DESCRIPTION

NOVEL METHOD FOR TREATING SPINAL CORD INJURY USING HMGB1 FRAGMENT

Technical Field

The present invention relates to novel therapeutic pharmaceutical compositions for injury of the spinal cord which comprise an HMGB1 fragment, and uses thereof.

Background Art

Bone marrow mesenchymal stem cells are pluripotent *in vivo* stem cells, and they are known to differentiate into osteoblasts, adipocytes, cartilage and such. Recently, it is beginning to be reported that in patients with tissue damage such as cerebral infarction, administration of their own bone marrow mesenchymal stem cells can promote healing of the tissue damage. However, since bone marrow mesenchymal stem cells are scarce cells in the bone marrow, there is a limit to the amount that can be collected from a patient. Therefore, obtaining the amount of bone marrow mesenchymal stem cells necessary for treatment of a wide range of tissue damages is difficult. At present, the method of culturing the bone marrow mesenchymal stem cells for proliferation to secure the number of cells needed for treatment is adopted. However, it is very difficult to culture bone marrow mesenchymal stem cells while maintaining their undifferentiated state. Furthermore, there are many associated problems to be solved, such as viral and bacterial contamination and canceration of cells. Furthermore, the cost for culturing cells that are guaranteed with safety and quality is huge.

On the other hand, bone marrow mesenchymal stem cells have been known to have an effect of facilitating the healing of spinal cord injury as well. This is assumed to arise from differentiation of pluripotent bone marrow mesenchymal stem cells into nerve cells, and supply of components having an effect of improving tissue damage such as growth factors by bone marrow mesenchymal stem cells accumulated at the damaged tissues.

Prior Art Documents

[Patent Documents]

[Patent Document 1] WO2008/053892
[Patent Document 2] WO2007/015546
[Patent Document 3] WO2009/133939
[Patent Document 4] WO2009/133943
[Patent Document 5] WO2009/133940

[Patent Document 6] WO2004/004763

[Non-patent Documents]
[Non-patent Document 1] Bustin *et al.*, Mol Cell Biol, 19: 5237-5246, 1999
[Non-patent Document 2] Hori *et al.*, J. Biol. Chem., 270, 25752-25761, 1995
[Non-patent Document 3] Wang *et al.*, Science, 285: 248-251, 1999
[Non-patent Document 4] Muller *et al.*, EMBO J, 20: 4337-4340, 2001
[Non-patent Document 5] Wang *et al.*, Science, 285: 248-251, 1999
[Non-patent Document 6] Germani *et al.*, J Leukoc Biol., 81(1): 41-5, 2007
[Non-patent Document 7] Palumbo *et al.*, J. Cell Biol., 164: 441-449, 2004
[Non-patent Document 8] Merenmies *et al.*, J. Biol. Chem., 266: 16722-16729, 1991
[Non-patent Document 9] Wu Y *et al.*, Stem cells, 25: 2648-2659, 2007
[Non-patent Document 10] Tamai *et al.*, Proc Natl Acad Sci U S A., 108(16): 6609-6614, 2011
[Non-patent Document 11] Yang *et al.*, J Leukoc Biol., 81(1): 59-66, 2007
[Non-patent Document 12] Basso *et al.*, J Neurotrauma., 23(5): 635-659, 2006
[Non-patent Document 13] Rahimi-Movaghar *et al.*, Int J Neurosci., 118(10): 1359-1373, 2008
[Non-patent Document 14] Quertainmont R *et al.*, PloS One., 7(6):e39500, 2012

Summary of the Invention

[Problems to be Solved by the Invention]

Spinal cord injury is a disease where patients experience extreme loss of quality of life such as difficulty in walking due to paralysis of the lower half of the body. However, spontaneous recovery cannot be expected and effective treatment methods have not been established. As described above, currently, there are expectations in applying regenerative medicine such as cell therapy to treatment of spinal cord injury, but it is still in the process of development. Furthermore, even if it is put to practical use, the problem of large medical expense has not yet been solved.

However, if healing of spinal cord injury can be promoted by administering a pharmaceutical having an activity of mobilizing bone marrow mesenchymal stem cells to the damaged site, it is expected that inexpensive and safe therapeutic methods can be provided to patients with spinal cord injury for which effective methods of treatment hardly exist at present.

[Means for Solving the Problems]

So far, the present inventors have revealed that High Mobility Group Box 1 (HMGB1) is a protein that has an activity of stimulating the migration of mesenchymal stem cells in the bone marrow and mobilizing the cells into blood. HMGB1 is primarily known to be a major

component of a non-histone nuclear protein, and has two DNA-binding domains, Box A and Box B, in the molecule. Furthermore, a known function of HMGB1 in the nucleus is to relax the nucleosome structure and to form a structure optimal for transcription reaction. However, in recent years, it has become clear that the nuclear protein HMGB1 is secreted to the outside of cells to exert various activities, even though it does not have a secretion signal. Research on its function as a mediator of inflammation is most advanced. For example, in a mouse sepsis model (LPS administration model), HMGB1 secreted from macrophages due to TNFα stimulation was found to be a mediator of sepsis (Wang *et al.*: Science 1999; 285: 248-251), and TLR4 is known to be a candidate receptor. Furthermore, the most well-known HMGB1 receptor is RAGE, and binding between this receptor and HMGB1 has been reported to influence migration activity of cells and inflammatory signal transduction.

