibody to thereby effect cell sorting of LNGFR⁺ Thy1⁺ cells. Without being limited to this embodiment, the above step where rapidly proliferating human mesenchymal stem cells are isolated, selected and cultured may alternatively comprise a step where the cell population containing human mesenchymal stem cells is analyzed by FCM for cells stained with anti-Ror2 monoclonal antibody to thereby effect cell sorting of Ror2⁺ cells.

[0014] Further, the above methods may each comprise a step where the above cell population is directly prepared from cells derived from each tissue, including bone marrow. On the other hand, the method comprising the step of effecting cell sorting of Ror2⁺ cells may comprise a step where the above cell population is prepared by adherent culture of cells derived from each tissue, including bone marrow. This is because cultured cells of RECs are not positive for LNGFR but are positive for Ror2.

[0015] In the above methods, the above cell sorting step may comprise a step where the positive cells are seeded in wells of a culture plate and the cells in each well

reaching confluence upon culture are then isolated and selected.

[0016] To achieve the above aim, the cell population of rapidly proliferating human mesenchymal stem cells is characterized in that from a cell population containing human mesenchymal stem cells, rapidly proliferating human mesenchymal stem cells are isolated, selected and cultured, and cells expressing Ror2 or Fzd5 (or the abundance ratio thereof) in the cell population thus isolated, selected and cultured are quantified to determine whether or not each cell population is acceptable, thus selecting only the cell population(s) determined to be acceptable.

[0017] In this characteristic, the cell population containing human mesenchymal stem cells may be analyzed by FCM for cells stained simultaneously with anti-LNGFR monoclonal antibody and anti-Thy1 monoclonal antibody to thereby effect cell sorting of LNGFR⁺ Thy1⁺ cells, and these dual positive cells may be seeded in wells of a culture plate and the cells in each well reaching confluence upon culture may be isolated and selected, prior to the above quantification.

[0018] Alternatively, in this characteristic, the cell population containing human mesenchymal stem cells may be analyzed by FCM for cells stained with anti-Ror2 monoclonal antibody to thereby effect cell sorting of Ror2⁺ cells, and these positive cells may be seeded in wells of a culture plate and the cells in each well reaching confluence upon culture may be isolated and selected, prior to the above quantification.

[0019] To achieve the above aim of the present invention, a novel monoclonal antibody according to the present invention is anti-Ror2 monoclonal antibody whose clone name is 7C9. In addition, another novel monoclonal antibody according to the present invention is anti-Fzd5 monoclonal antibody whose clone name is 6F5.

EFFECTS OF THE INVENTION

[0020] Proteins encoded by the identified two genes (Fzd5 and Ror2: their details will be described later) are expressed specifically in RECs, and their expression is not observed in cell populations of less quality. Moreover, these genes are essential for maintaining the undifferentiated state of RECs, and they serve as effective indicators which are closely related to cell functions and ensure cell performance, but not serve as mere biomarkers, in light of the following results: 1) inhibition of their expression incudes loss of cell performance; and 2) forced expression of these genes allows prolonged undifferentiated state, etc.

[0021] As described above, the present invention enables the provision of a method for quality evaluation of human mesenchymal stem cells, a method for isolation, selection and culture of human mesenchymal stem cells, a cell population of rapidly proliferating human mesenchymal stem cells, as well as monoclonal antibodies that specifically recognize rapidly proliferating human mesenchymal stem cells.

[0022] Other aims, constitutions and effects of the present invention will become apparent from the embodiments of the invention shown below.

BRIEF DESCRIPTION OF THE DRAWINGS

[0023] Figure 1 shows the steps of selection, isolation, culture and quality evaluation of high quality mesenchymal stem cells (RECs).

Figure 2 shows the results compared for various parameters among RECs, MECs and SECs.

Figure 3 shows figures and graphs which indicate that Ror2 and Fzd5 are expressed specifically in RECs.

Figure 4 shows figures and graphs which indicate that inhibition of Fzd5 induces loss of cell properties in RECs.

Figure 5 shows photographs and graphs which indicate that forced expression of Fzd5 includes the undifferentiated nature of RECs.

Figure 6 shows photographs and graphs which indicate the stainability of newly prepared anti-Fzd5 monoclonal antibody.

Figure 7 shows photographs and figures which indicate the stainability of newly prepared anti-Ror2 monoclonal antibody.

