ANTI-IL-33 ANTIBODIES AND USES THEREOF

FIELD OF THE INVENTION

[0001] The present invention relates to antibodies, and antigen-binding fragments thereof, which are specific for human IL-33, and methods of use thereof.

BACKGROUND

[0002] Interleukin-33 (IL-33) is a ligand for ST2, a toll-like/interleukin-1 receptor super-family member that associates with an accessory protein, IL-1RAcP (for reviews, *see*, *e.g.*, Kakkar and Lee, *Nature Reviews – Drug Discovery 7(10)*:827-840 (2008), Schmitz et al., Immunity 23:479-490 (2005); Liew et al*., Nature Reviews – Immunology 10*:103-110 (2010); US 2010/0260770; US 2009/0041718). Upon activation of ST2/IL-1RAcP by IL-33, a signaling cascade is triggered through downstream molecules such as MyD88 (myeloid differentiation factor 88) and TRAF6 (TNF receptor associated factor 6), leading to activation of NFκB (nuclear factor-κB), among others. IL-33 signaling has been implicated as a factor in a variety of diseases and disorders. (Liew et al*., Nature Reviews – Immunology 10*:103-110 (2010)).

BRIEF SUMMARY OF THE INVENTION

[0003] The present invention provides antibodies that bind human interleukin-33 ("IL-33"). The antibodies of the invention are useful, *inter alia*, for inhibiting IL-33-mediated signaling and for treating diseases and disorders caused by or related to IL-33 activity and/or signaling.

[0004] The antibodies of the invention can be full-length (for example, an IgG1 or IgG4 antibody) or may comprise only an antigen-binding portion (for example, a Fab, $F(ab')_2$ or scFv fragment), and may be modified to affect functionality, e.g., to eliminate residual effector functions (Reddy et al., 2000, J. Immunol. 164:1925-1933).

[0005] In one embodiment, the antibodies that bind specifically to human interleukin-33 are isolated fully human monoclonal antibodies.

[0006] In one embodiment, the antibodies that bind specifically to human interleukin-33, or antigen-binding fragments thereof inhibit or attenuate IL-33-mediated signaling.

[0007] In one embodiment, the antibodies that bind specifically to human interleukin-33, or antigen-binding fragments thereof block the interaction of IL-33 and ST2.

[0008] In one embodiment, the antibodies that bind specifically to human interleukin-33, or antigen-binding fragments thereof block the interaction of IL-33 and ST2 with an IC_{50} value of less than about 10 nM, or blocks greater than about 50% of the interaction of IL-33 and ST2 as measured in an *in vitro* receptor/ligand binding assay at 25°C.

[0009] In one embodiment, the antibodies that bind specifically to human interleukin-33, or antigen-binding fragments thereof do not block, or only partially block the interaction of IL-33

and ST2.

[0010] In one embodiment, the antibodies that bind specifically to human interleukin-33, or antigen-binding fragments thereof bind human IL-33 with a binding dissociation equilibrium constant (K_D) of less than about 1 nM as measured in a surface plasmon resonance assay at 37°C.

[0011] In one embodiment, the antibodies that bind specifically to human interleukin-33, or antigen-binding fragments thereof bind human IL-33 with a dissociative half-life (t½) of greater than about 8 minutes as measured in a surface plasmon resonance assay at 37°C.

[0012] In one embodiment, the antibodies that bind specifically to human interleukin-33, or antigen-binding fragments thereof inhibit IL-33-mediated degranulation of human basophils.

[0013] In one embodiment, the antibodies that bind specifically to human interleukin-33, or antigen-binding fragments thereof inhibit IL-33-mediated degranulation of human basophils with an IC_{50} of less than about 600 pM as measured in an *in vitro* basophil activation test (BAT).

[0014] In one embodiment, the antibodies that bind specifically to human interleukin-33, or antigen-binding fragments thereof inhibit IL-33-mediated IFN-gamma production from human PBMCs.

[0015] In one embodiment, the antibodies that bind specifically to human interleukin-33, or antigen-binding fragments thereof inhibit IL-33-mediated IFN-gamma production from human PBMCs with an IC_{50} of less than about 25 nM as measured in an *in vitro* PBMC IFN-gamma production assay.

[0016] In one embodiment, the antibodies that bind specifically to human interleukin-33, or antigen-binding fragments thereof inhibit IL-33-mediated IFN-gamma production from human PBMCs with an IC_{50} of less than about 3 nM as measured in an *in vitro* PBMC IFN-gamma production assay.

[0017] In one embodiment, the antibodies that bind specifically to human interleukin-33, or antigen-binding fragments thereof inhibit IL-33-mediated IFN-gamma production from human PBMCs with an IC_{50} of less than about 0.5 nM as measured in an *in vitro* PBMC IFN-gamma production assay.

[0018] In one embodiment, the antibodies that bind specifically to human interleukin-33, or antigen-binding fragments thereof reduce the frequency of CD4+ T cells, eosinophils and ILC2 cells in the lungs when administered to an animal model of allergen-induced lung inflammation.

[0019] In one embodiment, the antibodies that bind specifically to human interleukin-33, or antigen-binding fragments thereof reduces the level of IL-4 and IL-5 in the lungs when administered to an animal model of allergen-induced lung inflammation.

[0020] In one embodiment, the antibodies that bind specifically to human interleukin-33, or antigen-binding fragments thereof, when administered to an animal model of allergen-induced lung inflammation, result in at least a 4 fold reduction of IL-4 levels and/or at least a 5 fold

reduction in IL-5 levels when compared to allergen-challenged animals receiving an isotype control antibody.

[0021] The present invention provides antibodies, or antigen-binding fragments thereof comprising a heavy chain variable region (HCVR) having an amino acid sequence selected from the group consisting of SEQ ID NO: 2, 18, 34, 50, 66, 82, 98, 114, 130, 146, 162, 178, 194, 210, 226, 242, 258, 274, 290, and 308, or a substantially similar sequence thereof having at least 90%, at least 95%, at least 98% or at least 99% sequence identity.

[0022] The present invention also provides an antibody or antigen-binding fragment of an antibody comprising a light chain variable region (LCVR) having an amino acid sequence selected from the group consisting of SEQ ID NO: 10, 26, 42, 58, 74, 90, 106, 122, 138, 154, 170, 186, 202, 218, 234, 250, 266, 282, 298, and 316, or a substantially similar sequence thereof having at least 90%, at least 95%, at least 98% or at least 99% sequence identity.

[0023] The present invention also provides an antibody or antigen-binding fragment thereof comprising a HCVR and LCVR (HCVR/LCVR) sequence pair selected from the group consisting of SEQ ID NO: 2/10, 18/26, 34/42, 50/58, 66/74, 82/90, 98/106, 114/122, 130/138, 146/154, 162/170, 178/186, 194/202, 210/218, 226/234, 242/250, 258/266, 274/282, 290/298, and 308/316.

[0024] The present invention also provides an antibody or antigen-binding fragment of an antibody comprising a heavy chain CDR3 (HCDR3) domain having an amino acid sequence selected from the group consisting of SEQ ID NO: 8, 24, 40, 56, 72, 88, 104, 120, 136, 152, 168, 184, 200, 216, 232, 248, 264, 280, 296, and 314, or a substantially similar sequence thereof having at least 90%, at least 95%, at least 98% or at least 99% sequence identity; and a light chain CDR3 (LCDR3) domain having an amino acid sequence selected from the group consisting of SEQ ID NO: 16, 32, 48, 64, 80, 96, 112, 128, 144, 160, 176, 192, 208, 224, 240, 256, 272, 288, 304, and 322, or a substantially similar sequence thereof having at least 90%, at least 95%, at least 98% or at least 99% sequence identity.

[0025] In certain embodiments, the antibody or antigen-binding portion of an antibody comprises a HCDR3/LCDR3 amino acid sequence pair selected from the group consisting of SEQ ID NO: 8/16, 24/32, 40/48, 56/64, 72/80, 88/96, 104/112, 120/128, 136/144, 152/160, 168/176, 184/192, 200/208, 216/224, 232/240, 248/256, 264/272, 280/288, 296/304 and 314/322.