The present invention discloses novel therapeutic pharmaceutical compositions for injury of the spinal cord which comprises an HMGB1 fragment, and uses thereof.

Specifically, the present inventors produced a peptide consisting of the amino acids at positions 1 to 44 of the HMGB1 protein (SEQ ID NO: 5), and an HMGB1 fragment consisting of the amino acids at positions 11 to 44 (SEQ ID NO: 4) by peptide synthesis. Each of the produced HMGB1 fragments was administered to disease model mice that enable evaluation of therapeutic effects on injury of the spinal cord, and therapeutic effects of the fragments on injury of the spinal cord were confirmed.

Based on these findings, the present application provides the following invention:

[1] a pharmaceutical composition for use in the treatment of injury of the spinal cord, which comprises a HMGB1 fragment peptide;

[2] the pharmaceutical composition of [1], wherein the HMGB1 fragment peptide is a peptide comprising an amino acid sequence selected from the group consisting of SEQ ID NO: 3, SEQ ID NO: 4, and SEQ ID NO: 5;

[3] the pharmaceutical composition of [1], wherein the HMGB1 fragment peptide is a peptide consisting of an amino acid sequence selected from the group consisting of SEQ ID NO: 3, SEQ ID NO: 4, and SEQ ID NO: 5;

[4] a method for treating injury of the spinal cord, comprising the step of administering an HMGB1 fragment peptide;

[5] the method of [4], wherein the HMGB1 fragment peptide is a peptide comprising the amino acid sequence selected from the group consisting of SEQ ID NO: 3, SEQ ID NO: 4, and SEQ ID NO: 5;

[6] the method of [4], wherein the HMGB1 fragment peptide is a peptide consisting of the amino acid sequence selected from the group consisting of SEQ ID NO: 3, SEQ ID NO: 4, and SEQ ID NO: 5;

[7] an HMGB1 fragment peptide for use in the treatment of injury of the spinal cord;
[8] the HMGB1 fragment peptide of [7], wherein the HMGB1 fragment peptide is a peptide comprising the amino acid sequence selected from the group consisting of SEQ ID NO: 3, SEQ ID NO: 4, and SEQ ID NO: 5;
[9] the HMGB1 fragment peptide of [7], wherein the HMGB1 fragment peptide is a peptide consisting of the amino acid sequence selected from the group consisting of SEQ ID NO: 3, SEQ ID NO: 4, and SEQ ID NO: 5;
[10] use for the production of a medicament for use in the treatment of injury of the spinal cord, comprising an HMGB1 fragment peptide;
[11] the use of [10], wherein the HMGB1 fragment peptide is a peptide comprising the amino acid sequence selected from the group consisting of SEQ ID NO: 3, SEQ ID NO: 4, and SEQ ID NO: 5; and
[12] the use of [10], wherein the HMGB1 fragment peptide is a peptide consisting of the amino acid sequence selected from the group consisting of SEQ ID NO: 3, SEQ ID NO: 4, and SEQ ID NO: 5.

[Brief Description of the Drawings]

Fig. 1A shows photographs indicating the migration-stimulating activity of various synthetic peptides on established PDGFRα-positive bone marrow mesenchymal stem cells. All fragment peptides containing the smallest fragment, the HMGB1 fragment peptide (17-25), show cell migration-stimulating activity.

Fig. 1B is a photograph showing the migration-stimulating activity of HMGB1 fragment peptides with different lengths on established PDGFRα-positive bone marrow mesenchymal stem cells. Each peptide was prepared by peptide synthesis. The accompanying graph shows quantified cell migration-stimulating activity of each fragment peptide. This experiment shows that the HMGB1 fragment peptide (17-25) is the smallest fragment with migration-stimulating activity.

Fig. 2A shows that significant effects of improving neurologic symptoms were observed in the HMGB1 fragment (11-44)-administered group as compared to the negative control (PBS-administered) group. (*$p < 0.05$, **$p < 0.01$ VS. PBS)

Fig. 2B shows HE staining of the spinal cord. The size of the area of injury of the spinal cord decreased in the HMGB1 fragment (11-44)-administered group as compared to that of the negative control (PBS-administered) group, and therapeutic effects were also observed in the pathological tissues.

Fig. 3 is a graph that compares the full-length HMGB1-administered group and the HMGB1 fragment (11-44)-administered group for the effect of improving neurologic symptoms

in disease model animals inflicted with injury of the spinal cord over time.