Figure 8 shows a schematic diagram for quality evaluation of cultured MSCs using REC-specific antibody.

DESCRIPTION OF EMBODIMENTS

[0024] While referring to the drawings, the steps of selection, isolation and culture of RECs will be outlined below, followed by explanations about the purpose and details of each step. In the present invention, RECs are selected, isolated and cultured in Step 1, and the cultured RECs are evaluated in Step 2. Some exemplary combinations of these steps are listed in Table 1. All combinations except for those expressed as “Unable” in

the column “Process evaluation” are able to be implemented. First, the combinations under Process Nos. P1 and P2 will be described below.

[0025] [Table 1]

Process No.	Step 1					Step 2		Comment
	Cell source	FCM	Sorting	Culture	Well treatment	Cell evaluation	Process evaluation	
P1	Tissue (e.g., bone marrow)	LNGFR ⁺ Thy1 ⁺	Single	Culture for 2 weeks	Selection of confluent wells	Ror2 ⁺	Very good	Evaluation is possible while ensuring cell performance
P2	Tissue (e.g., bone marrow)	LNGFR ⁺ Thy1 ⁺	Single	Culture for 2 weeks	Selection of confluent wells	Fzd5 ⁺	Good	Fzd5 is expressed intracellularly and hence difficult to determine by FCM, but can be evaluated by immunostaining or the like while ensuring cell functions
P3	Tissue (e.g., bone marrow)	LNGFR ⁺ Thy1 ⁺	Single	Culture for 2 weeks	Selection of confluent wells	Thy1 ⁺	Unable	THY1 is also expressed in MECs and SECs and hence cannot be used for evaluation
P4	Tissue (e.g., bone marrow)	LNGFR ⁺ Thy1 ⁺	Single	Culture for 2 weeks	Selection of confluent wells	LNGFR ⁺	Unable	LNGFR is not expressed in cultured cells
P5	Tissue (e.g., bone marrow)	LNGFR ⁺ Thy1 ⁺	Multiple	Culture for 2 weeks	Selection of confluent wells	Ror2 ⁺	Less good	The proportion of cells other than RECs can be quantified, but purity is low
P6	Tissue (e.g., bone marrow)	Ror2 ⁺	Single	Culture for 2 weeks	Selection of confluent wells	Ror2 ⁺	Good	Sorting using Ror2 as an indicator results in a lower enrichment rate when compared to the LNGFR ⁺ Thy1 ⁺ case
P7	Tissue (e.g., bone marrow)	Ror2 ⁺	Single	Culture for 2 weeks	Selection of confluent wells	Fzd5 ⁺	Good	Fzd5 is expressed intracellularly and hence difficult to determine by FCM, but can be evaluated by immunostaining or the like while ensuring cell functions
P8	Tissue (e.g., bone marrow)	Fzd5 ⁺	Single	Culture for 2 weeks	Selection of confluent wells	Ror2 ⁺	Unable	Fzd5 is expressed intracellularly and hence difficult to detect by FCM, and is therefore difficult to use as a marker for cell isolation
P9	Tissue (e.g., bone marrow)	Ror2 ⁺	Multiple	Culture for 2 weeks	Selection of confluent wells	Ror2 ⁺	Less good	The proportion of cells other than RECs can be quantified, but purity is low
P10	Adherent cultured cells	LNGFR ⁺ Thy1 ⁺	Single	Culture for 2 weeks	Selection of confluent wells	Ror2 ⁺	Unable	LNGFR is not expressed in cultured cells, while THY1 is also expressed in cells other than RECs
P11	Adherent cultured cells	Ror2 ⁺	Single	Culture for 2 weeks	Selection of confluent wells	Ror2 ⁺	Good	Evaluation is possible while ensuring cell performance
P12	Adherent cultured cells	Ror2 ⁺	Single	Culture for 2 weeks	Selection of confluent wells	Fzd5 ⁺	Good	Fzd5 is expressed intracellularly and hence difficult to determine by FCM, but can be evaluated by immunostaining or the like while ensuring cell functions
P13	Adherent cultured cells	Fzd5 ⁺	Single	Culture for 2 weeks	Selection of confluent wells	Ror2 ⁺	Unable	Fzd5 is expressed intracellularly and hence difficult to detect by FCM, and is therefore difficult to use as a marker for cell isolation
P14	Adherent cultured cells	Ror2 ⁺	Multiple	Culture for 2 weeks	Selection of confluent wells	Ror2 ⁺	Less good	The proportion of cells other than RECs can be quantified, but purity is low
P15	Adherent cultured cells	Ror2 ⁺	Single	-	-	-	Good	Used without cell evaluation

[0026] [Step 1] Figure 1 illustrates the step of REC isolation by the single clone culture method.