[0026] The present invention also provides an antibody or fragment thereof further comprising a heavy chain CDR1 (HCDR1) domain having an amino acid sequence selected from the group consisting of SEQ ID NO: 4, 20, 36, 52, 68, 84, 100, 116, 132, 148, 164, 180, 196, 212, 228, 244, 260, 276, 292, and 310, or a substantially similar sequence thereof having at least 90%, at least 95%, at least 98% or at least 99% sequence identity; a heavy chain CDR2 (HCDR2) domain having an amino acid sequence selected from the group consisting of SEQ ID NO: 6,

22, 38, 54, 70, 86, 102, 118, 134, 150, 166, 182, 198, 214, 230, 246, 262, 278, 294, and 312, or a substantially similar sequence thereof having at least 90%, at least 95%, at least 98% or at least 99% sequence identity; a light chain CDR1 (LCDR1) domain having an amino acid sequence selected from the group consisting of SEQ ID NO: 12, 28, 44, 60, 76, 92, 108, 124, 140, 156, 172, 188, 204, 220, 236, 252, 268, 284, 300, and 318, or a substantially similar sequence thereof having at least 90%, at least 95%, at least 98% or at least 99% sequence identity; and a light chain CDR2 (LCDR2) domain having an amino acid sequence selected from the group consisting of SEQ ID NO: 14, 30, 46, 62, 78, 94, 110, 126, 142, 158, 174, 190, 206, 222, 238, 254, 270, 286, 302, and 320, or a substantially similar sequence thereof having at least 90%, at least 95%, at least 98% or at least 99% sequence identity.

[0027] Certain non-limiting, exemplary antibodies and antigen-binding fragments of the invention comprise HCDR1-HCDR2-HCDR3-LCDR1-LCDR2-LCDR3 domains, respectively, having the amino acid sequences selected from the group consisting of: SEQ ID NOs: 4-6-8-12-14-16 (*e.g.* H1M9559N); 20-22-24-28-30-32 (*e.g.* H1M9566N); 36-38-40-44-46-48 (*e.g.* H1M9568N); 52-54-56-60-62-64 (*e.g.* H4H9629P); 68-70-72-76-78-80 (*e.g.* H4H9633P); 84-86-88-92-94-96 (*e.g.* H4H9640P); 100-102-104-108-110-112 (*e.g.* H4H9659P); 116-118-120-124-126-128 (*e.g.* H4H9660P); 132-134-136-140-142-144 (*e.g.* H4H9662P); 148-150-152-156-158-160 (*e.g.*, H4H9663P); 164-166-168-172-174-176 (*e.g.* H4H9664P); 180-182-184-188-190-192 (*e.g.*, H4H9665P); 196-198-200-204-206-208 (*e.g.* H4H9666P); 212-214-216-220-222-224 (*e.g.* H4H9667P); 228-230-232-236-238-240 (*e.g.* H4H9670P); 244-246-248-252-254-256 (*e.g.* H4H9671P); 260-262-264-268-270-272 (*e.g.* H4H9672P); 276-278-280-284-286-288 (*e.g.* H4H9675P); 292-294-296-300-302-304 (*e.g.* H4H9676P); and 310-312-314-318-320-322 (H1M9565N).

[0028] In a related embodiment, the invention includes an antibody or antigen-binding fragment of an antibody which specifically binds IL-33, wherein the antibody or fragment comprises the heavy and light chain CDR domains contained within heavy and light chain variable region (HCVR/LCVR) sequences selected from the group consisting of SEQ ID NO: 2/10, 18/26, 34/42, 50/58, 66/74, 82/90, 98/106, 114/122, 130/138, 146/154, 162/170, 178/186, 194/202, 210/218, 226/234, 242/250, 258/266, 274/282, 290/298, and 308/316. Methods and techniques for identifying CDRs within HCVR and LCVR amino acid sequences are well known in the art and can be used to identify CDRs within the specified HCVR and/or LCVR amino acid sequences disclosed herein. Exemplary conventions that can be used to identify the boundaries of CDRs include, *e.g.*, the Kabat definition, the Chothia definition, and the AbM definition. In general terms, the Kabat definition is based on sequence variability, the Chothia definition is based on the location of the structural loop regions, and the AbM definition is a compromise between the Kabat and Chothia approaches. *See*, *e.g.*, Kabat, "Sequences of Proteins of Immunological Interest," National Institutes of Health, Bethesda, Md. (1991); Al-

Lazikani *et al.*, *J. Mol. Biol. 273*:927-948 (1997); and Martin *et al.*, *Proc. Natl. Acad. Sci. USA 86*:9268-9272 (1989). Public databases are also available for identifying CDR sequences within an antibody.

[0029] In another aspect, the invention provides nucleic acid molecules encoding anti-IL-33 antibodies or antigen-binding fragments thereof. Recombinant expression vectors carrying the nucleic acids of the invention, and host cells into which such vectors have been introduced, are also encompassed by the invention, as are methods of producing the antibodies by culturing the host cells under conditions permitting production of the antibodies, and recovering the antibodies produced.

[0030] In one embodiment, the invention provides an antibody or fragment thereof comprising a HCVR encoded by a nucleic acid sequence selected from the group consisting of SEQ ID NO: 1, 17, 33, 49, 65, 81, 97, 113, 129, 145, 161, 177, 193, 209, 225, 241, 257, 273, 289, and 307, or a substantially identical sequence having at least 90%, at least 95%, at least 98%, or at least 99% homology thereof.

[0031] The present invention also provides an antibody or fragment thereof comprising a LCVR encoded by a nucleic acid sequence selected from the group consisting of SEQ ID NO: 9, 25, 41, 57, 73, 89, 105, 121, 137, 153, 169, 185, 201, 217, 233, 249, 265, 281, 297, and 315, or a substantially identical sequence having at least 90%, at least 95%, at least 98%, or at least 99% homology thereof.

[0032] The present invention also provides an antibody or antigen-binding fragment of an antibody comprising a HCDR3 domain encoded by a nucleotide sequence selected from the group consisting of SEQ ID NO: 7, 23, 39, 55, 71, 87, 103, 119, 135, 151, 167, 183, 199, 215, 231, 247, 263, 279, 295, and 313, or a substantially identical sequence having at least 90%, at least 95%, at least 98%, or at least 99% homology thereof; and a LCDR3 domain encoded by a nucleotide sequence selected from the group consisting of SEQ ID NO: 15, 31, 47, 63, 79, 95, 111, 127, 143, 159, 175, 191, 207, 223, 239, 255, 271, 287, 303, and 321, or a substantially identical sequence having at least 90%, at least 95%, at least 98%, or at least 99% homology thereof.

[0033] The present invention also provides an antibody or fragment thereof which further comprises a HCDR1 domain encoded by a nucleotide sequence selected from the group consisting of SEQ ID NO: 3, 19, 35, 51, 67, 83, 99, 115, 131, 147, 163, 179, 195, 211, 227, 243, 259, 275, 291, and 309, or a substantially identical sequence having at least 90%, at least 95%, at least 98%, or at least 99% homology thereof; a HCDR2 domain encoded by a nucleotide sequence selected from the group consisting of SEQ ID NO: 5, 21, 37, 53, 69, 85, 101, 117, 133, 149, 165, 181, 197, 213, 229, 245, 261, 277, 293, and 311, or a substantially identical sequence having at least 90%, at least 95%, at least 98%, or at least 99% homology thereof; a LCDR1 domain encoded by a nucleotide sequence selected from the group consisting of SEQ

ID NO: 11, 27, 43, 59, 75, 91, 107, 123, 139, 155, 171, 187, 203, 219, 235, 251, 267, 283, 299, and 317, or a substantially identical sequence having at least 90%, at least 95%, at least 98%, or at least 99% homology thereof; and a LCDR2 domain encoded by a nucleotide sequence selected from the group consisting of SEQ ID NO: 13, 29, 45, 61, 77, 93, 109, 125, 141, 157, 173, 189, 205, 221, 237, 253, 269, 285, 301, and 319, or a substantially identical sequence having at least 90%, at least 95%, at least 98%, or at least 99% homology thereof.

[0034] According to certain embodiments, the antibody or fragment thereof comprises the heavy and light chain CDR sequences encoded by the nucleic acid sequences of SEQ ID NOs: 1 and 9 (*e.g.* H1M9559N), 17 and 25 (*e.g.* H1M9566N), 33 and 41 (*e.g.* H1M9568N), 49 and 57 (*e.g.* H4H9629P), 65 and 73 (*e.g.* H4H9633P), 81 and 89 (*e.g.* H4H9640P), 97 and 105 (*e.g.* H4H9659P), 113 and 121 (*e.g.* H4H9660P), 129 and 137 (*e.g.* H4H9662P), 145 and 153 (*e.g.* H4H9663P), 161 and 169 (*e.g.* H4H9664P), 177 and 185 (*e.g.* H4H9665P), 193 and 201 (*e.g.* H4H9666P), 209 and 217 (*e.g.* H4H9667P), 225 and 233 (*e.g.* H4H9670P), 241 and 249 (*e.g.* H4H9671P), 257 and 265 (*e.g.* H4H9672P), 273 and 281 (*e.g.* H4H9675P), 289 and 297 (*e.g.* H4H9676P), or 307 and 315 (H1M9565N).