Fig. 4 is a graph that compares the HMGB1 fragment (11-44 and 1-44)-administered groups for the effect of improving neurologic symptoms in disease model animals inflicted with injury of the spinal cord. (#: 1-44, #$p < 0.05$ VS. PBS; *: 11-44, *$p < 0.05$ VS. PBS)

[Mode for Carrying Out the Invention]

The present invention provides pharmaceutical compositions for use in the treatment of injury of the spinal cord, which comprises an HMGB1 fragment peptide having cell migration-stimulating activity. Herein, pharmaceutical compositions for use in the treatment of injury of the spinal cord of the present invention are also expressed as medicaments, pharmaceutical agents, or medicinal compositions.

In the present invention, "injury of the spinal cord" means extrinsic or intrinsic injury of the spinal cord. Extrinsic injury of the spinal cord includes, for example, traumatic injury of the spinal cord, but is not limited thereto. Herein, extrinsic injury of the spinal cord may be expressed simply as "spinal cord injury".

In the present invention, a cell migration-stimulating activity refers to the activity of stimulating cell migration. Herein, a cell migration-stimulating activity is also expressed as a cell migration-inducing activity or a cell-attracting activity.

The pharmaceutical compositions of the present invention can be administered/added to any sites. That is, the compositions can exert their effects no matter at which site they are administered, such as a site of injury of the spinal cord in need of regeneration, a site other than the lesion site, or blood. For example, when the compositions are administered/added, cells are recruited to the site of administration/addition or its nearby sites, thereby inducing or promoting regeneration of the lesion. Also, for example, when the compositions are administered/added to a lesion site or to the vicinity thereof, cells are recruited to the lesion, thereby inducing or promoting regeneration of the lesion. Further, for example, when the compositions are administered/added to a tissue other than a tissue in need of regeneration, bone marrow cells are mobilized from bone marrow to the tissue in need of regeneration through peripheral circulation, thereby inducing or promoting tissue regeneration. Here, "peripheral circulation" is also called "blood circulation" or "peripheral circulation bloodstream".

Administration to a tissue other than a tissue in need of regeneration refers to administration to a site that is not a site in need of regeneration (a site other than a site in need of regeneration). Accordingly, "a tissue other than a tissue in need of regeneration" can also be referred to as:

a site other than a tissue in need of regeneration; a site other than a site in need of regeneration; a site distant from a tissue in need of regeneration; a site distant from a site in need of

regeneration; a site distal to a site in need of regeneration; a tissue distal to a tissue in need of regeneration; a distal site; or a distal tissue.

Thus, compositions of the present invention are effectively used to regenerate tissues to which it is difficult to directly administer pharmaceutical agents from outside of the body. Examples of the tissue other than a tissue in need of regeneration include blood tissues, muscle tissues, subcutaneous tissues, intradermal tissues, abdominal cavity, and such.

In the present invention, cells that are stimulated to migrate or cells mobilized from bone marrow to peripheral blood include undifferentiated cells and cells in various stages of differentiation, but are not limited thereto. In the present invention, cells that are stimulated to migrate or cells mobilized from bone marrow to peripheral blood include stem cells, non-stem cells, and such, but are not limited thereto. Stem cells include circulatory stem cells and non-circulatory stem cells. Non-circulatory stem cells are, for example, stem cells residing in a tissue. Circulatory stem cells are, for example, circulatory stem cells in blood.

Further, cells stimulated to migrate or cells mobilized from bone marrow to peripheral blood include bone marrow-derived cells and hematopoietic stem cells, but are not limited thereto. In the present specification, "hematopoietic stem cells" are stem cells that can differentiate into blood cells such as red blood cells, platelets, mast cells, and dendritic cells, as well as white blood cells including neutrophils, eosinophils, basophils, lymphocytes, monocytes, macrophages, and such. Their markers are known to be CD34-positive and CD133-positive in human, and CD34-negative, c-Kit-positive, Sca-1-positive, and lineage marker-negative in mouse. Hematopoietic stem cells are difficult to be cultured alone when cultured in culture dishes, and they need to be co-cultured with stromal cells.

In the present specification, "bone marrow cells" means cells present inside bone marrow while "bone marrow-derived cells" means "bone marrow cells" mobilized from bone marrow to outside of bone marrow. "Bone marrow cells" include cells containing tissue progenitor cell populations present inside bone marrow. Further, "bone marrow-derived cells" may be cells containing mesoangioblasts or cells free of mesoangioblasts.

Tissue progenitor cells are defined as undifferentiated cells having a unidirectional potency to differentiate into cells of a specific tissue other than the blood system, and include undifferentiated cells having the potency to differentiate into mesenchymal tissues, epithelial tissues, nerve tissues, parenchymatous organs, and vascular endothelium as mentioned above.

Herein, "bone marrow mesenchymal stem cells", "bone marrow stromal pluripotent cells" or "bone marrow pluripotent stem cells" refer to cells existing in the bone marrow, which are directly collected from the bone marrow or indirectly collected from other tissues (blood, skin, fat, and other tissues), and can be cultured and proliferated as adherent cells on a culture dish (made of plastic or glass). These cells are characterized in having a potential to differentiate

into mesenchymal tissues such as bone, cartilage, and fat (mesenchymal stem cells), or into skeletal muscle, heart muscle, nervous tissues, and epithelial tissues (pluripotent stem cells), and can be obtained by collection of bone marrow cells.