1) Mononuclear cells are prepared from human bone marrow (or fat or placental chorion) and these bone marrow mononuclear cells are stained with anti-LNGFR and anti-Thy1 (LNGFR⁺ Thy1⁺ cells are referred to as LT cells).

2) Flow cytometry (FCM, cell sorter) is used to effect clone sorting of LNGFR⁺ Thy1⁺ cells in a 96-well culture plate (i.e., one cell is seeded per well; expressed as “Single” in Table 1).

It should be noted that anti-CD106 monoclonal antibody may be added to effect clone sorting of LNGFR⁺ Thy1⁺ cells that are also strongly positive for CD106.

3) After single cell culture for 2 weeks, the culture plate was observed under a microscope to select wells reaching confluence, and the cells contained in each of these wells are determined to be RECs (Rapidly Expanding Cells). Wells showing delayed cell expansion, i.e., MECs/SECs (Moderately/Slowly Expanding Cells) are discarded.

4) The cells contained in the wells selected as RECs are collected separately on a well-by-well basis. RECs collected from one well are defined as one lot.

[0027] [Step 2] Figure 1 further shows the evaluation of cultured cells using REC markers (anti-Ror2 and anti-Fzd5).

1) The RECs collected from the 96-well plate are transferred to culture dishes or culture flasks on a well-by-well basis, and cultured to reach confluence (expansion culture).

2) After expansion culture, the cells grown in adherent state are collected from all lots, and an aliquot (about 1 to 3 × 10³ cells) of each lot is sampled and single-stained with a monoclonal antibody against each REC marker (anti-Ror2 or anti-Fzd5).

3) REC marker-positive cells are analyzed by flow cytometry to determine the ratio of the REC marker-positive cells in the collected cells (mRNA expression of Ror2 may be quantified by quantitative PCR, or alternatively, this ratio may be determined manually under a microscope).

4) If the above positive ratio is equal to or greater than a given value (e.g., 65%), such a lot (cell population) is determined to be acceptable.

5) Cells in the acceptable lots are filled into freezing vials and stored in liquid nitrogen.

6) These frozen cells are defined as high quality human mesenchymal stem cells (product).

7) After the cells in each vial are thawed and then expanded on a culture dish or flask, a user is finally able to use at least 1×10^{10} high purity mesenchymal stem cells in a stable manner.

[0028] In the above steps, clone sorting of LT cells may be replaced with clone sorting of Ror2⁺ cells (P6 and P7 in Table 1). Moreover, LT cells or Ror2⁺ cells may be selected and seeded in groups of two or more per well of a 96-well culture plate (expressed as “Multiple” in Table 1; P5, P9 and P14). In this case, however, the purity is lower than that in clone sorting. It should be noted that the term “confluence” or “confluent” refers to a state where 90% or more of the culture vessel surface is coated with cultured cells. Likewise, the term “semi-confluence” or “semi-confluent” refers to a state where 70% to 80% of the culture vessel surface is coated with cultured cells. The size and type of culture devices to be used may be changed as appropriate depending on the growth rate of cells.

[0029] In the above embodiment, the above cell population is directly prepared from cells derived from each tissue, including bone marrow. However, in the case of sorting for Ror2⁺ cells, the above cell population may be prepared by adherent culture of cells derived from each tissue, including bone marrow (P10 to P15 in Table 1; expressed as “Adherent cultured cells”). In this case, bone marrow mononuclear cells are seeded on a medium supplemented with 10% to 20% serum and bFGF (at 37°C under 1% to 5% CO₂) and cultured for about 2 weeks to collect fibroblast-like adherent cells (CFU-F) appearing after culture. The step of preparing a cell population may comprise treatment of bone marrow with collagenase. Alternatively, this step may be designed such that a cell population is prepared from peripheral blood after G-CSF administration.

