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(71) Applicant(s)
The Board of Regents of the University of Texas System

(72) Inventor(s)
Jiang, Jean X.;An, Zhiqiang;Zhang, Ningyan;Xiong, Wei;Riquelme, Manuel A.;Gu, Sumin;Sayre, Naomi Ledene

(74) Agent / Attorney
Spruson & Ferguson, GPO Box 3898, Sydney, NSW, 2001, AU

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(71) Applicant: **THE BOARD OF REGENTS OF THE UNIVERSITY OF TEXAS SYSTEM** [US/US]; 201 West 7th Street, Austin, TX 78701 (US).

(72) Inventors: **JIANG, Jean, X.**; 8511 Mantano Ridge, Helotes, TX 78023 (US). **AN, Zhiqiang**; c/o UT Health Science Center at Houston, 7000 Fannin, Suite 1200, Houston, TX 77030 (US). **ZHANG, Ningyan**; c/o UT Health Science Center at Houston, 7000 Fannin, Suite 1200, Houston, TX 77030 (US). **XIONG, Wei**; c/o UT Health Science Center at Houston, 7000 Fannin, Suite 1200, Houston, TX 77030 (US). **RIQUELME, Manuel, A.**; 7458 Louis Pasteur Dr., Apt. 602, San Antonio, TX 78229 (US). **GU, Sumin**; 7131 Oakridge Dr., San Antonio, TX 78229 (US). **SAYRE, Naomi, Ledene**; c/o UT Health Science Center at San Antonio, 7703 Floyd Curl Dr., MC 7819, San Antonio, TX 78229 (US).

(74) Agent: **BYRD, Marshall, P.**; Parker Highlander PLLC, 1120 S. Capital of Texas Highway, Building One, Suite 200, Austin, TX 78746 (US).

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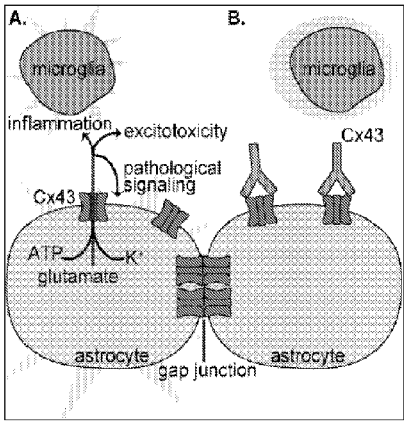


FIG. 1

(57) Abstract: Antibodies that bind to connexin 43 hemichannels and inhibit, or activate, channel opening are provided. In certain aspects, methods for detecting or treating cancers with antibodies that activate Cx43 channel opening are also provided. Likewise, methods for treating inflammatory diseases (e.g., osteoarthritis) and neurological injuries (e.g., spinal cord injury) with antibodies that inhibit Cx43 channel opening are provided.

WO 2017/147561 A1

CONNEXIN (Cx)43 HEMICHANNEL-BINDING ANTIBODIES AND USES THEREOF

DESCRIPTION

[0001] This application claims the benefit of United States Provisional Patent Application No. 62/300,492, filed February 26, 2016, the entirety of which is incorporated herein by reference.

BACKGROUND

1. Field of the Invention

[0002] The present invention, in some embodiments, relates generally to the field of molecular biology, cancer biology and rheumatology. More particularly, it concerns connexin (Cx)43 hemichannel-binding antibodies and their use for the treatment and detection of disease, such as cancer, neurological injury and osteoarthritis.

2. Description of Related Art

[0003] Traumatic spinal injury (SCI) and traumatic brain injury (TBI) are serious health problems worldwide and over 1.5 million patients annually are diagnosed with traumatic brain and spinal cord injuries. Patients with SCI and TBI not only can lose neuronal function, but are at greater risk for neuropathic pain and other complications associated with loss of nervous control. Secondary injury accounts for major post-traumatic loss of neurological function. Part of the post-injury neuroinflammatory process is the activation of astrocytes and formation of a glial scar resulting in an impermeable milieu for axonal regeneration. The therapeutic goals include limitation of the size of lesions and axonal loss with the innovative approach of targeting astrocytes, a class of support cells that play a major role in supporting neuronal function and glial scar formation. However, there remains a need for compositions that can be used to successfully limit glial scar formation.

[0004] Bone tissues are a preferred site of breast and prostate cancer metastasis. Bone metastasis occurs in up to 75% of patients with advanced cancers. Currently, there is no cure for metastatic breast cancer and no reliable intervention drug for treating bone metastasis that has minimal side effects.

[0005] Osteoarthritis (OA) is a prevalent disease that affects approximately 20% of U.S. adults. This disease causes the degeneration of joints including articular cartilage and subchondral bone. The pathology of OA is characterized by a loss of articular cartilage leading to narrowing of joint space, increased joint friction and potential structure remodeling. Current treatment includes exercise, lifestyle change and analgesics. If symptom becomes severe, joint replacement surgery is normally performed. Thus far, there is no specific pharmaceutical intervention available for the treatment of OA.

[0006] Connexin hemichannels play important roles in the cell and tissue function, and abnormal function of connexin hemichannels may be involved various pathological conditions, such as those described above. Thus, there remains a need for additional therapies for treating pathological conditions associated with hemichannels activity (*e.g.*, inflammation, SCI, TBI, bone metastasis), as well as methods for identifying such therapies.

[0006a] Any discussion of the prior art throughout the specification should in no way be considered as an admission that such prior art is widely known or forms part of common general knowledge in the field.

SUMMARY OF THE INVENTION

[0006b] In one aspect, the present disclosure provides a method of treating or preventing osteoporosis, osteopenia or cancer in a subject comprising administering to the subject an effective amount of an antibody that binds to a connexin 43 (Cx43) hemichannel and enhances channel opening or an expression vector encoding the antibody, wherein the antibody comprises: a heavy chain immunoglobulin variable region comprising: a complementarity determining region 1 comprising the sequence of SEQ ID NO: 19; a complementarity determining region 2 comprising the sequence of SEQ ID NO: 20; and a complementarity determining region 3 comprising the sequence of SEQ ID NO: 21; and a light chain immunoglobulin variable region comprising: (a) a complementarity determining region 1 comprising the sequence of SEQ ID NO: 49; (b) a complementarity determining region 2 comprising the sequence of SEQ ID NO: 50; and (c) a complementarity determining region 3 comprising the sequence of SEQ ID NO: 51.

[0006c] In another aspect, the present disclosure provides a recombinant connexin 43 (Cx43) hemichannel-binding antibody comprising: a heavy chain immunoglobulin variable region comprising: a) a complementarity determining region 1 comprising the sequence of SEQ ID NO: 19; b) a complementarity determining region 2 comprising the sequence of SEQ ID NO: 20; c) a complementarity determining region 3 comprising the sequence of SEQ ID NO: 21; and a light chain immunoglobulin variable region comprising: a) a complementarity determining region 1 comprising the sequence of SEQ ID NO: 49; b) a complementarity determining region 2 comprising the sequence of SEQ ID NO: 50; and c) a complementarity determining region 3 comprising the sequence of SEQ ID NO: 51.

[0006d] In another aspect, the present disclosure provides a method of treating cancer in a subject comprising administering an effective amount of a pharmaceutical composition comprising an antibody of the invention or an expression vector encoding an antibody of the invention to the subject.

[0006e] In another aspect, the present disclosure provides use of an antibody that binds to a connexin 43 (Cx43) hemichannel and enhances channel opening or an expression vector encoding the antibody in the manufacture of a medicament for the treatment or prevention of osteoporosis, osteopenia or cancer, wherein the antibody comprises: a heavy chain immunoglobulin variable region comprising: a complementarity determining region 1 comprising the sequence of SEQ ID NO: 19; a complementarity determining region 2 comprising the sequence of SEQ ID NO: 20; and a complementarity determining region 3 comprising the sequence of SEQ ID NO: 21; and a light chain immunoglobulin variable region comprising: (a) a complementarity determining region 1 comprising the sequence of SEQ ID NO: 49; (b) a complementarity determining region 2 comprising the sequence of SEQ ID NO: 50; and (c) a complementarity determining region 3 comprising the sequence of SEQ ID NO: 51.

[0006f] In another aspect, the present disclosure provides use of an antibody of the invention or an expression vector encoding an antibody of the invention in the manufacture of a medicament for the treatment of cancer.

[0007] In a first embodiment, the invention provides a method of treating or preventing cancer or bone metastasis in a subject having a cancer comprising administering to the subject an

effective amount of an antibody that binds to a connexin 43 (Cx43) hemichannel and enhances channel opening or an expression vector encoding the antibody (such as the Ab2 antibodies detailed herein). In a further embodiment, there is provided a method of treating or preventing osteoporosis or osteopenia in a subject comprising administering to the subject an effective amount of an antibody that binds to a connexin 43 (Cx43) hemichannel and enhances channel opening or an expression vector encoding the antibody (such as the Ab2 antibodies detailed herein). In certain aspects, the method comprises administering an effective amount of the antibody to the subject. In further aspects, the method comprises administering an effective amount of an expression vector encoding the antibody to the subject. In some aspects, the cancer is breast cancer, prostate cancer (*e.g.*, with bone metastasis), or osteosarcoma. In further aspects, the cancer is a cancer having bone metastases.

[0008] In further aspects, the expression vector encoding the antibody may be administered in a pharmaceutically acceptable composition. In certain aspects, the antibody may be administered systemically. In other aspects, the antibody may be administered intravenously, intradermally, intratumorally, intramuscularly, intraperitoneally, subcutaneously, or locally.

[0009] In several aspects, the antibody may comprise a first V_H CDR identical to SEQ ID NO: 19, a second V_H CDR identical to SEQ ID NO: 20, a third V_H CDR identical to SEQ ID NO: 21, a first V_L CDR identical to SEQ ID NO: 49, a second V_L CDR identical to SEQ ID NO: 50, and a third V_L CDR identical to SEQ ID NO: 51. In some aspects, the antibody is a humanized antibody. In certain aspects, the antibody may comprise a VH amino acid sequence at least 90% identical to SEQ ID NO: 58 and/or a VL amino acid sequence at least 90% identical to SEQ ID NO: 63. In a further aspect, the antibody comprises a VH amino acid sequence according to SEQ ID NO: 58 and/or a VL amino acid sequence according to SEQ ID NO: 63.

[0010] In still further aspects, the method may additionally comprise administering at least a second anticancer therapy to the subject. In certain aspects, the second anticancer therapy is a surgical therapy, chemotherapy, radiation therapy, cryotherapy, hormonal therapy, immunotherapy or cytokine therapy.

[0011] In a further embodiment, the invention provides a method of treating or preventing neurodegenerative disease or a neurological injury in a subject comprising administering to the subject an effective amount of an antibody that binds to a connexin 43 (Cx43) hemichannel and inhibits channel opening or an expression vector encoding the antibody (such as the Ab1 antibodies detailed herein). In several aspects, the method comprises administering an effective amount of the antibody to the subject. In other aspects, the method may comprise administering an effective amount of an expression vector encoding the antibody to the subject.

[0012] In some aspects, the method may additionally be defined as a method for treating or preventing a neurodegenerative disease. In a further aspect, the neurodegenerative disease may be multiple sclerosis or Alzheimer's disease. In other aspects, the method may additionally be defined as a method for treating or preventing a neurological injury. In certain aspects, the neurological injury comprises a spinal cord injury (SCI), stroke or traumatic brain injury (TBI). In some specific aspects, the subject has or has been diagnosed with a neurological injury. In several aspects, the expression vector encoding the antibody is administered in a pharmaceutically acceptable composition. In certain aspects, the antibody may be administered systemically. In further aspects, the antibody is administered intravenously, intradermally, intramuscularly, intraperitoneally, subcutaneously, or locally.

[0013] In several aspects, the antibody comprises a first V_H CDR identical to SEQ ID NO: 19, a second V_H CDR identical to SEQ ID NO: 20, a third V_H CDR identical to SEQ ID NO: 21, a first V_L CDR identical to SEQ ID NO: 31, a second V_L CDR identical to SEQ ID NO: 32, and a third V_L CDR identical to SEQ ID NO: 33. In some aspects, the antibody is a humanized antibody. In certain aspects, the antibody comprises a VH amino acid sequence at least 90% identical to SEQ ID NO: 58 and/or a VL amino acid sequence at least 90% identical to SEQ ID NO: 60. In some particular aspects, the antibody comprises a VH amino acid sequence according to SEQ ID NO: 58 and/or a VL amino acid sequence according to SEQ ID NO: 60.

[0014] In yet a further embodiment, there is provided a recombinant connexin 43 (Cx43) hemichannel-binding antibody. In certain aspects, the antibody comprises a first V_H CDR identical to SEQ ID NO: 19, a second V_H CDR identical to SEQ ID NO: 20, a third V_H CDR identical to SEQ ID NO: 21, a first V_L CDR identical to SEQ ID NO: 49, a second V_L CDR identical to SEQ ID NO: 50, and a third V_L CDR identical to SEQ ID NO: 51. In some aspects, the antibody is a humanized antibody. In certain particular aspects, the antibody comprises a VH amino acid sequence at least 90% identical to SEQ ID NO: 58 and/or a VL amino acid sequence at least 90% identical to SEQ ID NO: 63. In a specific aspect, the antibody may comprise a VH amino acid sequence according to SEQ ID NO: 58 and/or a VL amino acid sequence according to SEQ ID NO: 63.

[0015] In several aspects, the antibody may comprise a first V_H CDR identical to SEQ ID NO: 19, a second V_H CDR identical to SEQ ID NO: 20, a third V_H CDR identical to SEQ ID NO: 21, a first V_L CDR identical to SEQ ID NO: 31, a second V_L CDR identical to SEQ ID NO: 32, and a third V_L CDR identical to SEQ ID NO: 33. In certain aspects, the antibody is a humanized antibody. In some aspects, the antibody comprises a VH amino acid sequence at least 90% identical to SEQ ID NO: 58 and/or a VL amino acid sequence at least 90% identical to SEQ ID NO: 60. In certain specific aspects, the antibody comprises a VH amino acid sequence according to SEQ ID NO: 58 and/or a VL amino acid sequence according to SEQ ID NO: 60.

[0016] In still yet a further embodiment, the invention provides a method of treating cancer in a subject comprising administering an effective amount of a pharmaceutical composition comprising an antibody according to the embodiments and aspects described above or an expression vector encoding an antibody according to the embodiments and aspects

described above to the subject. In some aspects, the pharmaceutical composition comprises an expression vector encoding an antibody according to the embodiments and aspects described above to the subject. In other aspects, the pharmaceutical composition comprises an antibody according to the embodiments and aspects described above to the subject. In several aspects, the method may further be defined as a method for inhibiting or preventing cancer bone metastasis in the subject. In certain aspects, the pharmaceutical composition may be administered systemically. In specific aspects, the pharmaceutical composition is administered intravenously, intradermally, intratumorally, intramuscularly, intraperitoneally, subcutaneously, or locally.

[0017] In some aspects, the pharmaceutical composition may comprise a first V_H CDR identical to SEQ ID NO: 19, a second V_H CDR identical to SEQ ID NO: 20, a third V_H CDR identical to SEQ ID NO: 21, a first V_L CDR identical to SEQ ID NO: 31, a second V_L CDR identical to SEQ ID NO: 32, and a third V_L CDR identical to SEQ ID NO: 33. In several aspects, the method may further comprise administering at least a second anticancer therapy to the subject. In further aspects, the second anticancer therapy is a surgical therapy, chemotherapy, radiation therapy, cryotherapy, hormonal therapy, immunotherapy or cytokine therapy.

[0018] In a further aspect, the invention provides a method of treating an inflammatory disease, a neurodegenerative disease or a neurological injury in a subject comprising administering an effective amount of a pharmaceutical composition comprising an antibody according to the embodiments and aspects described above or an expression vector encoding an antibody according to the embodiments and aspects described above to the subject (an antibody that binds to a Cx43 hemichannel and inhibits channel opening, such as the Ab1 antibodies detailed herein). In certain aspects, the pharmaceutical composition comprises an expression vector encoding an antibody according to the embodiments and aspects described above to the subject. In specific aspects, the pharmaceutical composition comprises an antibody according to the embodiments and aspects described above to the subject.

[0019] In further aspects, the method may additionally be defined as a method for treating or preventing an inflammatory disease comprising administering to the subject an effective amount of an antibody that binds to a Cx43 hemichannel and inhibits channel opening or an expression vector encoding the antibody (such as the Ab1 antibodies detailed herein). In some specific aspects, the inflammatory disease is osteoarthritis. In some aspects, a method is

provided for promoting wound healing, such as skin or cornea wound healing comprising administering to a subject an effective amount of an antibody that binds to a connexin 43 (Cx43) hemichannel and inhibits channel opening or an expression vector encoding the antibody (such as the Ab1 antibodies detailed herein). In other aspects, the method may additionally be defined as a method for treating or preventing a neurodegenerative disease. In certain particular aspects, the neurodegenerative disease is multiple sclerosis or Alzheimer's. In several aspects, the method may further be defined as a method for treating or preventing a neurological injury. In some particular aspects, the neurological injury comprises a spinal cord injury (SCI), traumatic brain injury (TBI), or stroke. In certain aspects, the subject has or has been diagnosed with a neurological injury.

[0020] In some aspects, the pharmaceutical composition may be administered systemically. In specific aspects, the pharmaceutical composition is administered intravenously, intradermally, intratumorally, intramuscularly, intraperitoneally, subcutaneously, or locally.

[0021] In certain embodiments there are also provided antibodies directed against hemichannel polypeptides, and nucleic acid molecules encoding such antibodies. In certain aspects an antibody of the embodiments binds an epitope having an amino acid sequence of FLSRPTEKTI (SEQ ID NO:13), KRDPCPHQVD (SEQ ID NO:14), or LSAVYTCKR (SEQ ID NO:15). In a particular aspect an antibody binds an epitope having an amino acid sequence of FLSRPTEKTI (SEQ ID NO:13).

[0022] In further embodiments the antibodies for use according to the embodiments can be any of those described in international (PCT) patent publication no. WO 2015,027120, which is incorporated herein by reference. In one embodiment, the invention provides an isolated antibody which specifically binds to hemichannels, comprising a heavy chain having an amino acid sequence of SEQ ID NO:2 and a light chain having an amino acid sequence of SEQ ID NO:4.

[0023] In certain aspects a first heavy chain region comprises an amino acid sequence having an amino acid sequence of residues 13 to 37 of SEQ ID NO:2; a second heavy chain region having an amino acid sequence corresponding to residues 46 to 66 of SEQ ID NO:2; and a third heavy chain region comprising an amino acid sequence having an amino acid sequence of residues 97 to 116 of SEQ ID NO:2.

[0024] In another aspect a first light chain region comprises an amino acid sequence having an amino acid sequence of residues 9 to 40 of SEQ ID NO:4; a second light chain region having an amino acid sequence corresponding to residues 49 to 58 of SEQ ID NO:4; and a third light chain region comprising an amino acid sequence having an amino acid sequence of residues 64 to 108 of SEQ ID NO:4.

[0025] In one embodiment, the invention provides an isolated antibody which specifically binds to hemichannels and gap junctions, comprising a heavy chain having an amino acid sequence of SEQ ID NO:6 and a light chain having an amino acid sequence of SEQ ID NO:8.

[0026] In certain aspects a first heavy chain region comprises an amino acid sequence having an amino acid sequence of residues 13 to 37 of SEQ ID NO:6; a second heavy chain region having an amino acid sequence corresponding to residues 46 to 66 of SEQ ID NO:6; and a third heavy chain region comprising an amino acid sequence having an amino acid sequence of residues 97 to 116 of SEQ ID NO:6.

[0027] In another aspect a first light chain region comprises an amino acid sequence having an amino acid sequence of residues 9 to 42 of SEQ ID NO:8; a second light chain region having an amino acid sequence corresponding to residues 51 to 60 of SEQ ID NO:8; and a third light chain region comprising an amino acid sequence having an amino acid sequence of residues 66 to 125 of SEQ ID NO:8.

[0028] In one embodiment, the invention provides an isolated antibody which specifically binds to gap junctions, comprising a heavy chain having an amino acid sequence of SEQ ID NO:10 and a light chain having an amino acid sequence of SEQ ID NO:12.

[0029] In certain aspects a first heavy chain region comprises an amino acid sequence having an amino acid sequence of residues 10 to 34 of SEQ ID NO:10; a second heavy chain region having an amino acid sequence corresponding to residues 43 to 59 of SEQ ID NO:10; and a third heavy chain region comprising an amino acid sequence having an amino acid sequence of residues 94 to 109 of SEQ ID NO:10.

[0030] In another aspect a first light chain region comprises an amino acid sequence having an amino acid sequence of residues 9 to 40 of SEQ ID NO:12; a second light chain region having an amino acid sequence corresponding to residues 49 to 58 of SEQ ID NO:12;

and a third light chain region comprising an amino acid sequence having an amino acid sequence of residues 64 to 108 of SEQ ID NO:12.