"Bone marrow cells" and "bone marrow-derived cells" are hematopoietic stem cells and differentiated cells derived therefrom such as leukocytes, erythrocytes, platelets, osteoblasts, and fibrocytes, or are stem cells represented by cells which have been hitherto called bone marrow mesenchymal stem cells, bone marrow stromal pluripotent stem cells, or bone marrow pluripotent stem cells. As used herein, "bone marrow stem cells" refer to stem cells present inside bone marrow, while "bone marrow-derived stem cells" refer to "bone marrow stem cells" mobilized from bone marrow to outside of bone marrow. In the present invention, cells stimulated to migrate or cells mobilized from bone marrow to peripheral blood include "bone marrow-derived stem cells", but are not limited thereto. "Bone marrow cells" and "bone marrow-derived cells" can be isolated by bone marrow collection (bone marrow cell collection) or peripheral blood collection. Hematopoietic stem cells are nonadherent, while some of the "bone marrow cells" and "bone marrow-derived cells" are obtained as adherent cells by means of a cell culture of a monocyte fraction of blood obtained by the bone marrow collection (bone marrow cell collection) or peripheral blood collection.

Moreover, "bone marrow cells" and "bone marrow-derived cells" include mesenchymal stem cells, and have a potential to differentiate into, preferably, osteoblasts (which can be identified by observing calcification after inducing differentiation), chondrocytes (which can be identified by alcian blue positive staining, safranin O positive staining, or the like), adipocytes (which can be identified by Sudan III positive staining), and other mesenchymal cells such as fibroblasts, smooth muscle cells, stromal cells, and tendon cells; and further nerve cells, epithelial cells (for example, epidermal keratinocytes and intestinal epithelial cells express cytokeratin family), and vascular endothelial cells. The cells to be differentiated into are not limited to the above cells, and the potential to differentiate into cells of parenchymatous organs such as liver, kidney, and pancreas is also included.

On the other hand, "bone marrow-derived bone marrow mesenchymal stem cells", "bone marrow-derived bone marrow stromal pluripotent cells", or "bone marrow-derived bone marrow pluripotent stem cells" mobilized from bone marrow to outside of the bone marrow are cells that can be obtained by collection from peripheral blood, mesenchymal tissues such as fat, epithelial tissues such as skin, or nervous tissues such as brain.

In addition, these cells are also characterized in having a potential to differentiate into, for example, epithelial tissues such as keratinocytes that constitute skin, or nervous tissues that constitute brain, when administered to a lesion area of the living body immediately after collection or after once being adhered onto a culture dish.

Bone marrow mesenchymal stem cells, bone marrow stromal pluripotent stem cells, bone marrow pluripotent stem cells, or these cells recruited from bone marrow to outside of the bone marrow preferably have a potency to differentiate into: osteoblasts (which can be identified by observing calcification after inducing differentiation), chondrocytes (which can be identified by alcian blue positive staining, safranin O positive staining, or the like), adipocytes (which can be identified by Sudan III positive staining or the like), and other mesenchymal cells such as fibroblasts, smooth muscle cells, skeletal muscle cells, stromal cells, and tendon cells; nerve cells, pigment cells, epidermal cells, hair follicle cells (which express cytokeratin family, hair keratin family, or the like), epithelial cells (for example, epidermal keratinocytes and intestinal epithelial cells express cytokeratin family or the like), and endothelial cells; and further into cells of parenchymatous organs such as liver, kidney, and pancreas. However, differentiated cells are not limited to the above cells.

Human bone marrow cells and human bone marrow-derived cells can be exemplified by, but are not limited to, cells which can be directly obtained by collecting bone marrow (bone marrow cells), peripheral blood, or fat, or obtained as adherent cells through culturing of an isolated monocyte fraction. Markers for human bone marrow cells and human bone marrow-derived cells include, for example, all or some of the following but are not limited thereto: PDGFRα-positive, Lin-negative, CD45-negative, CD44-positive, CD90-positive, and CD29-positive, Flk-1-negative, CD105-positive, CD73-positive, CD90-positive, CD71-positive, Stro-1-positive, CD106-positive, CD166-positive, and CD31-negative.

Moreover, mouse bone marrow cells and mouse bone marrow-derived cells can be exemplified by, but are not limited to, cells which can be directly obtained by collecting bone marrow (bone marrow cells), peripheral blood, or fat, or obtained as adherent cells through culturing of an isolated monocyte fraction. Markers for mouse bone marrow cells and mouse bone marrow-derived cells include, for example, all or some of the following but are not limited thereto: CD44-positive, PDGFRα-positive, PDGFRβ-positive, CD45-negative, Lin-negative, Sca-1 positive, c-kit negative, CD90-positive, CD29-positive, and Flk-1-negative.