[0030] It should be noted that the evaluation prior to shipment (Step 2-2) and Step 2-3)) is not always necessary, and adherent cultured cells may be used and subjected to FCM sorting to isolate Ror2⁺ cells, optionally followed by expansion culture, and the thus obtained cells may be provided for treatment in Step 2-5) and the subsequent steps prior to shipment, as in Process P15 in Table 1.

[0031] While referring to Figure 2, a comparison will now be made of cell performance between RECs and MECs/SECs. Figure 2 shows the results obtained

when RECs, MECs and SECs were compared for their cell performance using various parameter data.

Figure 2A shows the results obtained when human bone marrow mononuclear cells were stained with antibodies against LNGFR and Thy1, followed by FCM analysis. The area within the ellipse represents LT cells.

Figure 2B is a schematic diagram for single cell isolation (clone sorting) of LT cells in a 96-well plate.

Figure 2C is a graph showing the results measured for cell counts after single cell culture at fixed time intervals. RECs show a higher proliferation rate than MECs/SECs, and their count reaches 0.5 to 1×10^4 within about 2 weeks. A cell count of 0.5 to 1×10^4 is required to establish confluence in a well of a 96-well plate.

Figure 2D shows the results obtained when RECs, MECs and SECs were induced to differentiate into bone and fat, followed by quantitative PCR to analyze gene expression specific to bone and fat cells. RECs were found to be particularly high in differentiation potency into fat cells when compared to MECs and SECs.

Figure 2E is a graph showing the results obtained when RECs, MECs and SECs were seeded again in a 96-well plate by clone sorting and wells showing secondary colony formation were then counted and compared. Secondary colony formation serves as an indicator for self-replication potency which is indicative of the undifferentiated state. About 33% of RECs show secondary colony formation, whereas only a few colonies are formed from MECs/SECs.

Figure 2F shows the results obtained when the following cell populations, each having been transformed with a Luc (luciferase) gene expression vector, i.e., WBMs (MSCs obtained in a standard manner; WBM is an abbreviation for Whole Bone Marrow), RECs and MECs/SECs, as well as non-luciferase-labeled WBMs prepared as a negative control group (Luc(-) Cultured MSCs) were each administered to immunodeficient mice via the intravenous route, followed by intraperitoneal administration of luciferin serving as a substrate for Luc to observe luminescence from luciferase by using an *in vitro* detection system (IVIS) at 24 hours after transplantation. The upper panel shows a graph obtained as follows: Luc luminescence intensity in each mouse was expressed numerically and, relative to the WBM MSC-transplanted group which was set to 100%, the luminescence ratio (%) was plotted for the mice transplanted with the other cells. The lower panel shows images of Luc luminescence in the recipient mice of the respective groups. As can be seen from these results, the

REC-transplanted mice show extremely low luminescence intensity in their lungs, thus indicating that RECs are rarely trapped into capillary vessels in the lungs, whereas MECs/SECs are trapped almost at the same level as WBM (cultured MSCs obtained in a standard manner) and remain in the lungs.

In view of all the above results, RECs are a cell population excellent in proliferation potency, differentiation potency and migration potency, and are particularly advantageous in that they have migration potency comparable to that of MSCs in fresh bone marrow, in terms of being able to be administered systemically against intractable diseases as described later.

[0032] According to the experiments made by the inventors, including those shown above, RECs are characterized by the following, when compared to normal MSCs:

1. being a morphologically very uniform cell population;
2. showing no cellular aging;
3. having a high division rate and being able to be cultured and amplified while retaining the undifferentiated nature;
4. begin a cell population easy to differentiate into bone and fat due to high differentiation potency; and
5. retaining migration potency

RECs are the most undifferentiated cell population among human MSCs, and have the most similar properties to MSCs in bone marrow. Moreover, when compared to MECs/SECs or MSCs obtained in a standard manner, RECs are a fresh and less mutated cell population ensuring cell performance due to their higher differentiation, proliferation and migration potency.

[0033] Next, while referring to Figure 3, an explanation will be made about the identification of undifferentiated MSC (REC)-specific genes Ror2 and Fzd5.

The expression levels of genes expressed in RECs, MECs and SECs were compared by the DNA array method, thus confirming that Fzd5, which is one of the Wnt receptors, and its co-receptor Ror2 were both specific to RECs.

Figure 3A shows a comparison of Ror2 mRNA expression in RECs, MECs and SECs, as measured by quantitative PCR.