[0031] In certain aspects antibodies include full length antibodies, antibody fragments, single chain antibodies, bispecific antibodies, minibodies, domain antibodies, synthetic antibodies and antibody fusions, and fragments thereof.

[0032] A further embodiment provides a pharmaceutical composition comprising an antibody as described herein with a pharmaceutically acceptable carrier. Also provided is an antibody or a pharmaceutical composition of the invention for use as a medicament or for use in therapy for cancer and to inhibit cancer metastasis.

[0033] A further embodiment provides a method of treating or preventing cancer metastasis. A method of treating can comprise administering to a subject in need thereof an effective amount of an isolated antibody described herein. Also provided is the use of an antibody as described herein in the manufacture of a medicament for the treatment or prevention of cancer metastasis.

[0034] Certain aspects are directed to *in vitro* methods of using an antibody, compounds or reagents to suppress inflamatory reactions in chondrocytes. In certain aspects methods are directed to determining the effect on inhibition of Cx43 hemichannel opening in chondrocytes by (i) determining hemichannel opening by dye uptake assay, using Lucifer yellow or Alexa dyes, (ii) assessing inhibitory effects on hemichannels opening by IL-1β, (iii) test inhibitory effects of the reagents on hemichannels opening by mechanical loading in the form of fluid flow shear stress.

[0035] Certain aspects are directed to methods of determining the effect of an antibody, compounds or reagents on suppressing of inflammatory responses evoked by IL-1 β and mechanical loading by (i) determining the inhibition of activation of nuclear factor-kappaB (NF-κB) induced by IL-1β, (ii) determining the inhibition of activation of NF-κB induced by fluid flow shear stress.

[0036] Other aspects are directed to an *in vivo* method of using a monoclonal antibody, compounds or reagents to treat OA or identify the same comprising (i) injecting antibody, compound or reagent into knee cap cavity, (ii) assessing the inhibition of activation of NF-κB

induced by IL-1β, (iii) assessing OA development by X-ray, histological analysis and physical movement.

[0037] As used herein, the term "antigen" is a molecule capable of being bound by an antibody or T-cell receptor. In certain embodiments, binding moieties other than antibodies and be engineered to specifically bind to an antigen, e.g., aptamers, avimers, and the like.

[0038] The term "antibody" or "immunoglobulin" is used to include intact antibodies and binding fragments/segments thereof. As used herein, the term "antibody" is intended to refer broadly to any immunologic binding agent, such as IgG, IgM, IgA, IgD, IgE, and genetically modified IgG as well as polypeptides comprising antibody CDR domains that retain antigen binding activity. The antibody may be selected from the group consisting of a chimeric antibody, an affinity matured antibody, a polyclonal antibody, a monoclonal antibody, a humanized antibody, a human antibody, or an antigen-binding antibody fragment or a natural or synthetic ligand. Typically, fragments compete with the intact antibody from which they were derived for specific binding to an antigen. Fragments include separate heavy chains, light chains, Fab, Fab' F(ab')2, Fabc, and Fv. Fragments/segments are produced by recombinant DNA techniques, or by enzymatic or chemical separation of intact immunoglobulins. The term "antibody" also includes one or more immunoglobulin chains that are chemically conjugated to, or expressed as, fusion proteins with other proteins. The term "antibody" also includes bispecific antibodies. A bispecific or bifunctional antibody is an artificial hybrid antibody having two different heavy/light chain pairs and two different binding sites. Bispecific antibodies can be produced by a variety of methods including fusion of hybridomas or linking of Fab' fragments. See, e.g., Songsivilai and Lachmann, *Clin Exp Immunol* 79:315-21, 1990; Kostelny et al., *J. Immunol.* 148:1547–53, 1992.

[0039] The term "isolated" can refer to a nucleic acid or polypeptide that is substantially free of cellular material, bacterial material, viral material, or culture medium (when produced by recombinant DNA techniques) of their source of origin, or chemical precursors or other chemicals (when chemically synthesized). Moreover, an isolated compound refers to one that can be administered to a subject as an isolated compound; in other words, the compound may not simply be considered "isolated" if it is adhered to a column or embedded in an agarose gel. Moreover, an "isolated nucleic acid fragment" or "isolated peptide" is a nucleic acid or protein fragment that is not naturally occurring as a fragment and/or is not typically in the functional state.

[0040] Moieties of the invention, such as polypeptides, peptides, antigens, or immunogens, may be conjugated or linked covalently or noncovalently to other moieties such as adjuvants, proteins, peptides, supports, fluorescence moieties, or labels. The term "conjugate" or "immunoconjugate" is broadly used to define the operative association of one moiety with another agent and is not intended to refer solely to any type of operative association, and is particularly not limited to chemical "conjugation."

[0041] The term "providing" is used according to its ordinary meaning "to supply or furnish for use." In some embodiments, the protein is provided directly by administering the protein, while in other embodiments, the protein is effectively provided by administering a nucleic acid that encodes the protein. In certain aspects the invention contemplates compositions comprising various combinations of nucleic acid, antigens, peptides, and/or epitopes.

[0042] The phrase "specifically binds" or "specifically immunoreactive" to a target refers to a binding reaction that is determinative of the presence of the molecule in the presence of a heterogeneous population of other biologics. Thus, under designated immunoassay conditions, a specified molecule binds preferentially to a particular target and does not bind in a significant amount to other biologics present in the sample. Specific binding of an antibody to a target under such conditions requires the antibody be selected for its specificity to the target. A variety of immunoassay formats may be used to select antibodies specifically immunoreactive with a particular protein. For example, solid-phase ELISA immunoassays are routinely used to select monoclonal antibodies specifically immunoreactive with a protein. See, e.g., Harlow and Lane, Antibodies: A Laboratory Manual, Cold Spring Harbor Press, 1988, for a description of immunoassay formats and conditions that can be used to determine specific immunoreactivity.

[0043] Other embodiments of the invention are discussed throughout this application. Any embodiment discussed with respect to one aspect of the invention applies to other aspects of the invention as well and vice versa. Each embodiment described herein is understood to be embodiments of the invention that are applicable to all aspects of the invention. It is contemplated that any embodiment discussed herein can be implemented with respect to any method or composition of the invention, and vice versa. Furthermore, compositions and kits of the invention can be used to achieve methods of the invention.

[0044] The use of the word "a" or "an" when used in conjunction with the term "comprising" in the claims and/or the specification may mean "one," but it is also consistent with the meaning of "one or more," "at least one," and "one or more than one."

[0045] Throughout this application, the term "about" is used to indicate that a value includes the standard deviation of error for the device or method being employed to determine the value.

[0046] The use of the term "or" in the claims is used to mean "and/or" unless explicitly indicated to refer to alternatives only or the alternatives are mutually exclusive, although the disclosure supports a definition that refers to only alternatives and "and/or."

[0047] As used in this specification and claim(s), the words "comprising" (and any form of comprising, such as "comprise" and "comprises"), "having" (and any form of having, such as "have" and "has"), "including" (and any form of including, such as "includes" and "include") or "containing" (and any form of containing, such as "contains" and "contain") are inclusive or open-ended and do not exclude additional, unrecited elements or method steps.

[0048] Other objects, features and advantages of the present invention will become apparent from the following detailed description. It should be understood, however, that the detailed description and the specific examples, while indicating specific embodiments of the invention, are given by way of illustration only, since various changes and modifications within the spirit and scope of the invention will become apparent to those skilled in the art from this detailed description.

DESCRIPTION OF THE DRAWINGS

[0049] The following drawings form part of the present specification and are included to further demonstrate certain aspects of the present invention. The invention may be better understood by reference to one or more of these drawings in combination with the detailed description of the specification embodiments presented herein.

[0050] FIG. 1 – Cx43 is normally localized into gap junctions between cells or as hemichannels on the plasma membrane. In side A) Pathological opening of Cx43 hemichannels result in propagation of secondary injury, activation of astro/microglia, and inflammation. Side B) illustrates the proposal that preventing pathological opening of Cx43

hemichannels prevents release of molecules, enabling astrocytes to act as caretaker cells and prevent further spread of secondary injury.

[0051] FIG. 2 – The activation of Cx43 hemichannels by IL-1β in human primary astrocytes was inhibited by both Cx43 hemichannel blocking mouse monoclonal antibody (M1) and mouse-human chimeric antibody HMAb1 (these antibodies comprise the same murine variable domains and CDRs). The hemichannel activity was determined by ethidium bromide uptake.

[0052] FIGS. 3A-3G – Mice were subjected to a single SCI and treated 30 minutes after injury with IP saline, control IgG, or HMAb1 (25 mg/kg). Glial scarring was measured at 14 and 56 days after injury. **(A-F)** Representative images of spinal cords in mice treated with **(A-C)** control IgG or **(D-F)** HMAb1 that were subjected to immunohistochemistry for the astrocyte marker GFAP. The lesion boundary is indicated with a dotted white line. **(G)** GFAP immunolabeling was quantified as the mean intensity multiplied by area of positive stain. Results are expressed as a percentage of Sham surgery, IgG treated mice. Results are averages with SEM. *$p<0.05$, ***$p<0.001$ compared to Igg w/ Tukey's HSD n=3-4.

[0053] FIGS. 4A-4C – Mice were subjected to SCI and treated with IgG or anti-Cx43 antibody (M1) at 30 minutes post injury. Two weeks after injury, tissue sections were analyzed for expression of the astrocyte marker GFAP. Representative images of spinal cord in **(A)** IgG treated or **(B)** M1-treated mice. The white dotted line marks the area of lesion. **C)** Quantification of images from n=3-5 mice shows averages with SEM of GFAP immunolabeling in sections. *significance tested using 2-way ANOVA then Tukey's HSD.

[0054] FIGS. 5A-5B – HMAb1 treatment improved the recovery of physical activity and coordination after SCI. Mice were subjected to a single SCI and treated 30 minutes after injury with IP saline, control IgG, or human-mouse chimeric anti-Cx43 antibody (HMAb1) (25 mg/kg). Behavioral measurements are in mice with a BMS score of 0-3 at the 6 hour time point after injury. **(A)** BMS: Hind limb function; 0=no hind limb function and 9=completely normal hind limb function. **(B)** Rotarod: Mice were tested for the ability to remain on an accelerating rotarod for up to 300 seconds to measure motor coordination. Results are averages with SEM. *$p<0.05$, **$p<0.01$, ***$p<0.001$ compared to Igg w/ Tukey's HSD.

[0055] FIGS. 6A-6G – Mice were subjected to a single SCI and treated 30 minutes after injury with IP saline, control Igg, or HMAb1 (25 mg/kg). Neuronal dendrites were

measured by immunolabeling against the neuronal marker MAP2. **(A-F)** Representative images of spinal cords in mice treated with **(A-C)** control IgG or **(D-F)** HMAb1 that were subjected to immunohistochemistry. The lesion boundary is indicated with a dotted white line. **(G)** MAP2 immunolabeling was quantified as the mean intensity multiplied by area of positive stain. Results are expressed as a percentage of Sham surgery, IgG treated mice. Results are averages with SEM. *p<0.05, **p<0.001 with Tukey's HSD, n=3-4.

[0056] FIG. 7A-7G – Mice were subjected to a single SCI and treated 30 minutes after injury with IP saline, control Igg, or HMAb1 (25 mg/kg). Neuronal nuclei were measured by immunolabeling against the neuronal marker NeuN. **(A-F)** Representative images of spinal cords in mice treated with **(A-C)** control IgG or **(D-F)** HMAb1 that were subjected to immunohistochemistry. The lesion boundary is indicated with a dotted white line. **(G)** NeuN immunolabeling was quantified as the mean intensity multiplied by area of positive stain. Results are expressed as a percentage of Sham surgery, IgG treated mice.

[0057] FIGS. 8A-8C – Breast cancer growth in bone was suppressed by human-mouse chimeric anti-Cx43 antibody HMAb2 (this antibody comprises the same murine variable domains and CDRs as the "M2" antibody). Py8119-Luc cells were injected into right tibias of control and cKO female mice. The left tibias were injected with PBS as controls. **(A)** The tumor growth was recorded every week for 4 weeks by bioluminescence imaging and quantified. Data are presented as means±SEM. **, $P<0.01$. n=7 per group. **(B)** Representative images of Cx43 cKO mice with tumor spread to the lungs and to the brain shown with white arrowheads. **(C)** Representative X-ray radiographs with tibia injected with Py8119 cells indicate where the tumor cells were injected and osteolytic lesions occurred (arrowheads). The left tibias injected with PBS showed no osteolytic lesions.

[0058] FIGS. 9A-9B – Cx43 hemichannels in MLO-Y4 osteocytes **(A)** or primary mouse osteocytes **(B)** were activated by HMAb2, but blocked by HMAb1. The cells were incubated with E2 (polyclonal), HMAb1 and HMAb2 antibody or carbenoxolone (CBX), a connexin channel blocker. Ethium bromide (EtBr) dye uptake assay was performed. Data presented as SEM. Compared to basal control, ***, $P<0.001$.

[0059] FIGS. 10A-10B – Activation of Hemichannels by MHAb2 in Osteocytes *in vivo*. Evans blue dye was injected into tail vein of WT mice and 25 μg/ml MHAb2 was IP injected. Mice were sacrificed two hours after injection and perfused with PBS. Tibias were

isolated and fixed tibial bone tissue sections were prepared. **(A)** Presence of antibodies was detected with rhodamine-conjugated anti-human IgG. Bar, 50 μm. **(B)** Dye uptake was measured in cortical and trabecular bones by Evans blue (EB) fluorescence and quantified. *, $P<0.05$; ***, $P<0.001$.

[0060] FIGS. 11A-11C – HMAb2 suppresses osteolytic growth of breast cancer cells and protects bone from fractures. (A) Py8119-Luc breast cancer cells were injected into tibias of female mice. **(B)** HMAb2 at 25 mg/kg was i.p. injected either once or twice per week for four weeks. Saline was injected twice per week in control mice. The tumor growth was recorded every week for 4 weeks by bioluminescence imaging and quantified (lower panel). Data are presented as means±SEM. n=6 for HMAb2 and saline. **(C)** The MHAb2 or saline injected mice were imaged by X-ray. *, $P<0.05$.

[0061] FIG. 12 – Cx43 is abundantly expressed in chondrocytes. Primary chondrocytes isolated from mouse bone were immunostained with anti-Cx43 antibody against C-terminal domain (Total) in permeable cells and Cx43E2 antibody in non-permeable cells.

[0062] FIG. 13 – HMAb1 blocked Cx43 hemichannels in chondrocytes. Primary chondrocytes isolated from mouse bone were pre-treated with carbenoxolone (connexin channel blocker) or HMAb1 antibody and then treated with or without IL-1β. Ethidium bromide dye uptake assay was performed to determine hemichannel activity.

[0063] FIG. 14 – HMAb1 blocked hemichannel activity in mouse chondrocytes *in vivo*. Evans blue dye was injected into tail vein of WT mice. Cx43(M1) mAb (25 mg/kg) was i.p. injected 2 hrs before dye injection. 30 min after dye injection, left tibias were mechanically loaded once for 10 min. Dye uptake was measured by Evans blue (EB) fluorescence and quantified. $P<0.001$. n=3.

[0064] FIG. 15 - Both HMAb2 and HAb2 antibodies recognize Cx43 and bind Cx43 on osteocyte cell surface. (A) Parental HeLa or HeLa cells expressing Cx43 were immunolabeled with HMAb2 (MHC2) or HAb2 (HC2) antibody. **(B)** Non-permeable osteocyte MLO-Y4 cells were immunofluoresently labeled with anti-HMAb2 (MHC2) or HAb2 (HC2) antibody.

[0065] FIG. 16 - Dose-dependent inhibition of osteolytic breast cancer growth by MHAb2. Py8119-Luc breast cancer cells were injected into tibias of female mice. HMAb2 at 5, 15 and 25 mg/kg was i.p. injected once per week for four weeks. Saline was injected once per week in control mice. The tumor growth was recorded every week for 4 weeks by bioluminescence imaging and quantified. Data are presented as means ± SEM. n=6 for HMAb2 and saline. *, $P<0.05$.

[0066] FIGS. 17A-17D - HMAb2 increases trabecular bone mass, volume and thickness. 4 month-old mice were i.p. injected with 25 mg/kg HMAb2 antibody or saline once a week for two weeks. The bone parameters, **(A)** bone volume; **(B)** Trabecular thickness; **(C)** trabecular number; and **(D)** bone mineral density (BMD) were determined by mciroCT imaging and quantified. Data are presented as means±SEM. n=6; *, $P<0.05$; **, $P<0.01$.

[0067] FIGS. 18A-18B - Inhibition of osteolytic human breast cancer growth by MHAb2. (A) MDA-MB231 human breast cancer cells were injected into tibias of female immune-compromised nude mice. HMAb2 at 25 mg/kg was i.p. injected once per week for 7 weeks. Saline or human IgG was injected once per week in control mice. The tumor growth was recorded every week for 7 weeks by bioluminescence imaging and quantified. Data are presented as means±SEM. n=6. *, $P<0.05$. **(B)** Mice were sacrificed after 7 weeks and tumors were isolated.

[0068] FIG. 19 - MHAb1 suppresses inflammatory response by inhibiting nuclear translocation of NF-kB. Primary mouse chondrocytes were treated with or without interleukin (IL) 1β and MHAb1, fixed and immunolabeled with antibody NF-kB antibody and countered labeled with FITC-WGA. The merged images are shown in right panels.

DESCRIPTION

[0069] Various cells are able to communicate with each other and with the extracellular environment through hemichannels and gap junctions formed by the protein connexin. Connexin proteins are ubiquitously expressed throughout the body. Six connexin proteins make up one hemichannel, and 2 hemichannels make up 1 gap junction channel. Gap junctions are a cluster of channels that are located in the plasma membrane between adjoining cells and they mediate intercellular communication. Hemichannels are a separate entity from gap junction channels. Hemichannels permit the exchange of molecules between the intracellular compartments and the extracellular environment.

[0070] Osteocytes express hemichannels known as connexin (Cx) 43 hemichannels. These osteocyte hemichannels are normally closed and can be opened when exposed to mechano-stimulation, which leads to the release of various factors into the bone microenvironment. The factors released by hemichannel opening can mediate other processes that can decrease tumor cell migration and bone metastasis.

[0071] Certain embodiments are directed to methods of identifying reagents that modulate the opening of connexin hemichannels. In certain aspects, the methods identify compounds or drugs that positively modulate the opening of connexin hemichannels. Other embodiments are directed to methods of treating cancer by administering a compound that open hemichannels to a patient having cancer, such as breast cancer or prostate cancer. In certain aspects, the patient has a primary tumor. In certain aspects, compounds that open Cx43 hemichannels can be used to inhibit or reduce metastasis to the bone. In other aspects, compounds that open Cx43 channels are used to treat osteoporosis, osteopenia, or osteosarcoma.

[0072] Cancer metastasis occurs when a cancer spreads from the part of the body where it originated (*e.g.*, breast or prostate) to other parts of the body (e.g., liver or bone) and establishes a secondary tumor. The bone is one of the most common sites of cancer metastasis. Cancers that metastasize to bone include, but are not limited to breast cancer, prostate cancer, lung cancer, and skin cancers (e.g., melanoma). Bone metastasis can be identified in up to 75% of patients with advanced breast and prostate cancers. Bone metastasis (mets) are associated with many significant clinical and quality of life consequences, such as, but not limited to intractable pain, pathological fractures, spinal cord and nerve compression, bone marrow infiltration, and impaired motility. In many cases the systemic presence of a cancer can also make the cancer incurable.

[0073] Normal bone is made up of three major cell types: bone-forming osteoblasts, bone-resorbing osteoclasts, and osteocytes. Osteocytes make up approximately 95% of bone cells and maintain the bone remodeling process by coordinating osteolytic and osteoblastic activities. When cancer cells invade the bone, many of the normal bone functions are affected. Cancer cells interact with the local microenvironment to promote cancer cell survival via bone destruction and vascularization.

[0074] Cx43 hemichannels in osteocytes have been shown to open by treatment with alendronate (AD), an efficacious and commonly used bisphosphonate drug. Bisphosphonates are a class of drugs known for treating many bone disorders including bone metastasis. Powles et al. have shown administration of bisphosphonates to be associated with a decrease in the incidence of bone metastasis and a decrease in death rate in patients with breast cancer. AD has been associated with decreased tumor growth as well as reduced bone destruction and pain. AD inhibits osteoclast activity and induces the opening of Cx43 hemichannels in osteocytes (Plotkin et al., 2002). However, AD administration is accompanied by multiple, severe side-effects.

I. ANTIBODIES

[0075] Certain aspects of the invention are directed to antibodies that modulate, positively or negatively, the function of hemichannels. An example of identifying and isolating a monoclonal antibody is described below.

[0076] The term "CDR" as used herein refers to a Complementarity Determining Region of an antibody variable domain. Systematic identification of residues included in the CDRs have been developed by Kabat et al. (1991, Sequences of Proteins of Immunological Interest, 5th Ed., United States Public Health Service, National Institutes of Health, Bethesda). Variable light chain (VL) CDRs are herein defined to include residues at positions 27-32 (CDR1), 50-56 (CDR2), and 91-97 (CDR3). Variable heavy chain (VH) CDRs are herein defined to include residues at positions 27-33 (CDR1), 52-56 (CDR2), and 95-102 (CDR3).