In the present invention, cells stimulated to migrate include PDGFRα-positive cells, but are not limited thereto. In addition, PDGFRα-positive cells stimulated to migrate are not particularly limited, but preferably are bone marrow-derived PDGFRα-positive cells. Further, markers other than PDGFRα can be exemplified by all or some of CD29-positive, CD44-positive, CD90-positive, CD271-positive, CD11b-negative, and Flk-1-negative, but are not limited thereto. PDGFRα-positive cells include, but are not limited to, for example, PDGFRα-positive bone marrow-derived cells, PDGFRα-positive bone marrow-derived mesenchymal stem cells, tissue cells residing in PDGFRα-positive tissues (for example, fibroblasts and such), PDGFRα-positive bone marrow-derived cells obtained as adherent cells by means of cell culture

of a monocyte fraction of blood obtained by bone marrow collection (bone marrow cell collection) or peripheral blood collection.

The HMGB1 protein in the present invention includes, but is not limited to, for example, a protein comprising the amino acid sequence of SEQ ID NO: 1 as a human-derived HMGB1 protein, and DNA encoding said protein includes, but is not limited to, for example, a DNA comprising the nucleotide sequence of SEQ ID NO: 2.

In the present invention, "an HMGB1 fragment peptide having a cell migration-stimulating activity" refers to a peptide consisting of a portion of an HMGB1 protein and having a cell migration-stimulating activity. Fragment peptides consisting of a portion of the HMGB1 protein of the present invention are not particularly limited as long as they have a cell migration-stimulating activity, but are preferably an HMGB1 fragment peptide that comprises at least the amino acid sequence of positions 17 to 25 of the HMGB1 protein (SEQ ID NO: 3), which is confirmed by experiments performed by the present inventors to be the smallest peptide fragment among the fragments with cell migration-stimulating activity (Fig. 1).

In the present invention, peptides consisting of an HMGB1 fragment that has cell migration-stimulating activity are, for example, the fragments below, but are not limited thereto.

In the present invention, HMGB1 fragments which have a cell migration-stimulating activity include a fragment peptide comprising an amino acid sequence selected from the group consisting of the amino acid sequences of SEQ ID NO: 3, SEQ ID NO: 4, and SEQ ID NO: 5, which is an HMGB1 fragment peptide having cell migration-stimulating activity. These fragment peptides include, for example, a fragment peptide comprising at least the fragment peptide (17-25) of SEQ ID NO: 3 with the upper limit being the fragment peptide (11-44) of SEQ ID NO: 4; a fragment peptide comprising at least the fragment peptide (11-44) of SEQ ID NO: 4 with the upper limit being the fragment peptide (1-44) of SEQ ID NO: 5; or a fragment peptide comprising at least the fragment peptide (17-25) of SEQ ID NO: 3 with the upper limit being the fragment peptide (1-44) of SEQ ID NO: 5; but are not limited thereto.

In the present invention, HMGB1 fragment peptides which have a cell migration-stimulating activity include, for example, a fragment peptide consisting of an amino acid sequence selected from the group consisting of the amino acid sequences of SEQ ID NO: 3, SEQ ID NO: 4, and SEQ ID NO: 5, which is an HMGB1 fragment peptide having cell migration-stimulating activity.

Methods for administering a composition of the present invention include oral administration and parenteral administration. Specifically, parenteral administration includes, but is not limited to, injection, transnasal administration, transpulmonary administration, transdermal administration, and such. As examples of injection, intravenous injection, intramuscular injection, intraperitoneal injection, subcutaneous injection, and such can be used to

administer a composition of the present invention systemically or locally (for example, under the skin, in the skin, on the surface of skin, eyeball or palpebral conjunctiva, nasal cavity mucosa, intraoral mucosa and mucosa of the gastrointestinal tract, vaginal mucosa/intrauterine mucosa, damage site or such).

Methods of administering a composition of the present invention include, but are not limited to, for example, intravascular administration (intra-arterial administration, intravenous administration, or such), blood administration, intramuscular administration, subcutaneous administration, intradermal administration, intraperitoneal administration.

There is no limitation on the site of administration, and for example, it may be a tissue site in need of regeneration or its nearby region, a site different from the tissue in need of regeneration, or a site distant to and different from the tissue in need of regeneration. The site is, for example, in the blood (in arteries, in veins, or such), muscle, under the skin, in the skin, in the abdominal cavity, or such, without being limited thereto.

The method of administration may be appropriately selected according to the age and the symptoms of the patient. When a peptide of the present invention is administered, the dose per time of the peptide can be selected within a range of 0.0000001 mg to 1000 mg per kg body weight of a patient. Alternatively, the dose can be selected within a range of 0.00001 mg to 100000 mg per body of patient, for example. When administering cells secreting a peptide of the present invention or gene therapy vectors inserted with DNA encoding the peptide, they may be administered such that the amount of the peptide is within the above range. However, the dose of pharmaceutical compositions of the present invention is not limited thereto.