Figure 3B shows a comparison of Fzd5 mRNA expression in RECs, MECs and SECs, as measured by quantitative PCR.

Figure 3C shows a comparison of Fzd5 protein expression, as measured by Western blotting.

Figure 3D shows photographs compared for intracellular localization of Fzd5 protein, as observed by immunofluorescent staining.

As a result of evaluation by the above several analysis methods, it can be confirmed that the expression of Fzd5 and Ror2 is specific to RECs. Thus, the respective expression of Fzd5 and Ror2, when detected and quantified, would be effective as an indicator for cell quality evaluation of RECs. Moreover, the newly prepared anti-Fzd5 monoclonal antibody and anti-Ror2 monoclonal antibody are able to detect and quantify their target protein antigens in any technique selected from flow cytometry, Western blotting and immunofluorescent staining.

[0034] Next, while referring to Figure 4, an examination will be made of cellular aging induction by loss of function of Fzd5.

The RNA interference method is a technique to examine the function of a target gene by introduction of short RNA (shRNA) having a sequence complementary to target mRNA into cells to thereby disrupt the target mRNA. Figure 4 shows the results obtained from a series of experiments on cell properties in RECs when Fzd5 mRNA was disrupted by shRNA having a sequence complementary to Fzd5 (shFZD5), in comparison with the control group (shCTRL; shRNA having a random sequence not complementary to Fzd5).

Figure 4A is a graph showing the mRNA level of Fzd5, as quantified by quantitative PCR, after introduction of shFZD5 or shCTRL into RECs. When the mRNA level of Fzd5 in the control group (shCTRL, short hairpin control) was set to 100, the mRNA level of Fzd5 was reduced to about 40% in RECs forced to express shFZD5.

Figure 4B is a graph whose vertical axis plots cell counts in the group forced to express shFZD5 after introduction of shFZD5 or shCTRL into RECs, relative to cell counts in the control group which are set to 1, and whose horizontal axis plots the number of days after shRNA introduction. RECs forced to express shFZD5 showed a sudden reduction in their cell count when compared to the control group, thus suggesting that Fzd5 inhibition would induce a reduction in proliferation potency.

Figure 4C shows images of fat droplets stained with Oil-Red-O at 14 days of culture, after introduction of shFZD5 or shCTRL into RECs and the subsequent induction of their differentiation into fat cells. Fzd5 inhibition was found to induce a reduction in differentiation potency into fat cells, when compared to the control group.

The activity of SA- β -gal serving as an indicator for cellular aging can be

detected by blue staining upon addition of its substrate X-gal. Figure 4D shows images stained by x-gal staining after introduction of shFZD5 or shCTRL into RECs, along with a graph which plots the frequency of cells having SA- β -gal activity in each cell population.

Figure 4E is a graph showing the mRNA level of p16(INK4a) serving as an indicator for cellular aging, as quantified by quantitative PCR. When the control group was set to 100, the mRNA level of p16 in shFZD5-receiving RECs was about 300, thus indicating that inhibition of Fzd5 expression induced cellular aging.

Figure 4F shows images observed for stress fiber formation by intracellular staining with anti-F-actin antibody in each cell population after introduction of shFZD5 or shCTRL into RECs, along with a graph which plots the averaged area (cell size) of individual cells in these respective cell populations.

In view of the above results, inhibition of the Fzd5 function in RECs induces a reduction in proliferation potency, a reduction in differentiation potency, cellular aging, as well as a reduction in migration potency and an increase in cell size due to stress fiber formation, thus resulting in the same properties as in MECs/SECs. This suggests that Fzd5 would be a functional molecule ensuring the maintenance of cell performance in RECs, but is not a mere biomarker.

[0035] Next, while referring to Figure 5, a discussion will be made about the long-term maintenance of proliferation potency by gain of function of Fzd5.

The full-length cDNA of Fzd5 was forced to be expressed in RECs to cause constitutive expression of Fzd5 mRNA, and the effect thereof on cell functions was confirmed. For this purpose, an expression vector is constructed to carry Fzd5 cDNA and a fluorescent protein GFP (Green Fluorescent Protein) in tandem to thereby allow co-expression of GFP in Fzd5 gene-receiving cells, so that the expression of the introduced gene can be confirmed under a fluorescence microscope.