[0077] As will be appreciated by those in the art, the CDRs disclosed herein may also include variants. Generally, the amino acid identity between individual variant CDRs is at least 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% . Thus, a "variant CDR" is one with the specified identity to the parent CDR of the invention, and shares biological function, including, but not limited to, at least 80%, 81%, 82%, 83%, 84%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, or 99% of the specificity and/or activity of the parent CDR.

[0078] While the site or region for introducing an amino acid sequence variation is predetermined, the mutation per se need not be predetermined. For example, in order to optimize the performance of a mutation at a given site, random mutagenesis may be conducted at the target codon or region and the expressed antigen binding protein CDR variants screened

for the optimal combination of desired activity. Techniques for making substitution mutations at predetermined sites in DNA having a known sequence are well known, for example, M13 primer mutagenesis and PCR mutagenesis. Screening of the mutants is done using assays of antigen binding protein activities as described herein.

[0079] Amino acid substitutions are typically of single residues; insertions usually will be on the order of from about one (1) to about twenty (20) amino acid residues, although considerably larger insertions may be tolerated. Deletions range from about one (1) to about twenty (20) amino acid residues, although in some cases deletions may be much larger.

[0080] Substitutions, deletions, insertions or any combination thereof may be used to arrive at a final derivative or variant. Generally these changes are done on a few amino acids to minimize the alteration of the molecule, particularly the immunogenicity and specificity of the antigen binding protein. However, larger changes may be tolerated in certain circumstances.

[0081] By "Fab" or "Fab region" as used herein is meant the polypeptide that comprises the VH, CH1, VL, and CL immunoglobulin domains. Fab may refer to this region in isolation, or this region in the context of a full length antibody, antibody fragment or Fab fusion protein, or any other antibody embodiments as outlined herein.

[0082] By "Fv" or "Fv fragment" or "Fv region" as used herein is meant a polypeptide that comprises the VL and VH domains of a single antibody.

[0083] By "framework" as used herein is meant the region of an antibody variable domain exclusive of those regions defined as CDRs. Each antibody variable domain framework can be further subdivided into the contiguous regions separated by the CDRs (FR1, FR2, FR3 and FR4).

[0084] The term "antigen-binding portion" of an antibody (or simply "antibody portion"), as used herein, refers to one or more fragments of an antibody that retain the ability to specifically bind to an antigen (e.g., hemichannel). It has been shown that the antigen-binding function of an antibody can be performed by fragments of a full-length antibody. Examples of binding fragments encompassed within the term "antigen-binding portion" of an antibody include (i) a Fab fragment, a monovalent fragment consisting of the VL/VK, VH, CL and CH1 domains; (ii) a F(ab')2 fragment, a bivalent fragment comprising two Fab fragments linked by a disulfide bridge at the hinge region; (iii) a Fab′ fragment, which is essentially an

Fab with part of the hinge region (see, FUNDAMENTAL IMMUNOLOGY (Paul ed., 3rd ed. 1993); (iv) a Fd fragment consisting of the VH and CH1 domains; (v) a Fv fragment consisting of the VL and VH domains of a single arm of an antibody; (vi) a dAb fragment (Ward et al., (1989) Nature 341:544-546), which consists of a VH domain; (vii) an isolated complementarity determining region (CDR); and (viii) a nanobody, a heavy chain variable region containing a single variable domain and two constant domains.

[0085] The term "specifically binds" (or "immunospecifically binds") is not intended to indicate that an antibody binds exclusively to its intended target. Rather, an antibody "specifically binds" if its affinity for its intended target is about 5-fold greater when compared to its affinity for a non-target molecule. Suitably there is no significant cross-reaction or cross-binding with undesired substances. The affinity of the antibody will, for example, be at least about 5 fold, such as 10 fold, such as 25-fold, especially 50-fold, and particularly 100-fold or more, greater for a target molecule than its affinity for a non-target molecule. In some embodiments, specific binding between an antibody or other binding agent and an antigen means a binding affinity of at least 10^6 M^{-1}. Antibodies may, for example, bind with affinities of at least about 10^7 M^{-1}, such as between about 10^8 M^{-1} to about 10^9 M^{-1}, about 10^9 M^{-1} to about 10^{10} M^{-1}, or about $10^{10}M^{-1}$ to about 10^{11} M^{-1}. Antibodies may, for example, bind with an EC_{50} of 50 nM or less, 10 nM or less, 1 nM or less, 100 pM or less, or more preferably 10 pM or less.

[0086] In certain embodiments, an antibody or a fragment thereof that binds to at least a portion of Cx43 protein and inhibits Cx43 signaling and cancer cell proliferation are contemplated. Preferably, the anti-Cx43 antibody is a monoclonal antibody or a humanized antibody. Thus, by known means and as described herein, polyclonal or monoclonal antibodies, antibody fragments, and binding domains and CDRs (including engineered forms of any of the foregoing) may be created that are specific to Cx43 protein, one or more of its respective epitopes, or conjugates of any of the foregoing, whether such antigens or epitopes are isolated from natural sources or are synthetic derivatives or variants of the natural compounds.

[0087] Examples of antibody fragments suitable for the present embodiments include, without limitation: (i) the Fab fragment, consisting of V_L, V_H, C_L, and C_{H1} domains; (ii) the "Fd" fragment consisting of the V_H and C_{H1} domains; (iii) the "Fv" fragment consisting of the V_L and V_H domains of a single antibody; (iv) the "dAb" fragment, which consists of a V_H

domain; (v) isolated CDR regions; (vi) F(ab')2 fragments, a bivalent fragment comprising two linked Fab fragments; (vii) single chain Fv molecules ("scFv"), wherein a V_H domain and a V_L domain are linked by a peptide linker that allows the two domains to associate to form a binding domain; (viii) bi-specific single chain Fv dimers (see U.S. Pat. No. 5,091,513); and (ix) diabodies, multivalent or multispecific fragments constructed by gene fusion (US Patent App. Pub. 20050214860). Fv, scFv, or diabody molecules may be stabilized by the incorporation of disulphide bridges linking the V_H and V_L domains. Minibodies comprising a scFv joined to a CH3 domain may also be made (Hu *et al.*, 1996).

[0088] Antibody-like binding peptidomimetics are also contemplated in embodiments. Liu *et al.* (2003) describe "antibody like binding peptidomimetics" (ABiPs), which are peptides that act as pared-down antibodies and have certain advantages of longer serum half-life as well as less cumbersome synthesis methods.

[0089] Animals may be inoculated with an antigen, such as a Cx43 extracellular domain protein, in order to produce antibodies specific for Cx43 protein. Frequently an antigen is bound or conjugated to another molecule to enhance the immune response. As used herein, a conjugate is any peptide, polypeptide, protein, or non-proteinaceous substance bound to an antigen that is used to elicit an immune response in an animal. Antibodies produced in an animal in response to antigen inoculation comprise a variety of non-identical molecules (polyclonal antibodies) made from a variety of individual antibody producing B lymphocytes. A polyclonal antibody is a mixed population of antibody species, each of which may recognize a different epitope on the same antigen. Given the correct conditions for polyclonal antibody production in an animal, most of the antibodies in the animal's serum will recognize the collective epitopes on the antigenic compound to which the animal has been immunized. This specificity is further enhanced by affinity purification to select only those antibodies that recognize the antigen or epitope of interest.

[0090] A monoclonal antibody is a single species of antibody wherein every antibody molecule recognizes the same epitope because all antibody producing cells are derived from a single B-lymphocyte cell line. The methods for generating monoclonal antibodies (MAbs) generally begin along the same lines as those for preparing polyclonal antibodies. In some embodiments, rodents such as mice and rats are used in generating monoclonal antibodies. In some embodiments, rabbit, sheep, or frog cells are used in generating monoclonal antibodies.

The use of rats is well known and may provide certain advantages. Mice (*e.g.*, BALB/c mice) are routinely used and generally give a high percentage of stable fusions.

[0091] Hybridoma technology involves the fusion of a single B lymphocyte from a mouse previously immunized with a Cx43 antigen with an immortal myeloma cell (usually mouse myeloma). This technology provides a method to propagate a single antibody-producing cell for an indefinite number of generations, such that unlimited quantities of structurally identical antibodies having the same antigen or epitope specificity (monoclonal antibodies) may be produced.

[0092] Plasma B cells may be isolated from freshly prepared rabbit peripheral blood mononuclear cells of immunized rabbits and further selected for Cx43 binding cells. After enrichment of antibody producing B cells, total RNA may be isolated and cDNA synthesized. DNA sequences of antibody variable regions from both heavy chains and light chains may be amplified, constructed into a phage display Fab expression vector, and transformed into E. coli. Cx43 specific binding Fab may be selected out through multiple rounds enrichment panning and sequenced. Selected Cx43 binding hits may be expressed as full length IgG in rabbit and rabbit/human chimeric forms using a mammalian expression vector system in human embryonic kidney (HEK293) cells (Invitrogen) and purified using a protein G resin with a fast protein liquid chromatography (FPLC) separation unit.

[0093] In one embodiment, the antibody is a chimeric antibody, for example, an antibody comprising antigen binding sequences from a non-human donor grafted to a heterologous non-human, human, or humanized sequence (*e.g.*, framework and/or constant domain sequences). Methods have been developed to replace light and heavy chain constant domains of the monoclonal antibody with analogous domains of human origin, leaving the variable regions of the foreign antibody intact. Alternatively, "fully human" monoclonal antibodies are produced in mice transgenic for human immunoglobulin genes. Methods have also been developed to convert variable domains of monoclonal antibodies to more human form by recombinantly constructing antibody variable domains having both rodent, for example, mouse, and human amino acid sequences. In "humanized" monoclonal antibodies, only the hypervariable CDR is derived from mouse monoclonal antibodies, and the framework and constant regions are derived from human amino acid sequences (see U.S. Pat. Nos. 5,091,513 and 6,881,557). It is thought that replacing amino acid sequences in the antibody that are characteristic of rodents with amino acid sequences found in the corresponding position

of human antibodies will reduce the likelihood of adverse immune reaction during therapeutic use. A hybridoma or other cell producing an antibody may also be subject to genetic mutation or other changes, which may or may not alter the binding specificity of antibodies produced by the hybridoma.

[0094] Methods for producing polyclonal antibodies in various animal species, as well as for producing monoclonal antibodies of various types, including humanized, chimeric, and fully human, are well known in the art and highly predictable. For example, the following U.S. patents and patent applications provide enabling descriptions of such methods: U.S. Patent Application Nos. 2004/0126828 and 2002/0172677; and U.S. Pat. Nos. 3,817,837; 3,850,752; 3,939,350; 3,996,345; 4,196,265; 4,275,149; 4,277,437; 4,366,241; 4,469,797; 4,472,509; 4,606,855; 4,703,003; 4,742,159; 4,767,720; 4,816,567; 4,867,973; 4,938,948; 4,946,778; 5,021,236; 5,164,296; 5,196,066; 5,223,409; 5,403,484; 5,420,253; 5,565,332; 5,571,698; 5,627,052; 5,656,434; 5,770,376; 5,789,208; 5,821,337; 5,844,091; 5,858,657; 5,861,155; 5,871,907; 5,969,108; 6,054,297; 6,165,464; 6,365,157; 6,406,867; 6,709,659; 6,709,873; 6,753,407; 6,814,965; 6,849,259; 6,861,572; 6,875,434; and 6,891,024. All patents, patent application publications, and other publications cited herein and therein are hereby incorporated by reference in the present application.

[0095] Antibodies may be produced from any animal source, including birds and mammals. Preferably, the antibodies are ovine, murine (*e.g.*, mouse and rat), rabbit, goat, guinea pig, camel, horse, or chicken. In addition, newer technology permits the development of and screening for human antibodies from human combinatorial antibody libraries. For example, bacteriophage antibody expression technology allows specific antibodies to be produced in the absence of animal immunization, as described in U.S. Pat. No. 6,946,546, which is incorporated herein by reference. These techniques are further described in: Marks (1992); Stemmer (1994); Gram *et al.* (1992); Barbas *et al.* (1994); and Schier *et al.* (1996).

[0096] It is fully expected that antibodies to Cx43 will have the ability to neutralize or counteract the effects of Cx43 regardless of the animal species, monoclonal cell line, or other source of the antibody. Certain animal species may be less preferable for generating therapeutic antibodies because they may be more likely to cause allergic response due to activation of the complement system through the "Fc" portion of the antibody. However, whole antibodies may be enzymatically digested into "Fc" (complement binding) fragment, and into antibody fragments having the binding domain or CDR. Removal of the Fc portion

reduces the likelihood that the antigen antibody fragment will elicit an undesirable immunological response, and thus, antibodies without Fc may be preferential for prophylactic or therapeutic treatments. As described above, antibodies may also be constructed so as to be chimeric or partially or fully human, so as to reduce or eliminate the adverse immunological consequences resulting from administering to an animal an antibody that has been produced in, or has sequences from, other species.

[0097] Substitutional variants typically contain the exchange of one amino acid for another at one or more sites within the protein, and may be designed to modulate one or more properties of the polypeptide, with or without the loss of other functions or properties. Substitutions may be conservative, that is, one amino acid is replaced with one of similar shape and charge. Conservative substitutions are well known in the art and include, for example, the changes of: alanine to serine; arginine to lysine; asparagine to glutamine or histidine; aspartate to glutamate; cysteine to serine; glutamine to asparagine; glutamate to aspartate; glycine to proline; histidine to asparagine or glutamine; isoleucine to leucine or valine; leucine to valine or isoleucine; lysine to arginine; methionine to leucine or isoleucine; phenylalanine to tyrosine, leucine or methionine; serine to threonine; threonine to serine; tryptophan to tyrosine; tyrosine to tryptophan or phenylalanine; and valine to isoleucine or leucine. Alternatively, substitutions may be non-conservative such that a function or activity of the polypeptide is affected. Non-conservative changes typically involve substituting a residue with one that is chemically dissimilar, such as a polar or charged amino acid for a nonpolar or uncharged amino acid, and vice versa.

[0098] Proteins may be recombinant, or synthesized *in vitro*. Alternatively, a non-recombinant or recombinant protein may be isolated from bacteria. It is also contemplated that a bacteria containing such a variant may be implemented in compositions and methods. Consequently, a protein need not be isolated.

[0099] It is contemplated that in compositions there is between about 0.001 mg and about 10 mg of total polypeptide, peptide, and/or protein per ml. Thus, the concentration of protein in a composition can be about, at least about or at most about 0.001, 0.010, 0.050, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, 5.0, 5.5, 6.0, 6.5, 7.0, 7.5, 8.0, 8.5, 9.0, 9.5, 10.0 mg/ml or more (or any range derivable therein). Of this, about, at least about, or at most about 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45,

46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74, 75, 76, 77, 78, 79, 80, 81, 82, 83, 84, 85, 86, 87, 88, 89, 90, 91, 92, 93, 94, 95, 96, 97, 98, 99, or 100% may be an antibody that binds Cx43.

[00100] An antibody or preferably an immunological portion of an antibody, can be chemically conjugated to, or expressed as, a fusion protein with other proteins. For purposes of this specification and the accompanying claims, all such fused proteins are included in the definition of antibodies or an immunological portion of an antibody.

[00101] Embodiments provide antibodies and antibody-like molecules against Cx43, polypeptides and peptides that are linked to at least one agent to form an antibody conjugate or payload. In order to increase the efficacy of antibody molecules as diagnostic or therapeutic agents, it is conventional to link or covalently bind or complex at least one desired molecule or moiety. Such a molecule or moiety may be, but is not limited to, at least one effector or reporter molecule. Effector molecules comprise molecules having a desired activity, *e.g.*, cytotoxic activity. Non-limiting examples of effector molecules that have been attached to antibodies include toxins, therapeutic enzymes, antibiotics, radio-labeled nucleotides and the like. By contrast, a reporter molecule is defined as any moiety that may be detected using an assay. Non-limiting examples of reporter molecules that have been conjugated to antibodies include enzymes, radiolabels, haptens, fluorescent labels, phosphorescent molecules, chemiluminescent molecules, chromophores, luminescent molecules, photoaffinity molecules, colored particles or ligands, such as biotin.

[00102] Several methods are known in the art for the attachment or conjugation of an antibody to its conjugate moiety. Some attachment methods involve the use of a metal chelate complex employing, for example, an organic chelating agent such a diethylenetriaminepentaacetic acid anhydride (DTPA); ethylenetriaminetetraacetic acid; N-chloro-p-toluenesulfonamide; and/or tetrachloro-3-6-diphenylglycouril-3 attached to the antibody. Monoclonal antibodies may also be reacted with an enzyme in the presence of a coupling agent such as glutaraldehyde or periodate. Conjugates with fluorescein markers are prepared in the presence of these coupling agents or by reaction with an isothiocyanate.

II. TREATMENT OF DISEASES

[00103] Certain aspects of the present embodiments can be used to prevent or treat a disease or disorder associated with Cx43 signaling. Signaling of Cx43 may be reduced

by any suitable drugs to prevent cancer cell proliferation. Preferably, such substances would be an anti-Cx43 antibody.

[00104] "Treatment" and "treating" refer to administration or application of a therapeutic agent to a subject or performance of a procedure or modality on a subject for the purpose of obtaining a therapeutic benefit of a disease or health-related condition. For example, a treatment may include administration of a pharmaceutically effective amount of an antibody that inhibits the Cx43 signaling.

[00105] "Subject" and "patient" refer to either a human or non-human, such as primates, mammals, and vertebrates. In particular embodiments, the subject is a human.

[00106] The term "therapeutic benefit" or "therapeutically effective" as used throughout this application refers to anything that promotes or enhances the well-being of the subject with respect to the medical treatment of this condition. This includes, but is not limited to, a reduction in the frequency or severity of the signs or symptoms of a disease. For example, treatment of cancer may involve, for example, a reduction in the size of a tumor, a reduction in the invasiveness of a tumor, reduction in the growth rate of the cancer, or prevention of metastasis. Treatment of cancer may also refer to prolonging survival of a subject with cancer.

A. Pharmaceutical Compositions

[00107] Certain aspects include a composition, e.g., a pharmaceutical composition, containing one or a combination of monoclonal antibodies, or antigen-binding portion(s) thereof formulated with a pharmaceutically acceptable carrier. Such compositions may include one or a combination of (e.g., two or more different) antibodies, or immunoconjugates described herein. For example, a pharmaceutical composition of the invention can comprise a combination of antibodies that bind to different epitopes on the target antigen or that have complementary activities.

[00108] Pharmaceutical compositions of the invention also can be administered as combination therapy, i.e., combined with other agents. For example, the combination therapy can include an anti-hemichannel antibody combined with at least one other anti-cancer agent.

[00109] As used herein, "pharmaceutically acceptable carrier" includes any and all solvents, dispersion media, coatings, antibacterial and antifungal agents, isotonic and

absorption delaying agents, and the like that are physiologically compatible. Preferably, the carrier is suitable for intravenous, intramuscular, subcutaneous, or parenteral administration (e.g., by injection or infusion). Depending on the route of administration, the active compound, i.e., antibody, or immunoconjugate, may be coated in a material to protect the compound from the action of acids and other natural conditions that may inactivate the compound.

[00110] Examples of suitable aqueous and nonaqueous carriers that may be employed in the pharmaceutical compositions of the invention include water, ethanol, polyols (such as glycerol, propylene glycol, polyethylene glycol, and the like), and suitable mixtures thereof, vegetable oils, such as olive oil, and injectable organic esters, such as ethyl oleate. Proper fluidity can be maintained, for example, by the use of coating materials, such as lecithin, by the maintenance of the required particle size in the case of dispersions, and by the use of surfactants.

[00111] Pharmaceutically acceptable carriers include sterile aqueous solutions or dispersions and sterile powders for the extemporaneous preparation of sterile injectable solutions or dispersion. The use of such media and agents for pharmaceutically active substances is known in the art. Except insofar as any conventional media or agent is incompatible with the active compound, use thereof in the pharmaceutical compositions of the invention is contemplated. Supplementary active compounds can also be incorporated into the compositions.

[00112] Therapeutic compositions typically must be sterile and stable under the conditions of manufacture and storage. The composition can be formulated as a solution, microemulsion, liposome, or other ordered structure suitable to high drug concentration. The carrier can be a solvent or dispersion medium containing, for example, water, ethanol, polyol (for example, glycerol, propylene glycol, and liquid polyethylene glycol, and the like), and suitable mixtures thereof. The proper fluidity can be maintained, for example, by the use of a coating such as lecithin, by the maintenance of the required particle size in the case of dispersion and by the use of surfactants. In many cases, it will be preferable to include isotonic agents, for example, sugars, polyalcohols such as mannitol, sorbitol, or sodium chloride in the composition. Prolonged absorption of the injectable compositions can be brought about by including in the composition an agent that delays absorption, for example, monostearate salts and gelatin.