HMGB1 peptide fragments of the present invention can be obtained as recombinants by incorporating a DNA encoding the peptide into an appropriate expression system, or can be synthesized artificially. Pharmaceutical compositions of the present invention can be formulated according to the usual methods (for example, Remington's Pharmaceutical Science, latest edition, Mark Publishing Company, Easton, U.S.A), and may contain pharmaceutically acceptable carriers and additives together. Examples include surfactants, excipients, colorants, perfumes, preservatives, stabilizers, buffers, suspending agents, isotonizing agents, binders, disintegrants, lubricants, flow promoters, and flavoring agents, although they are not limited thereto and other common carriers may be appropriately used. Specific examples include light anhydrous silicic acid, lactose, crystalline cellulose, mannitol, starch, carmellose calcium, carmellose sodium, hydroxypropylcellulose, hydroxypropylmethylcellulose, polyvinylacetaldiethylamino acetate, polyvinylpyrrolidone, gelatin, medium-chain fatty acid triglyceride, polyoxyethylene hydrogenated castor oil 60, white sugar, carboxymethyl cellulose, corn starch, and inorganic salts.

All prior art documents cited herein are incorporated herein by reference.

Herein below, the present invention will be further illustrated with reference to

Examples, but it is not to be construed as being limited thereto.

[Example 1]

Assessment of synthetic peptides for migration-promoting activity

(Methods)

The peptides listed below were custom synthesized using the solid phase method by Medical & Biological Laboratories (MBL). The peptides were synthesized based on the mouse HMGB1 sequence. Amino acid sequences from positions 1 to 169 of mouse HMGB1 and human HMGB1 are identical, *i.e.*, shares 100% sequence homology.

A synthetic peptide consisting of the amino acid sequence from positions 1 to 10 of HMGB1 (1-10);

a synthetic peptide consisting of the amino acid sequence from positions 1 to 34 of HMGB1 (1-34);

a synthetic peptide consisting of the amino acid sequence from positions 11 to 20 of HMGB1 (11-20);

a synthetic peptide consisting of the amino acid sequence from positions 11 to 25 of HMGB1 (11-25);

a synthetic peptide consisting of the amino acid sequence from positions 11 to 30 of HMGB1 (11-30);

a synthetic peptide consisting of the amino acid sequence from positions 11 to 34 of HMGB1 (11-34);

a synthetic peptide consisting of the amino acid sequence from positions 11 to 44 of HMGB1 (11-44); and

the full-length mouse HMGB1 produced in HEK293 (1-215(HEK)) as a positive control were adjusted to 100 μg/ml and placed in the lower chamber of a chemotaxis chamber to assess the migration-promoting activity on mouse bone marrow mesenchymal stem cell line (MSC-1 cell; produced by Osaka University, Tamai *et al.*, (Tamai *et al.*, Proc Natl Acad Sci U S A., 108(16): 6609-6614, 2011)).

(Results)

At least synthetic peptides (11-34), (1-34), (11-44), (1-44), and (11-30) were found to have the activity comparable to or higher than that of the positive control (Fig. 1A). Furthermore, synthetic peptide (11-25) was also found to have the activity (Fig. 1A).

(Methods)

In order to narrow down the location of the active center, the shorter peptides listed

below were synthesized.
a synthetic peptide consisting of the amino acid sequence from positions 11 to 25 of HMGB1 (11-25),
a synthetic peptide consisting of the amino acid sequence from positions 12 to 25 of HMGB1 (12-25),
a synthetic peptide consisting of the amino acid sequence from positions 13 to 25 of HMGB1 (13-25),
a synthetic peptide consisting of the amino acid sequence from positions 14 to 25 of HMGB1 (14-25),
a synthetic peptide consisting of the amino acid sequence from positions 15 to 25 of HMGB1 (15-25),
a synthetic peptide consisting of the amino acid sequence from positions 16 to 25 of HMGB1 (16-25), and
a synthetic peptide consisting of the amino acid sequence from positions 17 to 25 of HMGB1 (17-25).

As positive controls, centrifuged supernatant of the skin of a one-day-old mouse (one individual) incubated in PBS at 4°C for 12 hours, and the full-length mouse HMGB1 produced in HEK293 (1-215(HEK)) were used. Cells of a bone marrow mesenchymal stem cell line (MSC-1) were placed in the upper chamber of a chemotaxis chamber, and the protein and synthetic peptides were added at a concentration of 5 μM or 10 μM to the lower chamber of the chemotaxis chamber. The migration assay was carried out by the same method as described above.

(Results)

All synthetic peptides were found to have activity (Fig. 1B). The HMGB1 fragment peptide (17-25) was shown to be the smallest fragment that has the migration-stimulating activity.