Figure 5A shows photographs observed for morphology of GFP-expressing cells under a fluorescence microscope. These images show cell morphology at 28 days after gene transfer in the cell population transformed with Fzd5 cDNA and GFP (Fzd5) as well as the control group transformed with the GFP gene alone (CTRL).

In the control group, there appear many large-sized multipolar cells which are characteristic of cellular aging, as indicated with the arrows in the figure, whereas almost all of the Fzd5-expressing RECs retain their bipolar morphology with small cytoplasm.

Figure 5B is a graph whose vertical axis plots cell counts of Fzd5-expressing RECs, relative to cell counts in the control group which are set to 1, and whose horizontal axis plots the number of days after gene transfer. RECs forced to express Fzd5 were found to retain their proliferation potency for a long period of time, when compared to the control group.

In view of the above results, Fzd5-mediated stimulation of Wnt signaling would be expected to allow long-term culture amplification in a state maintaining the undifferentiated nature.

[0036] Subsequently, while referring to Figure 6, an explanation will be made about the preparation of a novel monoclonal antibody against human Fzd5.

The extracellular region of a human Fzd5 antigen was used as an immunogen to immunize host mice and hybridomas were then prepared in accordance with standard procedures, followed by screening with Ba/F3 cells engineered to express the Fzd5 gene, thereby obtaining a novel anti-Fzd5 monoclonal antibody (clone name: 6F5).

This antibody was used to confirm whether or not the Fzd5 protein was able to be detected by various techniques.

Ba/F3 cells forced to express the extracellular region of Fzd5 were stained with biotin-labeled 6F5 antibody and then fluorescently labeled with streptavidin (SAV)-PE, followed by flow cytometry analysis. Figure 6A shows a histogram whose horizontal axis plots the fluorescence intensity of PE. The shaded histogram in the figure represents a negative control where an isotype control was added as a primary antibody, while the open histogram represents the PE fluorescence intensity in the sample stained with 6F5. The range indicated with the horizontal bar in the figure represents the range of Fzd5⁺ cells, while the numerical value represents the positive rate (%).

Figure 6B shows the results of Western blotting obtained when intracellular proteins were prepared from three different clones of RECs and the Fzd5 protein was detected using 6F5 as a primary antibody. For use as a negative control, intracellular proteins were prepared from the monkey kidney-derived cell line COS7.

Figure 6C shows images obtained when REC cells were stained with 6F5-biotin as a primary antibody and then fluorescently labeled with streptavidin (SAV)-Alexa 555, followed by observation under a fluorescence microscope. The anti-Fzd5 antibody (6F5) was found to be available for use in all of flow cytometry, Western blotting and immunofluorescent staining.

[0037] Next, while referring to Figure 7, an explanation will be made about the

preparation of a novel monoclonal antibody against a human Ror2 antigen.

A human Ror2 antigen was used as an immunogen to newly prepare an anti-Ror2 antibody (clone name: 7C9).

Figure 7A shows the results obtained when REC cells were stained with 7C9-biotin as a primary antibody and then labeled with SAV-PE, followed by flow cytometry to detect PE fluorescence. A sample prepared by adding an isotype control antibody as a primary antibody is used as a negative control. Figure 7A is a two-dimensional dot plot whose vertical axis plots FITC fluorescence (REC cells are all negative because they are not stained) and whose horizontal axis plots PE fluorescence. Compare to the area that are free from PE fluorescence-emitting cells in the negative control group (i.e., the area within the trapezoid in the figure: 0.011%), a Ror2 expressing cell population was found as a PE fluorescence in the sample stained with clone 7C9 (69.3%).

Figure 7B is an image obtained when REC cells were immunostained with 7C9-biotin as a primary antibody and fluorescently labeled with streptavidin-Alexa 488, and then observed for expression of the Ror2 protein under a fluorescence microscope. Most of these REC cells were confirmed to express the Ror2 protein.