[00113] Sterile injectable solutions can be prepared by incorporating the active compound in the required amount in an appropriate solvent with one or a combination of ingredients enumerated above, as required, followed by sterilization microfiltration. Generally, dispersions are prepared by incorporating the active compound into a sterile vehicle that contains a basic dispersion medium and the required other ingredients from those enumerated above. In the case of sterile powders for the preparation of sterile injectable solutions, the preferred methods of preparation are vacuum drying and freeze-drying (lyophilization) that yield a powder of the active ingredient plus any additional desired ingredient from a previously sterile-filtered solution thereof.

[00114] The amount of active ingredient which can be combined with a carrier material to produce a single dosage form will vary depending upon the subject being treated, and the particular mode of administration. The amount of active ingredient which can be combined with a carrier material to produce a single dosage form will generally be that amount of the composition which produces a therapeutic effect. Generally, out of one hundred percent, this amount will range from about 0.01 percent to about ninety-nine percent of active ingredient, preferably from about 0.1 percent to about 70 percent, most preferably from about 1 percent to about 30 percent of active ingredient in combination with a pharmaceutically acceptable carrier.

[00115] Dosage regimens are adjusted to provide the optimum desired response (e.g., a therapeutic response). For example, a single bolus may be administered, several divided doses may be administered over time or the dose may be proportionally reduced or increased as indicated by the exigencies of the therapeutic situation. It is especially advantageous to formulate parenteral compositions in dosage unit form for ease of administration and uniformity of dosage. Dosage unit form as used herein refers to physically discrete units suited as unitary dosages for the subjects to be treated; each unit contains a predetermined quantity of active compound calculated to produce the desired therapeutic effect in association with the required pharmaceutical carrier. The specification for the dosage unit forms of the invention are dictated by and directly dependent on (a) the unique characteristics of the active compound and the particular therapeutic effect to be achieved, and (b) the limitations inherent in the art of compounding such an active compound for the treatment of sensitivity in individuals.

[00116] For administration of the antibody, the dosage ranges from about 0.0001 to 100 mg/kg, and more usually 0.01 to 5 mg/kg, of the host body weight. For example dosages

can be 0.3 mg/kg body weight, 1 mg/kg body weight, 3 mg/kg body weight, 5 mg/kg body weight or 10 mg/kg body weight or within the range of 1-10 mg/kg. An exemplary treatment regime entails administration once per week, once every two weeks, once every three weeks, once every four weeks, once a month, once every 3 months or once every three to 6 months. Preferred dosage regimens for an anti-hemichannel antibody of the invention include 1 mg/kg body weight or 3 mg/kg body weight via intravenous administration, with the antibody being given using one of the following dosing schedules: (i) every four weeks for six dosages, then every three months; (ii) every three weeks; (iii) 3 mg/kg body weight once followed by 1 mg/kg body weight every three weeks.

[00117] In some methods, two or more monoclonal antibodies with different binding specificities are administered simultaneously, in which case the dosage of each antibody administered falls within the ranges indicated. Antibody is usually administered on multiple occasions. Intervals between single dosages can be, for example, weekly, monthly, every three months or yearly. Intervals can also be irregular as indicated by measuring blood levels of antibody to the target antigen in the patient. In some methods, dosage is adjusted to achieve a plasma antibody concentration of about 1-1000 μg/ml and in some methods about 25-300 μg/ml.

[00118] Actual dosage levels of the active ingredients in the pharmaceutical compositions of the present invention may be varied so as to obtain an amount of the active ingredient which is effective to achieve the desired therapeutic response for a particular patient, composition, and mode of administration, without being toxic to the patient. The selected dosage level will depend upon a variety of pharmacokinetic factors including the activity of the particular compositions of the present invention employed, the route of administration, the time of administration, the rate of excretion of the particular compound being employed, the duration of the treatment, other drugs, compounds and/or materials used in combination with the particular compositions employed, the age, sex, weight, condition, general health and prior medical history of the patient being treated, and like factors well known in the medical arts.

[00119] A "therapeutically effective dosage" of an anti-hemichannel antibody results in a decrease in severity of disease symptoms, an increase in frequency and duration of disease symptom-free periods, or a prevention of impairment or disability due to the disease affliction. A therapeutically effective amount of a therapeutic compound or antibody can decrease tumor metastasis, or otherwise ameliorate symptoms in a subject. One of ordinary

skill in the art would be able to determine such amounts based on such factors as the subject's size, the severity of the subject's symptoms, and the particular composition or route of administration selected.

[00120] A composition of the present invention can be administered via one or more routes of administration using one or more of a variety of methods known in the art. As will be appreciated by the skilled artisan, the route and/or mode of administration will vary depending upon the desired results. Preferred routes of administration for antibodies of the invention include intravenous, intramuscular, intradermal, intraperitoneal, subcutaneous, or other parenteral routes of administration, for example by injection or infusion. The phrase "parenteral administration" as used herein means modes of administration other than enteral and topical administration, usually by injection, and includes, without limitation, intravenous, intramuscular, intraarterial, intraperitoneal, transtracheal, subcutaneous, subcuticular, intraarticular injection and infusion.

B. Combination Treatments

[00121] In certain embodiments, the compositions and methods of the present embodiments involve an antibody or an antibody fragment against Cx43 to inhibit its activity in cancer cell proliferation, in combination with a second or additional therapy. Such therapy can be applied in the treatment of any disease that is associated with Cx43-mediated cell proliferation. For example, the disease may be cancer.

[00122] The methods and compositions, including combination therapies, enhance the therapeutic or protective effect, and/or increase the therapeutic effect of another anti-cancer or anti-hyperproliferative therapy. Therapeutic and prophylactic methods and compositions can be provided in a combined amount effective to achieve the desired effect, such as the killing of a cancer cell and/or the inhibition of cellular hyperproliferation. This process may involve contacting the cells with both an antibody or antibody fragment and a second therapy. A tissue, tumor, or cell can be contacted with one or more compositions or pharmacological formulation(s) comprising one or more of the agents (i.e., antibody or antibody fragment or an anti-cancer agent), or by contacting the tissue, tumor, and/or cell with two or more distinct compositions or formulations, wherein one composition provides 1) an antibody or antibody fragment, 2) an anti-cancer agent, or 3) both an antibody or antibody fragment and an anti-cancer agent. Also, it is contemplated that such a combination therapy

can be used in conjunction with chemotherapy, radiotherapy, surgical therapy, or immunotherapy.

[00123] The terms "contacted" and "exposed," when applied to a cell, are used herein to describe the process by which a therapeutic construct and a chemotherapeutic or radiotherapeutic agent are delivered to a target cell or are placed in direct juxtaposition with the target cell. To achieve cell killing, for example, both agents are delivered to a cell in a combined amount effective to kill the cell or prevent it from dividing.

[00124] An inhibitory antibody may be administered before, during, after, or in various combinations relative to an anti-cancer treatment. The administrations may be in intervals ranging from concurrently to minutes to days to weeks. In embodiments where the antibody or antibody fragment is provided to a patient separately from an anti-cancer agent, one would generally ensure that a significant period of time did not expire between the time of each delivery, such that the two compounds would still be able to exert an advantageously combined effect on the patient. In such instances, it is contemplated that one may provide a patient with the antibody therapy and the anti-cancer therapy within about 12 to 24 or 72 h of each other and, more particularly, within about 6-12 h of each other. In some situations it may be desirable to extend the time period for treatment significantly where several days (2, 3, 4, 5, 6, or 7) to several weeks (1, 2, 3, 4, 5, 6, 7, or 8) lapse between respective administrations.

[00125] In certain embodiments, a course of treatment will last 1-90 days or more (this such range includes intervening days). It is contemplated that one agent may be given on any day of day 1 to day 90 (this such range includes intervening days) or any combination thereof, and another agent is given on any day of day 1 to day 90 (this such range includes intervening days) or any combination thereof. Within a single day (24-hour period), the patient may be given one or multiple administrations of the agent(s). Moreover, after a course of treatment, it is contemplated that there is a period of time at which no anti-cancer treatment is administered. This time period may last 1-7 days, and/or 1-5 weeks, and/or 1-12 months or more (this such range includes intervening days), depending on the condition of the patient, such as their prognosis, strength, health, etc. It is expected that the treatment cycles would be repeated as necessary.

[00126] Various combinations may be employed. For the example below an antibody therapy is "A" and an anti-cancer therapy is "B":

A/B/A B/A/B B/B/A A/A/B A/B/B B/A/A A/B/B/B B/A/B/B
B/B/B/A B/B/A/B A/A/B/B A/B/A/B A/B/B/A B/B/A/A
B/A/B/A B/A/A/B A/A/A/B B/A/A/A A/B/A/A A/A/B/A

[00127] Administration of any compound or therapy of the present embodiments to a patient will follow general protocols for the administration of such compounds, taking into account the toxicity, if any, of the agents. Therefore, in some embodiments there is a step of monitoring toxicity that is attributable to combination therapy.

i. Chemotherapy

[00128] A wide variety of chemotherapeutic agents may be used in accordance with the present embodiments. The term "chemotherapy" refers to the use of drugs to treat cancer. A "chemotherapeutic agent" is used to connote a compound or composition that is administered in the treatment of cancer. These agents or drugs are categorized by their mode of activity within a cell, for example, whether and at what stage they affect the cell cycle. Alternatively, an agent may be characterized based on its ability to directly cross-link DNA, to intercalate into DNA, or to induce chromosomal and mitotic aberrations by affecting nucleic acid synthesis.

[00129] Examples of chemotherapeutic agents include alkylating agents, such as thiotepa and cyclosphosphamide; alkyl sulfonates, such as busulfan, improsulfan, and piposulfan; aziridines, such as benzodopa, carboquone, meturedopa, and uredopa; ethylenimines and methylamelamines, including altretamine, triethylenemelamine, trietylenephosphoramide, triethiylenethiophosphoramide, and trimethylolomelamine; acetogenins (especially bullatacin and bullatacinone); a camptothecin (including the synthetic analogue topotecan); bryostatin; callystatin; CC-1065 (including its adozelesin, carzelesin and bizelesin synthetic analogues); cryptophycins (particularly cryptophycin 1 and cryptophycin 8); dolastatin; duocarmycin (including the synthetic analogues, KW-2189 and CB1-TM1); eleutherobin; pancratistatin; a sarcodictyin; spongistatin; nitrogen mustards, such as chlorambucil, chlornaphazine, cholophosphamide, estramustine, ifosfamide, mechlorethamine, mechlorethamine oxide hydrochloride, melphalan, novembichin, phenesterine, prednimustine, trofosfamide, and uracil mustard; nitrosureas, such as carmustine, chlorozotocin, fotemustine, lomustine, nimustine, and ranimnustine; antibiotics, such as the enediyne antibiotics (e.g., calicheamicin, especially calicheamicin gammaI and calicheamicin omegaI1); dynemicin, including dynemicin A; bisphosphonates, such as clodronate; an

esperamicin; as well as neocarzinostatin chromophore and related chromoprotein enediyne antiobiotic chromophores, aclacinomysins, actinomycin, authrarnycin, azaserine, bleomycins, cactinomycin, carabicin, carminomycin, carzinophilin, chromomycinis, dactinomycin, daunorubicin, detorubicin, 6-diazo-5-oxo-L-norleucine, doxorubicin (including morpholino-doxorubicin, cyanomorpholino-doxorubicin, 2-pyrrolino-doxorubicin and deoxydoxorubicin), epirubicin, esorubicin, idarubicin, marcellomycin, mitomycins, such as mitomycin C, mycophenolic acid, nogalarnycin, olivomycins, peplomycin, potfiromycin, puromycin, quelamycin, rodorubicin, streptonigrin, streptozocin, tubercidin, ubenimex, zinostatin, and zorubicin; anti-metabolites, such as methotrexate and 5-fluorouracil (5-FU); folic acid analogues, such as denopterin, pteropterin, and trimetrexate; purine analogs, such as fludarabine, 6-mercaptopurine, thiamiprine, and thioguanine; pyrimidine analogs, such as ancitabine, azacitidine, 6-azauridine, carmofur, cytarabine, dideoxyuridine, doxifluridine, enocitabine, and floxuridine; androgens, such as calusterone, dromostanolone propionate, epitiostanol, mepitiostane, and testolactone; anti-adrenals, such as mitotane and trilostane; folic acid replenisher, such as frolinic acid; aceglatone; aldophosphamide glycoside; aminolevulinic acid; eniluracil; amsacrine; bestrabucil; bisantrene; edatraxate; defofamine; demecolcine; diaziquone; elformithine; elliptinium acetate; an epothilone; etoglucid; gallium nitrate; hydroxyurea; lentinan; lonidainine; maytansinoids, such as maytansine and ansamitocins; mitoguazone; mitoxantrone; mopidanmol; nitraerine; pentostatin; phenamet; pirarubicin; losoxantrone; podophyllinic acid; 2-ethylhydrazide; procarbazine; PSKpolysaccharide complex; razoxane; rhizoxin; sizofiran; spirogermanium; tenuazonic acid; triaziquone; 2,2',2”-trichlorotriethylamine; trichothecenes (especially T-2 toxin, verracurin A, roridin A and anguidine); urethan; vindesine; dacarbazine; mannomustine; mitobronitol; mitolactol; pipobroman; gacytosine; arabinoside (“Ara-C”); cyclophosphamide; taxoids, e.g., paclitaxel and docetaxel gemcitabine; 6-thioguanine; mercaptopurine; platinum coordination complexes, such as cisplatin, oxaliplatin, and carboplatin; vinblastine; platinum; etoposide (VP-16); ifosfamide; mitoxantrone; vincristine; vinorelbine; novantrone; teniposide; edatrexate; daunomycin; aminopterin; xeloda; ibandronate; irinotecan (e.g., CPT-11); topoisomerase inhibitor RFS 2000; difluorometlhylornithine (DMFO); retinoids, such as retinoic acid; capecitabine; carboplatin, procarbazine,plicomycin, gemcitabien, navelbine, farnesyl-protein tansferase inhibitors, transplatinum, and pharmaceutically acceptable salts, acids, or derivatives of any of the above.

ii. Radiotherapy

[00130] Other factors that cause DNA damage and have been used extensively include what are commonly known as γ-rays, X-rays, and/or the directed delivery of radioisotopes to tumor cells. Other forms of DNA damaging factors are also contemplated, such as microwaves, proton beam irradiation (U.S. Patents 5,760,395 and 4,870,287), and UV-irradiation. It is most likely that all of these factors affect a broad range of damage on DNA, on the precursors of DNA, on the replication and repair of DNA, and on the assembly and maintenance of chromosomes. Dosage ranges for X-rays range from daily doses of 50 to 200 roentgens for prolonged periods of time (3 to 4 wk), to single doses of 2000 to 6000 roentgens. Dosage ranges for radioisotopes vary widely, and depend on the half-life of the isotope, the strength and type of radiation emitted, and the uptake by the neoplastic cells.

iii. Immunotherapy

[00131] The skilled artisan will understand that additional immunotherapies may be used in combination or in conjunction with methods of the embodiments. In the context of cancer treatment, immunotherapeutics, generally, rely on the use of immune effector cells and molecules to target and destroy cancer cells. Rituximab (RITUXAN®) is such an example. The immune effector may be, for example, an antibody specific for some marker on the surface of a tumor cell. The antibody alone may serve as an effector of therapy or it may recruit other cells to actually affect cell killing. The antibody also may be conjugated to a drug or toxin (chemotherapeutic, radionuclide, ricin A chain, cholera toxin, pertussis toxin, etc.) and serve as a targeting agent. Alternatively, the effector may be a lymphocyte carrying a surface molecule that interacts, either directly or indirectly, with a tumor cell target. Various effector cells include cytotoxic T cells and NK cells

[00132] In one aspect of immunotherapy, the tumor cell must bear some marker that is amenable to targeting, i.e., is not present on the majority of other cells. Many tumor markers exist and any of these may be suitable for targeting in the context of the present embodiments. Common tumor markers include CD20, carcinoembryonic antigen, tyrosinase (p97), gp68, TAG-72, HMFG, Sialyl Lewis Antigen, MucA, MucB, PLAP, laminin receptor, erb B, and p155. An alternative aspect of immunotherapy is to combine anticancer effects with immune stimulatory effects. Immune stimulating molecules also exist including: cytokines, such as IL-2, IL-4, IL-12, GM-CSF, gamma-IFN, chemokines, such as MIP-1, MCP-1, IL-8, and growth factors, such as FLT3 ligand.

[00133] Examples of immunotherapies currently under investigation or in use are immune adjuvants, e.g., Mycobacterium bovis, Plasmodium falciparum, dinitrochlorobenzene, and aromatic compounds (U.S. Patents 5,801,005 and 5,739,169; Hui and Hashimoto, 1998; Christodoulides et al., 1998); cytokine therapy, e.g., interferons α, β, and γ, IL-1, GM-CSF, and TNF (Bukowski et al., 1998; Davidson et al., 1998; Hellstrand et al., 1998); gene therapy, e.g., TNF, IL-1, IL-2, and p53 (Qin et al., 1998; Austin-Ward and Villaseca, 1998; U.S. Patents 5,830,880 and 5,846,945); and monoclonal antibodies, e.g., anti-CD20, anti-ganglioside GM2, and anti-p185 (Hollander, 2012; Hanibuchi et al., 1998; U.S. Patent 5,824,311). It is contemplated that one or more anti-cancer therapies may be employed with the antibody therapies described herein.

iv. Surgery

[00134] Approximately 60% of persons with cancer will undergo surgery of some type, which includes preventative, diagnostic or staging, curative, and palliative surgery. Curative surgery includes resection in which all or part of cancerous tissue is physically removed, excised, and/or destroyed and may be used in conjunction with other therapies, such as the treatment of the present embodiments, chemotherapy, radiotherapy, hormonal therapy, gene therapy, immunotherapy, and/or alternative therapies.Tumor resection refers to physical removal of at least part of a tumor. In addition to tumor resection, treatment by surgery includes laser surgery, cryosurgery, electrosurgery, and microscopically-controlled surgery (Mohs' surgery).

[00135] Upon excision of part or all of cancerous cells, tissue, or tumor, a cavity may be formed in the body. Treatment may be accomplished by perfusion, direct injection, or local application of the area with an additional anti-cancer therapy. Such treatment may be repeated, for example, every 1, 2, 3, 4, 5, 6, or 7 days, or every 1, 2, 3, 4, and 5 weeks or every 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, or 12 months. These treatments may be of varying dosages as well.

v. Other Agents

[00136] It is contemplated that other agents may be used in combination with certain aspects of the present embodiments to improve the therapeutic efficacy of treatment. These additional agents include agents that affect the upregulation of cell surface receptors and GAP junctions, cytostatic and differentiation agents, inhibitors of cell adhesion, agents that

increase the sensitivity of the hyperproliferative cells to apoptotic inducers, or other biological agents. Increases in intercellular signaling by elevating the number of GAP junctions would increase the anti-hyperproliferative effects on the neighboring hyperproliferative cell population. In other embodiments, cytostatic or differentiation agents can be used in combination with certain aspects of the present embodiments to improve the anti-hyperproliferative efficacy of the treatments. Inhibitors of cell adhesion are contemplated to improve the efficacy of the present embodiments. Examples of cell adhesion inhibitors are focal adhesion kinase (FAKs) inhibitors and Lovastatin. It is further contemplated that other agents that increase the sensitivity of a hyperproliferative cell to apoptosis, such as the antibody c225, could be used in combination with certain aspects of the present embodiments to improve the treatment efficacy.

III. Kits and Diagnostics

[00137] In various aspects of the embodiments, a kit is envisioned containing therapeutic agents and/or other therapeutic and delivery agents. In some embodiments, the present embodiments contemplates a kit for preparing and/or administering a therapy of the embodiments. The kit may comprise one or more sealed vials containing any of the pharmaceutical compositions of the present embodiments. The kit may include, for example, at least one Cx43antibody as well as reagents to prepare, formulate, and/or administer the components of the embodiments or perform one or more steps of the inventive methods. In some embodiments, the kit may also comprise a suitable container, which is a container that will not react with components of the kit, such as an eppendorf tube, an assay plate, a syringe, a bottle, or a tube. The container may be made from sterilizable materials such as plastic or glass.

[00138] The kit may further include an instruction sheet that outlines the procedural steps of the methods set forth herein, and will follow substantially the same procedures as described herein or are known to those of ordinary skill in the art. The instruction information may be in a computer readable media containing machine-readable instructions that, when executed using a computer, cause the display of a real or virtual procedure of delivering a pharmaceutically effective amount of a therapeutic agent.

IV. Examples

[00139] The following examples are included to demonstrate preferred embodiments of the invention. It should be appreciated by those of skill in the art that the techniques disclosed in the examples which follow represent techniques discovered by the inventors to function well in the practice of the invention, and thus can be considered to constitute preferred modes for its practice. However, those of skill in the art should, in light of the present disclosure, appreciate that many changes can be made in the specific embodiments which are disclosed and still obtain a like or similar result without departing from the spirit and scope of the invention.