[0035] The present invention includes anti-IL-33 antibodies having a modified glycosylation pattern. In some applications, modification to remove undesirable glycosylation sites may be useful, or an antibody lacking a fucose moiety present on the oligosaccharide chain, for example, to increase antibody dependent cellular cytotoxicity (ADCC) function (see Shield et al. (2002) JBC 277:26733). In other applications, modification of galactosylation can be made in order to modify complement dependent cytotoxicity (CDC).

In another aspect, the invention provides a pharmaceutical composition comprising a recombinant human antibody or fragment thereof, which specifically binds IL-33 and a pharmaceutically acceptable carrier. In a related aspect, the invention features a composition which is a combination of an anti-IL-33 antibody and a second therapeutic agent. In one embodiment, the second therapeutic agent is any agent that is advantageously combined with an anti-IL-33 antibody. Exemplary agents that may be advantageously combined with an anti-IL-33 antibody include, without limitation, other agents that inhibit IL-33 activity (including other antibodies or antigen-binding fragments thereof, peptide inhibitors, small molecule antagonists, etc.) and/or agents, which do not directly bind IL-33 but nonetheless interfere with, block or attenuate IL-33-mediated signaling. In one embodiment the second therapeutic agent may be selected from the group consisting of a non-steroidal anti-inflammatory (NSAID), a corticosteroid, a bronchial dilator, an antihistamine, epinephrine, a decongestant, a thymic stromal lymphopoietin (TSLP) antagonist, an IL-13 antagonist, an IL-4 antagonist, an IL-4/IL-13 dual antagonist, an IL-5 antagonist, an IL-6 antagonist, an IL-12/23 antagonist, an IL-22 antagonist, an IL-25 antagonist, an IL-17 antagonist, an IL-31 antagonist, an oral PDE4 inhibitor

and another IL-33 antagonist or a different antibody to IL-33.

[0036] In certain embodiments, the cytokine antagonist may be a small molecule inhibitor (synthetic or naturally derived), or a protein (*e.g.* an antibody) that interacts with either the cytokine itself, or to a receptor for the cytokine, or to a complex comprising both the cytokine and its receptor(s) (*e.g.* an antibody to IL-4 or IL-6, or an antibody to the receptor for IL-4 or IL-6). Additional combination therapies and co-formulations involving the anti-IL-33 antibodies of the present invention are disclosed elsewhere herein.

[0037] In yet another aspect, the invention provides therapeutic methods for inhibiting IL-33 activity using an anti-IL-33 antibody or antigen-binding portion of an antibody of the invention, wherein the therapeutic methods comprise administering a therapeutically effective amount of a pharmaceutical composition comprising an antibody or antigen-binding fragment of an antibody of the invention. The disorder treated is any disease or condition which is improved, ameliorated, inhibited or prevented by removal, inhibition or reduction of IL-33 activity or signaling. The anti-IL-33 antibodies or antibody fragments of the invention may function to block the interaction between IL-33 and an IL-33 binding partner (*e.g.*, an IL-33 receptor component), or otherwise inhibit the signaling activity of IL-33.

[0038] In one embodiment, the invention provides a method for treating an inflammatory disease or disorder, or at least one symptom associated with the inflammatory disease or disorder, the method comprising administering an antibody that binds specifically to IL-33, or an antigen-binding fragment thereof, or a pharmaceutical composition comprising an antibody that binds specifically to IL-33, or an antigen-binding fragment thereof, to a patient in need thereof, wherein the inflammatory disease or disorder is alleviated, or reduced in severity, duration or frequency of occurrence, or at least one symptom associated with the inflammatory disease or disorder is alleviated, or reduced in severity, duration, or frequency of occurrence.

[0039] In one embodiment, the inflammatory disease or condition is selected from the group consisting of asthma, atopic dermatitis, chronic obstructive pulmonary disease (COPD), inflammatory bowel disease, multiple sclerosis, arthritis, allergic rhinitis, eosinophilic esophagitis and psoriasis.

[0040] In one embodiment, the invention provides a method for treating a patient who demonstrates a sensitivity to an allergen, the method comprising administering an effective amount of an antibody or antigen binding fragment thereof that binds specifically to IL-33, or a pharmaceutical composition comprising an antibody that binds specifically to IL-33, or an antigen-binding fragment thereof, to a patient in need thereof, wherein the patient demonstrates a reduced sensitivity to, or a diminished allergic reaction against the allergen, or does not experience any sensitivity or allergic reaction to, or anaphylactic response to the allergen following administration of the antibody or a composition comprising the antibody.

[0041] In one embodiment, the invention provides for administering an effective amount of a

second therapeutic agent useful for alleviating the inflammatory disease or disorder, or at least one symptom of the inflammatory disease or disorder, or for diminishing an allergic response to an allergen. As noted above, the the second therapeutic agent may be selected from the group consisting of a non-steroidal anti-inflammatory (NSAID), a corticosteroid, a bronchial dilator, an antihistamine, epinephrine, a decongestant, a thymic stromal lymphopoietin (TSLP) antagonist, an IL-13 antagonist, an IL-4 antagonist, an IL-5 antagonist, an IL-6 antagonist, an IL-25 antagonist, an IL-17 antagonist, and another IL-33 antagonist or a different antibody to IL-33.

[0042] In a related aspect, the invention provides an anti-IL-33 antibody of the invention, or an antigen-binding fragment thereof, or a pharmaceutical composition comprising the antibody or an-gen-binding fragment thereof for use in treating a disease or disorder related to, or caused by IL-33 activity in a patient. In one embodiment, the disease or disorder related to, or caused by IL-33 activity in a patient is an inflammatory disease or disorder, wherein the inflammatory disease or disorder is selected from the group consisting of asthma, atopic dermatitis, chronic obstructive pulmonary disease (COPD), inflammatory bowel disease, multiple sclerosis, arthritis, allergic rhinitis, eosinophilic esophagitis and psoriasis.

[0043] The present invention also includes the use of an anti-IL-33 antibody or antigen binding portion of an antibody of the invention in the manufacture of a medicament for the treatment of a disease or disorder related to or caused by IL-33 activity in a patient. In one embodiment, the disease or disorder related to, or caused by IL-33 activity in a patient is an inflammatory disease or disorder, wherein the inflammatory disease or disorder is selected from the group consisting of asthma, atopic dermatitis, chronic obstructive pulmonary disease (COPD), inflammatory bowel disease, multiple sclerosis, arthritis, allergic rhinitis, eosinophilic esophagitis and psoriasis..

[0044] Other embodiments will become apparent from a review of the ensuing detailed description.

BRIEF DESCRIPTION OF THE FIGURES

[0045] **Figure 1.** Cross Competition between Anti-IL-33 Antibodies for Human IL-33

[0046] **Figure 2.** Cross Competition between Anti-IL-33 Antibodies for Recombinant Monkey IL-33

DETAILED DESCRIPTION

[0047] Before the present invention is described, it is to be understood that this invention is not limited to particular methods and experimental conditions described, as such methods and conditions may vary. It is also to be understood that the terminology used herein is for the purpose of describing particular embodiments only, and is not intended to be limiting, since the scope of the present invention will be limited only by the appended claims.

[0048] Unless defined otherwise, all technical and scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this invention

belongs. As used herein, the term "about," when used in reference to a particular recited numerical value, means that the value may vary from the recited value by no more than 1 %. For example, as used herein, the expression "about 100" includes 99 and 101 and all values in between (e.g., 99.1, 99.2, 99.3, 99.4, etc.).

[0049] Although any methods and materials similar or equivalent to those described herein can be used in the practice or testing of the present invention, the preferred methods and materials are now described.

Definitions

[0050] The expressions "interleukin-33," "IL-33," and the like, as used herein, refer to a human IL-33 protein as obtained from, for example, R & D Systems, catalogue #3625-IL-010/CF. All references to proteins, polypeptides and protein fragments herein are intended to refer to the human version of the respective protein, polypeptide or protein fragment unless explicitly specified as being from a non-human species (*e.g.*, "mouse IL-33," "monkey IL-33," etc.).

[0051] As used herein, "an antibody that binds IL-33" or an "anti-IL-33 antibody" includes antibodies, and antigen-binding fragments thereof, that bind a soluble fragment of an IL-33 protein. Soluble IL-33 molecules include natural IL-33 proteins as well as recombinant IL-33 protein variants such as, e.g., monomeric and dimeric IL-33 constructs.

[0052] The term "antibody", as used herein, means any antigen-binding molecule or molecular complex comprising at least one complementarity determining region (CDR) that specifically binds to or interacts with a particular antigen (e.g., IL-33). The term "antibody" includes immunoglobulin molecules comprising four polypeptide chains, two heavy (H) chains and two light (L) chains inter-connected by disulfide bonds, as well as multimers thereof (e.g., IgM).