Figure 7C shows the results obtained when fresh bone marrow cells were triple stained with LNGFR-APC, Thy1-FITC and Ror2-PE (monoclonal antibodies against their respective antigens), followed by flow cytometry analysis. The left panel shows a figure whose vertical axis plots LNGFR expression and whose horizontal axis plots Thy1 expression, and the boxed area represents a LNGFR⁺ Thy1⁺ cell population containing human MSCs with high frequency. The right figure shows the LNGFR⁺ Thy1⁺ cell population extracted alone. The horizontal axis plots FSC serving as an indicator for cell size, while the vertical axis plots PE fluorescence from anti-Ror2-biotin antibody (7C9) labeled with SAV-PE. The boxed area represents the Ror2-positive area determined on the basis of the negative control, and the numerical value represents the positive rate (%). In the case of using clone 7C9, 92.3% of LNGFR⁺ Thy1⁺ cells are Ror2-positive; and hence clone 7C9 can be used as a selection marker for MSCs to replace LNGFR Thy1.

Using the newly prepared anti-Ror2 monoclonal antibody, the Ror2 protein can be detected and quantified by flow cytometry and immunofluorescent staining (Figures 7A and 7B).

Furthermore, the newly prepared anti-Ror2 can also be used as a marker for MSCs contained in bone marrow (Figure 7C).

[0038] Next, while referring to Figure 8, an explanation will be made about the procedures for cell quality evaluation using anti-Ror2 antibody or anti-Fzd5 antibody.

Human MSCs cultured in standard adherent culture (or subcultured RECs) are collected and stained with REC-specific monoclonal antibody (anti-Ror2 antibody or anti-Fzd5 antibody).

The frequency (% content) of positive cells is measured by flow cytometry. Alternatively, the frequency (% content) of positive cells may be measured under a fluorescence microscope, instead. These measurements allow quantification of how many RECs are contained in the cell population, which in turn allows evaluation of cell quality, i.e., evaluation of what degree of differentiation, proliferation and migration potency is possessed by the target MSCs. According to the experiments made by the inventors, the Ror2-positive rate of RECs was $72\% \pm 8.9\%$ averaged from five lots. Thus, for example, the lowest value, i.e., at least 63% or at least 65% may be used as a reference value for acceptability determination.

INDUSTRIAL APPLICABILITY

[0039] The present invention enables the provision of a technique for efficient isolation and culture of human mesenchymal stem cells available for use in the treatment of systemic diseases, and also enables quality evaluation on which to determine whether or not the resulting cell population is suitable for transplantation and/or exerts efficacy.

Among newly prepared monoclonal antibodies showing stainability specific to high purity mesenchymal stem cells, candidates suitable for cell isolation can be provided as reagents for isolation of mesenchymal stem cells by being immobilized on magnetic nanoparticles. Moreover, as reagents for cell evaluation to test the quality of the isolated mesenchymal stem cells, fluorescent substance-labeled antibodies or cell staining reagents can be provided for practical use.

Mesenchymal stem cells are not only used as materials for biomaterials, as previously known, but also can be expected to have various applications by taking advantage of their pluripotency, as exemplified by administration to myasthenia gravis, chronic rheumatism and other diseases, as well as co-transplantation as supporting cells to provide a tissue scaffold (niche) for cell therapy required for treatment of severe diseases including spinal cord injury, heart and vascular failure, chronic liver failure and

so on. In particular, the use of RECs retaining their migration potency would be expected to provide a therapeutic effect never seen before when applied to metabolic diseases such as systemic bone and cartilage diseases including hypophosphatasia, for which no therapy has been found, as well as GVHD and all other diseases whose treatment requires administration via the intravenous route.

CLAIMS

1. A method for quality evaluation of human mesenchymal stem cells, which comprises:
 - a step where from a cell population containing human mesenchymal stem cells, rapidly proliferating human mesenchymal stem cells are isolated, selected and cultured; and
 - a step where the abundance ratio of cells expressing Ror2 or Fzd5 in the cell population thus isolated, selected and cultured is quantified to determine whether or not each cell population is acceptable.
2. The method for quality evaluation of human mesenchymal stem cells according to claim 1, wherein the cells expressing Ror2 or Fzd5 are quantified by using anti-Ror2 monoclonal antibody or anti-Fzd5 monoclonal antibody.
3. The method for quality evaluation of human mesenchymal stem cells according to claim 2, wherein the cells expressing mRNA of Ror2 are quantified by quantitative PCR.
4. The method for quality evaluation of human mesenchymal stem cells according to claim 2, wherein the cells expressing Ror2 or Fzd5 are quantified by immunostaining.
5. A method for isolation, selection and culture of human mesenchymal stem cells, which comprises:
 - a step where from a cell population containing human mesenchymal stem cells, rapidly proliferating human mesenchymal stem cells are isolated, selected and cultured; and
 - a step where the abundance ratio of cells expressing Ror2 or Fzd5 in the cell population thus isolated, selected and cultured is quantified to determine whether or not each cell population is acceptable, thus selecting only the cell population(s) determined to be acceptable.
6. The method for isolation, selection and culture of human mesenchymal stem cells according to claim 5, wherein the cells expressing Ror2 or Fzd5 are quantified by

using anti-Ror2 monoclonal antibody or anti-Fzd5 monoclonal antibody.