Example 1 – Anti-Cx43 Monoclonal Antibodies

[00140] Anti-Cx43 monoclonal antibodies were generated and clones were identified that produced Cx43-binding monoclonal antibodies. CDR sequences of both DNA and amino acids for all antibody sequences are shown in the tables below along with the correct pairing for each of the characterized antibodies.

[00141] Table 1: Pairing of heavy chain and light chain for two functional antibodies.

Antibody Name	Heavy chain	Light chain
M1 (HmAb1)	M1H	M1K1
M2 (HmAb2)	M1H	M1M7K

[00142] Table 2: Sequence of antibody chains from the hybridomas.

mAb	CDR-1	CDR-2	CDR-3
M1H	ggctacaccttcaccagctactat (SEQ ID NO: 16)	attaatcctagcaatggtggta ct (SEQ ID NO: 17)	acaagagagggtaacccctactatactatgaac tac (SEQ ID NO: 18)
	GYTFTSYY (SEQ ID NO: 19)	INPSNGGT (SEQ ID NO: 20)	TREGNPYYTMNY (SEQ ID NO: 21)
M7H	ggctacatcttcaccacctactgg (SEQ ID NO: 22)	attagtcctagcaacggtcgtt ct (SEQ ID NO: 23)	gcacgattcgacgagggggacttc (SEQ ID NO: 24)
	GYIFTTYW (SEQ ID NO: 25)	ISPSNGRS (SEQ ID NO: 26)	ARFDEGDF (SEQ ID NO: 27)
M1K1	cagagtctgttaaacagtggaaatcaaaagacc tac (SEQ ID NO: 28)	ggggcatcc (SEQ ID NO: 29)	cagaatgatcatagttatccattcacg (SEQ ID NO: 30)
	QSLLNSGNQKTY (SEQ ID NO: 31)	GAS (SEQ ID NO: 32)	QNDHSYPFT (SEQ ID NO: 33)
M1K2	aaaagtgtcagtacatctggctatagttat	cttgtatcc	cagcacattagggagcttacacg

	(SEQ ID NO: 34)	SEQ ID NO: 35)	(SEQ ID NO: 36)
	KSVSTSGYSY (SEQ ID NO: 37)	LVS (SEQ ID NO: 38)	QHIRELT (SEQ ID NO: 39)
M2K	aaaagtgtcagtacatctggctatagttat (SEQ ID NO: 40)	cttgtatcc (SEQ ID NO: 41)	cagcacattagggagcttacacgt (SEQ ID NO: 42)
	KSVSTSGYSY (SEQ ID NO: 43)	LVS (SEQ ID NO: 44)	QHIRELTR (SEQ ID NO: 45)
M1M7K	gagcctcttagaaagcgatggaaagacatat (SEQ ID NO: 46)	ctggtgtct (SEQ ID NO: 47)	tggcaaggtacacattttccgtggacg (SEQ ID NO: 48)
	QSLLESDGKTY (SEQ ID NO: 49)	LVS (SEQ ID NO: 50)	WQGTHFPWT (SEQ ID NO: 51)

[00143] Cloned variable domains are shown in the charts below.

[00144] Chart 1. DNA sequences:

>M1H

GAGGTCCAACTCCAGCAGCCTGGGGCTGAACTGGTGAAGCCTGGGGCTTCAGTGAAGTTGTC
CTGCAAGGCTTCTGGCTACACCTTCACCAGCTACTATATGTACTGGGTGAAGCAGAGGCCTG
GACAAGGCCTTGAGTGGATTGGGGGAATTAATCCTAGCAATGGTGGTACTAACTTCAATGAG
AAGTTCAAGAACAAGGCCACACTGACTGTAGACAAATCCTCCAGCACAGCCTACATGCAACT
CAGCAGCCTGACATCTGAGGACTCTGCGGTCTATTACTGTACAAGAGAGGGTAACCCCTACT
ATACTATGAACTACTGGGGTCAAGGAACCTCAGTCACCGTCTCCTCA (SEQ ID NO: 52)

>M7H

GAGGTCCAACTCCAGCAACCTGGGGCTGAACTGGTGAGGCCTGGGGCTTCAGTAATGCTGTC
CTGCAAGGCTTCTGGCTACATCTTCACCACCTACTGGATGCACTGGCTGAAGCAGAGGCCTG
GACAAGGCCTTGACTGGATTGGAGAGATTAGTCCTAGCAACGGTCGTTCTAATTACAATAAG
AAGTTCAAGAGCAAGGCCACACTGACTGTAGACAAATCCTCCAGCACAGCCTACATGCAACT
CAGCAGCCTGACATCTGAGGACTCTGCGGTCTATTACTGTGCACGATTCGACGAGGGGGACT
TCTGGGGCCAAGGCACCACTCTCATAGTCTCCTCA (SEQ ID NO: 53)

>M1K1

GACATTGTGATGACGCAGTCTCCATCCTCCCTGAGTGTGTCAGCAGGAGAGAAGGTCACTAT
GAGCTGCAAGTCCAGTCAGAGTCTGTTAAACAGTGGAAATCAAAAGACCTACTTGGCCTGGT
ACCAGCAGAAACCAGGGCAGCCTCCTAAACTGTTGATCTACGGGGCATCCACTAGGGAATCT

GGGGTCCCTGATCGCTTCACAGGCAGTGGATCTGGAACCGATTTCACTCTTACCATCAGCAG
TGTGCAGGCTGAAGACCTGGCAGTTTATTACTGTCAGAATGATCATAGTTATCCATTCACGT
TCGGCTCGGGGACAAAGTTGGAAATAAAA (SEQ ID NO: 54)

>M1K2
GACATTGTGTTGACACAGTCTCCTGCTTCCTTAGCTGTATCTCTGGGGCAGAGGGCCACCAT
CTCATACAGGGCCAGCAAAAGTGTCAGTACATCTGGCTATAGTTATATGCACTGGAACCAAC
AGAAACCAGGACAGCCACCCAGACTCCTCATCTATCTTGTATCCAACCTAGAATCTGGGGTC
CCTGCCAGGTTCAGTGGCAGTGGGTCTGGGACAGACTTCACCCTCAACATCCATCCTGTGGA
GGAGGAGGATGCTGCAACCTATTACTGTCAGCACATTAGGGAGCTTACACGTTCGGAGGGGG
GACCAAGCTGGAAATCAAAC (SEQ ID NO: 55)

>M2K
GATATTGTGATGACCCAGTCTCCCGCTTCCTTAGCTGTATCTCTGGGGCAGAGGGCCACCAT
CTCATACAGGGCCAGCAAAAGTGTCAGTACATCTGGCTATAGTTATATGCACTGGAACCAAC
AGAAACCAGGACAGCCACCCAGACTCCTCATCTATCTTGTATCCAACCTAGAATCTGGGGTC
CCTGCCAGGTTCAGTGGCAGTGGGTCTGGGACAGACTTCACCCTCAACATCCATCCTGTGGA
GGAGGAGGATGCTGCAACCTATTACTGTCAGCACATTAGGGAGCTTACACGTTCGGAGGGGG
GGACCAAGCTGGAAATCAAA (SEQ ID NO: 56)

>M1M7
KGACGTTGTGATGACCCAGACTCCACTCACTTTGTCGGTTACCATTGGACAACCAGCCTCC
ATCTCTTGCAAGTCAAGTCAGAGCCTCTTAGAAAGCGATGGAAAGACATATTTGAATTGGT
TGTTACAGAGGCCAGGCCAGTCTCCAAAGCGCCTAATCTATCTGGTGTCTAAACTGGACTC
TGGAGTCCCTGACAGGTTCACTGGCAGTGGATCAGGGACAGATTTCACACTGAAAATCAGC
AGAGTGGAGGCTGAGGATTTGGGAGTTTATTATTGCTGGCAAGGTACACATTTTCCGTGGA
CGTTCGGTGGAGGCACCAAGCTGGAAATCAAA (SEQ ID NO: 57)

[00145] Chart 2. Amino acid sequences:

>M1H
EVQLQQPGAELVKPGASVKLSCKASGYTFTSYYMYWVKQRPGQGLEWIGGINPSNG
GTNFNEKFKNKATLTVDKSSSTAYMQLSSLTSEDSAVYYCTREGNPYYTMNYWGQ
GTSVTVSS (SEQ ID NO: 58)

>M7H
EVQLQQPGAELVRPGASVMLSCKASGYIFTTYWMHWLKQRPGQGLDWIGEISPSNG
RSNYNKKFKSKATLTVDKSSSTAYMQLSSLTSEDSAVYYCARFDEGDFWGQGTTLI
VSS (SEQ ID NO: 59)

>M1K1
DIVMTQSPSSLSVSAGEKVTMSCKSSQSLLNSGNQKTYLAWYQQKPGQPPKLLIYGA
STRESGVPDRFTGSGSGTDFTLTISSVQAEDLAVYYCQNDHSYPFTFGSGTKLEIK
(SEQ ID NO: 60)

>M1K2
DIVLTQSPASLAVSLGQRATISYRASKSVSTSGYSYMHWNQQKPGQPPRLLIYLVSNL
ESGVPARFSGSGSGTDFTLNIHPVEEEDAATYYCQHIRELTRSEGGPSWKSN (SEQ ID
NO: 61)

>M2-K
DIVMTQSPASLAVSLGQRATISYRASKSVSTSGYSYMHWNQQKPGQPPRLLIYLVSN
LESGVPARFSGSGSGTDFTLNIHPVEEEDAATYYCQHIRELTRSEGGTKLEIK (SEQ ID
NO: 62)

>M1M7-K
DVVMTQTPLTLSVTIGQPASISCKSSQSLLESDGKTYLNWLLQRPGQSPKRLIYLVSK
LDSGVPDRFTGSGSGTDFTLKISRVEAEDLGVYYCWQGTHFPWTFGGGTKLEIK
(SEQ ID NO: 63)

Example 2 – Spinal Cord and Neuronal Injury (SCI) Therapeutic Use

[00146] As illustrated in FIG 1, Cx43 is normally localized into gap junctions between cells or as hemichannels on the plasma membrane. Pathological opening of Cx43 hemichannels result in propagation of secondary injury, activation of astro/microglia, and inflammation. It is proposed that preventing pathological opening of Cx43 hemichannels prevents release of molecules, enabling astrocytes to act as caretaker cells and prevent further spread of secondary injury.

[00147] The activation of Cx43 hemichannels by IL-1β in human primary astrocytes was inhibited by both Cx43 hemichannel blocking mouse monoclonal antibody (M1) and mouse-human chimeric antibody HMAb1. The hemichannel activity was determined by ethidium bromide uptake. The results are shown in FIG. 2.

[00148] Mice treated with HMAb1 had decreased glial scarring. Mice were subjected to a single SCI and treated 30 minutes after injury with IP saline, control Igg, or HMAb1 (25 mg/kg). Glial scarring was measured at 14 and 56 days after injury. Spinal cord tissue sections were subjected to immunohistochemistry for the astrocyte marker GFAP (red). Representative images of spinal cords in mice treated with the control IgG are shown in FIGS. 3A-C and those treated with HMAb1 are shown in FIGS. 3D-F. The lesion boundary is indicated with a dotted white line. GFAP immunolabeling was quantified as the mean intensity multiplied by area of positive stain in FIG. 3G. Results are expressed as a percentage of Sham surgery, IgG treated mice. Results are averages with SEM. *$p<0.05$, ***$p<0.001$ compared to Igg w/ Tukey's HSD n=3-4.

[00149] Glial scarring was also reduced in mice treated with anti-Cx43 after SCI. Mice were subjected to SCI and treated with IgG or anti-Cx43 antibody (M1) at 30 minutes post injury. Two weeks after injury, tissue sections were analyzed for expression of the astrocyte marker GFAP. Respresentative images are shown in FIGS. 4A and 4B. The results are quantified in FIG. 4C.

[00150] Mice with SCI recover hind limb function after treatment with HMAb1 (FIGS. 5A-5B). Mice were subjected to a single SCI and treated 30 minutes after injury with IP saline, control IgG, or human-mouse chimeric anti-Cx43 antibody (HMAb1) (25 mg/kg).

[00151] Mice treated with HMAb1 were found to have more neuronal dendrites in the perilesional area 14 days post SCI. As described above, mice were subjected to a single SCI and treated 30 minutes after injury with IP saline, control Igg, or HMAb1 (25 mg/kg). Neuronal dendrites were measured by immunolabeling against the neuronal marker MAP2. Immunohistochemistry representative images of spinal cords in mice treated with control IgG are shown in FIGS. 6A-C and those treated with HMAb1 are shown in 6D-F. The lesion boundary is indicated with a dotted white line. MAP2 immunolabeling was quantified as the mean intensity multiplied by area of positive stain, illustrated in FIG. 6G. Results are expressed as a percentage of Sham surgery, IgG treated mice.

[00152] Mice treated with HMAb1 also were observed to have more neuronal nuclei in the perilesional area 14 days post SCI. Mice were again subjected to a single SCI and treated 30 minutes after injury with IP saline, control IgG, or HMAb1 (25 mg/kg). Neuronal nuclei were measured by immunolabeling against the neuronal marker NeuN. Immunohistochemistry representative images of spinal cords in mice treated with control IgG are shown in FIGS. 7A-C and those treated with HMAb1 are shown in 7D-F. The lesion boundary is indicated with a dotted white line. NeuN immunolabeling was quantified as the mean intensity multiplied by area of positive stain, shown in FIG. 7G. Results are expressed as a percentage of Sham surgery, IgG treated mice.

Example 3 – Diagnostic and Cancer Therapeutic Use

[00153] There are approximately 40,000 deaths from metastatic breast cancer annually in the United States. About 70-80% of patients with advanced breast cancer develop skelatal metastases. Bone metastases alone account for two-thirds of the cost of breast cancer treatment.

[00154] It was found that osteolytic tumor growth was augmented in osteocyte-specific Cx43 knockout mice. Py8119-Luc cells were injected into right tibias of control and cKO female mice. The left tibias were injected with PBS as controls. The tumor growth was recorded every week for 4 weeks by bioluminescence imaging and quantified (FIGS. 8A-8C).

[00155] MLO-Y4 osteocytes and primary mouse osteocytes were incubated with E2 (polyclonal), HMAb1 and HMAb2 antibody or carbenoxolone (CBX), a connexin channel blocker. Ethium bromide (EtBr) dye uptake assay was performed (FIGS. 9A-9B). It was found that Cx43 HMAb2 antibody activates hemichannels.

[00156] Additionally, Cx43(M1) antibody was delivered to osteocytes *in vivo* and found to block Evans blue uptake induced by tibial loading. Evans blue dye was injected into tail vein of WT, osteocyte-specific Cx43 KO. Mouse IgG or Cx43(M1) mAb (25 mg/kg) was i.p. injected 2 hrs before dye injection. 30 min after dye injection, left tibias were mechanically loaded once for 10 min. Mice were sacrified and perfused with PBS. Tibias were isolated and fixed tibial bone tissue sections were prepared. The results are shown in FIGS. 10A-10C.

[00157] The inhibition of osteolytic tumor growth by HMAb2 was also observed. Py8119-Luc cells were injected into right tibias of female mice (FIG. 11A). The left tibias were injected with PBS as controls. HMAb2 at 25 mg/kg was i.p. injected either once or twice per week for four weeks. Saline was injected twice per week in control mice. The tumor growth was recorded every week for 4 weeks by bioluminescence imaging and quantified (FIG. 11B).

Example 4 – Osteoarthritis Treatment

[00158] Primary chondrocytes isolated from mouse bone were immunostained with anti-Cx43 antibody against C-terminal domain (Total) in permeable cells and Cx43E2 antibody in non-permeable cells (FIG. 12). Cx43 expression was observed on the cell surface of the primary chondrocytes.

[00159] In another study, primary chondrocytes isolated from mouse bone were pre-treated with carbenoxolone (connexin channel blocker) or HMAb1 antibody and then treated with or without IL-1β. Ethidium bromide dye uptake assay was performed to determine hemichannel activity (FIG. 13). It was observed that HMAb1 antibody inhibits hemichannel opening by IL-1β in primary chondrocytes.

[00160] As in the above example, Evans blue uptake induced by tibial loading was blocked by Cx43 hemichannel blocking antibody *in vivo*. Evans blue dye was injected into tail vein of WT mice. Cx43(M1) mAb (25 mg/kg) was i.p. injected 2 hrs before dye injection. 30 min after dye injection, left tibias were mechanically loaded once for 10 min. Dye uptake was measured by Evans blue (EB) fluorescence and quantified (FIG. 14).

* * *

[00161] All of the methods disclosed and claimed herein can be made and executed without undue experimentation in light of the present disclosure. While the compositions and methods of this invention have been described in terms of preferred embodiments, it will be apparent to those of skill in the art that variations may be applied to the methods and in the steps or in the sequence of steps of the method described herein without departing from the concept, spirit and scope of the invention. More specifically, it will be apparent that certain agents which are both chemically and physiologically related may be substituted for the agents described herein while the same or similar results would be achieved.

All such similar substitutes and modifications apparent to those skilled in the art are deemed to be within the spirit, scope and concept of the invention as defined by the appended claims.

CLAIMS

1. A method of treating or preventing osteoporosis, osteopenia or cancer in a subject comprising administering to the subject an effective amount of an antibody that binds to a connexin 43 (Cx43) hemichannel and enhances channel opening or an expression vector encoding the antibody, wherein the antibody comprises:

a heavy chain immunoglobulin variable region comprising:

(a) a complementarity determining region 1 comprising the sequence of SEQ ID NO: 19;

(b) a complementarity determining region 2 comprising the sequence of SEQ ID NO: 20; and

(c) a complementarity determining region 3 comprising the sequence of SEQ ID NO: 21; and

a light chain immunoglobulin variable region comprising:

(a) a complementarity determining region 1 comprising the sequence of SEQ ID NO: 49;

(b) a complementarity determining region 2 comprising the sequence of SEQ ID NO: 50; and

(c) a complementarity determining region 3 comprising the sequence of SEQ ID NO: 51.

2. The method of claim 1, further defined as a method for treating or preventing osteoporosis or osteopenia.

3. The method of claim 1, further defined as a method for treating a cancer or a method for treating or preventing bone metastasis in a subject having a cancer.

4. The method of claim 1, comprising administering an effective amount of the antibody to the subject.

5. The method of claim 1, comprising administering an effective amount of an expression vector encoding the antibody to the subject.

6. The method of claim 3, wherein the cancer is breast cancer, prostate cancer, or osteosarcoma.

7. The method of claim 1, wherein the antibody or the expression vector encoding the antibody is administered in a pharmaceutically acceptable composition.

8. The method of claim 1, wherein the antibody is administered systemically, intravenously, intradermally, intratumorally, intramuscularly, intraperitoneally, subcutaneously, or locally.

9. The method of claim 1, wherein the antibody is a humanized antibody.

10. The method of claim 3, further comprising administering at least a second anticancer therapy to the subject.

11. The method of claim 10, wherein the second anticancer therapy is a surgical therapy, chemotherapy, radiation therapy, cryotherapy, hormonal therapy, immunotherapy or cytokine therapy.

12. A recombinant connexin 43 (Cx43) hemichannel-binding antibody comprising:

a heavy chain immunoglobulin variable region comprising:

a) a complementarity determining region 1 comprising the sequence of SEQ ID NO: 19;

b) a complementarity determining region 2 comprising the sequence of SEQ ID NO: 20;

c) a complementarity determining region 3 comprising the sequence of SEQ ID NO: 21; and

a light chain immunoglobulin variable region comprising:

a) a complementarity determining region 1 comprising the sequence of SEQ ID NO: 49;

b) a complementarity determining region 2 comprising the sequence of SEQ ID NO: 50; and

c) a complementarity determining region 3 comprising the sequence of SEQ ID NO: 51.

13. The antibody of claim 12, wherein the antibody is a humanized antibody.

14. The antibody of claim 12, wherein the antibody comprises a VH amino acid sequence at least 90% identical to SEQ ID NO: 58 and/or a VL amino acid sequence at least 90% identical to SEQ ID NO: 63.

15. The antibody of claim 12, wherein the antibody comprises a VH amino acid sequence according to SEQ ID NO: 58 and/or a VL amino acid sequence according to SEQ ID NO: 63.

16. A method of treating cancer in a subject comprising administering an effective amount of a pharmaceutical composition comprising an antibody according to any one of claims 12-15 or an expression vector encoding an antibody according to any one of claims 12-15 to the subject.

17. The method of claim 16, wherein the pharmaceutical composition comprises an expression vector encoding an antibody according to any one of claims 12-15 to the subject.

18. The method of claim 16, wherein the pharmaceutical composition comprises an antibody according to any one of claims 12-15 to the subject.

19. The method of claim 16, wherein the cancer is breast cancer, prostate cancer or osteosarcoma.

20. The method of claim 16, further defined as a method for inhibiting or preventing cancer bone metastasis in the subject.

21. The method of claim 16, wherein the pharmaceutical composition is administered systemically, intravenously, intradermally, intratumorally, intramuscularly, intraperitoneally, subcutaneously, or locally.

