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(54) **ANTIBODY THAT RECOGNIZES
NEOEPITOPE OF ACTIVATED
INTERLEUKIN-18 PROTEINS AND
APPLICATION THEREOF**

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(57) **ABSTRACT**

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Antibodies 9-10.2 and 8-4.1 that recognize YFGKLESK, which is 8 amino acids present in a neoepitope formed as a result of a precursor pro-IL-18 being cleaved by caspase-1 or caspase-4 are prepared. Accordingly, an antibody that recognizes only activated IL-18 can be provided.

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Specification includes a Sequence Listing.

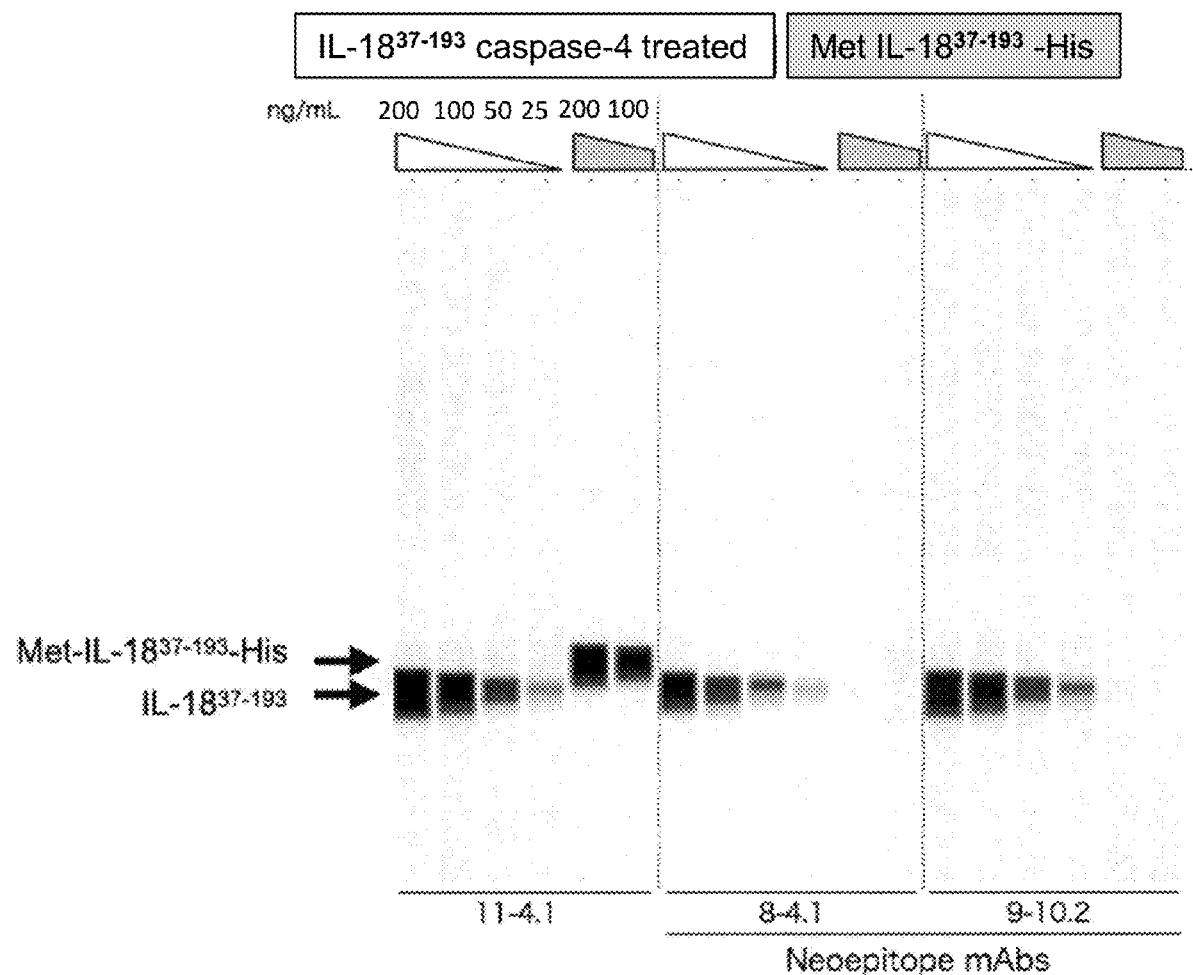


Figure 1

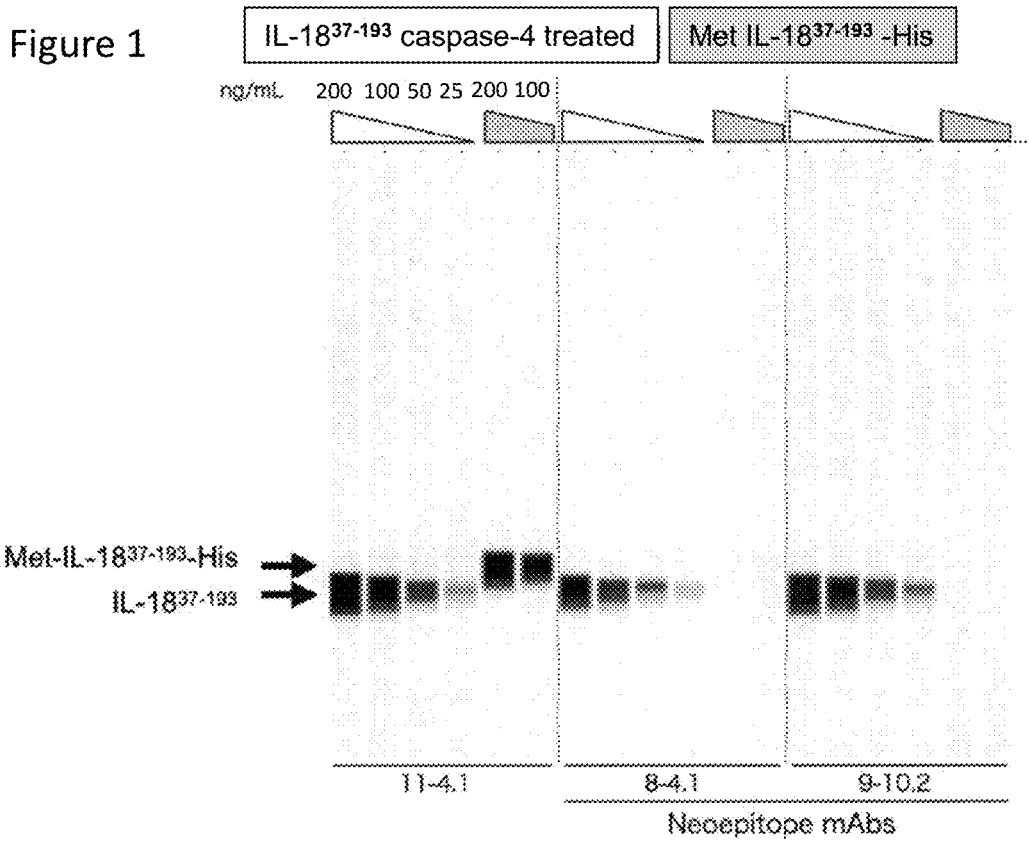


Figure 2 Purified protein from E.coli

IL-1837-103

AOSD case (10-fold dilution)

#1 #2 #3 #4 #5 #6 #7 #8 #9 #10 #11#12#13#14

IL-1837-193

IGH

101

ng/mL	40	20	10	5	2.5	94.7	167.2	40.2	28.2	25.6	36.4	82.5
						16.1	109.9	26.6	32.9	273.9	30.0	57.1