[Example 2]
(Methods)

Seven-week-old female C57BL6/J mice were used as test animals. After the mice were anesthetized by isoflurane inhalation, skin incision was made along the dorsal midline, and the vertebral arch of the ninth thoracic vertebra was exposed and excised. Dura mater was exposed at the same site, and the spinal cord was held epidurally for three seconds using a microneedle holder to produce a traumatic injury of the spinal cord. After generation of injury of the spinal cord, the skin was sutured. Injury of the spinal cord was confirmed on the next day of operation by assessing paralysis of both hindlimbs, and mice that did not show paralysis were excluded

from the assay. The assay reagent was prepared by diluting 100 μg of an HMGB1 fragment (amino acid sequence: amino acids of positions 11 to 44; synthesized peptide produced at MBL) in 200 μL of Dulbecco's PBS (D-PBS). 200 μL of D-PBS was used for the negative control. On the next day of operation, the first administration was performed through the tail vein, and this was followed by a total of five daily administrations. Neurologic symptoms were assessed using the Basso Mouse Scale (BMS) score on Days 1, 3, 7, 10, 14, 17, and 21 post operation.

(Results)

Based on the BMS scores, significant improvement of neurologic symptoms was observed from Day 3 post operation in the HMGB1 fragment-administered group as compared to the PBS-administered group. In particular, remarkable improvement of symptoms was observed on Days 3, 7, 14, and 17 post operation (Fig. 2A). Furthermore, while the HE staining images of the damaged region of the spinal cord for the negative control group showed damage in a wide range (D1), the damaged region (D2) for the HMGB1 fragment (11-44 peptide)-administered group was reduced, and therapeutic effects were observed histopathologically as well (Fig. 2B).

(Discussion)

Clear improvement of neurologic symptoms of mice inflicted with injury of the spinal cord was observed by HMGB1 fragment administration. Bone marrow mesenchymal stem cell-mobilizing activity has been found for the HMGB1 fragments used in this examination, and therapeutic effects of the mobilized bone marrow mesenchymal stem cells on injury of the spinal cord were expected. The effects of bone marrow mesenchymal stem cells on tissue damages are expected to be tissue regeneration through differentiation into nerve cells by pluripotency, as well as protective action of growth factors, cytokines, and such secreted by the bone marrow mesenchymal stem cells on damaged tissues. In the present assay, short-term effects up to the first week after the operation may be due to the latter action, and subsequently, the former action may be involved.

[Example 3]

(Methods)

Seven-week-old female C57BL6/J mice were used as test animals. After the mice were anesthetized by isoflurane inhalation, skin incision was made along the dorsal midline, and the vertebral arch of the ninth thoracic vertebra was exposed and excised. Dura mater was exposed at the same site, and the spinal cord was held epidurally for three seconds using a microneedle holder to produce a traumatic injury of the spinal cord. After production of injury of the spinal cord, the skin was sutured. Injury of the spinal cord was confirmed on the next day of operation

by assessing paralysis of both hindlimbs, and mice that did not show paralysis were excluded from the assay. An HMGB1 fragment (amino acid sequence: the amino acids of positions 11 to 44; synthetic peptide produced at MBL) was prepared by diluting 100 μg of the fragment in 200 μL of Dulbecco's PBS (D-PBS). The full-length HMGB1 protein was produced by expressing it in HEK293 as reported previously, and the purified HMGB1 (100 μg) was dissolved in 200 μL of D-PBS. 200 μL of D-PBS was used for the negative control. On the next day of operation, the first administration was performed through the tail vein, and this was followed by a total of five daily administrations. Neurologic symptoms were assessed using the BMS score on Days 1, 3, 7, and 14 post operation.

(Results)

Effects on the improvement of neurologic symptoms were assessed using the BMS scores. The therapy was most effective in the HMGB1 fragment (amino acids at positions 11-44)-administered group on both Days 7 and 14. While the therapeutic effect was observed in the HMGB1 (full-length)-administered group when compared to that in the negative control group, it was not as effective as that in the HMGB1 fragment (amino acids at positions 11-44)-administered group (Fig. 3).

(Discussion)

After production of injury of the spinal cord, in the early stage, the therapeutic effect in the full-length HMGB1-administered group was found to be intermediate between the effect in the HMGB1 fragment (amino acids at positions 11-44)-administered group and that in the negative control group; however, by Day 14 post production of injury of the spinal cord, a much more satisfactory improvement of the therapeutic effect was observed in the HMGB1 fragment (amino acids at positions 11-44)-administered group than in other groups. These experiments revealed that rather than the full-length protein, the fragment shows greater therapeutic effects on injuries of the spinal cord. Peptides that can be chemically synthesized, such as this fragment, may be extremely useful in practical applications, since they allow production of inexpensive and homogenous products in large quantities in pharmaceutical production.

[Example 4]

(Methods)

Seven-week-old female C57BL6/J mice were used as test animals. The mice were anesthetized by isoflurane inhalation, skin incision was made along the dorsal midline, and the vertebral arch of the ninth thoracic vertebra was exposed and excised. Dura mater was exposed at the same site, and the spinal cord was held epidurally for three seconds using a microneedle

holder to produce a traumatic injury of the spinal cord. After production of injury of the spinal cord, the skin was sutured. Injury of the spinal cord was confirmed on the next day of operation by assessing paralysis of both hindlimbs, and mice that did not show paralysis were excluded from the assay. HMGB1 fragments (amino acid sequences: amino acids from positions 11 to 44 and amino acids from positions 1 to 44; synthetic peptides produced at MBL) were prepared by diluting 100 μg of the fragment in 200 μL of D-PBS. 200 μL of D-PBS was used for the negative control. On the next day of operation, the first administration was performed *via* the tail vein, and this was followed by a total of five daily administrations. Neurologic symptoms were assessed using the BMS score on Days 1, 3, 7, 10, 14, 17, 21, and 28 post operation.