22. The method of claim 16, further comprising administering at least a second anticancer therapy to the subject.

23. The method of claim 22, wherein the second anticancer therapy is a surgical therapy, chemotherapy, radiation therapy, cryotherapy, hormonal therapy, immunotherapy or cytokine therapy.

24. The method of claim 1, wherein the antibody comprises a VH amino acid sequence at least 90% identical to SEQ ID NO: 58 and/or a VL amino acid sequence at least 90% identical to SEQ ID NO: 63.

25. The method of claim 24, wherein the antibody comprises a VH amino acid sequence according to SEQ ID NO: 58 and/or a VL amino acid sequence according to SEQ ID NO: 63.

26. Use of an antibody that binds to a connexin 43 (Cx43) hemichannel and enhances channel opening or an expression vector encoding the antibody in the manufacture of a medicament for the treatment or prevention of osteoporosis, osteopenia or cancer, wherein the antibody comprises:

a heavy chain immunoglobulin variable region comprising:

(a) a complementarity determining region 1 comprising the sequence of SEQ ID NO: 19;

(b) a complementarity determining region 2 comprising the sequence of SEQ ID NO: 20; and

(c) a complementarity determining region 3 comprising the sequence of SEQ ID NO: 21; and

a light chain immunoglobulin variable region comprising:

(a) a complementarity determining region 1 comprising the sequence of SEQ ID NO: 49;

(b) a complementarity determining region 2 comprising the sequence of SEQ ID NO: 50; and

(c) a complementarity determining region 3 comprising the sequence of SEQ ID NO: 51.

27. Use of an antibody according to any one of claims 12-15 or an expression vector encoding an antibody according to any one of claims 12-15 in the manufacture of a medicament for the treatment of cancer.

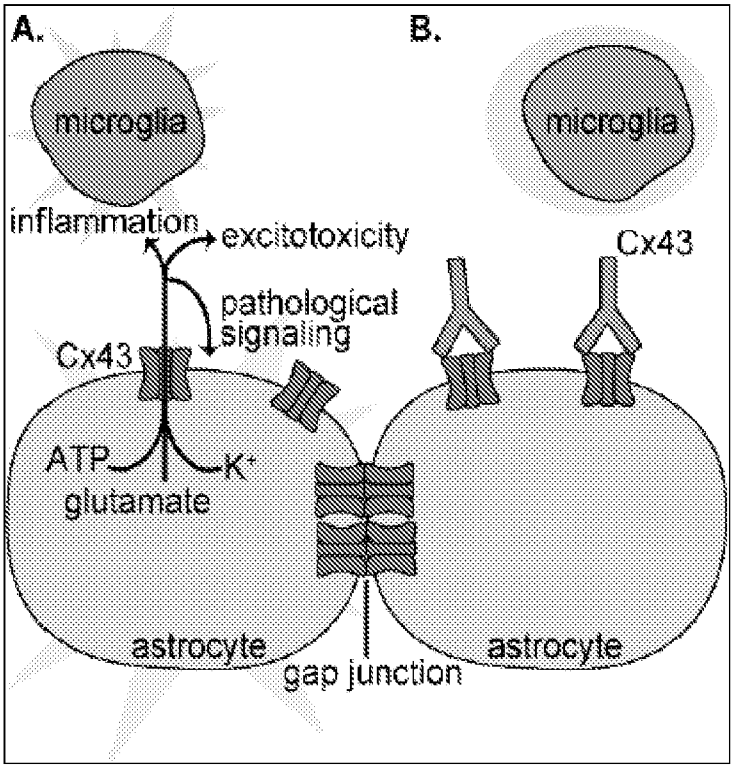

A.
B.
microglia
microglia
inflammation
excitotoxicity
pathological
signaling
Cx43
Cx43
ATP
K+
glutamate
astrocyte
astrocyte
gap junction

FIG. 1

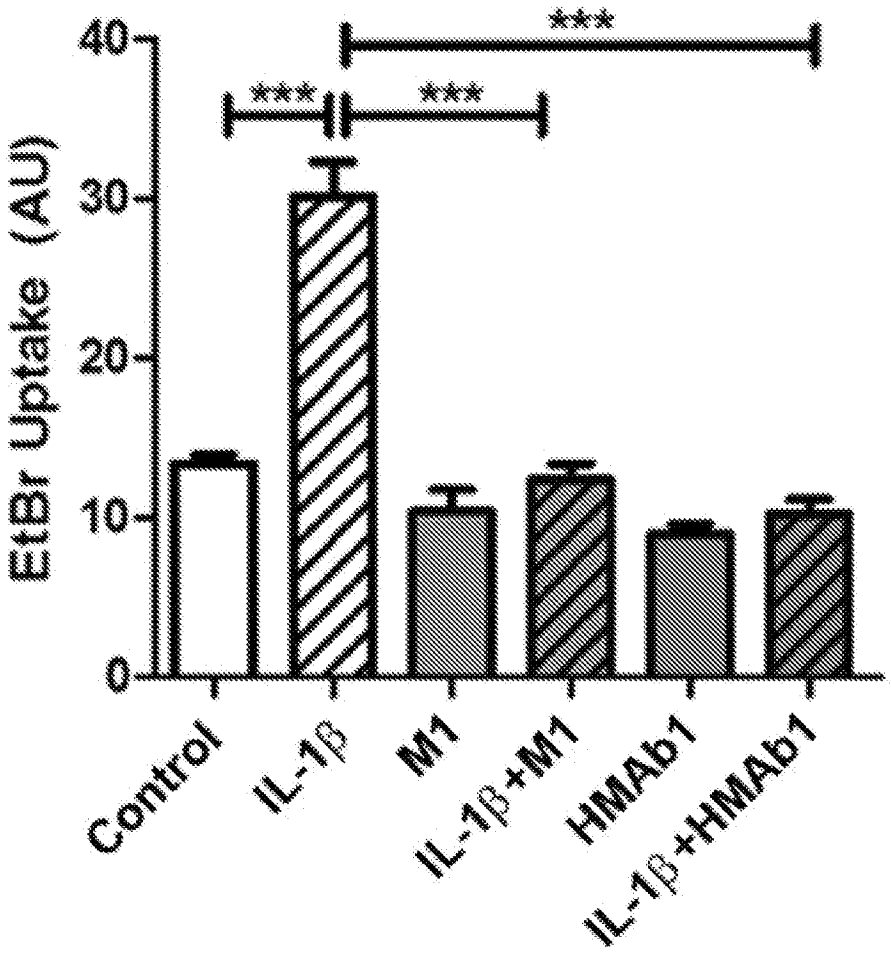
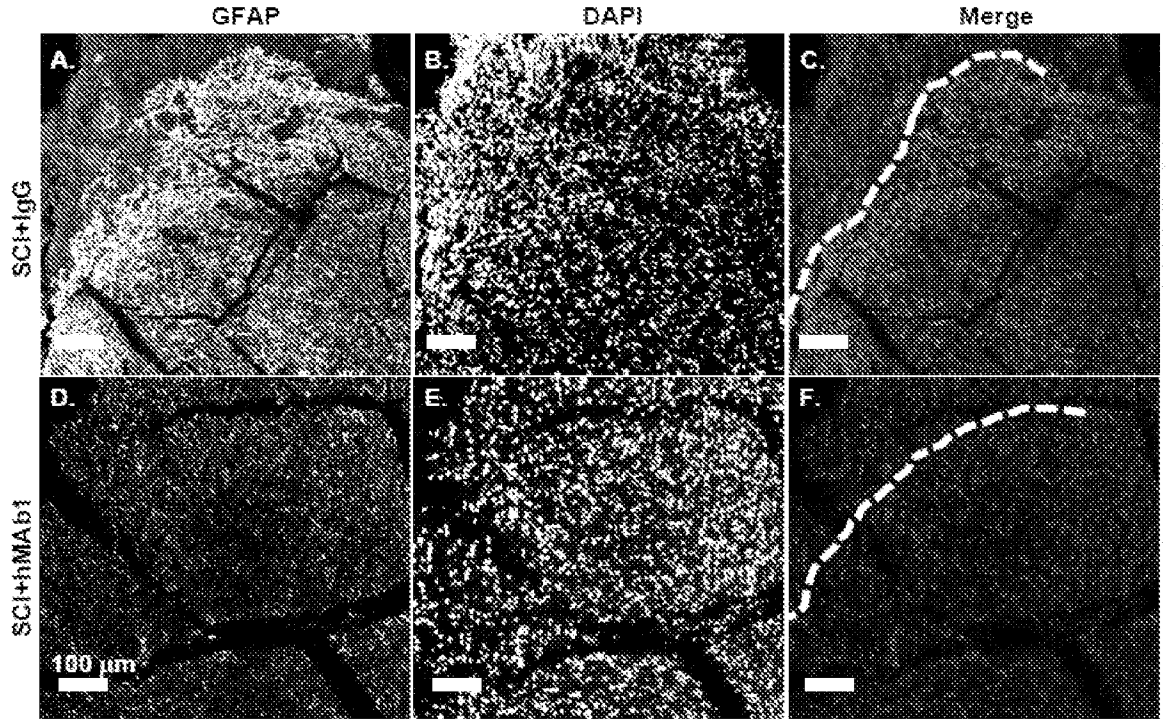
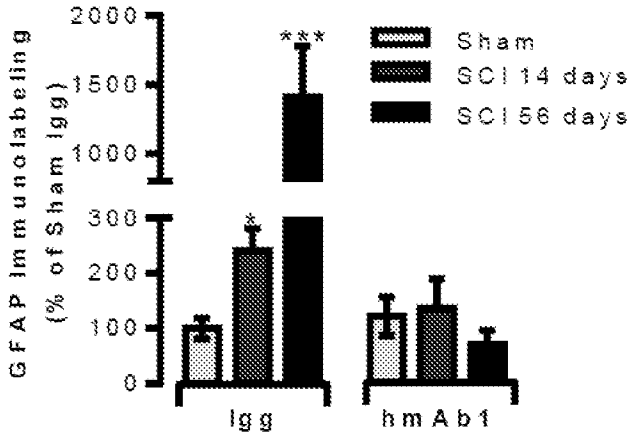

EtBr Uptake (AU)
40
30
20
10
0
***
***
***
Control
IL-1β
M1
IL-1β+M1
HMAb1
IL-1β+HMAb1

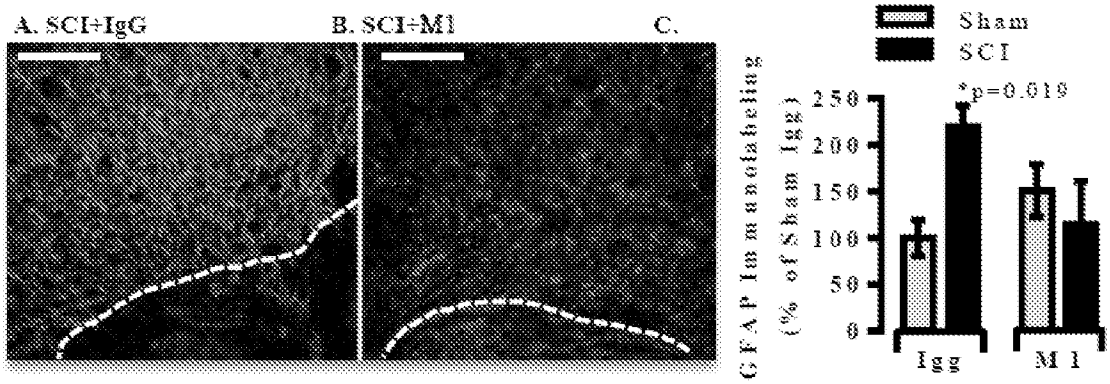
FIG. 2


GFAP
DAPI
Merge
A.
B.
C.
D.
E.
F.
SCI+IgG
SCI+hMAb1
100 µm

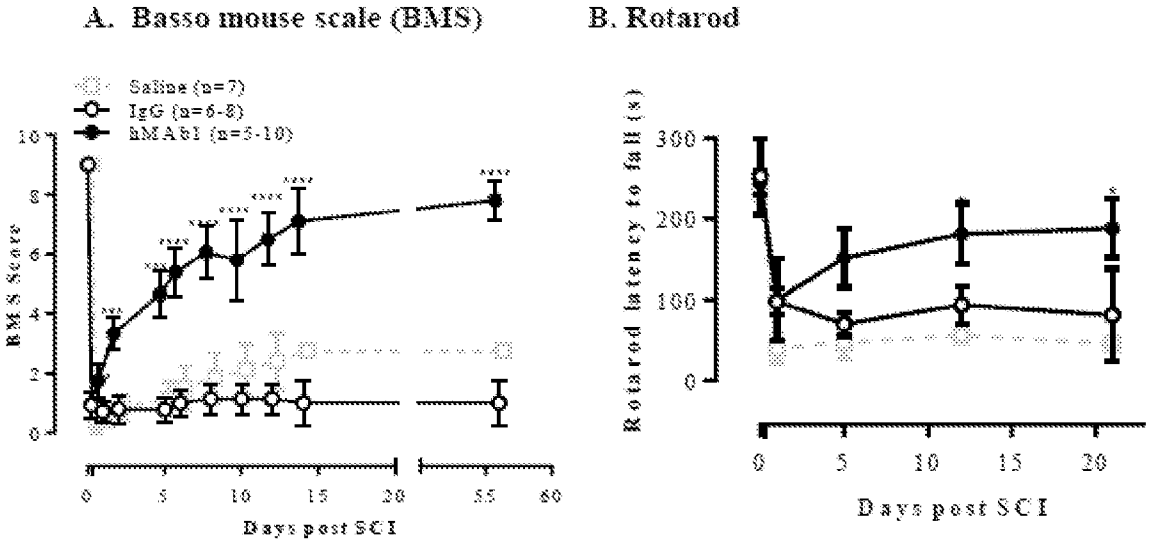
G.


GFAP Immunolabeling (% of Sham Igg)
2000
1500
1000
300
200
100
0
***
*
Sham
SCI 14 days
SCI 56 days
Igg
hmAb1

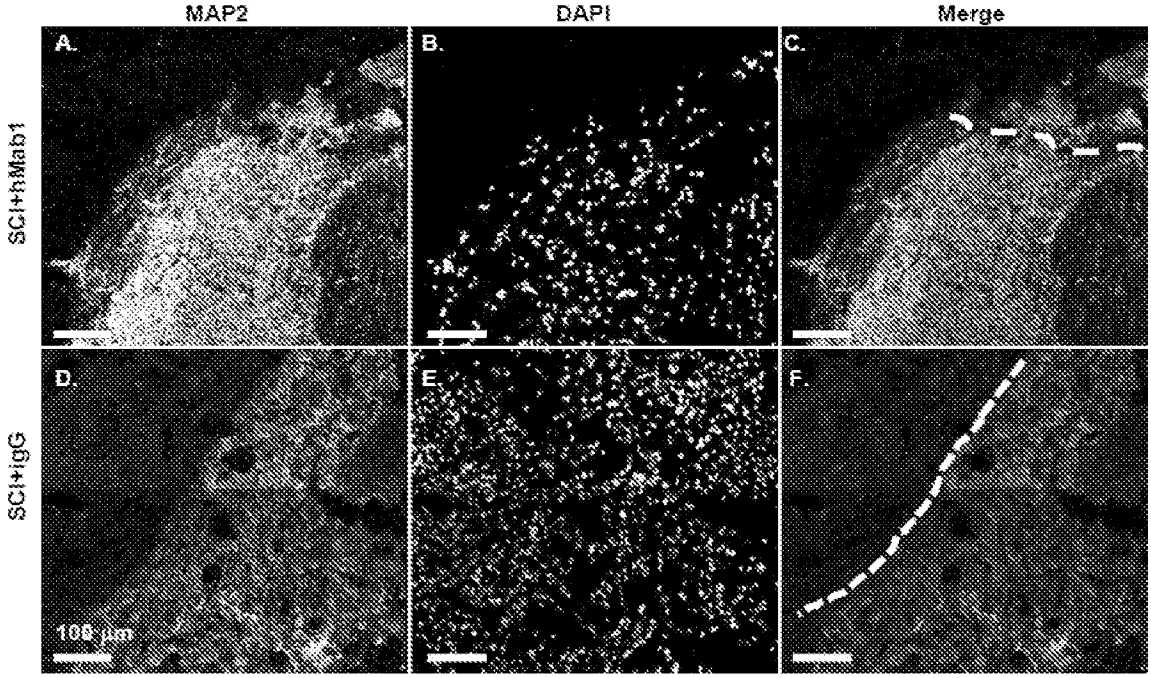
FIGS. 3A-3G



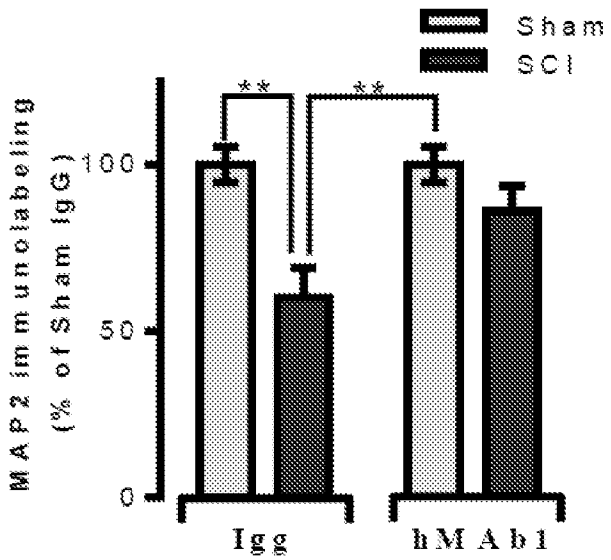
FIGS. 4A-4C



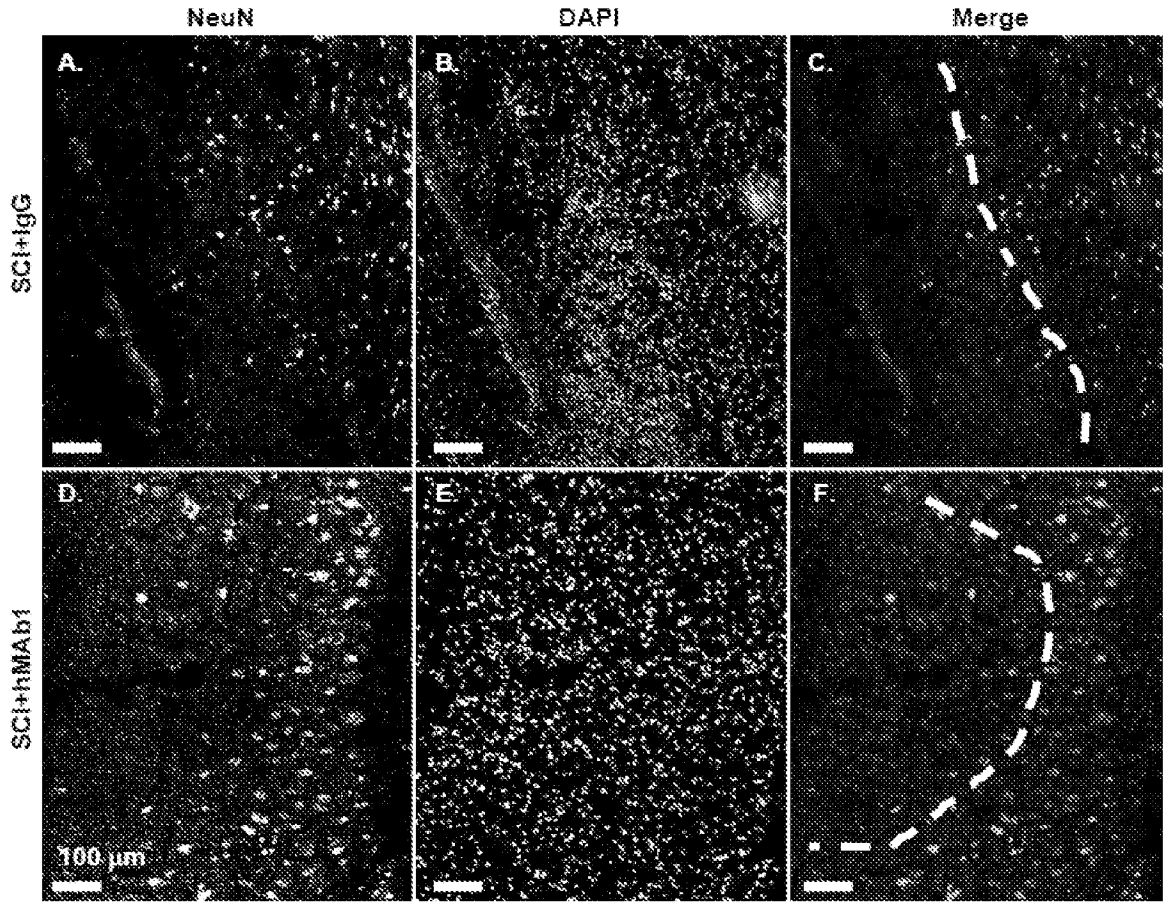
FIGS. 5A-5B


MAP2
DAPI
Merge
A.
B.
C.
D.
E.
F.
SCI+hMab1
SCI+igG
100 μm

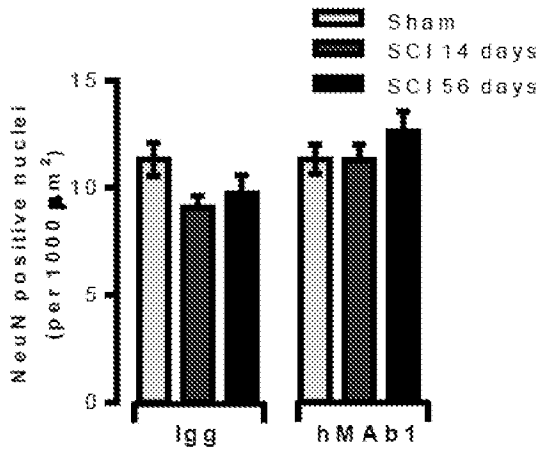
G.