Figure 3

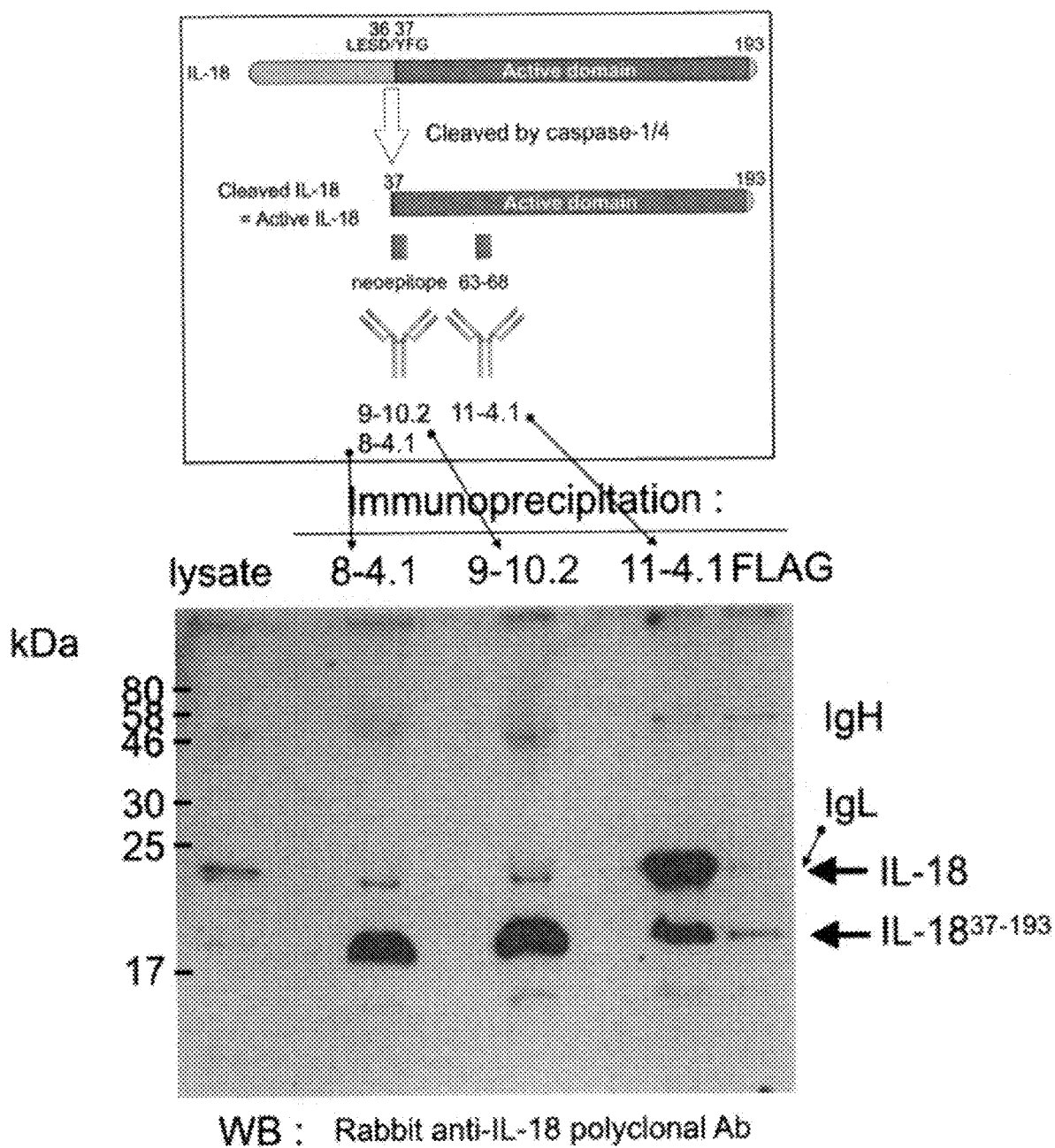


Figure 4

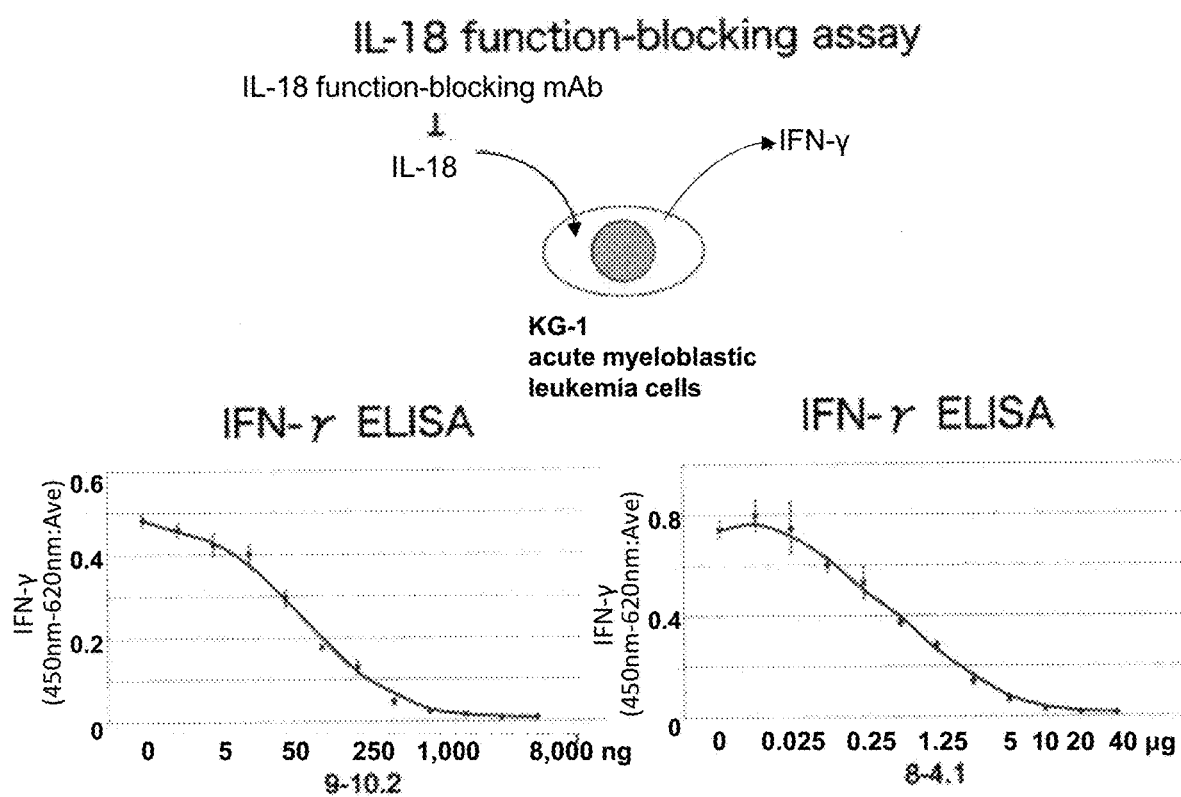


Figure 5

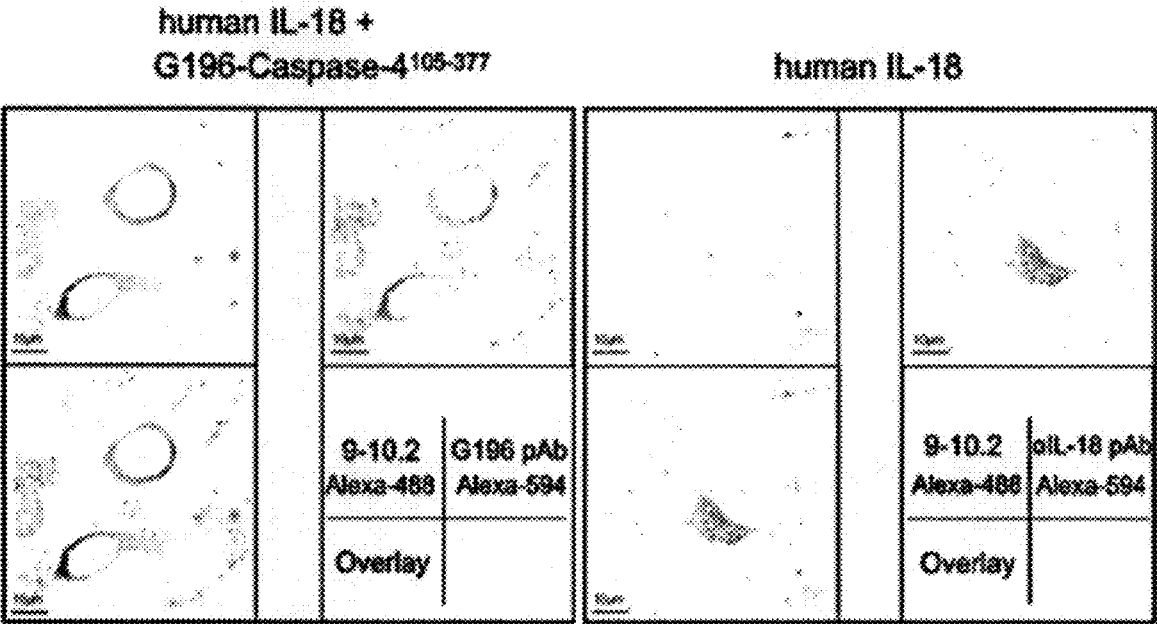
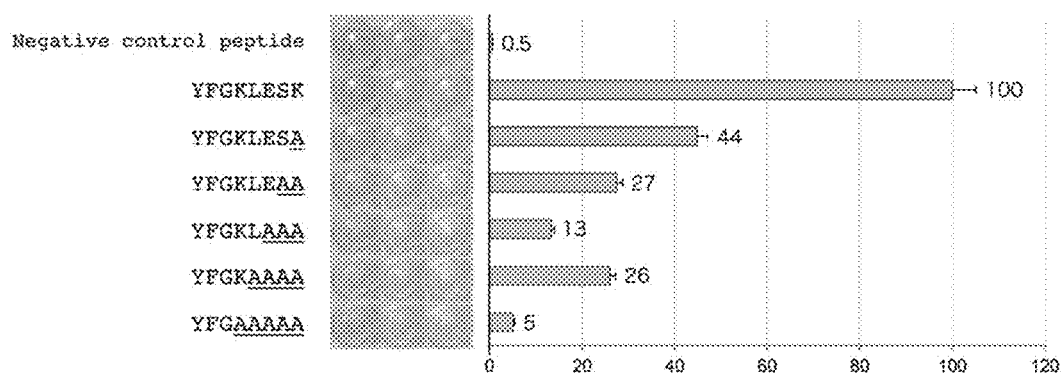