Each heavy chain comprises a heavy chain variable region (abbreviated herein as HCVR or V_H) and a heavy chain constant region. The heavy chain constant region comprises three domains, C_H1, C_H2 and C_H3. Each light chain comprises a light chain variable region (abbreviated herein as LCVR or V_L) and a light chain constant region. The light chain constant region comprises one domain (C_L1). The V_H and V_L regions can be further subdivided into regions of hypervariability, termed complementarity determining regions (CDRs), interspersed with regions that are more conserved, termed framework regions (FR). Each V_H and V_L is composed of three CDRs and four FRs, arranged from amino-terminus to carboxy-terminus in the following order: FR1 , CDR1 , FR2, CDR2, FR3, CDR3, FR4. In different embodiments of the invention, the FRs of the anti-IL-33 antibody (or antigen-binding portion thereof) may be identical to the human germline sequences, or may be naturally or artificially modified. An amino acid consensus sequence may be defined based on a side-by-side analysis of two or more CDRs.

[0053] The term "antibody", as used herein, also includes antigen-binding fragments of full antibody molecules. The terms "antigen-binding portion" of an antibody, "antigen-binding fragment" of an antibody, and the like, as used herein, include any naturally occurring,

enzymatically obtainable, synthetic, or genetically engineered polypeptide or glycoprotein that specifically binds an antigen to form a complex. Antigen-binding fragments of an antibody may be derived, *e.g.*, from full antibody molecules using any suitable standard techniques such as proteolytic digestion or recombinant genetic engineering techniques involving the manipulation and expression of DNA encoding antibody variable and optionally constant domains. Such DNA is known and/or is readily available from, *e.g.*, commercial sources, DNA libraries (including, *e.g.*, phage-antibody libraries), or can be synthesized. The DNA may be sequenced and manipulated chemically or by using molecular biology techniques, for example, to arrange one or more variable and/or constant domains into a suitable configuration, or to introduce codons, create cysteine residues, modify, add or delete amino acids, etc.

[0054] Non-limiting examples of antigen-binding fragments include: (i) Fab fragments; (ii) F(ab')2 fragments; (iii) Fd fragments; (iv) Fv fragments; (v) single-chain Fv (scFv) molecules; (vi) dAb fragments; and (vii) minimal recognition units consisting of the amino acid residues that mimic the hypervariable region of an antibody (*e.g.*, an isolated complementarity determining region (CDR) such as a CDR3 peptide), or a constrained FR3-CDR3-FR4 peptide. Other engineered molecules, such as domain-specific antibodies, single domain antibodies, domain-deleted antibodies, chimeric antibodies, CDR-grafted antibodies, diabodies, triabodies, tetrabodies, minibodies, nanobodies (*e.g.* monovalent nanobodies, bivalent nanobodies, etc.), small modular immunopharmaceuticals (SMIPs), and shark variable IgNAR domains, are also encompassed within the expression "antigen-binding fragment," as used herein.

[0055] An antigen-binding fragment of an antibody will typically comprise at least one variable domain. The variable domain may be of any size or amino acid composition and will generally comprise at least one CDR which is adjacent to or in frame with one or more framework sequences. In antigen-binding fragments having a V_H domain associated with a V_L domain, the V_H and V_L domains may be situated relative to one another in any suitable arrangement. For example, the variable region may be dimeric and contain V_H-V_H, V_H-V_L or V_L-V_L dimers. Alternatively, the antigen-binding fragment of an antibody may contain a monomeric V_H or V_L domain.

[0056] In certain embodiments, an antigen-binding fragment of an antibody may contain at least one variable domain covalently linked to at least one constant domain. Non-limiting, exemplary configurations of variable and constant domains that may be found within an antigen-binding fragment of an antibody of the present invention include: (i) V_H-C_H1; (ii) V_H-C_H2; (iii) V_H-C_H3; (iv) V_H-C_H1-C_H2; (v) V_H-C_H1-C_H2-C_H3; (vi) V_H-C_H2-C_H3; (vii) V_H-C_L; (viii) V_L-C_H1; (ix) V_L-C_H2; (x) V_L-C_H3; (xi) V_L-C_H1-C_H2; (xii) V_L-C_H1-C_H2-C_H3; (xiii) V_L-C_H2-C_H3; and (xiv) V_L-C_L. In any configuration of variable and constant domains, including any of the exemplary configurations listed above, the variable and constant domains may be either directly linked to one another or may be linked by a full or partial hinge or linker region. A hinge region may consist of at least 2

(*e.g.*, 5, 10, 15, 20, 40, 60 or more) amino acids which result in a flexible or semi-flexible linkage between adjacent variable and/or constant domains in a single polypeptide molecule. Moreover, an antigen-binding fragment of an antibody of the present invention may comprise a homo-dimer or hetero-dimer (or other multimer) of any of the variable and constant domain configurations listed above in non-covalent association with one another and/or with one or more monomeric V_H or V_L domain (*e.g.*, by disulfide bond(s)).

[0057] As with full antibody molecules, antigen-binding fragments may be monospecific or multispecific (*e.g.*, bispecific). A multispecific antigen-binding fragment of an antibody will typically comprise at least two different variable domains, wherein each variable domain is capable of specifically binding to a separate antigen or to a different epitope on the same antigen. Any multispecific antibody format, including the exemplary bispecific antibody formats disclosed herein, may be adapted for use in the context of an antigen-binding fragment of an antibody of the present invention using routine techniques available in the art.

[0058] The antibodies of the present invention may function through complement-dependent cytotoxicity (CDC) or antibody-dependent cell-mediated cytotoxicity (ADCC). "Complement-dependent cytotoxicity" (CDC) refers to lysis of antigen-expressing cells by an antibody of the invention in the presence of complement. "Antibody-dependent cell-mediated cytotoxicity" (ADCC) refers to a cell-mediated reaction in which nonspecific cytotoxic cells that express Fc receptors (FcRs) (*e.g.*, Natural Killer (NK) cells, neutrophils, and macrophages) recognize bound antibody on a target cell and thereby lead to lysis of the target cell. CDC and ADCC can be measured using assays that are well known and available in the art. (*See*, *e.g.*, U.S. Patent Nos 5,500,362 and 5,821,337, and Clynes *et al.* (1998) Proc. Natl. Acad. Sci. (USA) *95*:652-656). The constant region of an antibody is important in the ability of an antibody to fix complement and mediate cell-dependent cytotoxicity. Thus, the isotype of an antibody may be selected on the basis of whether it is desirable for the antibody to mediate cytotoxicity.

[0059] In certain embodiments of the invention, the anti-IL-33 antibodies of the invention are human antibodies. The term "human antibody", as used herein, is intended to include antibodies having variable and constant regions derived from human germline immunoglobulin sequences. The human antibodies of the invention may include amino acid residues not encoded by human germline immunoglobulin sequences (e.g., mutations introduced by random or site-specific mutagenesis *in vitro* or by somatic mutation *in vivo*), for example in the CDRs and in particular CDR3. However, the term "human antibody", as used herein, is not intended to include antibodies in which CDR sequences derived from the germline of another mammalian species, such as a mouse, have been grafted onto human framework sequences.

[0060] The antibodies of the invention may, in some embodiments, be recombinant human antibodies. The term "recombinant human antibody", as used herein, is intended to include all human antibodies that are prepared, expressed, created or isolated by recombinant means,

such as antibodies expressed using a recombinant expression vector transfected into a host cell (described further below), antibodies isolated from a recombinant, combinatorial human antibody library (described further below), antibodies isolated from an animal (e.g., a mouse) that is transgenic for human immunoglobulin genes (see e.g., Taylor et al. (1992) Nucl. Acids Res. 20:6287-6295) or antibodies prepared, expressed, created or isolated by any other means that involves splicing of human immunoglobulin gene sequences to other DNA sequences. Such recombinant human antibodies have variable and constant regions derived from human germline immunoglobulin sequences. In certain embodiments, however, such recombinant human antibodies are subjected to *in vitro* mutagenesis (or, when an animal transgenic for human Ig sequences is used, *in vivo* somatic mutagenesis) and thus the amino acid sequences of the V_H and V_L regions of the recombinant antibodies are sequences that, while derived from and related to human germline V_H and V_L sequences, may not naturally exist within the human antibody germline repertoire *in vivo*.

[0061] Human antibodies can exist in two forms that are associated with hinge heterogeneity. In one form, an immunoglobulin molecule comprises a stable four chain construct of approximately 150-160 kDa in which the dimers are held together by an interchain heavy chain disulfide bond. In a second form, the dimers are not linked via inter-chain disulfide bonds and a molecule of about 75-80 kDa is formed composed of a covalently coupled light and heavy chain (half-antibody). These forms have been extremely difficult to separate, even after affinity purification.