Sham
SCI
**
**
MAP2 immunolabeling
(% of Sham IgG)
100
50
0
Igg
hMAb1

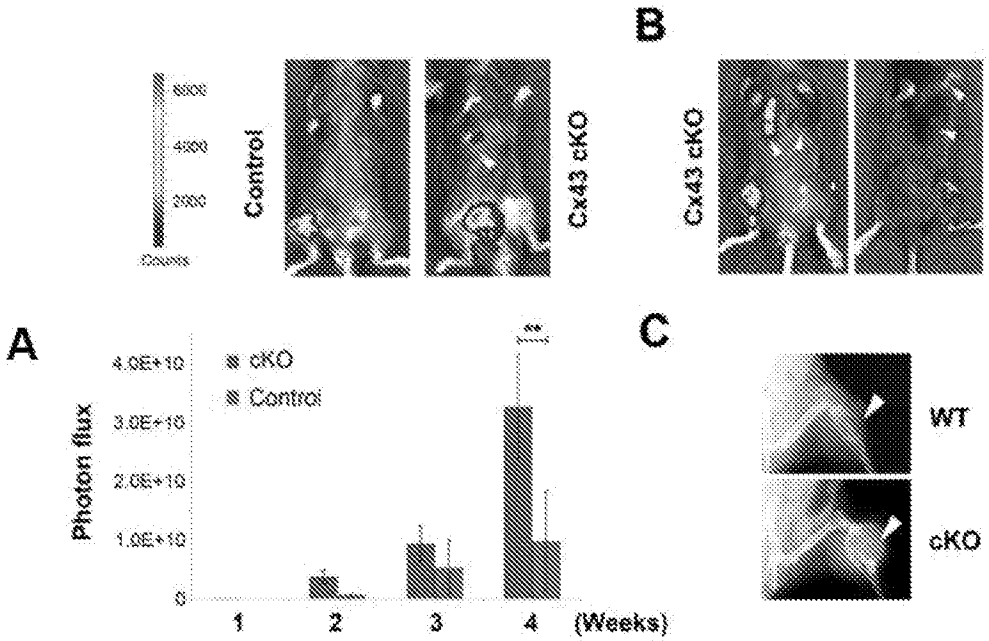
FIGS. 6A-6G


NeuN
DAPI
Merge
A.
B.
C.
D.
E.
F.
SCI+IgG
SCI+hMAb1
100 μm

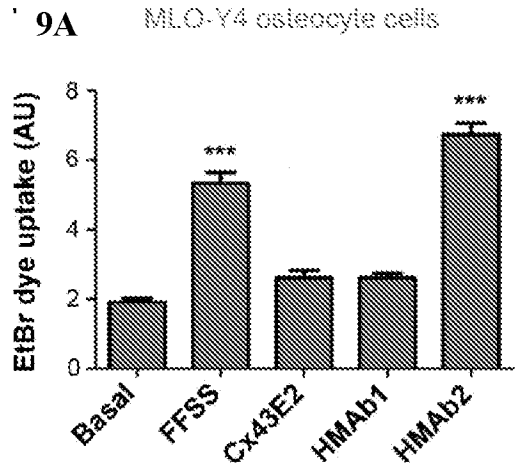
G.

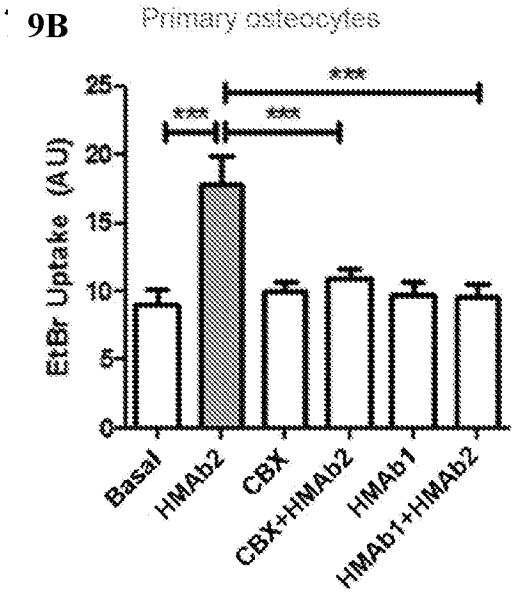

Sham
SCI 14 days
SCI 56 days
NeuN positive nuclei (per 1000 μm²)
15
10
5
0
Igg
hMAb1

FIGS. 7A-7G

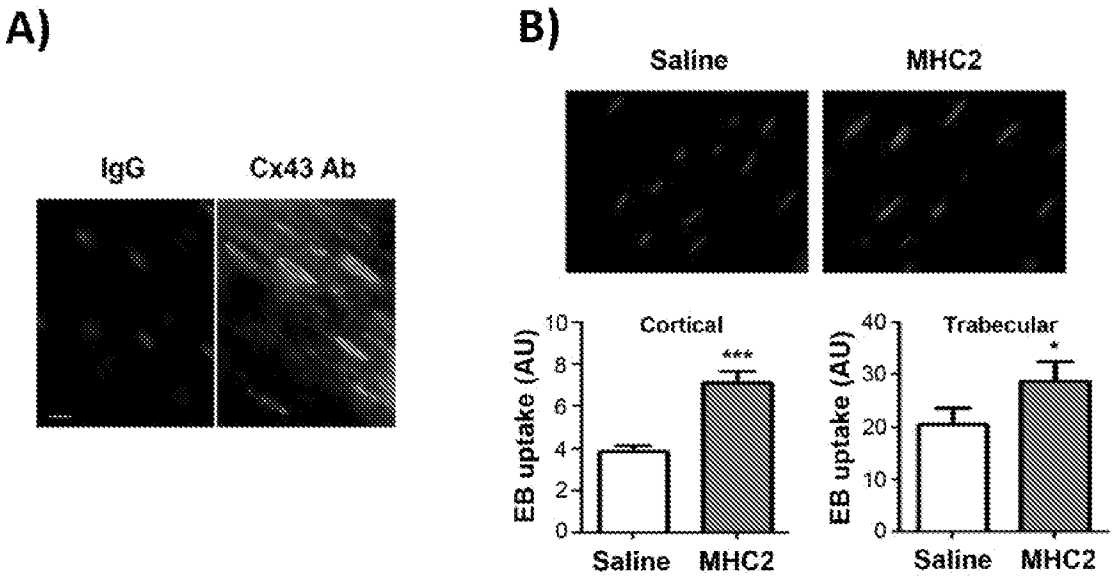

B
Control
Cx43 cKO
Cx43 cKO
A
C
cKO
Control
Photon flux
4.0E+10
3.0E+10
2.0E+10
1.0E+10
0
1
2
3
4
(Weeks)
WT
cKO

FIGS. 8A-8C

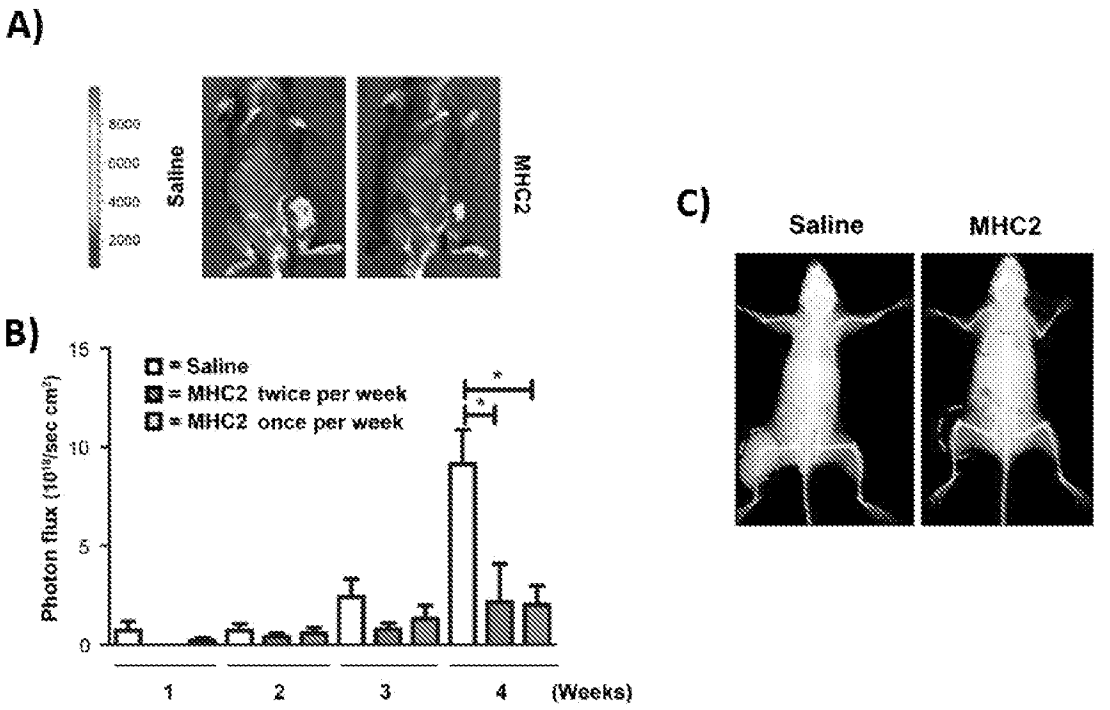

9A
MLO-Y4 osteocyte cells
EtBr dye uptake (AU)
0
2
4
6
8
***
***
Basal
FFSS
Cx43E2
HMAb1
HMAb2


9B
Primary osteocytes
EtBr Uptake (AU)
0
5
10
15
20
25
***
***
***
Basal
HMAb2
CBX
CBX+HMAb2
HMAb1
HMAb1+HMAb2

FIGS. 9A-9B


A)
IgG
Cx43 Ab
B)
Saline
MHC2
Cortical
Trabecular
EB uptake (AU)
***
*
Saline
MHC2

FIGS. 10A-10B



FIGS. 11A-11B

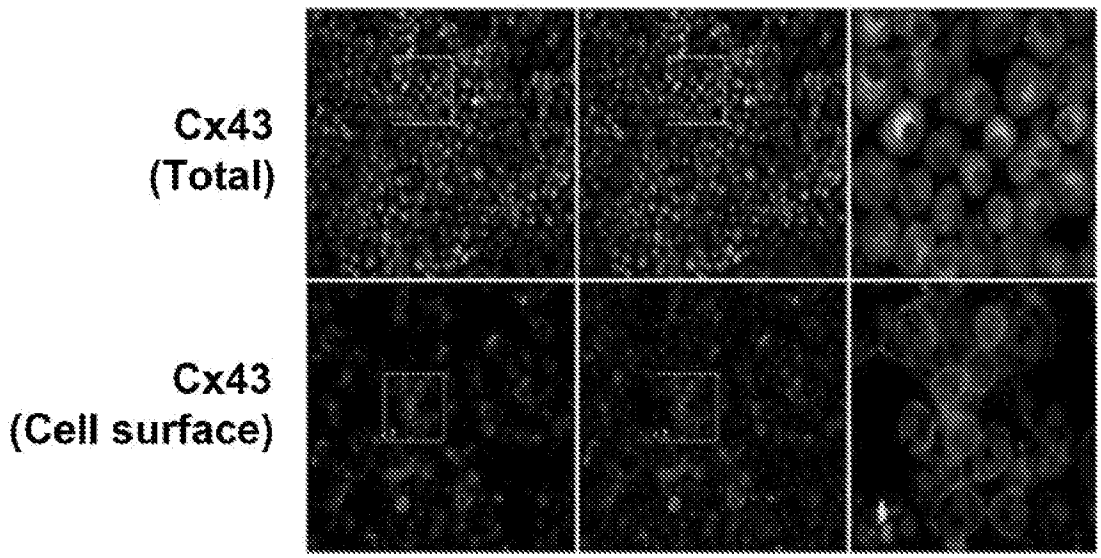


FIG. 12

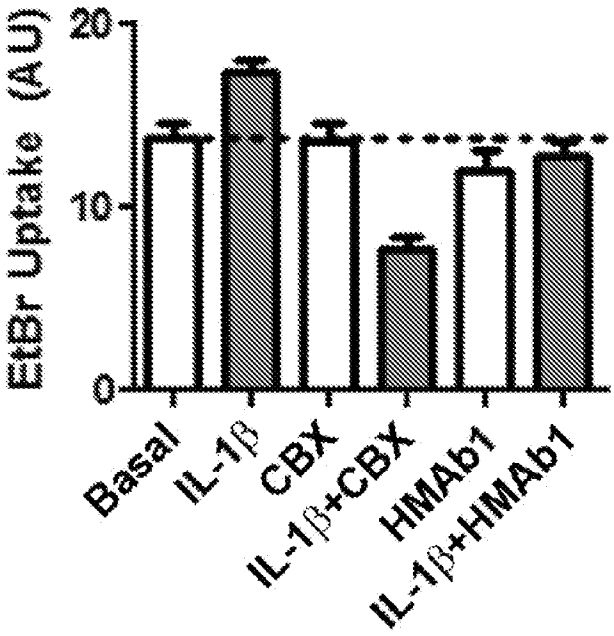

EtBr Uptake (AU)
20
10
0
Basal
IL-1β
CBX
IL-1β+CBX
HMAb1
IL-1β+HMAb1

FIG. 13

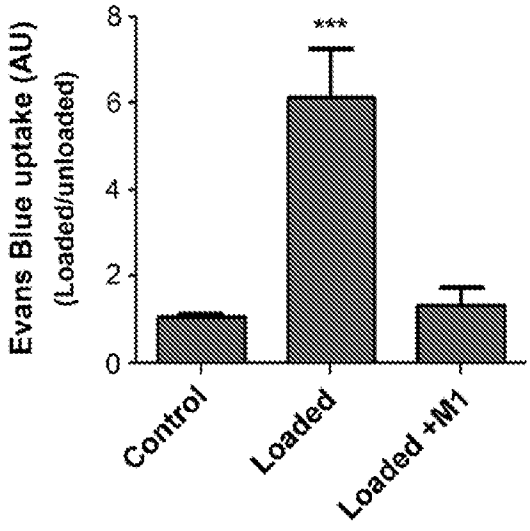

Evans Blue uptake (AU)
(Loaded/unloaded)
8
6
4
2
0
***
Control
Loaded
Loaded +M1

FIG. 14

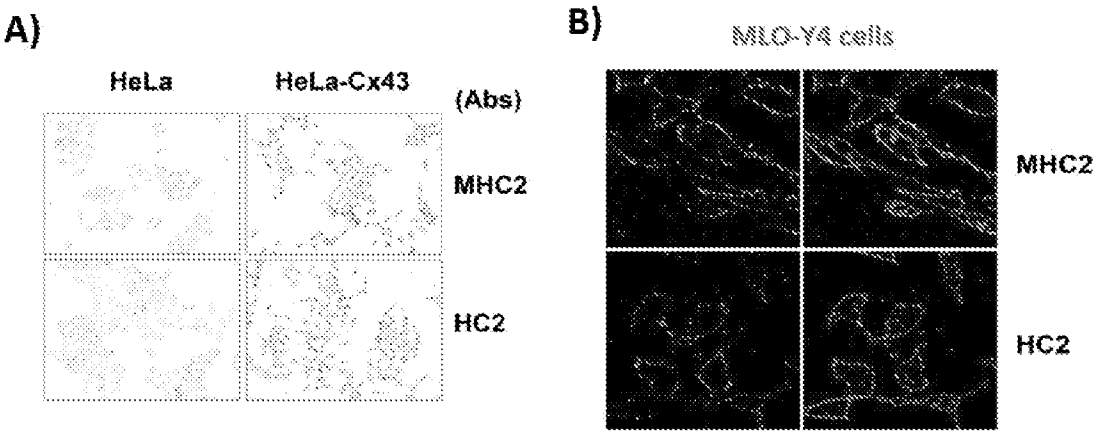

A)
HeLa
HeLa-Cx43
(Abs)
MHC2
HC2
B)
MLO-Y4 cells
MHC2
HC2

FIG. 15

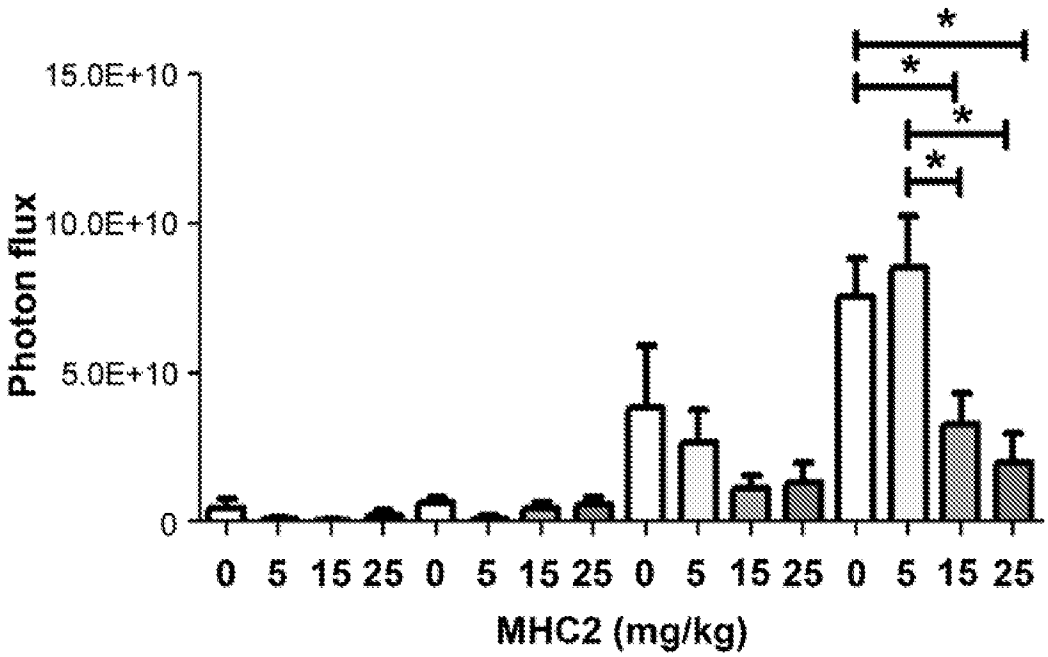

15.0E+10
10.0E+10
5.0E+10
0
Photon flux
0 5 15 25 0 5 15 25 0 5 15 25 0 5 15 25
MHC2 (mg/kg)
*
*
*
*