Figure 6A

9-10.2



8-4.1

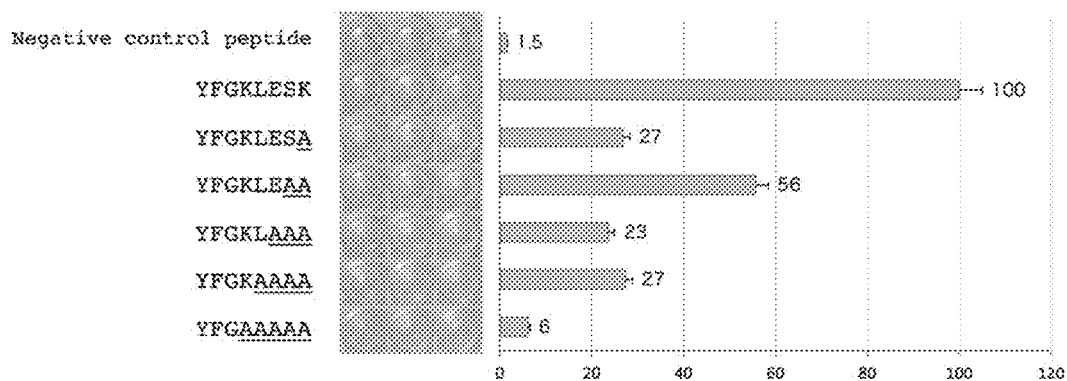


Figure 6B

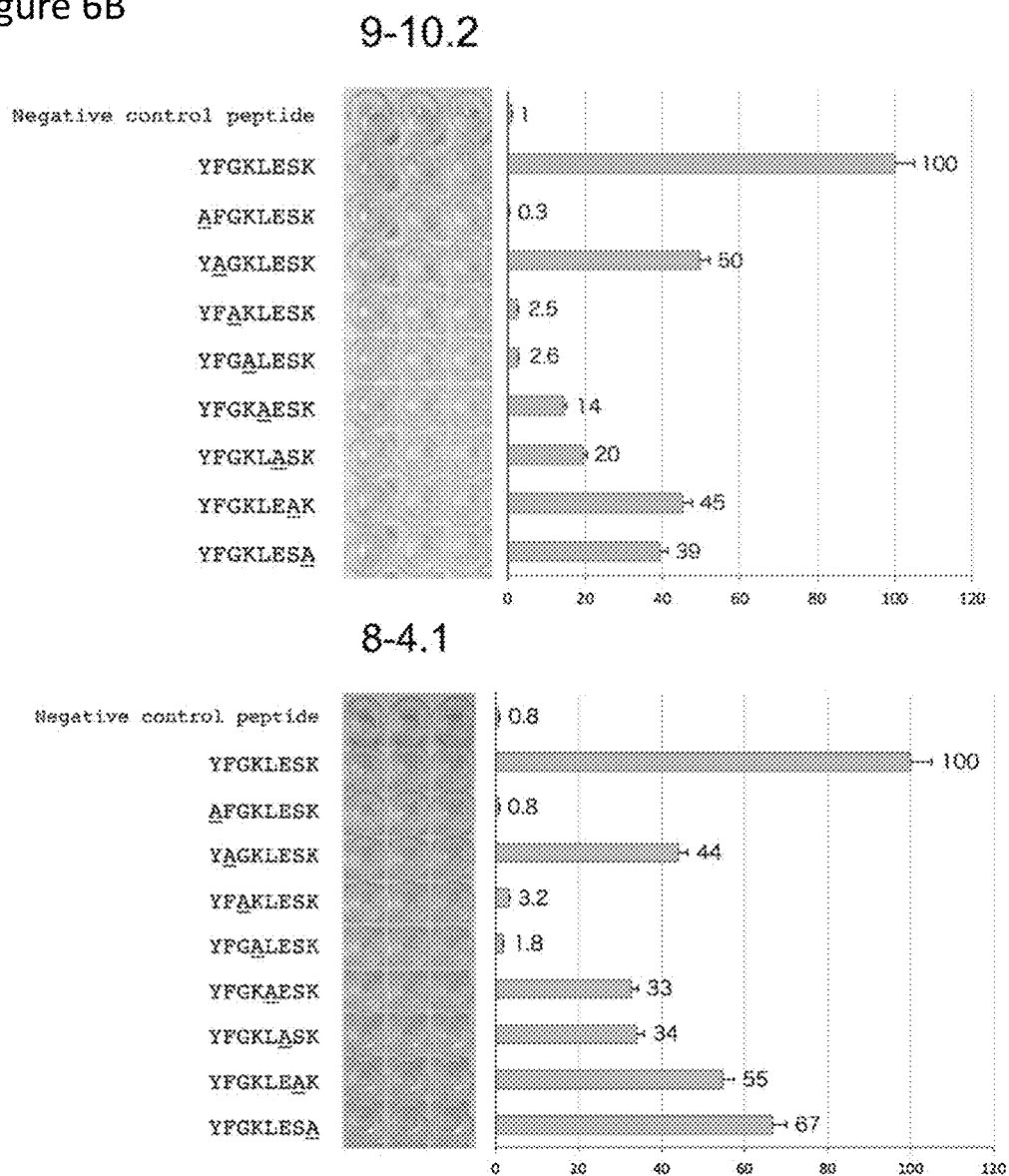


Figure 7A

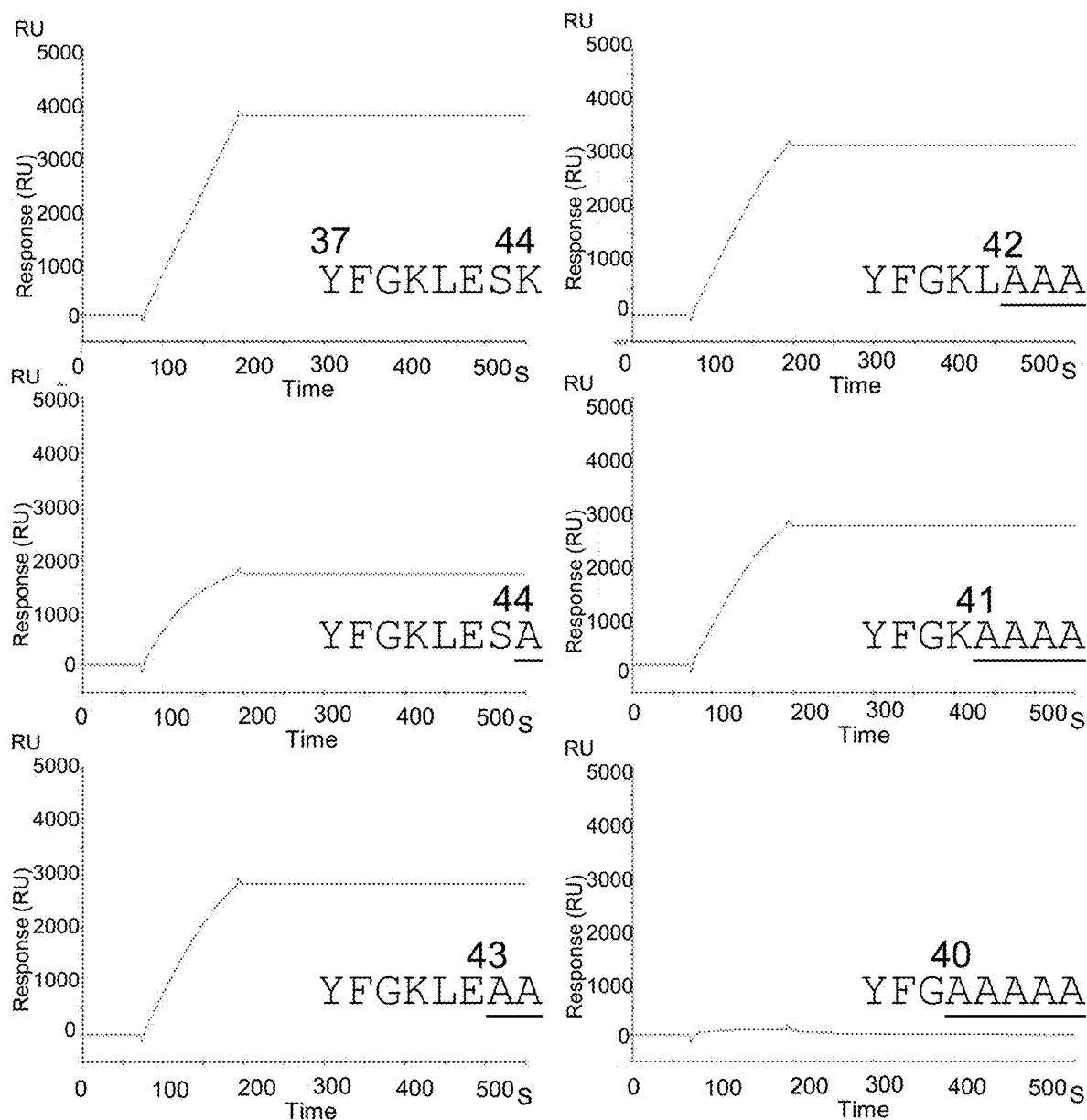


Figure 7B

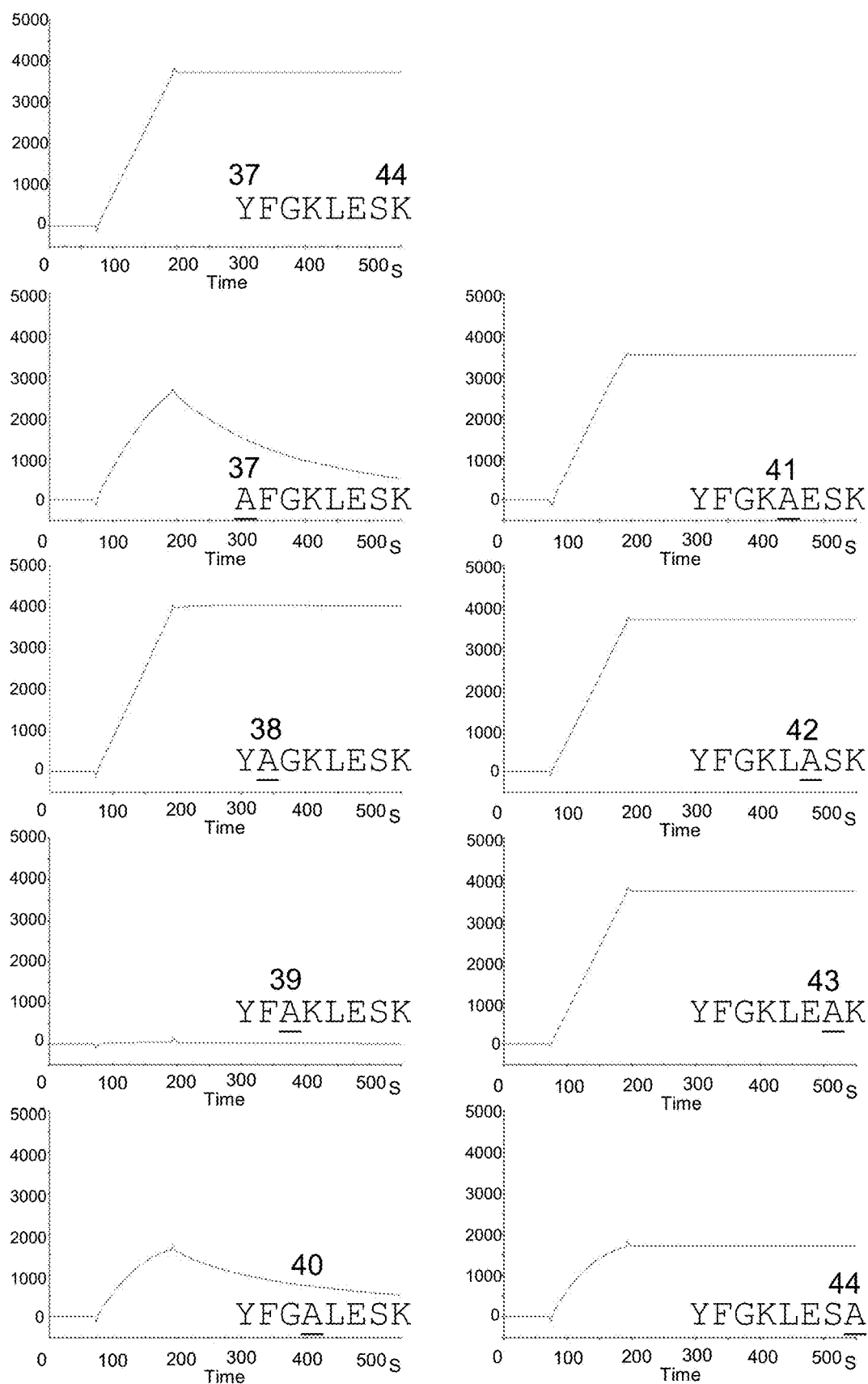


Figure 7C

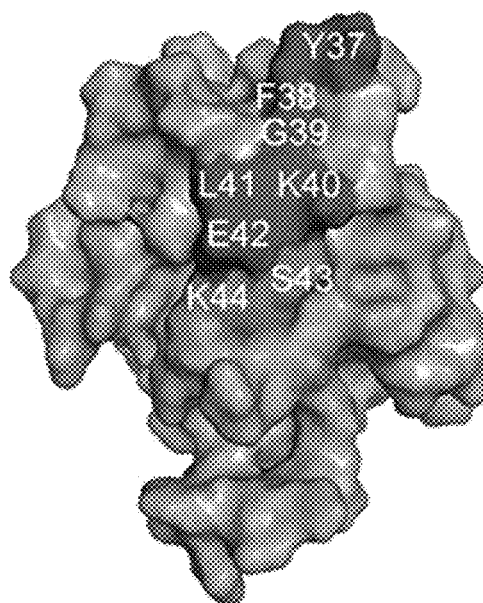


Figure 8

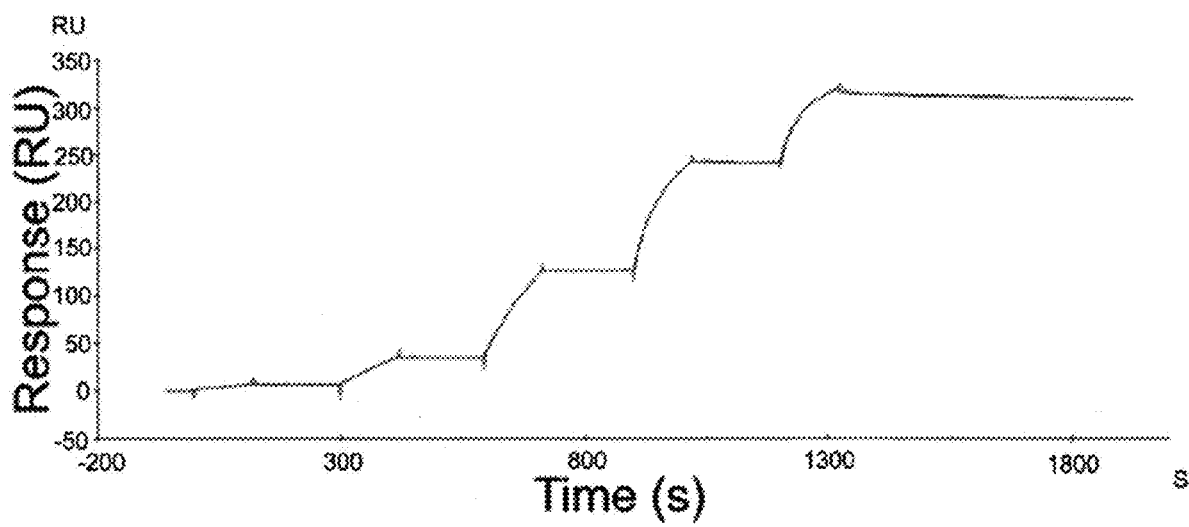
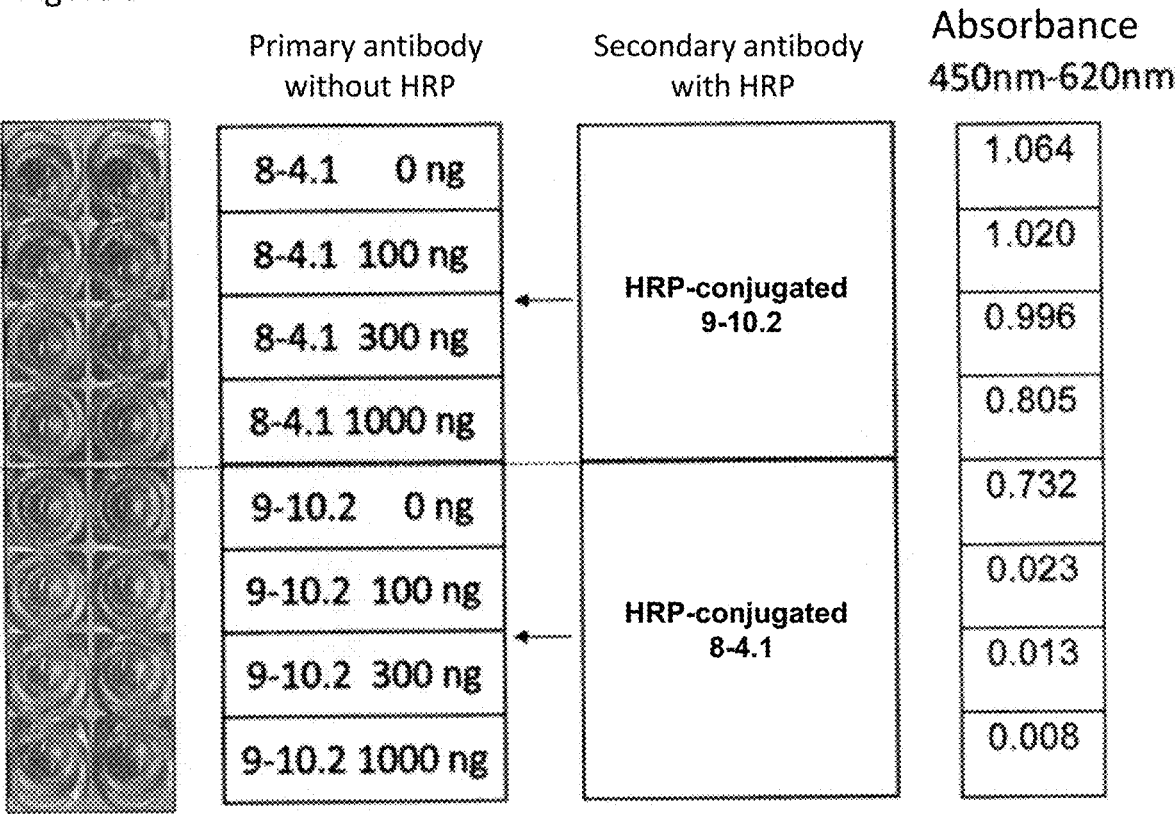


Figure 9



ANTIBODY THAT RECOGNIZES NEOEPITOPE OF ACTIVATED INTERLEUKIN-18 PROTEINS AND APPLICATION THEREOF

TECHNICAL FIELD

[0001] The present invention relates to an antibody that recognizes only activated interleukin-18 (hereinafter referred to as IL-18) protein that is an inflammatory cytokine, and an application thereof.

BACKGROUND ART

[0002] IL-18 is a cytokine of the IL-1 β family, and is mainly expressed in macrophages, but also expressed in various cells such as dendritic cells, epithelial cells, and keratinocytes. In addition, IL-18 receptors are expressed in various cells such as B cells, neutrophils, macrophages, vascular endothelial cells, and smooth muscle cells, besides NK cells, NKT cells, and CD4⁺ T cells. The diversity of IL-18-expressing cells and IL-18 receptor-expressing cells indicates the diversity of IL-18 functions, and IL-18 is known to be involved in various immune systems.

[0003] IL-18 was shown to play an important role in the defense mechanism against pathogens such as parasites and bacterial infections, when initially discovered, but has also been shown to play an important role in allergic diseases and autoimmune diseases (Non Patent Literatures 1 and 2).

[0004] Unlike cytokines such as TNF, IL-18 is not regulated in production at mRNA level and is abundantly present in cells as an inactive precursor (pro-IL-18). The precursor pro-IL-18 is cleaved by caspase-1 or caspase-4 into a peptide at positions 37-193, thereby forming a neoepitope, becoming active, and being released extracellularly. Thus, measuring the amount of mRNA expression or the precursor protein in the cell does not measure the activity of IL-18.

[0005] IL-18 is involved in various immune systems, and there are many diseases that are believed to be caused by excessive extracellular release of activated IL-18. Thus, if the measurement of activated IL-18 is achieved, it can be used to diagnose and treat IL-18-related diseases.

[0006] Numerous antibodies that specifically recognize IL-18 have been reported (e.g., Patent Literatures 1 to 10). Many of these serve as neutralizing antibodies, and only a few antibodies are disclosed for epitopes. In addition, despite many disclosures for antibodies, there have been no reports of an antibody that recognizes only activated IL-18.

CITATION LIST

Patent Literatures

- [0007]** Patent Literature 1: WO 2016/139297
- [0008]** Patent Literature 2: WO 2015/032932
- [0009]** Patent Literature 3: WO 2014/080866
- [0010]** Patent Literature 4: WO 2012/085015
- [0011]** Patent Literature 5: WO 2014/037899