[0062] The frequency of appearance of the second form in various intact IgG isotypes is due to, but not limited to, structural differences associated with the hinge region isotype of the antibody. A single amino acid substitution in the hinge region of the human IgG4 hinge can significantly reduce the appearance of the second form (Angal et al. (1993) Molecular Immunology 30:105) to levels typically observed using a human IgG1 hinge. The instant invention encompasses antibodies having one or more mutations in the hinge, C_H2 or C_H3 region which may be desirable, for example, in production, to improve the yield of the desired antibody form.

[0063] The antibodies of the invention may be isolated antibodies. An "isolated antibody," as used herein, means an antibody that has been identified and separated and/or recovered from at least one component of its natural environment. For example, an antibody that has been separated or removed from at least one component of an organism, or from a tissue or cell in which the antibody naturally exists or is naturally produced, is an "isolated antibody" for purposes of the present invention. An isolated antibody also includes an antibody *in situ* within a recombinant cell. Isolated antibodies are antibodies that have been subjected to at least one purification or isolation step. According to certain embodiments, an isolated antibody may be substantially free of other cellular material and/or chemicals.

[0064] The present invention includes neutralizing and/or blocking anti-IL-33 antibodies. A "neutralizing" or "blocking" antibody, as used herein, is intended to refer to an antibody whose binding to IL-33: (i) interferes with the interaction between IL-33 or an IL-33 fragment and an IL-33 receptor component (*e.g.*, ST2, IL-1RAcP, etc.); and/or (ii) results in inhibition of at least one biological function of IL-33. The inhibition caused by an IL-33 neutralizing or blocking antibody need not be complete so long as it is detectable using an appropriate assay. Exemplary assays for detecting IL-33 inhibition are described in the working Examples herein.

[0065] The anti-IL-33 antibodies disclosed herein may comprise one or more amino acid substitutions, insertions and/or deletions in the framework and/or CDR regions of the heavy and light chain variable domains as compared to the corresponding germline sequences from which the antibodies were derived. Such mutations can be readily ascertained by comparing the amino acid sequences disclosed herein to germline sequences available from, for example, public antibody sequence databases. The present invention includes antibodies, and antigen-binding fragments thereof, which are derived from any of the amino acid sequences disclosed herein, wherein one or more amino acids within one or more framework and/or CDR regions are mutated to the corresponding residue(s) of the germline sequence from which the antibody was derived, or to the corresponding residue(s) of another human germline sequence, or to a conservative amino acid substitution of the corresponding germline residue(s) (such sequence changes are referred to herein collectively as "germline mutations"). A person of ordinary skill in the art, starting with the heavy and light chain variable region sequences disclosed herein, can easily produce numerous antibodies and antigen-binding fragments which comprise one or more individual germline mutations or combinations thereof. In certain embodiments, all of the framework and/or CDR residues within the V_H and/or V_L domains are mutated back to the residues found in the original germline sequence from which the antibody was derived. In other embodiments, only certain residues are mutated back to the original germline sequence, *e.g.*, only the mutated residues found within the first 8 amino acids of FR1 or within the last 8 amino acids of FR4, or only the mutated residues found within CDR1, CDR2 or CDR3. In other embodiments, one or more of the framework and/or CDR residue(s) are mutated to the corresponding residue(s) of a different germline sequence (*i.e.*, a germline sequence that is different from the germline sequence from which the antibody was originally derived). Furthermore, the antibodies of the present invention may contain any combination of two or more germline mutations within the framework and/or CDR regions, *e.g.*, wherein certain individual residues are mutated to the corresponding residue of a particular germline sequence while certain other residues that differ from the original germline sequence are maintained or are mutated to the corresponding residue of a different germline sequence. Once obtained, antibodies and antigen-binding fragments that contain one or more germline mutations can be easily tested for one or more desired property such as, improved binding specificity, increased

binding affinity, improved or enhanced antagonistic or agonistic biological properties (as the case may be), reduced immunogenicity, etc. Antibodies and antigen-binding fragments obtained in this general manner are encompassed within the present invention.

[0066] The present invention also includes anti-IL-33 antibodies comprising variants of any of the HCVR, LCVR, and/or CDR amino acid sequences disclosed herein having one or more conservative substitutions. For example, the present invention includes anti-IL-33 antibodies having HCVR, LCVR, and/or CDR amino acid sequences with, *e.g.*, 10 or fewer, 8 or fewer, 6 or fewer, 4 or fewer, etc. conservative amino acid substitutions relative to any of the HCVR, LCVR, and/or CDR amino acid sequences disclosed herein.

[0067] The term "epitope" refers to an antigenic determinant that interacts with a specific antigen binding site in the variable region of an antibody molecule known as a paratope. A single antigen may have more than one epitope. Thus, different antibodies may bind to different areas on an antigen and may have different biological effects. Epitopes may be either conformational or linear. A conformational epitope is produced by spatially juxtaposed amino acids from different segments of the linear polypeptide chain. A linear epitope is one produced by adjacent amino acid residues in a polypeptide chain. In certain circumstance, an epitope may include moieties of saccharides, phosphoryl groups, or sulfonyl groups on the antigen.

[0068] The term "substantial identity" or "substantially identical," when referring to a nucleic acid or fragment thereof, indicates that, when optimally aligned with appropriate nucleotide insertions or deletions with another nucleic acid (or its complementary strand), there is nucleotide sequence identity in at least about 95%, and more preferably at least about 96%, 97%, 98% or 99% of the nucleotide bases, as measured by any well-known algorithm of sequence identity, such as FASTA, BLAST or Gap, as discussed below. A nucleic acid molecule having substantial identity to a reference nucleic acid molecule may, in certain instances, encode a polypeptide having the same or substantially similar amino acid sequence as the polypeptide encoded by the reference nucleic acid molecule.

[0069] As applied to polypeptides, the term "substantial similarity" or "substantially similar" means that two peptide sequences, when optimally aligned, such as by the programs GAP or BESTFIT using default gap weights, share at least 95% sequence identity, even more preferably at least 98% or 99% sequence identity. Preferably, residue positions which are not identical differ by conservative amino acid substitutions. A "conservative amino acid substitution" is one in which an amino acid residue is substituted by another amino acid residue having a side chain (R group) with similar chemical properties (e.g., charge or hydrophobicity). In general, a conservative amino acid substitution will not substantially change the functional properties of a protein. In cases where two or more amino acid sequences differ from each other by conservative substitutions, the percent sequence identity or degree of similarity may be adjusted upwards to correct for the conservative nature of the substitution. Means for making

this adjustment are well-known to those of skill in the art. *See, e.g.*, Pearson (1994) Methods Mol. Biol. 24: 307-331. Examples of groups of amino acids that have side chains with similar chemical properties include (1) aliphatic side chains: glycine, alanine, valine, leucine and isoleucine; (2) aliphatic-hydroxyl side chains: serine and threonine; (3) amide-containing side chains: asparagine and glutamine; (4) aromatic side chains: phenylalanine, tyrosine, and tryptophan; (5) basic side chains: lysine, arginine, and histidine; (6) acidic side chains: aspartate and glutamate, and (7) sulfur-containing side chains are cysteine and methionine. Preferred conservative amino acids substitution groups are: valine-leucine-isoleucine, phenylalanine-tyrosine, lysine-arginine, alanine-valine, glutamate-aspartate, and asparagine-glutamine. Alternatively, a conservative replacement is any change having a positive value in the PAM250 log-likelihood matrix disclosed in Gonnet *et al.* (1992) Science 256: 1443-1445. A "moderately conservative" replacement is any change having a nonnegative value in the PAM250 log-likelihood matrix.

[0070] Sequence similarity for polypeptides, which is also referred to as sequence identity, is typically measured using sequence analysis software. Protein analysis software matches similar sequences using measures of similarity assigned to various substitutions, deletions and other modifications, including conservative amino acid substitutions. For instance, GCG software contains programs such as Gap and Bestfit which can be used with default parameters to determine sequence homology or sequence identity between closely related polypeptides, such as homologous polypeptides from different species of organisms or between a wild type protein and a mutein thereof. *See, e.g.*, GCG Version 6.1. Polypeptide sequences also can be compared using FASTA using default or recommended parameters, a program in GCG Version 6.1. FASTA (e.g., FASTA2 and FASTA3) provides alignments and percent sequence identity of the regions of the best overlap between the query and search sequences (Pearson (2000) supra). Another preferred algorithm when comparing a sequence of the invention to a database containing a large number of sequences from different organisms is the computer program BLAST, especially BLASTP or TBLASTN, using default parameters. *See, e.g.*, Altschul *et al.* (1990) J. Mol. Biol. 215:403-410 and Altschul *et al.* (1997) Nucleic Acids Res. 25:3389-402.