FIG. 16

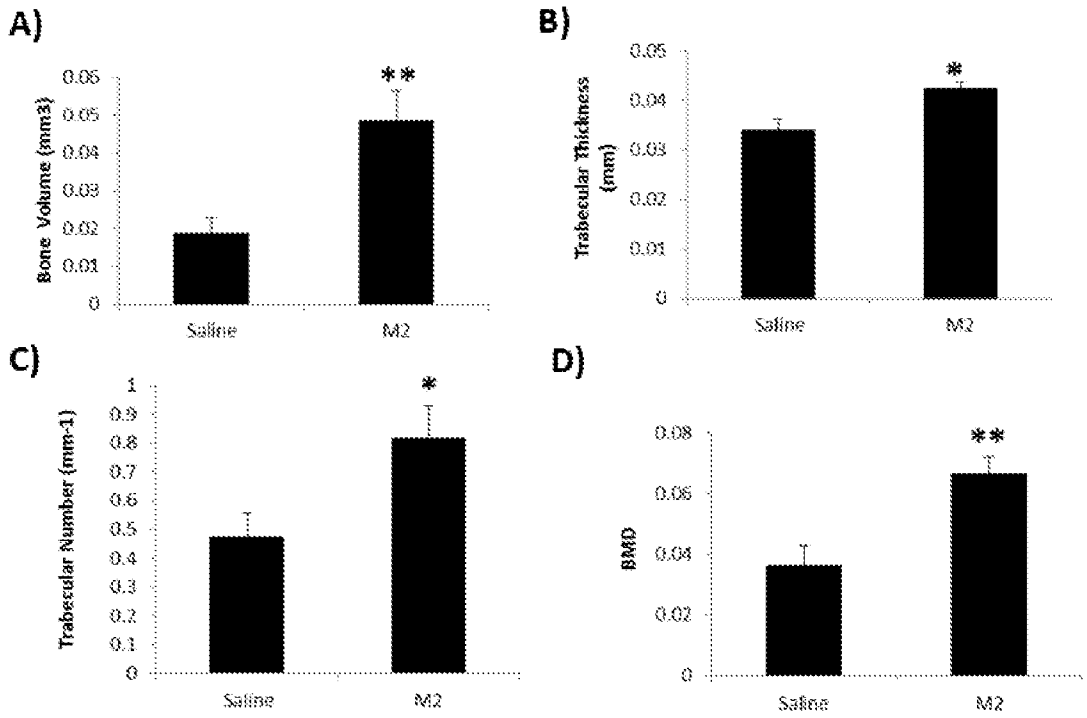


FIG. 17A-D

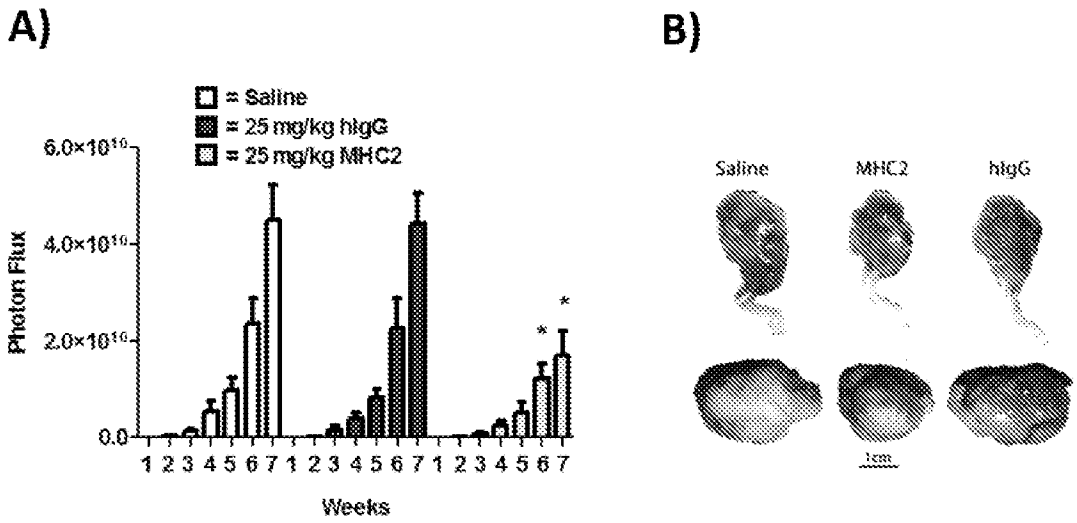


FIG. 18A-B

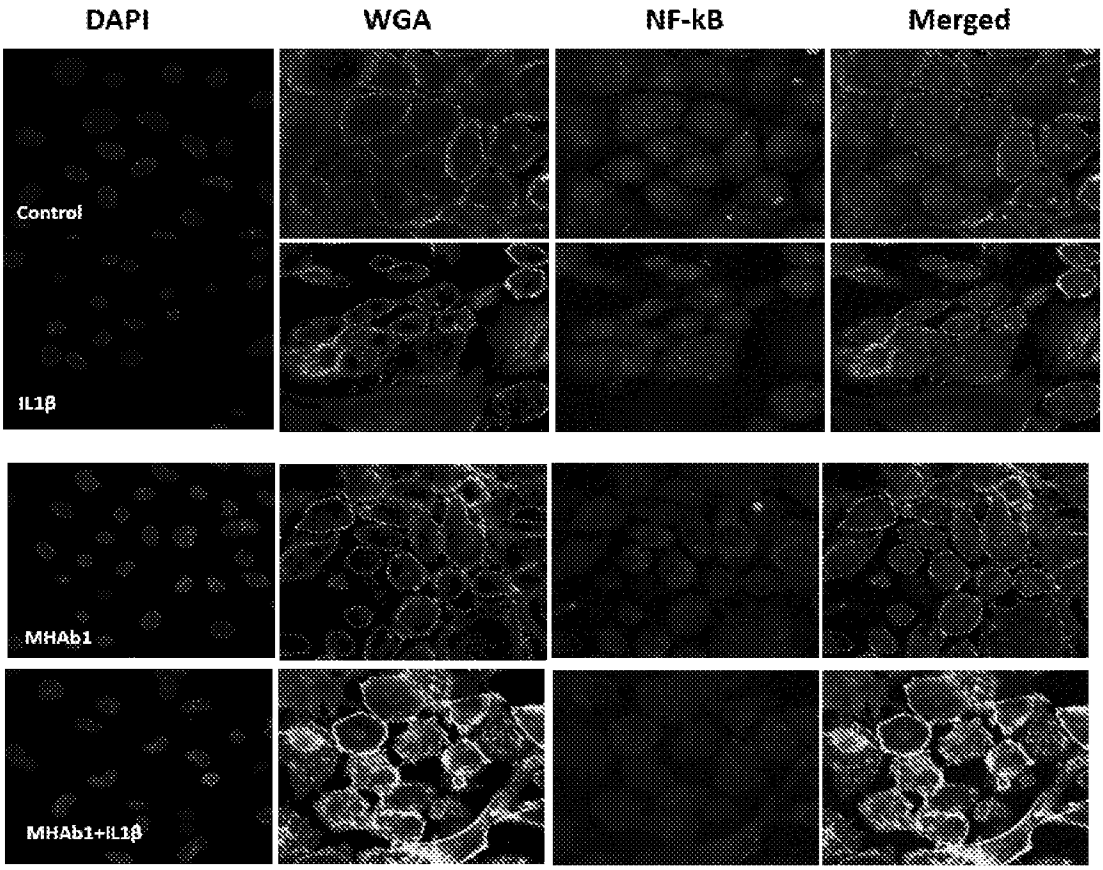


FIG. 19

SEQUENCE LISTING

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<130> UTFH.P0329WO

<140> Unkown
<141> 2017-02-27

<150> US 62/300,492
<151> 2016-02-26

<160> 63

<170> PatentIn version 3.5

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cctggacaag gccttgagtg gattggggga attaatccta gcaatggtgg tactaacttc 180

aatgagaagt tcaagaacaa ggccacactg actgtagaca aatcctccag cacagcctac 240

atgcaactca gcagcctgac atctgaggac tctgcggtct attactgtac aagagagggt 300

aacccctact atactatgaa ctactggggt caaggaacct cagtcaccgt ctcctcagcc 360

aaaacgacac ccccatctgt ctat 384

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<213> Mus musculus

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Tyr Met Tyr Trp Val Lys Gln Arg Pro Gly Gln Gly Leu Glu Trp Ile
35 40 45

Gly Gly Ile Asn Pro Ser Asn Gly Gly Thr Asn Phe Asn Glu Lys Phe
50 55 60

Lys Asn Lys Ala Thr Leu Thr Val Asp Lys Ser Ser Ser Thr Ala Tyr
65 70 75 80

Met Gln Leu Ser Ser Leu Thr Ser Glu Asp Ser Ala Val Tyr Tyr Cys
85 90 95

Thr Arg Glu Gly Asn Pro Tyr Tyr Thr Met Asn Tyr Trp Gly Gln Gly
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Thr Ser Val Thr Val Ser Ser Ala Lys Thr Thr Pro Pro Ser Val Tyr
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<212> DNA
<213> Mus musculus

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atctcataca gggccagcaa aagtgtcagt acatctggct atagttatat gcactggaac 120

caacagaaac caggacagcc acccagactc ctcatctatc ttgtatccaa cctagaatct 180

ggggtccctg ccaggttcag tggcagtggg tctgggacag acttcaccct caacatccat 240

cctgtggagg aggaggatgc tgcaacctat tactgtcagc acattaggga gcttacacgt 300

tcggaggggg gaccaagctg gaaa 324

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20 25 30

Gly Tyr Ser Tyr Met His Trp Asn Gln Gln Lys Pro Gly Gln Pro Pro
35 40 45

Arg Leu Leu Ile Tyr Leu Val Ser Asn Leu Glu Ser Gly Val Pro Ala
50 55 60

Arg Phe Ser Gly Ser Gly Ser Gly Thr Asp Phe Thr Leu Asn Ile His
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Glu Leu Thr Arg Ser Glu Gly Gly Pro Ser Trp Lys
100 105

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cctggacaag gccttgagtg gattggggga attaatccta gcaatggtgg tactaacttc 180

aatgagaagt tcaagaacaa ggccacactg actgtagaca aatcctccag cacagcctac 240

atgcaactca gcagcctgac atctgaggac tctgcggtct attactgtac aagagagggt 300

aacccctact atactatgaa ctactggggt caaggaacct cagtcaccgt ctcctcagcc 360

aaaacgacac ccccatctgt ctat 384

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20 25 30

Tyr Met Tyr Trp Val Lys Gln Arg Pro Gly Gln Gly Leu Glu Trp Ile
35 40 45

Gly Gly Ile Asn Pro Ser Asn Gly Gly Thr Asn Phe Asn Glu Lys Phe
50 55 60

Lys Asn Lys Ala Thr Leu Thr Val Asp Lys Ser Ser Ser Thr Ala Tyr
65 70 75 80

Met Gln Leu Ser Ser Leu Thr Ser Glu Asp Ser Ala Val Tyr Tyr Cys
85 90 95

Thr Arg Glu Gly Asn Pro Tyr Tyr Thr Met Asn Tyr Trp Gly Gln Gly
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tggtaccagc agaaaccagg gcagcctcct aaactgttga tctacggggc atccactagg 180

gaatctgggg tccctgatcg cttcacaggc agtggatctg gaaccgattt cactcttacc 240

atcagcagtg tgcaggctga agacctggca gtttattact gtcagaatga tcatagttat 300

ccattcacgt tcggctcggg gacaaagttg gaaataaaac gggctgatgc tgcaccaact 360

gtatccgcat gcacc 375

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20 25 30

Gly Asn Gln Lys Thr Tyr Leu Ala Trp Tyr Gln Gln Lys Pro Gly Gln
35 40 45

Pro Pro Lys Leu Leu Ile Tyr Gly Ala Ser Thr Arg Glu Ser Gly Val
50 55 60

Pro Asp Arg Phe Thr Gly Ser Gly Ser Gly Thr Asp Phe Thr Leu Thr
65 70 75 80

Ile Ser Ser Val Gln Ala Glu Asp Leu Ala Val Tyr Tyr Cys Gln Asn
85 90 95

Asp His Ser Tyr Pro Phe Thr Phe Gly Ser Gly Thr Lys Leu Glu Ile
100 105 110

Lys Arg Ala Asp Ala Ala Pro Thr Val Ser
115 120

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ggccttgact ggattggaga gattagtcct agcaacggtc gttctaatta caataagaag 180

ttcaagagca aggccacact gactgtagac aaatcctcca gcacagccta catgcaactc 240

agcagcctga catctgagga ctctgcggtc tattactgtg cacgattcga cgaggggggac 300

ttctggggcc aaggcaccac tctcatagtc tcctcagcca aaacaacagc cccatcggtc 360

tatccactgg cccctgtgtg tggagataca actggctcct cggtg 405

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<213> Mus musculus

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Trp Leu Lys Gln Arg Pro Gly Gln Gly Leu Asp Trp Ile Gly Glu Ile
        35                  40                  45

Ser Pro Ser Asn Gly Arg Ser Asn Tyr Asn Lys Lys Phe Lys Ser Lys
    50                  55                  60

Ala Thr Leu Thr Val Asp Lys Ser Ser Ser Thr Ala Tyr Met Gln Leu
65                  70                  75                  80

Ser Ser Leu Thr Ser Glu Asp Ser Ala Val Tyr Tyr Cys Ala Arg Phe
                85                  90                  95

Asp Glu Gly Asp Phe Trp Gly Gln Gly Thr Thr Leu Ile Val Ser Ser
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Ala Lys Thr Thr Ala Pro Ser Val Tyr Pro Leu Ala Pro Val Cys Gly
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Asp Thr Thr Gly Ser Ser Val
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<212> DNA
<213> Mus musculus

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caacagaaac caggacagcc acccagactc ctcatctatc ttgtatccaa cctagaatct      180

ggggtccctg ccaggttcag tggcagtggg tctgggacag acttcaccct caacatccat      240

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tcggaggggg gaccaagctg gaaa                                             324
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<213> Mus musculus

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20 25 30

Gly Tyr Ser Tyr Met His Trp Asn Gln Gln Lys Pro Gly Gln Pro Pro
35 40 45

Arg Leu Leu Ile Tyr Leu Val Ser Asn Leu Glu Ser Gly Val Pro Ala
50 55 60

Arg Phe Ser Gly Ser Gly Ser Gly Thr Asp Phe Thr Leu Asn Ile His
65 70 75 80

Pro Val Glu Glu Glu Asp Ala Ala Thr Tyr Tyr Cys Gln His Ile Arg
85 90 95

Glu Leu Thr Arg Ser Glu Gly Gly Pro Ser Trp Lys
100 105

<210> 13
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<210> 27
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Ala Arg Phe Asp Glu Gly Asp Phe
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<210> 30
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<210> 31
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<400> 33

Gln Asn Asp His Ser Tyr Pro Phe Thr
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<400> 38

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<400> 39

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cctggacaag gccttgagtg gattggggga attaatccta gcaatggtgg tactaacttc 180

aatgagaagt tcaagaacaa ggccacactg actgtagaca aatcctccag cacagcctac 240

atgcaactca gcagcctgac atctgaggac tctgcggtct attactgtac aagagagggt 300

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tcctgcaagg cttctggcta catcttcacc acctactgga tgcactggct gaagcagagg 120

cctggacaag gccttgactg gattggagag attagtccta gcaacggtcg ttctaattac 180

aataagaagt tcaagagcaa ggccacactg actgtagaca aatcctccag cacagcctac 240

atgcaactca gcagcctgac atctgaggac tctgcggtct attactgtgc acgattcgac 300

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<223> Synthetic peptide

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tggtaccagc agaaaccagg gcagcctcct aaactgttga tctacggggc atccactagg 180

gaatctgggg tccctgatcg cttcacaggc agtggatctg gaaccgattt cactcttacc 240

atcagcagtg tgcaggctga agacctggca gtttattact gtcagaatga tcatagttat 300

ccattcacgt tcggctcggg gacaaagttg gaaataaaa 339

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<213> Artificial sequence

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caacagaaac caggacagcc acccagactc ctcatctatc ttgtatccaa cctagaatct 180

ggggtccctg ccaggttcag tggcagtggg tctgggacag acttcaccct caacatccat 240

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tcggaggggg gaccaagctg gaaatcaaac 330

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<212> DNA
<213> Artificial sequence

<220>
<223> Synthetic peptide

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atctcataca gggccagcaa aagtgtcagt acatctggct atagttatat gcactggaac 120

caacagaaac caggacagcc acccagactc ctcatctatc ttgtatccaa cctagaatct 180

ggggtccctg ccaggttcag tggcagtggg tctgggacag acttcaccct caacatccat 240

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<220>
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catctcttgc aagtcaagtc agagcctctt agaaagcgat ggaaagacat atttgaattg 120

gttgttacag aggccaggcc agtctccaaa gcgcctaatc tatctggtgt ctaaactgga 180

ctctggagtc cctgacaggt tcactggcag tggatcaggg acagatttca cactgaaaat 240

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gtggacgttc ggtggaggca ccaagctgga aatcaaa 337

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<211> 119
<212> PRT
<213> Artificial sequence

<220>
<223> Synthetic polypeptide

<400> 58

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Ser Val Lys Leu Ser Cys Lys Ala Ser Gly Tyr Thr Phe Thr Ser Tyr
20 25 30

Tyr Met Tyr Trp Val Lys Gln Arg Pro Gly Gln Gly Leu Glu Trp Ile
35 40 45

Gly Gly Ile Asn Pro Ser Asn Gly Gly Thr Asn Phe Asn Glu Lys Phe
50 55 60

Lys Asn Lys Ala Thr Leu Thr Val Asp Lys Ser Ser Ser Thr Ala Tyr
65 70 75 80

Met Gln Leu Ser Ser Leu Thr Ser Glu Asp Ser Ala Val Tyr Tyr Cys
85 90 95

Thr Arg Glu Gly Asn Pro Tyr Tyr Thr Met Asn Tyr Trp Gly Gln Gly
100 105 110

Thr Ser Val Thr Val Ser Ser
115

<210> 59
<211> 115
<212> PRT
<213> Artificial sequence

<220>
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<400> 59

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1 5 10 15

Ser Val Met Leu Ser Cys Lys Ala Ser Gly Tyr Ile Phe Thr Thr Tyr
20 25 30

Trp Met His Trp Leu Lys Gln Arg Pro Gly Gln Gly Leu Asp Trp Ile
35 40 45

Gly Glu Ile Ser Pro Ser Asn Gly Arg Ser Asn Tyr Asn Lys Lys Phe
50 55 60

Lys Ser Lys Ala Thr Leu Thr Val Asp Lys Ser Ser Ser Thr Ala Tyr
65 70 75 80

Met Gln Leu Ser Ser Leu Thr Ser Glu Asp Ser Ala Val Tyr Tyr Cys
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Ala Arg Phe Asp Glu Gly Asp Phe Trp Gly Gln Gly Thr Thr Leu Ile
100 105 110

Val Ser Ser
115

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<400> 60

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Glu Lys Val Thr Met Ser Cys Lys Ser Ser Gln Ser Leu Leu Asn Ser
20 25 30

Gly Asn Gln Lys Thr Tyr Leu Ala Trp Tyr Gln Gln Lys Pro Gly Gln
35 40 45

Pro Pro Lys Leu Leu Ile Tyr Gly Ala Ser Thr Arg Glu Ser Gly Val
50 55 60

Pro Asp Arg Phe Thr Gly Ser Gly Ser Gly Thr Asp Phe Thr Leu Thr
65 70 75 80

Ile Ser Ser Val Gln Ala Glu Asp Leu Ala Val Tyr Tyr Cys Gln Asn
85 90 95

Asp His Ser Tyr Pro Phe Thr Phe Gly Ser Gly Thr Lys Leu Glu Ile
100 105 110

Lys

<210> 61
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<212> PRT
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<223> Synthetic polypeptide

<400> 61

Asp Ile Val Leu Thr Gln Ser Pro Ala Ser Leu Ala Val Ser Leu Gly
1 5 10 15

Gln Arg Ala Thr Ile Ser Tyr Arg Ala Ser Lys Ser Val Ser Thr Ser
20 25 30

Gly Tyr Ser Tyr Met His Trp Asn Gln Gln Lys Pro Gly Gln Pro Pro
35 40 45

Arg Leu Leu Ile Tyr Leu Val Ser Asn Leu Glu Ser Gly Val Pro Ala
50 55 60

Arg Phe Ser Gly Ser Gly Ser Gly Thr Asp Phe Thr Leu Asn Ile His
65 70 75 80

Pro Val Glu Glu Glu Asp Ala Ala Thr Tyr Tyr Cys Gln His Ile Arg
85 90 95

Glu Leu Thr Arg Ser Glu Gly Gly Pro Ser Trp Lys Ser Asn
100 105 110

<210> 62
<211> 110
<212> PRT
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Asp Ile Val Met Thr Gln Ser Pro Ala Ser Leu Ala Val Ser Leu Gly
1 5 10 15

Gln Arg Ala Thr Ile Ser Tyr Arg Ala Ser Lys Ser Val Ser Thr Ser
20 25 30

Gly Tyr Ser Tyr Met His Trp Asn Gln Gln Lys Pro Gly Gln Pro Pro
35 40 45

Arg Leu Leu Ile Tyr Leu Val Ser Asn Leu Glu Ser Gly Val Pro Ala
50 55 60

Arg Phe Ser Gly Ser Gly Ser Gly Thr Asp Phe Thr Leu Asn Ile His
65 70 75 80

Pro Val Glu Glu Glu Asp Ala Ala Thr Tyr Tyr Cys Gln His Ile Arg
85 90 95

Glu Leu Thr Arg Ser Glu Gly Gly Thr Lys Leu Glu Ile Lys
100 105 110

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Asp Val Val Met Thr Gln Thr Pro Leu Thr Leu Ser Val Thr Ile Gly
1               5                  10                  15

Gln Pro Ala Ser Ile Ser Cys Lys Ser Ser Gln Ser Leu Leu Glu Ser
            20                  25                  30

Asp Gly Lys Thr Tyr Leu Asn Trp Leu Leu Gln Arg Pro Gly Gln Ser
        35                  40                  45

Pro Lys Arg Leu Ile Tyr Leu Val Ser Lys Leu Asp Ser Gly Val Pro
    50                  55                  60

Asp Arg Phe Thr Gly Ser Gly Ser Gly Thr Asp Phe Thr Leu Lys Ile
65                  70                  75                  80

Ser Arg Val Glu Ala Glu Asp Leu Gly Val Tyr Tyr Cys Trp Gln Gly
                85                  90                  95

Thr His Phe Pro Trp Thr Phe Gly Gly Gly Thr Lys Leu Glu Ile Lys
            100                 105                 110
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