- [0012]** Patent Literature 6: Japanese Patent Laid-Open No. 2012-139224
- [0013]** Patent Literature 7: Japanese Patent Laid-Open No. 2012-139223
- [0014]** Patent Literature 8: WO 2011/098424
- [0015]** Patent Literature 9: WO 2010/048183
- [0016]** Patent Literature 10: WO 2010/020593
- [0017]** Patent Literature 11: WO 2012/124683

Non Patent Literatures

- [0018]** Non Patent Literature 1: Arend, W. P. et al., Immunol. Rev., 2008, Vol. 223, p. 20-38.
- [0019]** Non Patent Literature 2: Sanders, N. L. & Mishra, A., Cytokine Growth Factor Rev., 2016, Vol. 32, pp. 31-39.
- [0020]** Non Patent Literature 3: Hirel, P-H. et al., Proc. Natl. Acad. Sci. USA, 1989, Vol. 89, pp. 8247-8251.
- [0021]** Non Patent Literature 4: Dalboge, H. et al., FEBS Lett., 1990, Vol. 266(1-2), pp. 1-3.
- [0022]** Non Patent Literature 5: Girard, C. et al., Rheumatology (Oxford), 2016, Vol. 55(12), pp. 2237-2247.
- [0023]** Non Patent Literature 6: Okamura, H. et al., Nature, 1995, Vol. 378(6652), pp. 88-91.
- [0024]** Non Patent Literature 7: Krumm, B. et al., Proc. Natl. Acad. Sci. USA, 2008, Vol. 105, pp. 20711-20715.
- [0025]** Non Patent Literature 8: Krumm, B. et al., PLOS Pathogens, 2012, Vol. 8, Issue 8, e1002876.

SUMMARY OF INVENTION

Technical Problem

[0026] Several groups, including the group of the present inventors, have attempted to produce an antibody that recognizes only activated IL-18. However, to date, no antibody that recognizes activated IL-18 has been produced.

[0027] The present inventors attempted to produce an antibody that recognizes only activated IL-18, by cleaving pro-IL-18 by caspase 1/4, then immunizing with activated IL-18. However, while six monoclonal antibodies that recognize positions 62-70 of IL-18 and two antibodies that recognize the region at positions 128-142 were obtained, they recognize both activated IL-18 and pro-IL-18, and no antibody that recognizes only activated IL-18 was obtained.

[0028] Most antibodies disclosed in Patent Literatures 1 to 10 are antibodies that exhibit neutralizing activity. For example, antibodies disclosed in Patent Literatures 1 to 4 are antibodies that bind to a binding site of an IL-18 binding protein (IL-18BP) or a vicinity thereof. Patent Literature 5 discloses antibodies that do not bind to IL-18 bound by IL-18BP. Patent Literature 6 discloses antibodies that inhibit IL-18 activity. Although the peptide sequence of the N-terminus (amino acid positions 37 to 50) of activated IL-18 is also disclosed as an epitope, the epitope of the antibody actually obtained is a different region, and it is not disclosed that the antibody recognizes only activated IL-18. Patent Literatures 7 and 8 disclose antibodies having neutralizing activity against IL-18. Patent Literatures 9 and 10 describe antibodies that can be used for treatment. However, none of the antibodies disclosed in these literatures is an antibody that recognizes only activated IL-18.