[0071] An "inflammatory disease or disorder", as used herein, refers to a disease, disorder or pathological condition where the pathology results, in whole or in part, from, *e.g.*, a change in number, change in rate of migration, or change in activation, of cells of the immune system. Cells of the immune system include, e.g., T cells, B cells, monocytes or macrophages, antigen presenting cells (APCs), dendritic cells, microglia, NK cells, neutrophils, eosinophils, mast cells, or any other cell specifically associated with the immunology, for example, cytokine-producing endothelial or epithelial cells. As used herein, in one embodiment, the "inflammatory disease or disorder" is an immune disorder or condition selected from the group consisting of asthma, (including steroid resistant asthma, steroid sensitive asthma, eosinophilic asthma or non-

eosinophilic asthma, allergy, anaphylaxis, multiple sclerosis, inflammatory bowel disorder (*e.g.* Crohn's disease or ulcerative colitis), chronic obstructive pulmonary disease (COPD, which may or may not be related to, caused in part by, or resulting from, exposure to first or second hand cigarette smoke), lupus, atopic dermatitis, psoriasis, scleroderma and other fibrotic diseases, sjogren's syndrome, vasculitis (behcet's disease, Giant cell arteritis, Henoch-Schonlein purpura and Churg Strauss syndrome) and arthritis. In another embodiment, the arthritis is selected from the group consisting of rheumatoid arthritis, osteoarthritis, and psoriatic arthritis. In another embodiment, the "inflammatory disease or disorder" is an immune disorder or condition comprises a TH_1-type response or a TH_2-type response.

[0072] The phrase "Inhibits or attenuates IL-33-mediated signaling", as used herein, refers to the degree to which IL-33 stimulates signal transduction through ST2 and IL-1RAcP, which is diminished in the presence of an antagonist, such as an IL-33 antibody as described herein, relative to the degree to which IL-33 stimulates signal transduction through ST2 and IL-1RAcP in the absence of the antagonist such as an IL-33 antibody as described herein. To examine the extent of inhibition, a sample is treated with a potential inhibitor/antagonist and is compared to a control sample without the inhibitor/antagonist. Control samples, *i.e.*, not treated with antagonist, are assigned a relative activity value of 100%. Inhibition is achieved when the activity value relative to the control is about 90%, 85%, 80%, 75%, 70%, 65%, 60%, 55%, 50%, 45%, 40%, 35%, 30%, 25%, or 20% or less. An endpoint in inhibition may comprise a predetermined quantity or percentage of, *e.g.*, an indicator of inflammation, or cell degranulation,secretion or activation, such as the release of a cytokine. Inhibition of IL-33 signal transduction through ST2 and IL-1RAcP can be determined by assaying for IL-33 signal transduction in an *in vitro* assay, such as that described herein in Example 6. In addition, *in vivo* assays can be used to determine whether a molecule is an antagonist of IL-33. For example, an *in vivo* assay such as that described in Examples 11 and 12 may be used to assess the effect of an antibody to IL-33 on lung inflammation in allergen-sensitized animals that are homozygous for expression of human IL-33. Following sensitization of the animals with allergen, a subset of the animals is treated with either an anti-IL-33 antibody of the invention or a negative isotype control antibody. Afterwards, the animals are sacrificed and the lungs are harvested for assessment of cellular infiltrates, as well as cytokine measurements (IL-4 and IL-5). An IL-33 antibody that is effective as an antagonist should demonstrate a trend towards reduction in inflammatory cells in the lung, as well as a trend towards reduction in cytokines such as IL-4 and IL-5.

Biological Characteristics of the Antibodies

[0073] The present invention includes anti-IL-33 antibodies and antigen-binding fragments thereof that bind human IL-33 and inhibit or attenuate IL-33-mediated signaling. An anti-IL-33 antibody is deemed to "inhibit or attenuate IL-33-mediated signaling" if, *e.g.*, the antibody exhibits one or more properties selected from the group consisting of: (1) inhibition of IL-33-

mediated signaling in a cell-based bioassay; (2) inhibition of IL-33-induced degranulation of human basophils; (3) inhibition of IL-33-induced IFNγ production from human PBMCs; (4) reduction in cytokine levels that are elevated in a mammal as a result of exposure to an allergen, *e.g.* IL-4 or IL-5; and (5) inhibition of lung inflammation resulting from acute or chronic exposure to an allergen (*e.g.* house dust mites (HDM)).

[0074] Inhibition of IL-33-mediated signaling in a cell-based bioassay means that an anti-IL-33 antibody or antigen-binding fragment thereof inhibits or reduces the signal produced in cells that express an IL-33 receptor and a reporter element that produces a detectable signal in response to IL-33 binding, *e.g.*, using the assay format as defined in Example 6 herein, or a substantially similar assay. For example, the present invention includes antibodies and antigen-binding fragments thereof that block IL-33-mediated signaling in cells expressing human ST2, with an IC_{50} of less than about 2 nM, less than about 1 nM, less than about 900 pM, less than about 800 pM, less than about 700 pM, less than about 600 pM, less than about 500 pM, less than about 400 pM, less than about 350 pM, less than about 300 pM, less than about 250 pM, less than about 200 pM, less than about 150 pM, less than about 100 pM, less than about 90 pM, less than about 80 pM, less than about 70 pM, less than about 60 pM, less than about 50 pM, less than about 40 pM, less than about 30 pM, less than about 20 pM, or less than about 10 pM, as measured in a cell-based blocking bioassay, *e.g.*, using the assay format as defined in Example 5 herein, or a substantially similar assay.

[0075] Inhibition of IL-33-induced degranulation of human basophils means that an anti-IL-33 antibody or antigen-binding fragment thereof inhibits or reduces the extent of IL-33-induced basophil degranulation *in vitro*, *e.g.*, as measured using the assay system of Example 7 or a substantially similar assay. For example, the present invention includes antibodies and antigen-binding fragments thereof that inhibit degranulation of human basophils in the presence of human IL-33 (*e.g.*, about 100 pM final concentration), with an IC_{50} of less than about 500 pM, less than about 400 pM, less than about 350 pM, less than about 300 pM, less than about 250 pM, less than about 200 pM, less than about 150 pM, less than about 100 pM, less than about 90 pM, less than about 80 pM, less than about 70 pM, less than about 60 pM, less than about 50 pM, less than about 40 pM, less than about 30 pM, less than about 20 pM, or less than about 10 pM, as measured in an *in vitro* human basophil degranulation assay, *e.g.*, using the assay format as defined in Example 7 herein, or a substantially similar assay.

[0076] Inhibition of IL-33-induced IFNγ production from human PBMCs means that an anti-IL-33 antibody or antigen-binding fragment thereof inhibits or reduces the amount of IFNγ released from PBMCs treated with human IL-33 in the presence of human IL-12, *e.g.*, as measured using the assay system of Example 8 or a substantially similar assay. For example, the present invention includes antibodies and antigen-binding fragments thereof that inhibit IL-33-induced release of IFNγ, in the presence of human IL-12, with an IC_{50} of less than about 50 nM, less

than about 25 nM, less than about 20 nM, less than about 15 nM, less than about 10 nM, less than about 5 nM, less than about 1 nM, less than about 900 pM, less than about 800 pM, less than about 700 pM, less than about 600 pM, less than about 500 pM, less than about 400 pM or less than about 300 pM, as measured in an IL-33-induced IFNγ release assay, *e.g.*, using the assay format as defined in Example 8 herein, or a substantially similar assay.

[0077] In certain embodiments, the anti-IL-33 antibodies and antigen-binding fragments of the present invention block the binding of IL-33 to an IL-33 receptor (*e.g.*, ST2). For example, the present invention includes anti-IL-33 antibodies that block the binding of IL-33 to ST2 *in vitro*, with an IC_{50} value of less than about 15 nM, as measured by an ELISA-based immunoassay, *e.g.*, using the assay format as defined in Example 4 herein, or a substantially similar assay. In certain embodiments, the antibodies or antigen-binding fragments of the present invention block the binding of IL-33 to ST2 *in vitro* with an IC_{50} value of less than about 10 nM, less than about 5 nM, less than about 900 pM, less than about 800 pM, less than about 700 pM, less than about 600 pM, less than about 500 pM, less than about 400 pM, less than about 300 pM, less than about 280 pM, less than about 260 pM, less than about 250 pM, less than about 240 pM, less than about 230 pM, less than about 220 pM, less than about 200 pM, less than about 180 pM, less than about 160 pM, or less than about 150 pM, as measured by an ELISA-based immunoassay, *e.g.*, using the assay format as defined in Example 4 herein, or a substantially similar assay.