(Results)

Effects on the improvement of neurologic symptoms were assessed using the BMS scores. In comparison to the negative control group, therapeutic effects were observed in the HMGB1 fragment (amino acids at positions 11-44 and amino acids at positions 1-44)-administered groups on Days 17, 21, and 28. The HMGB1 fragment consisting of the amino acids from positions 11 to 44 and the HMGB1 fragment consisting of the amino acids from positions 1 to 44 had comparable therapeutic effects (Fig. 4).

(Discussion)

HMGB1 fragments 11-44 and 1-44 were both found to be effective in treating injury of the spinal cord. As shown in Fig. 1, the present inventors elucidated that one of the core domains of HMGB1 for the activity of recruiting bone marrow mesenchymal stem cells is a peptide consisting of the amino acids from positions 17 to 25. Both the 11-44 fragment and the 1-44 fragment include positions 17 to 25, and the core peptide that exhibits efficacy of these peptides is predicted to be the sequence of positions 17 to 25. It has been reported that RAGE is not involved in the mobilization of bone marrow mesenchymal stem cells by the full-length HMGB1 protein (Tamai, 2011, PNAS; and such), and since there are no reports that the 11-44 fragment and the 1-44 fragment are ligands for a known receptor such as RAGE, these fragments are expected to target a receptor that is still unknown.

Industrial Applicability

The present invention provides novel uses of HMGB1 fragment peptides that retain the activity of recruiting PDGFRα-positive cells for treating injury of the spinal cord. The HMGB1 fragment peptides of the present invention are fragment peptides with a molecular weight of about 20 percent or less of the full-length HMGB1 protein consisting of 215 amino acids. Such fragment peptides can be produced by chemical synthesis using peptide synthesizers, and are

thus expected to improve purity, provide stable production, and reduce costs in the situation of producing peptides as pharmaceuticals.

Moreover, full-length HMGB1 is known to have an activity to bind to lipopolysaccharides (LPS) which are one type of endotoxin. Contamination of even a trace amount of LPS in pharmaceuticals causes fever and such, and often results in serious side effects. Thus, LPS contamination in pharmaceuticals is strictly regulated. As HMGB1 has affinity for LPS, it is difficult to completely eliminate LPS from pharmaceuticals contaminated therewith. However, making HMGB1 into peptides reduces its affinity to LPS, and thus it is expected to reduce LPS contamination in pharmaceuticals. Accordingly, by using an HMGB1 fragment comprising the portion for recruiting PDGFRα-positive cells as specified in the present invention, it is possible to develop safer pharmaceutical compositions for treating injury of the spinal cord.

Direct administration of the HMGB1 fragment of the present invention to the injury of spinal cord site in need of regeneration, or to the vicinity thereof, may induce or enhance regeneration of the lesion. Further, regeneration of injury of the spinal cord may be induced or enhanced by administering the HMGB1 fragment of the present invention to a site different from the site in need of regeneration by means such as intravenous administration. As such, the present invention enables treatment of injury of the spinal cord with intravenous administration, which is widely performed in general practice; and thus, therapeutic agents can be safely and easily administered at arbitrary concentrations for an arbitrary number of times. This fact is one of the extremely superior aspects of the present invention in comparison to conventional therapeutic methods.

In current practice of regenerative medicine or cell therapy, scarce bone marrow pluripotent stem cells derived from patients are cultured *ex vivo* and used for therapies after proliferation; however, since the culturing process carries the risk of cell deterioration (canceration or contamination of bacteria, viruses, and such), sufficient safety control is required. In contrast, therapeutic agents based on the present invention do not include the step of taking cells outside the body or the step of including manual operation, and thus, they are believed to be relatively safe. This fact is also one of the superior aspects of the present invention in comparison to conventional therapeutic methods.

CLAIMS

1. A pharmaceutical composition for use in the treatment of injury of the spinal cord, which comprises a HMGB1 fragment peptide.

2. The pharmaceutical composition of claim 1, wherein the HMGB1 fragment peptide is a peptide comprising an amino acid sequence selected from the group consisting of SEQ ID NO: 3, SEQ ID NO: 4, and SEQ ID NO: 5.

3. The pharmaceutical composition of claim 1, wherein the HMGB1 fragment peptide is a peptide consisting of an amino acid sequence selected from the group consisting of SEQ ID NO: 3, SEQ ID NO: 4, and SEQ ID NO: 5.

SEQUENCE LISTING

<110> Genomix Co., Ltd.
Osaka University

<120> Novel Method for Treating Spinal Cord Injury Using HMGB1 Fragment

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