[0029] As mentioned above, since no antibody that detects only activated IL-18 has been obtained, activated IL-18 has been analyzed by confirming the molecular weight by western blot technique. Because western blot technique is time consuming and laborious, examination for the presence of activated IL-18 has not been implemented in clinical sites, even for diseases suspected of involving IL-18.

[0030] If an antibody that recognizes only activated IL-18 is obtained, it is possible to measure the amount of activated IL-18 by a simple method such as ELISA and the measurement can be used to diagnose an IL-18-related disease. An

object of the present invention is to obtain an antibody that specifically recognizes activated IL-18.

Solution to Problem

[0031] The present invention relates to a substance that binds to the neopeptide described below, a polyclonal antibody, a monoclonal antibody, a functional fragment of the antibody, and a kit containing the antibody, and a gene encoding the monoclonal antibody or the functional fragment, an amino acid sequence, a humanized antibody, a human antibody, and a pharmaceutical composition. The present invention also relates to a new method for identifying a range of neopeptide, and a kit for use in the method.

(1) An anti-IL-18 antibody that recognizes only activated IL-18.

(2) The anti-IL-18 antibody according to (1), wherein the antibody recognizes a neopeptide of human IL-18.

(3) The anti-IL-18 antibody according to (1) or (2), wherein the anti-IL-18 antibody is a monoclonal antibody and includes: a heavy chain variable domain containing a CDR1H region consisting of an amino acid sequence of GFSLSSSGMG (SEQ ID NO: 24), a CDR2H region consisting of an amino acid sequence of IWDDDK (SEQ ID NO: 25), and a CDR3H region consisting of an amino acid sequence of TRTRTYSNFGGGMAY (SEQ ID NO: 26); and a light chain variable domain containing a CDR1L region consisting of an amino acid sequence of QSIAHSNGYTY (SEQ ID NO: 27), a CDR2L region consisting of an amino acid sequence of KVS (SEQ ID NO: 28), and a CDR3L region consisting of an amino acid sequence of VQGSHVPLT (SEQ ID NO: 29).

(4) The anti-IL-18 antibody according to (1) or (2), wherein the anti-IL-18 antibody is a monoclonal antibody and includes: a heavy chain variable domain containing a CDR1H region consisting of an amino acid sequence of GFSLTSYG (SEQ ID NO: 36), a CDR2H region consisting of an amino acid sequence of IWAGGST (SEQ ID NO: 37), and a CDR3H region consisting of an amino acid sequence of ARESSYDAMDY (SEQ ID NO: 38); and a light chain variable domain containing a CDR1L region consisting of an amino acid sequence of ENVVYTY (SEQ ID NO: 39), a CDR2L region consisting of an amino acid sequence of GAS (SEQ ID NO: 40), and a CDR3L region consisting of an amino acid sequence of GQGYSYPYT (SEQ ID NO: 41).

(5) The anti-IL-18 antibody according to (3), wherein an amino acid sequence of an H chain variable region is SEQ ID NO: 11 and an amino acid sequence of an L chain variable region is SEQ ID NO: 15.

(6) The anti-IL-18 antibody according to (4), wherein an amino acid sequence of an H chain variable region is SEQ ID NO: 13 and an amino acid sequence of an L chain variable region is SEQ ID NO: 17.

(7) A gene comprising a gene encoding the CDR sequence described in (3) or (4), or the variable region described in (5) or (6), as an open reading frame.

(8) A functional fragment of the anti-IL-18 monoclonal antibody according to any one of (3) to (6).

(9) A kit for detecting and/or quantifying activated IL-18, comprising the anti-IL-18 antibody according to any one of (1) to (6) or the functional fragment of the anti-IL-18 monoclonal antibody according to (8).

(10) An anti-IL-18 monoclonal antibody comprising the CDR sequence described in (3) or (4), or the variable region

described in (5) or (6), wherein the monoclonal antibody is a humanized antibody or a human antibody.

(11) A functional fragment of the anti-IL-18 monoclonal antibody according to (10).

(12) A pharmaceutical composition for use in treating an IL-18-related disease, comprising the anti-IL-18 monoclonal antibody according to (10) or the functional fragment according to (11) as an active ingredient.

(13) An antibody, or a fragment consisting of a functional fragment thereof, or a binding substance, which binds to an amino acid represented by SEQ ID NO: 5 (YFGK).

(14) An antibody, or a fragment consisting of a functional fragment thereof, or a binding substance, which binds to an amino acid represented by SEQ ID NO: 4 (YFGKLESK).

(15) A method for analyzing a region of neopeptide recognized by an antibody, comprising: producing a peptide of a length of 5 to 15 amino acids from a cleaved end of neopeptide, substituting amino acid of the peptide with alanine or glycine by sequentially and successively from the N-terminus or C-terminus opposite to the cleaved end of neopeptide in a peptide; and analyzing the region of neopeptide recognized by the antibody by measuring binding of the antibody to the peptides.

(16) A kit used for the method for analyzing a region of neopeptide recognized by an antibody according to (15), comprising a substrate, a reagent for crosslinking a peptide, and a reagent for visualizing binding of the antibody.

(17) A method of treating an IL-18-related disease, comprising administering the monoclonal antibody according to any one of (3) to (6) and (10) or the functional fragment of the monoclonal antibody according to any one of (8) and (11) to a subject.

(18) The method of treating according to (17), wherein the subject has a higher value of activated IL-18 than a healthy person.

(19) The method according to (17) or (18), wherein the IL-18-related disease is any one of adult onset Still's disease, macrophage-activated syndrome/blood cell phagocytosis syndrome, ulcerative colitis, Crohn's disease, interstitial lung disease, bronchial asthma, allergic rhinitis, type 2 diabetes, ischemic nephritis, systemic lupus erythematosus, multiple sclerosis, atopic dermatitis, psoriasis, gout, or rheumatoid arthritis.

(20) A diagnostic method, comprising: examining an amount of activated IL-18 using the monoclonal antibody according to any one of (3) to (6) and (10), the functional fragment of the monoclonal antibody according to any one of (8) and (11), or the kit according to (9); and determining as an IL-18-related disease when the activated IL-18 shows a higher value than that in a healthy individual.

BRIEF DESCRIPTION OF DRAWINGS

[0032] FIG. 1 is a diagram showing analysis by capillary western immunoassay method to confirm that monoclonal antibodies 9-10.2 and 8-4.1 recognize activated IL-18.

[0033] FIG. 2 is a diagram showing the detection results of activated IL-18 in serum of patients with adult onset Still's disease (AOSD).

[0034] FIG. 3 is a diagram showing the results of application to immunoprecipitation method.

[0035] FIG. 4 is a diagram showing inhibitory activity of monoclonal antibodies 9-10.2 and 8-4.1 to human IL-18 function.

[0036] FIG. 5 is a diagram showing application to cell immunostaining method.

[0037] FIG. 6A is a diagram showing the results of epitope analysis by neopeptide fine analysis method of the epitopes of monoclonal antibodies 9-10.2 and 8-4.1.

[0038] FIG. 6B is a diagram showing the results of epitope analysis by alanine scanning.

[0039] FIG. 7A shows a sensorgram of surface plasmon resonance analysis by neopeptide fine analysis method for monoclonal antibody 9-10.2 with IL-18³⁷⁻⁴⁴ peptide. FIG. 7B shows a sensorgram of surface plasmon resonance analysis by alanine scanning. FIG. 7C is a diagram showing the position of the epitope on a three-dimensional structure.

[0040] FIG. 8 shows a sensorgram of surface plasmon resonance analysis for antibody 9-10.2 with IL-18³⁷⁻⁴⁴ peptide.

[0041] FIG. 9 is a diagram showing the results of a competition experiment of monoclonal antibodies 9-10.2 and 8-4.1.

DESCRIPTION OF EMBODIMENTS

[0042] The “epitope” refers to a region of an antigen (in the present invention, activated IL-18) recognized by an antibody. The “neopeptide” refers to a protein cleaved end which is newly formed from a protein cleaved by a proteolytic enzyme and is not present in the original protein. In IL-18, pro-IL-18 is cleaved by caspase 1/4 to become activated IL-18. A newly formed cleaved end in activated IL-18 is referred to as a neopeptide of IL-18. The “activated IL-18” refers to a peptide at positions 37 to 193 of IL-18 having a neopeptide.

[0043] The antibody of the present invention refers to a monoclonal antibody or a derivative that specifically binds to activated IL-18 as shown below. The antibody of the present invention also includes a polyclonal antibody that can be obtained in the same manner as the monoclonal antibody. Furthermore, it includes a functional fragment of the antibody, which exhibits substantially the same antigen specificity as the original antibody. Examples of the functional fragment of the antibody include functional fragments of the antibody such as Fab, Fab', F(ab')₂, a single chain antibody (scFv), a disulfide-stabilized V region fragment (dsFv), or a peptide containing CDR.

[0044] The antibody of the present invention also include: a humanized antibody such as humanized chimeric antibody and humanized CDR-grafted antibody obtained by using genetic recombination technology, and a human antibody produced by using a genetically modified mouse or a phage display method, from the monoclonal antibody that specifically binds to activated IL-18 identified in the present invention. When administered to a human, a humanized antibody and a human antibody have fewer side effects and exhibit their therapeutic effects longer than antibodies produced by animals other than human.

[0045] Furthermore, a substance that binds to the epitope of the cleaved end of activated IL-18 identified in the present invention can also be used for detection of activated IL-18, and the like. Examples of such a substance include a substance other than an antibody, such as a peptide aptamer or a nucleic acid aptamer, which specifically binds to the neopeptide. The aptamer can be produced by a known method such as two-hybrid method or SELEX method.