[0078] In other embodiments, however, certain anti-IL-33 antibodies and antigen-binding fragments of the present invention, despite having the ability to inhibit or attenuate IL-33-mediated signaling, do not block or only partially block the interaction of IL-33 and ST2. Such antibodies and antigen-binding fragments thereof, may be referred to herein as "indirect blockers." Without being bound by theory, it is believed that the indirect blockers of the invention function by binding to IL-33 at an epitope that does overlap, or overlaps only partially, with the ST2-binding domain of IL-33, but nonetheless interfere with IL-33-mediated signaling without blocking the IL-33/ST2 interaction directly.

[0079] The present invention includes anti-IL-33 antibodies and antigen-binding fragments thereof that bind soluble IL-33 molecules with high affinity. For example, the present invention includes antibodies and antigen-binding fragments of antibodies that bind IL-33 (*e.g.*, at 25°C or 37°C) with a K_D of less than about 10 nM as measured by surface plasmon resonance, *e.g.*, using the assay format as defined in Example 3 herein. In certain embodiments, the antibodies or antigen-binding fragments of the present invention bind IL-33 with a K_D of less than about 5 nM, less than about 2 nM, less than about 1 nM, less than about 800 pM, less than about 600 pM, less than about 500 pM, less than about 400 pM, less than about 300 pM, less than about 200 pM, less than about 180 pM, or less than about 160 pM, as measured by surface plasmon resonance, *e.g.*, using the assay format as defined in Example 3 herein, or a substantially

similar assay.

[0080] The present invention also includes anti-IL-33 antibodies and antigen-binding fragments thereof that specifically bind to IL-33 with a dissociative half-life (t½) of greater than about 10 minutes as measured by surface plasmon resonance at 25°C or 37°C, *e.g.*, using the assay format as defined in Example 3 herein, or a substantially similar assay. In certain embodiments, the antibodies or antigen-binding fragments of the present invention bind IL-33 with a t½ of greater than about 20 minutes, greater than about 30 minutes, greater than about 40 minutes, greater than about 50 minutes, greater than about 60 minutes, greater than about 70 minutes, greater than about 80 minutes, greater than about 90 minutes, greater than about 100 minutes, as measured by surface plasmon resonance at 25°C or 37°C, *e.g.*, using the assay format as defined in Example 3 herein, or a substantially similar assay.

[0081] The antibodies of the present invention may possess one or more of the aforementioned biological characteristics, or any combinations thereof. Other biological characteristics of the antibodies of the present invention will be evident to a person of ordinary skill in the art from a review of the present disclosure including the working Examples herein.

Anti-IL-33 Antibodies Comprising Fc Variants

[0082] According to certain embodiments of the present invention, anti-IL-33 antibodies are provided comprising an Fc domain comprising one or more mutations which enhance or diminish antibody binding to the FcRn receptor, *e.g.*, at acidic pH as compared to neutral pH. For example, the present invention includes anti- IL-33 antibodies comprising a mutation in the C_H2 or a C_H3 region of the Fc domain, wherein the mutation(s) increases the affinity of the Fc domain to FcRn in an acidic environment (*e.g.,* in an endosome where pH ranges from about 5.5 to about 6.0). Such mutations may result in an increase in serum half-life of the antibody when administered to an animal. Non-limiting examples of such Fc modifications include, *e.g.*, a modification at position 250 (e.g., E or Q); 250 and 428 (e.g., L or F); 252 (e.g., L/Y/F/W or T), 254 (e.g., S or T), and 256 (e.g., S/R/Q/E/D or T); or a modification at position 428 and/or 433 (e.g., H/L/R/S/P/Q or K) and/or 434 (*e.g.,* H/F or Y); or a modification at position 250 and/or 428; or a modification at position 307 or 308 (*e.g.,* 308F, V308F), and 434. In one embodiment, the modification comprises a 428L (*e.g.,* M428L) and 434S (*e.g.,* N434S) modification; a 428L, 259I (*e.g.,* V259I), and 308F (*e.g.,* V308F) modification; a 433K (*e.g.,* H433K) and a 434 (*e.g.,* 434Y) modification; a 252, 254, and 256 (*e.g.,* 252Y, 254T, and 256E) modification; a 250Q and 428L modification (*e.g.,* T250Q and M428L); and a 307 and/or 308 modification (*e.g.,* 308F or 308P). In yet another embodiment, the modification comprises a 265A (*e.g.*, D265A) and/or a 297A (*e.g.*, D297A) modification.

[0083] For example, the present invention includes anti-IL-33 antibodies comprising an Fc domain comprising one or more pairs or groups of mutations selected from the group consisting

of: 250Q and 248L (*e.g.*, T250Q and M248L); 252Y, 254T and 256E (*e.g.*, M252Y, S254T and T256E); 428L and 434S (*e.g.*, M428L and N434S); and 433K and 434F (*e.g.*, H433K and N434F). All possible combinations of the foregoing Fc domain mutations, and other mutations within the antibody variable domains disclosed herein, are contemplated within the scope of the present invention.

[0084] The present invention also includes anti-IL-33 antibodies comprising a chimeric heavy chain constant (C_H) region, wherein the chimeric C_H region comprises segments derived from the C_H regions of more than one immunoglobulin isotype. For example, the antibodies of the invention may comprise a chimeric C_H region comprising part or all of a C_H2 domain derived from a human IgG1, human IgG2 or human IgG4 molecule, combined with part or all of a C_H3 domain derived from a human IgG1, human IgG2 or human IgG4 molecule. According to certain embodiments, the antibodies of the invention comprise a chimeric C_H region having a chimeric hinge region. For example, a chimeric hinge may comprise an "upper hinge" amino acid sequence (amino acid residues from positions 216 to 227 according to EU numbering) derived from a human IgG1, a human IgG2 or a human IgG4 hinge region, combined with a "lower hinge" sequence (amino acid residues from positions 228 to 236 according to EU numbering) derived from a human IgG1, a human IgG2 or a human IgG4 hinge region. According to certain embodiments, the chimeric hinge region comprises amino acid residues derived from a human IgG1 or a human IgG4 upper hinge and amino acid residues derived from a human IgG2 lower hinge. An antibody comprising a chimeric C_H region as described herein may, in certain embodiments, exhibit modified Fc effector functions without adversely affecting the therapeutic or pharmacokinetic properties of the antibody. (*See*, *e.g.*, U.S. Provisional Appl. No. 61/759,578, filed February 1, 2013).

Epitope Mapping and Related Technologies

[0085] The present invention includes anti-IL-33 antibodies which interact with one or more amino acids of IL-33. For example, the present invention includes anti-IL-33 antibodies that interact with one or more amino acids located within the ST2-interacting domain of IL-33. The epitope to which the antibodies bind may consist of a single contiguous sequence of 3 or more (*e.g.*, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20 or more) amino acids of IL-33. Alternatively, the epitope may consist of a plurality of non-contiguous amino acids (or amino acid sequences) of IL-33.

[0086] Various techniques known to persons of ordinary skill in the art can be used to determine whether an antibody "interacts with one or more amino acids" within a polypeptide or protein. Exemplary techniques include, *e.g.*, routine cross-blocking assay such as that described Antibodies, Harlow and Lane (Cold Spring Harbor Press, Cold Spring Harb., NY), alanine scanning mutational analysis, peptide blots analysis (Reineke, 2004, Methods Mol Biol 248:443-463), and peptide cleavage analysis. In addition, methods such as epitope excision,

epitope extraction and chemical modification of antigens can be employed (Tomer, 2000, Protein Science 9:487-496). Another method that can be used to identify the amino acids within a polypeptide with which an antibody interacts is hydrogen/deuterium exchange detected by mass spectrometry. In general terms, the hydrogen/deuterium exchange method involves deuterium-labeling the protein of interest, followed by binding the antibody to the deuterium-labeled protein. Next, the protein/antibody complex is transferred to water to allow hydrogen-deuterium exchange to occur at all residues except for the residues protected by the antibody (which remain deuterium-labeled). After dissociation of the antibody, the target protein is subjected to protease cleavage and mass spectrometry analysis, thereby revealing the deuterium-labeled residues which correspond to the specific amino acids with which the antibody interacts. *See, e.g.*, Ehring (1999) *Analytical Biochemistry* 267(2):252-259; Engen and Smith (2001) *Anal. Chem. 73*:256A-265A.