7. The method for isolation, selection and culture of human mesenchymal stem cells according to claim 6, wherein the cells expressing mRNA of Ror2 are quantified by quantitative PCR.

8. The method for isolation, selection and culture of human mesenchymal stem cells according to claim 6, wherein the cells expressing Ror2 or Fzd5 are quantified by immunostaining.

9. The method for isolation, selection and culture of human mesenchymal stem cells according to claim 5, wherein the step where rapidly proliferating human mesenchymal stem cells are isolated, selected and cultured comprises a step where the cell population containing human mesenchymal stem cells is analyzed by flow cytometry (hereinafter referred to as "FCM") for cells stained simultaneously with anti-LNGFR monoclonal antibody and anti-Thy1 monoclonal antibody to thereby effect cell sorting of LNGFR⁺ Thy1⁺ cells.

10. The method for isolation, selection and culture of human mesenchymal stem cells according to claim 5, wherein the step where rapidly proliferating human mesenchymal stem cells are isolated, selected and cultured comprises a step where the cell population containing human mesenchymal stem cells is analyzed by FCM for cells stained with anti-Ror2 monoclonal antibody to thereby effect cell sorting of Ror2⁺ cells.

11. The method for isolation, selection and culture of human mesenchymal stem cells according to claim 9 or 10, which comprises a step where the cell population is directly prepared from cells derived from bone marrow or other tissues.

12. The method for isolation, selection and culture of human mesenchymal stem cells according to claim 10, which comprises a step where the cell population is prepared by adherent culture of cells derived from bone marrow or other tissues.

13. The method for isolation, selection and culture of human mesenchymal stem cells according to claim 9 or 10, wherein the cell sorting step comprises a step where the

positive cells are seeded in wells of a culture plate and the cells in each well reaching confluence upon culture are then isolated and selected.

14. A cell population of rapidly proliferating human mesenchymal stem cells, which is obtained by:

a step where from a cell population containing human mesenchymal stem cells, rapidly proliferating human mesenchymal stem cells are isolated, selected and cultured; and

a step where the abundance ratio of cells expressing Ror2 or Fzd5 in the cell population thus isolated, selected and cultured is quantified to determine whether or not each cell population is acceptable, thus selecting only the cell population(s) determined to be acceptable.

15. The cell population of rapidly proliferating human mesenchymal stem cells according to claim 14, which is obtained such that the cell population containing human mesenchymal stem cells is analyzed by FCM for cells stained simultaneously with anti-LNGFR monoclonal antibody and anti-Thy1 monoclonal antibody to thereby effect cell sorting of LNGFR⁺ Thy1⁺ cells, and these dual positive cells are seeded in wells of a culture plate and the cells in each well reaching confluence upon culture are isolated and selected, prior to the quantification.

16. The cell population of rapidly proliferating human mesenchymal stem cells according to claim 14, which is obtained such that the cell population containing human mesenchymal stem cells is analyzed by FCM for cells stained with anti-Ror2 monoclonal antibody to thereby effect cell sorting of Ror2⁺ cells, and these positive cells are seeded in wells of a culture plate and the cells in each well reaching confluence upon culture are isolated and selected, prior to the quantification.

17. A monoclonal antibody specifically recognizing rapidly proliferating human mesenchymal stem cells, which is anti-Ror2 monoclonal antibody.

18. The monoclonal antibody specifically recognizing rapidly proliferating human mesenchymal stem cells according to claim 17, whose clone name is 7C9.

19. A monoclonal antibody specifically recognizing rapidly proliferating human mesenchymal stem cells, which is anti-Fzd5 monoclonal antibody.

20. The monoclonal antibody specifically recognizing rapidly proliferating human mesenchymal stem cells according to claim 19, whose clone name is 6F5.