[0046] As used herein, the “IL-18-related disease” refers to a disease caused by excessive extracellular release of

activated IL-18 or a disease that may be exacerbated by IL-18. The IL-18-related disease is a disease that is developed and exacerbated by overexpression of IL-18. Examples of the IL-18-related disease include adult onset Still's disease (AOSD), juvenile Still's disease, malignant tumors such as pancreatic cancer, lung cancer and colon cancer, cryopyrin-associated cyclic fever syndrome, systemic lupus erythematosus (SLE), multiple sclerosis, juvenile idiopathic arthritis (JIA), bronchial asthma, bronchiectasis, chronic obstructive pulmonary disease (COPD), transfusion-related lung injury, bronchopulmonary dysplasia (BPD), acute respiratory distress syndrome (ARDS), interstitial pulmonary disease (ILD), idiopathic pulmonary fibrosis, cystic fibrosis, rheumatoid arthritis, metabolic bone disease, severe organ injury in the liver and intestines, heart failure, amyotrophic lateral sclerosis (ALS), dry eye disease (DED), keratitis, corneal angiogenesis, pathological intraocular angiogenesis, iritis, glaucoma, macular degeneration, Sjogren's syndrome, autoimmune uveitis, Behcet's disease, conjunctivitis, allergic conjunctivitis, eyelid dermatitis, allergic rhinitis, type 2 diabetes, non-alcoholic fatty liver disease (NAFLD), steatohepatitis, ischemic reperfusion injury, familial Mediterranean fever, TNF receptor-associated periodic syndrome, high IgD syndrome, gout, Schnitzler's syndrome, microscopic polyangiitis, granulomatous polyangiitis, ANCA-associated vasculitis composed of eosinophilic granulomatous polyangiitis, Hashimoto's disease, Crohn's disease, ulcerative colitis, immunoglobulin-4 (IgG4)-related diseases, pulmonary arterial hypertension, atopic dermatitis, and NLRC4-related autoinflammatory disease (or NLRC4 inflammasome disease).

[0047] In these IL-18-related diseases, a therapeutic effect is expected to be obtained by an agent that inhibits the function of IL-18. Accordingly, by examining the expression amount of activated IL-18 in a patient suspected of having an IL-18-related disease, it is possible to determine whether an agent that inhibits a function of IL-18 should be applied to the patient. Furthermore, since the antibody that recognizes neopeptide itself suppresses a function of IL-18 as shown in the Examples below, the antibody that recognizes the neopeptide can be used for treatment.

[0048] As used herein, the “kit” refers to a packaged combination of components such as a reagent and an instrument necessary for detecting, quantifying, or evaluating the function of IL-18 using an antibody disclosed in the present description by, but not limited to, western blotting, capillary western immunoassay, immunoprecipitation, immunostaining, or ELISA shown in the Examples below. In addition, the kit for analyzing a neopeptide refers to a packaged combination of components such as a substrate and a color development reagent necessary for a method for analyzing a neopeptide.

EXAMPLES

[0049] In the following Examples, the present invention is described in detail, but the scope of the present invention is not limited thereto.

[Example 1] Production of Antibodies

[0050] For production of antibodies, an application for approval of the animal experiment plan was filed with the Animal Experiment Committee, Shimane University, and the experiment was implemented after obtaining approval.

[0051] A peptide (SEQ ID NO: 1, YFGKLESKC) in which cysteine (C) was added to the C-terminus of the peptide at positions 37 to 44 located at the N-terminal sequence of activated IL-18 protein was synthesized according to a conventional method.

[0052] Keyhole-limpet hemocyanin (hereinafter referred to as KLH) was crosslinked to the peptide of SEQ ID NO: 1 as a sensitizing antigen using Inject Maleimide-Activated mKHL spin kit (Thermo Scientific), and then mice were immunized with the obtained peptide according to a conventional method.

[0053] The same peptide was crosslinked to bovine serum albumin (hereinafter referred to as BSA) using Inject Maleimide-Activated BSA spin kit (Thermo Scientific), then a screening was performed by ELISA with the obtained peptide. Hybridomas 9-10.2 and 8-4.1 were selected and established. The antibodies produced by hybridomas 9-10.2 and 8-4.1 are referred to as antibody 9-10.2 and antibody 8-4.1, respectively.

[0054] Isotypes of monoclonal antibodies 9-10.2 and 8-4.1, which recognize activated IL-18 produced by the hybridomas 9-10.2 and 8-4.1, were confirmed using IsoStrip mouse monoclonal antibody isotyping kit (Sigma), and it was found that they are both IgG1, κ .

[Example 2] Evaluation of Antibodies 9-10.2 and 8-4.1 (By Capillary Western Immunoassay)

[0055] Antibodies 9-10.2 and 8-4.1 were compared for their performance with anti-IL-18 antibody having different recognition site (11-4.1, epitope: region at positions 63 to 68 of IL-18, SEQ ID NO: 2, RPLFED). The antibody 11-4.1 is a monoclonal antibody produced by a hybridoma established by the present inventors and has already been shown to detect IL-18 with high sensitivity.

[0056] Purified full-length IL-18 expressed in *E. coli* was mixed with purified active caspase-4¹⁰⁵⁻³⁷⁷ which was expressed in *E. coli* (which means a peptide at positions 105 to 377 of caspase-4. Hereinafter, the peptide may be specified and described with the amino acid positions at the N-terminus and the C-terminus.). Thereby activated IL-18 protein (IL-18³⁷⁻¹⁹³) was obtained and purified. The N-terminal sequence of the purified protein was determined by the Edman degradation and found to be YFGKL as expected. This corresponds to tyrosine at position 37, which is the N-terminus of activated IL-18, to leucine at position 41.

[0057] Also, an IL-18 protein (positions 37 to 193) with additions of a start codon ATG and a His tag at the C-terminus was expressed in *E. coli* and purified. In this case, it is considered that, since the next amino acid to initiation methionine (Met) is tyrosine (³⁷Y), methionine aminopeptidase cannot act (Non Patent Literatures 3, 4), thus the initiation methionine does not leave and Met-IL-18³⁷⁻¹⁹³-His protein is obtained. When the purified protein was subjected to a determination of the N-terminal sequence by Edman degradation, the addition of initiation methionine was found as expected.

[0058] Using these proteins, antibodies 9-10.2 and 8-4.1 were compared to the anti-IL-18 antibody having different recognition site (11-4.1, epitope: ⁶³RPLFED⁶⁸ of IL-18).

[0059] Detection of activated IL-18 protein cleaved with activated caspase-4¹⁰⁵⁻³⁷⁷ at concentration of 200, 100, 50, and 25 ng/mL and detection of Met-IL-18³⁷⁻¹⁹³-His protein with initiation methionine added to the N-terminus at concentrations of 200 and 100 ng/mL were performed by

capillary western immunoassay method using Wes (Protein-Simple). As the primary antibody, each purified antibody was used after adjusted to 0.4 mg/mL and diluted to 125-fold. All other conditions including the secondary antibody and exposure time were the same. The results are shown in FIG. 1.

[0060] Although antibodies 9-10.2 and 8-4.1 recognized activated IL-18 protein IL-18³⁷⁻¹⁹³, they did not recognize Met-IL-18³⁷⁻¹⁹³-His protein in which methionine was added to the N-terminus of activated IL-18. Meanwhile, antibody 11-4.1 whose epitope is positions 63 to 68 of IL-18 recognized both activated IL-18 (IL-18³⁷⁻¹⁹³) and Met-IL-18³⁷⁻¹⁹³-His protein in the same way.

[0061] Activated IL-18 and Met-IL-18³⁷⁻¹⁹³-His protein both contain a region at positions 37 to 193 of IL-18. However, antibodies 9-10.2 and 8-4.1 did not recognize Met-IL-18³⁷⁻¹⁹³-His protein. That is, these antibodies cannot recognize a peptide in which an amino acid is added to the N-terminus side of tyrosine at position 37, indicating that they recognize IL-18³⁷⁻¹⁹³ protein, i.e., the neopeptide present in activated IL-18.

[Example 3] Evaluation of Antibodies 9-10.2 and 8-4.1 with Clinical Specimens (Capillary Western Immunoassay Method)

[0062] Adult onset Still's disease (AOSD) is a disease which is reported that IL-18 protein is shown at high levels (Non Patent Literature 5). With approval of the Ethics Committee of the Faculty of Medicine, Shimane University, IL-18 protein in patient serum was detected by capillary western immunoassay method. The patient serum was diluted 10-fold, and the antibody 9-10.2 was used as the primary antibody after adjusted to 0.4 mg/mL and diluted 1:125-fold. The amount and the molecular weight of activated IL-18 contained in the patient serum were analyzed in the same manner as in Example 2, where activated IL-18 protein (IL-18³⁷⁻¹⁹³) used in Example 2 was used as the standard protein. The results are shown in FIG. 2. In ten patients, the band was detected in the same size as activated IL-18, i.e., IL-18³⁷⁻¹⁹³ used as the standard protein. As shown in lower part of FIG. 2 as the amount of activated IL-18 present in the patient serum, it was also possible to quantify a very small amount of activated IL-18.

[0063] As shown in Example 3, the antibodies 9-10.2 and 8-4.1, which recognize activated IL-18, can be used to detect activated IL-18 by a very simple method.

[Example 4] Application of Antibodies 9-10.2 and 8-4.1 to Immunoprecipitation Method

[0064] The usefulness of antibodies 9-10.2 and 8-4.1 in immunoprecipitation method was evaluated in comparison to the recognition site-different antibody 11-4.1. IL-18 protein in full-length was expressed in 293T cells with active caspase-4¹⁰⁵⁻³⁷⁷. A ready-made Flag-tagged antibody (M2) was used as a negative control antibody. The immunoprecipitation products were detected by western blotting method with a self-made anti-IL-18 rabbit polyclonal antibody. The results are shown in FIG. 3.

[0065] The upper section of FIG. 3 schematically shows full-length IL-18, activated IL-18, and the sites recognized by each antibody. When full-length IL-18 and active caspase-4 are expressed in 293 T cells, full-length IL-18 protein is cleaved by active caspase-4, but uncleaved full-

length IL-18 is still present in the cells. The result of immunoprecipitation with antibody 11-4.1 showed a lot of full-length IL-18 protein immunoprecipitated, indicating that a lot of uncleaved pro-IL-18 is present in the cells. Meanwhile, when immunoprecipitation was performed with antibodies 8-4.1 or 9-10.2, full-length IL-18 was not immunoprecipitated, and more IL-18³⁷⁻¹⁹³ was immunoprecipitated. That is, it has been revealed that antibodies 9-10.2 and 8-4.1 are monoclonal antibodies that can specifically recognize and efficiently immunoprecipitate active IL-18³⁷⁻¹⁹³ protein cleaved by caspase-4¹⁰⁵⁻³⁷⁷ in cells.

[Example 5] Inhibitory Activity of Antibodies 9-10.2 and 8-4.1 to Human IL-18 Function

[0066] It is known that addition of purified active IL-18 protein expressed in *E. coli* to acute myeloid leukemia cell line KG-1 (JCRB0065) causes production of IFN- γ (Non Patent Literature 6). If the antibody is an IL-18 function-inhibitory antibody, it inhibits IFN- γ production by IL-18 (see the schematic diagram in upper part of FIG. 4).

[0067] To KG-1 cells, 0.5 ng of activated IL-18 and varying concentrations of antibodies 9-10.2 or 8-4.1 were added, and the production of IFN- γ was detected by IFN- γ detection ELISA (Diaclone, Inc., IFN- γ ELISA set). As a result, antibodies 9-10.2 and 8-4.1 exhibited inhibitory activity against production of IFN- γ in an amount-dependent manner (FIG. 4, lower part). Since antibodies 9-10.2 and 8-4.1 both act as an antibody that inhibits human IL-18 function, they can be used to treat diseases caused or exacerbated by overexpression of IL-18. In particular, 9-10.2 showed a very strong inhibitory activity with IC₅₀ of 2.8 nM.

[Example 6] Application of Antibodies 9-10.2 and 8-4.1 to Immunocytochemical Method

[0068] Full-length IL-18 protein (human IL-18) was expressed in 293T cells in the presence of active caspase-4¹⁰⁵⁻³⁷⁷ (G196-Caspase-4¹⁰⁵⁻³⁷⁷) fused with G196 tag (DLVPR, SEQ ID NO: 3, Patent Literature 11) (FIG. 5, left) or in the absence thereof (FIG. 5, right). After immobilization with formalin, the protein was subjected to immunocytochemical staining with antibody 9-10.2 according to a conventional method.

[0069] The presence of active caspase-4¹⁰⁵⁻³⁷⁷ was detected by a rabbit polyclonal antibody that recognizes G196 (G196 pAb) (FIG. 5, left, upper right). The presence of IL-18 in the absence of active caspase-4 was detected by a rabbit polyclonal antibody that recognizes IL-18 (aIL-18 pAb) (FIG. 5, right, upper right). In the presence of active caspase-4 (FIG. 5, left), the presence of IL-18 was confirmed by antibody 9-10.2. Meanwhile, in the absence of caspase-4 (FIG. 5, right), despite the presence of IL-18 confirmed by the rabbit polyclonal antibody, IL-18 was not detected by antibody 9-10.2. That is, it indicates that antibody 9-10.2 is a monoclonal antibody that can specifically recognize active IL-18³⁷⁻¹⁹³ protein cleaved by caspase-4¹⁰⁵⁻³⁷⁷ in cells when used also in immunocytochemical method.

[Example 7] Investigation of Epitopes of Antibodies 9-10.2 and 8-4.1

[0070] When a protein is cleaved by a proteolytic enzyme such as a caspase as described above, a neoepitope that is a protein cleaved end not present in the original protein is

formed. In the neoepitope peptide used for antibody production, peptides were substituted by sequentially and successively with alanine from the amino acid at the N-terminus or C-terminus opposite to the neoepitope cleaved end important for antibody recognition; and the region of neoepitope recognized by the antibody was identified. This method of determining a region of a neoepitope recognized by an antibody was named “neoepitope fine analysis method”. The neoepitope fine analysis method is a method of determining an epitope of an antibody by successively substituting with alanine, unlike an alanine scanning method in which one amino acid is substituted with alanine at a time. The neoepitope fine analysis method is an excellent method for determining a binding region of an antibody in a neoepitope. Although quantitative analysis was performed by ELISA as shown below, the analysis can also be performed by SPR method or the like, not limited to ELISA. In addition, although analysis was performed by substituting with alanine in the Examples below, the analysis can also be performed with an amino acid having a small molecular weight and not causing a major structural change, such as glycine.

[0071] Neoepitope peptides (positions 37 to 44) substituted with alanine by sequentially and successively starting from lysine at position 44 (K44) at the C-terminus and Cys for crosslinking was added to the C-terminus were synthesized according to a conventional method. To each peptide, BSA was crosslinked with Impject Maleimide-Activated BSA spin Kit, and the recognition sites of the antibodies 9-10.2 and 8-4.1 were analyzed by ELISA. In the right of the ELISA plate photograph in FIG. 6 (A), the absorbance obtained with a plate reader was shown along with the standard deviation with setting the wild-type peptide as 100.

[0072] Both antibodies exhibit little reactivity to the peptides in which lysine at positions 40 to 44 are substituted with alanine, but exhibit to the peptides having the presence of lysine at position 40 at reactivity of about 1/4 of the wild-type peptide. In addition, a decrease in the number of alanine substituting from positions 41 to 43 does almost not alter the reactivity of the antibody.

[0073] Next, epitope analysis was performed by alanine scanning method. The peptide of the N-terminal sequence (positions 37 to 44) of activated IL-18 protein added cysteine for crosslinking at the C-terminus (YFGKLESKC, SEQ ID NO: 1), alanine variants of each amino acid in the peptide were synthesized according to a conventional method. In the same way as described above, recognition site analysis of antibodies 9-10.2 and 8-4.1 was performed by ELISA with each peptide crosslinked by BSA (FIG. 6(B)).

[0074] Both antibodies 9-10.2 and 8-4.1 were almost unable to recognize the peptide (Y37A) in which the first amino acid (tyrosine (Y) at position 37) of the N-terminal sequence of activated IL-18 protein was replaced with alanine (A), and peptide G39A and peptide K40A were also not recognized. Furthermore, antibodies 9-10.2 and 8-4.1 showed weak binding to the variants of L41A, and E42A, and approximately 50% binding to the variants of F38A, S43A, and K44A.

[0075] Surface plasmon resonance analysis was further performed using the same peptides. Neoepitope peptides (positions 37 to 44) substituted with alanine sequentially and successively from lysine at position 44 (K44) at the C-terminus and added Cys for crosslinking to the C-terminus

were each immobilized to sensor chip CM5 (GE Healthcare, BR100012) by ligand thiol coupling method. Purified antibody 9-10.2 was subjected to “neopeptide fine analysis” at a concentration of 50 nM by measuring with Biacore X100 (GE Healthcare) by single-cycle (FIG. 7(A)).

[0076] The antibody did not bind at all to the peptides in which lysine at positions 40 to 44 were substituted with alanine, but showed binding to the peptide having the presence of lysine at position 40. In addition, with the presence of lysine at position 40, a decrease in the number of alanine substituting from positions 41 to 43 did almost not alter the reactivity of the antibody for dissociation from the peptide.

[0077] Next, alanine variants of each amino acid in a peptide (YFGKLESKC, SEQ ID NO: 1), where cysteine for crosslinking was added to the C-terminus of the N-terminal sequence (positions 37 to 44) of activated IL-18 protein, were immobilized to sensor chip CM5 by ligand thiol coupling method. Purified antibody 9-10.2 was subjected to “alanine scanning analysis” at a concentration of 50 nM by measuring with Biacore X100 by single-cycle (FIG. 7(B)).

[0078] The antibody 9-10.2 was unable to recognize the peptide (G39A) in which the third amino acid (glycine (G) at position 39) of the N-terminal sequence of activated IL-18 protein was replaced with alanine (A). It has been found that antibody 9-10.2 easily dissociates from Y37A and K40A variants, and has no changes of dissociation for the variants of F38A, L41A, E42A, S43A and K44A.

[0079] The same result was obtained in surface plasmon resonance analysis as that in analysis by ELISA shown in FIG. 6. Core regions important for binding can be obtained by “neopeptide fine analysis”, and information on amino acids important for binding can be obtained by “alanine scanning analysis”.

[0080] Considering together with known NMR structural analysis of human IL-18 (PDB: 1JOS, FIG. 7(C)), it is believed that 8 amino acids from tyrosine at position 37 (Y37) to lysine at position 44 (K44) exposed to the structural surface are important for recognition by antibodies 9-10.2 and 8-4.1.

[0081] Furthermore, from the results of the above neopeptide fine analysis method, it has been revealed that peptides from positions 37 to 40 are particularly important for the recognition by antibodies 9-10.2 and 8-4.1. In other words, it has been revealed that both antibodies 9-10.2 and 8-4.1 recognize YFGKLESK (SEQ ID NO: 4) as epitope and YFGK (SEQ ID NO: 5) as minimal epitope.

[0082] The peptide YFGKLESK or YFGK is an epitope to which an antibody that recognizes activated IL-18 binds. Thus, there are possibilities that they can be used as a vaccine containing a peptide having the sequence as an immunogen, or as a therapeutic agent including a region containing this peptide and a peptide of another IL-18 region that binds to an IL-18 receptor in combination.

[0083] Among IL-18BPs, binding sites of IL-18 to 3F62 (IL-18BP of poxvirus) and 4EEE (IL-18BP of yatapovirus) are structurally analyzed and contain the regions of Y37, F38, and G39 (Non Patent Literatures 7 and 8). Although structural analysis of human IL18BP has not yet been performed, they are similar in the primary sequence, thus human IL18BP is likely to bind to the same region. It is believed that antibodies 9-10.2 and 8-4.1 do not bind to IL-18 bound by IL-18BP. Thus, by using these antibodies, it is possible to measure IL-18 free of bound by IL-18BP.

[0084] Specifically, antibodies 9-10.2 or 8-4.1 are coated onto a substrate and reacted with serum. Antibodies 9-10.2 and 8-4.1 cannot bind to IL-18 bound by IL-18BP, and only capture activated IL-18 in which the neopeptide is exposed. The captured IL-18 may be reacted with an antibody that recognizes another site to be measured. Thus, it is also possible to easily measure IL-18 free of bound by IL-18BP, which was previously measured in a cumbersome manner by ELISA.

[Example 8] Affinity Analysis Between Antibody 9-10.2 and IL-18³⁷⁻⁴⁴ Peptide (Surface Plasmon Resonance Analysis)

[0085] The peptide (YFGKLESKC, SEQ ID NO: 1) in which cysteine for crosslinking was added to the C-terminus of the neopeptide peptide (positions 37 to 44) of activated IL-18 protein was immobilized to sensor chip CM5 by ligand thiol coupling method. Purified antibody 9-10.2 was used at 5 concentrations in the range of 0.4 nM to 250 nM with a series of 5-fold dilution to measure with Biacore X100 by single-cycle (FIG. 8). The analysis was performed by bivalent analysis.

[0086] The results were K_D : 1.9×10^{-10} M, K_a : 2.1×10^5 M⁻¹s⁻¹, and K_d : 4.0×10^{-3} s⁻¹. It has been revealed that antibody 9-10.2 binds to the N-terminal sequence peptide of activated IL-18 protein with very high affinity.

[Example 9] Competitive Experimental Analysis of Monoclonal Antibodies 9-10.2 and 8-4.1

[0087] From the epitope analysis of Example 7, it is believed that monoclonal antibodies 9-10.2 and 8-4.1 recognize the same epitope. Furthermore, from the results of Example 8, it was revealed that antibody 9-10.2 binds to the neopeptide with very high affinity. Thus, competitive experiments between monoclonal antibodies 9-10.2 and 8-4.1 were performed, and to analyze whether antibodies 9-10.2 and 8-4.1 recognize the same epitope (FIG. 9).

[0088] The peptide of SEQ ID NO: 1 (YFGKLESKC) was crosslinked to BSA, adjusted to 5 ng/100 μ l with 50 mM NaHCO₃, and coated on an ELISA plate overnight at 4° C. The ELISA plate was blocked and washed by a conventional method, and an antibody solution of 9-10.2 or 8-4.1 adjusted to 0, 100, 300, or 1000 ng/100 μ l was added, and the reaction was carried out at 25° C. for 1 hour. The wells without antibody were only added with a wash solution (see FIG. 9, primary antibody without addition of HRP).

[0089] Next, each antibody labeled with HRP (0.5 μ g/ μ l) was diluted 100-fold with the wash solution. Then, antibody 9-10.2 labeled with HRP was added at 100 μ l to the wells in which antibody 8-4.1 was bound to the peptide as the primary antibody, and the antibody 8-4.1 labeled with HRP was added at 100 μ l to the wells in which antibody 9-10.2 was bound to the peptide, and then the wells were incubated at 25° C. for 1 hour (see FIG. 9, secondary antibody with addition of HRP). Afterwards, the wells were washed, color was developed, and absorbance was measured (see FIG. 9, absorbance 450 nm to 620 nm).

[0090] It has been shown that, when antibody 8-4.1 is used as the primary antibody, and antibody 9-10.2 labeled with HRP is used as the secondary antibody, antibody 9-10.2 binds to the peptide as the result of competition with antibody 8-4.1 that is the primary antibody. Accordingly, it has been revealed that antibodies 9-10.2 and 8-4.1 compete

with each other and antibody 9-10.2 has high affinity to activated IL-18 compared to antibody 8-4.1.

[Example 10] Gene Analysis of Antibody

[0091] Next, gene analysis of each antibody was performed. RNA was extracted from hybridomas 9-10.2 and 8-4.1, and then reverse-transcribed with an oligo-dT primer to generate cDNA. The synthesized cDNA was used to determine the sequence of the hypervariable region of the antibody gene and the amino acid sequence by direct sequencing using a primer set of H and L chains.

[0092] The primer sequences of the H and L chains used are as follows.

H-chain primer

VH1-1S:

(SEQ ID NO: 6)
5'-gggggatcc ag gts mar ctg cag sag tcw gg-3'
s = g + c, m = a + c, r = a + g, w = a + t

IgG2-1AS:

(SEQ ID NO: 7)
5'-gggaattc ctt gac cag gca tcc tag agt ca-3'

-continued

L-chain primer

VK-1S:

(SEQ ID NO: 8)
5'-gggggatcc gay att gtg mts acm car wct mca-3
y = c + t, m = a + c, s = g + c, r = a + g,
w = a + t

CK-2AS:

(SEQ ID NO: 9)
5'-gggaattc gaa gat gga tac agt tgg tgc-3'

[0093] Note that the underlines indicate recognition sites of restriction enzymes.

[0094] By gene analysis of the H chain, the nucleotide sequence (SEQ ID NO: 10) and the amino acid sequence (SEQ ID NO: 11) of the H chain of antibody 9-10.2, and the nucleotide sequence (SEQ ID NO: 12) and the amino acid sequence (SEQ ID NO: 13) of the H chain of antibody 8-4.1 were determined. Also, by gene analysis of the L chain, the nucleotide sequence (SEQ ID NO: 14) and the amino acid sequence (SEQ ID NO: 15) of the L chain of antibody 9-10.2, and the nucleotide sequence (SEQ ID NO: 16) and the amino acid sequence (SEQ ID NO: 17) of the L chain of antibody 8-4.1 were determined.

[0095] The amino acid sequences and the nucleotide sequences of complementarity determining regions (CDRs) of antibodies 9-10.2 and 8-4.1 are summarized below.

TABLE 1

Nucleotide Sequence of 9-10.2 Antibody					
	Heavy Chain	SEQ ID		Light Chain	SEQ ID
CDRH1	GGGTTTTCAGTGG CAGTTCTGGTATGG GT	18	CDRL1	CAGAGCATTGCACA TAGTAATGGATACA C CTAT	21
CDRH2	ATTGTTGGGATGA TGATAAG	19	CDRL2	AAAGTTTCC	22
CDRH3	ACTCGAACGAGGAC GTATAGTAACCTCGG A GGTGGTATGGCCTAC	20	CDRL3	GTTCAAGGTTTACA TGTTCCGCTCACG	23

TABLE 2

Amino Acid Sequence of 9-10.2 Antibody					
	Heavy Chain	SEQ ID		Light Chain	SEQ ID
CDRH1	GFSLSSSGMG	24	CDRL1	QSIHNSNGYTY	27
CDRH2	IWWDDDK	25	CDRL2	KVS	28
CDRH3	TRTRTYSNFGGMAY	26	CDRL3	VQGSHPVPLT	29

TABLE 3

Nucleotide Sequence of 8-4.1 Antibody					
	Heavy Chain	SEQ ID		Light Chain	SEQ ID
CDRH1	GGGTTTTCATTAAC CAGCTATGGT	30	CDRL1	GAGAATGTGGTTAC TTAT	33

TABLE 3-continued

Nucleotide Sequence of 8-4.1 Antibody					
	Heavy Chain	SEQ ID		Light Chain	SEQ ID
CDRH2	ATATGGGCTGGTGG AAGCACA	31	CDRL2	GGGGCATCC	34
CDRH3	GCCAGAGAAAGTAG CTACGATGCTATGGA CTAC	32	CDRL3	GGACAGGGTTACAG CTATCCGTACACG	35

TABLE 4

Amino Acid Sequence of 8-4.1 Antibody				
	Heavy Chain	SEQ ID	Light Chain	SEQ ID
CDRH1	GFSLTSYG	36	CDRL1	ENVVTY
CDRH2	IWAGGST	37	CDRL2	GAS
CDRH3	ARESSYDAMDY	38	CDRL3	GQGYSYPYT

[0096] As shown in the Examples, the antibody having the above CDR is an antibody that specifically recognizes

activated IL-18 with high sensitivity and specificity. Thus, it enables to detect activated IL-18 by a method that can be easily carried out in clinical sites, such as ELISA. As a result, it is possible to easily determine in the clinical site whether it is an IL-18-related disease or not, and the determination can be used to formulate a treatment strategy. In addition, since the antibody can be applied to various methods such as western blotting, capillary western immunoassay, immunoprecipitation, and immunocytochemical staining, it can also be widely used as a research reagent. Furthermore, since it has been revealed that the function of IL-18 can be inhibited, the antibody is also very useful as an agent for treating an IL-18-related disease.

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Ala His Ile Trp Trp Asp Asp Asp Lys Asn Tyr Asn Pro Gly Leu Lys
35          40          45
Ser Arg Leu Thr Ile Ser Lys Asp Thr Ser Lys Asn Gln Val Phe Leu
50          55          60
Lys Ile Ala Asn Val Asp Thr Ala Asp Ala Ala Thr Tyr Tyr Cys Thr
65          70          75          80
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gatttcacac tcaagatcag cagagtggag gctgaggatc tgggagttta ttactgcgtt    240
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Gln Ser Pro Lys Leu Leu Ile Tyr Lys Val Ser Asn Arg Phe Ser Gly
35 40 45

Val Pro Asp Arg Phe Ser Gly Ser Gly Ser Gly Thr Asp Phe Thr Leu
50 55 60

Lys Ile Ser Arg Val Glu Ala Glu Asp Leu Gly Val Tyr Tyr Cys Val
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35          40          45
Tyr Gly Ala Ser Asn Arg Tyr Thr Gly Val Pro Asp Arg Phe Thr Gly
50          55          60
Ser Gly Ser Ala Thr Asp Phe Thr Leu Thr Ile Ser Ser Val Gln Ala
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1-16. (canceled)

17. An anti-IL-18 antibody that recognizes only activated IL-18.

18. The anti-IL-18 antibody according to claim **17**, wherein the antibody recognizes a neoepitope of human IL-18.

19. The anti-IL-18 antibody according to claim **17**, wherein the anti-IL-18 antibody is a monoclonal antibody and includes:

- a heavy chain variable domain containing a CDR1H region consisting of an amino acid sequence of GFSLSSSGMG (SEQ ID NO: 24),

- a CDR2H region consisting of an amino acid sequence of IWDDDK (SEQ ID NO: 25), and

- a CDR3H region consisting of an amino acid sequence of TRTRTYSNFGGGMAY (SEQ ID NO: 26); and

- a light chain variable domain containing a CDR1L region consisting of an amino acid sequence of QSIAHSNGYTY (SEQ ID NO: 27),

- a CDR2L region consisting of an amino acid sequence of KVS (SEQ ID NO: 28), and

- a CDR3L region consisting of an amino acid sequence of VQGSHVPLT (SEQ ID NO: 29).

20. The anti-IL-18 antibody according to claim **19**, wherein an amino acid sequence of an H chain variable

region is SEQ ID NO: 11 and an amino acid sequence of an L chain variable region is SEQ ID NO: 15.

21. A gene comprising a gene encoding the CDR sequence described in claim **19** as an open reading frame.

22. A gene comprising a gene encoding the variable region described in claim **20** as an open reading frame.

23. A functional fragment of the anti-IL-18 monoclonal antibody according to claim **19**.

24. A kit for detecting and/or quantifying activated IL-18, comprising the anti-IL-18 antibody according to claim **17**.

25. An anti-IL-18 monoclonal antibody comprising the CDR sequence described in claim **19**, wherein the monoclonal antibody is a humanized antibody or a human antibody.

26. A functional fragment of the anti-IL-18 monoclonal antibody according to claim **25**.

27. A pharmaceutical composition for use in treating an IL-18-related disease, comprising the anti-IL-18 monoclonal antibody according to claim **25** as an active ingredient.

28. A pharmaceutical composition for use in treating an IL-18-related disease, comprising the functional fragment according to claim **26** as an active ingredient.

29. A method of treating an IL-18-related disease, comprising administering the monoclonal antibody according to claim **19** to a subject.

30. The method of treating according to claim **29**, wherein the subject has a higher value of activated IL-18 than a healthy person.

31. The method according to claim **29**, wherein the IL-18-related disease is any one of adult onset Still's disease, macrophage-activated syndrome/blood cell phagocytosis syndrome, ulcerative colitis, Crohn's disease, interstitial lung disease, bronchial asthma, allergic rhinitis, type 2 diabetes, ischemic nephritis, systemic lupus erythematosus, multiple sclerosis, atopic dermatitis, psoriasis, gout, or rheumatoid arthritis.

32. A diagnostic method, comprising: examining an amount of activated IL-18 using the monoclonal antibody according to claim **19**; and determining as an IL-18-related disease when the activated IL-18 shows a higher value than that in a healthy individual.

* * * * *