[0087] The present invention further includes anti-IL-33 antibodies that bind to the same epitope as any of the specific exemplary antibodies described herein (*e.g.* H1M9559N, H1M9566N, H1M9568N, H4H9629P, H4H9633P, H4H9640P, H4H9659P, H4H9660P, H4H9662P, H4H9663P, H4H9664P, H4H9665P, H4H9666P, H4H9667P, H4H9670P, H4H9671P, H4H9672P, H4H9675P, H4H9676P, H1M9565N, etc.). Likewise, the present invention also includes anti-IL-33 antibodies that compete for binding to IL-33 with any of the specific exemplary antibodies described herein (*e.g.* H1M9559N, H1M9566N, H1M9568N, H4H9629P, H4H9633P, H4H9640P, H4H9659P, H4H9660P, H4H9662P, H4H9663P, H4H9664P, H4H9665P, H4H9666P, H4H9667P, H4H9670P, H4H9671P, H4H9672P, H4H9675P, H4H9676P, H1M9565N, etc.).

[0088] One can easily determine whether an antibody binds to the same epitope as, or competes for binding with, a reference anti-IL-33 antibody by using routine methods known in the art and exemplified herein. For example, to determine if a test antibody binds to the same epitope as a reference anti-IL-33 antibody of the invention, the reference antibody is allowed to bind to an IL-33 protein. Next, the ability of a test antibody to bind to the IL-33 molecule is assessed. If the test antibody is able to bind to IL-33 following saturation binding with the reference anti-IL-33 antibody, it can be concluded that the test antibody binds to a different epitope than the reference anti-IL-33 antibody. On the other hand, if the test antibody is not able to bind to the IL-33 molecule following saturation binding with the reference anti-IL-33 antibody, then the test antibody may bind to the same epitope as the epitope bound by the reference anti-IL-33 antibody of the invention. Additional routine experimentation (*e.g.*, peptide mutation and binding analyses) can then be carried out to confirm whether the observed lack of binding of the test antibody is in fact due to binding to the same epitope as the reference antibody or if steric blocking (or another phenomenon) is responsible for the lack of observed binding. Experiments of this sort can be performed using ELISA, RIA, Biacore, flow cytometry

or any other quantitative or qualitative antibody-binding assay available in the art. In accordance with certain embodiments of the present invention, two antibodies bind to the same (or overlapping) epitope if, *e.g.*, a 1-, 5-, 10-, 20- or 100-fold excess of one antibody inhibits binding of the other by at least 50% but preferably 75%, 90% or even 99% as measured in a competitive binding assay (see, e.g., Junghans et al., Cancer Res. 1990:50:1495-1502). Alternatively, two antibodies are deemed to bind to the same epitope if essentially all amino acid mutations in the antigen that reduce or eliminate binding of one antibody reduce or eliminate binding of the other. Two antibodies are deemed to have "overlapping epitopes" if only a subset of the amino acid mutations that reduce or eliminate binding of one antibody reduce or eliminate binding of the other.

[0089] To determine if an antibody competes for binding (or cross-competes for binding) with a reference anti-IL-33 antibody, the above-described binding methodology is performed in two orientations: In a first orientation, the reference antibody is allowed to bind to an IL-33 protein under saturating conditions followed by assessment of binding of the test antibody to the IL-33 molecule. In a second orientation, the test antibody is allowed to bind to an IL-33 molecule under saturating conditions followed by assessment of binding of the reference antibody to the IL-33 molecule. If, in both orientations, only the first (saturating) antibody is capable of binding to the IL-33 molecule, then it is concluded that the test antibody and the reference antibody compete for binding to IL-33. As will be appreciated by a person of ordinary skill in the art, an antibody that competes for binding with a reference antibody may not necessarily bind to the same epitope as the reference antibody, but may sterically block binding of the reference antibody by binding an overlapping or adjacent epitope.

Preparation of Human Antibodies

[0090] Methods for generating monoclonal antibodies, including fully human monoclonal antibodies are known in the art. Any such known methods can be used in the context of the present invention to make human antibodies that specifically bind to human IL-33.

[0091] Using VELOCIMMUNE™ technology, for example, or any other known method for generating fully human monoclonal antibodies, high affinity chimeric antibodies to IL-33 are initially isolated having a human variable region and a mouse constant region. As in the experimental section below, the antibodies are characterized and selected for desirable characteristics, including affinity, selectivity, epitope, etc. If necessary, mouse constant regions are replaced with a desired human constant region, for example wild-type or modified IgG1 or IgG4, to generate a fully human anti-IL-33 antibody. While the constant region selected may vary according to specific use, high affinity antigen-binding and target specificity characteristics reside in the variable region. In certain instances, fully human anti-IL-33 antibodies are isolated directly from antigen-positive B cells.

Bioequivalents

[0092] The anti-IL-33 antibodies and antibody fragments of the present invention encompass proteins having amino acid sequences that vary from those of the described antibodies but that retain the ability to bind human IL-33. Such variant antibodies and antibody fragments comprise one or more additions, deletions, or substitutions of amino acids when compared to parent sequence, but exhibit biological activity that is essentially equivalent to that of the described antibodies. Likewise, the anti-IL-33 antibody-encoding DNA sequences of the present invention encompass sequences that comprise one or more additions, deletions, or substitutions of nucleotides when compared to the disclosed sequence, but that encode an anti-IL-33 antibody or antibody fragment that is essentially bioequivalent to an anti-IL-33 antibody or antibody fragment of the invention. Examples of such variant amino acid and DNA sequences are discussed above.

[0093] Two antigen-binding proteins, or antibodies, are considered bioequivalent if, for example, they are pharmaceutical equivalents or pharmaceutical alternatives whose rate and extent of absorption do not show a significant difference when administered at the same molar dose under similar experimental conditions, either single does or multiple dose. Some antibodies will be considered equivalents or pharmaceutical alternatives if they are equivalent in the extent of their absorption but not in their rate of absorption and yet may be considered bioequivalent because such differences in the rate of absorption are intentional and are reflected in the labeling, are not essential to the attainment of effective body drug concentrations on, *e.g.*, chronic use, and are considered medically insignificant for the particular drug product studied.

[0094] In one embodiment, two antigen-binding proteins are bioequivalent if there are no clinically meaningful differences in their safety, purity, and potency.

[0095] In one embodiment, two antigen-binding proteins are bioequivalent if a patient can be switched one or more times between the reference product and the biological product without an expected increase in the risk of adverse effects, including a clinically significant change in immunogenicity, or diminished effectiveness, as compared to continued therapy without such switching.

[0096] In one embodiment, two antigen-binding proteins are bioequivalent if they both act by a common mechanism or mechanisms of action for the condition or conditions of use, to the extent that such mechanisms are known.

[0097] Bioequivalence may be demonstrated by in vivo and in vitro methods. Bioequivalence measures include, e.g., (a) an in vivo test in humans or other mammals, in which the concentration of the antibody or its metabolites is measured in blood, plasma, serum, or other biological fluid as a function of time; (b) an in vitro test that has been correlated with and is reasonably predictive of human in vivo bioavailability data; (c) an in vivo test in humans or other

mammals in which the appropriate acute pharmacological effect of the antibody (or its target) is measured as a function of time; and (d) in a well-controlled clinical trial that establishes safety, efficacy, or bioavailability or bioequivalence of an antibody.

[0098] Bioequivalent variants of anti-IL-33 antibodies of the invention may be constructed by, for example, making various substitutions of residues or sequences or deleting terminal or internal residues or sequences not needed for biological activity. For example, cysteine residues not essential for biological activity can be deleted or replaced with other amino acids to prevent formation of unnecessary or incorrect intramolecular disulfide bridges upon renaturation. In other contexts, bioequivalent antibodies may include anti-IL-33 antibody variants comprising amino acid changes which modify the glycosylation characteristics of the antibodies, *e.g.*, mutations which eliminate or remove glycosylation.

Species Selectivity and Species Cross-Reactivity

[0099] The present invention, according to certain embodiments, provides anti-IL-33 antibodies that bind to human IL-33 but not to IL-33 from other species. The present invention also includes anti-IL-33 antibodies that bind to human IL-33 and to IL-33 from one or more non-human species. For example, the anti-IL-33 antibodies of the invention may bind to human IL-33 and may bind or not bind, as the case may be, to one or more of mouse, rat, guinea pig, hamster, gerbil, pig, cat, dog, rabbit, goat, sheep, cow, horse, camel, cynomologous, marmoset, rhesus or chimpanzee IL-33. According to certain exemplary embodiments of the present invention, anti-IL-33 antibodies are provided which specifically bind human IL-33 and cynomolgus monkey (*e.g.*, *Macaca fascicularis*) IL-33.

Immunoconjugates

[0100] The invention encompasses anti-IL-33 monoclonal antibodies conjugated to a therapeutic moiety ("immunoconjugate"), such as a cytotoxin, a chemotherapeutic drug, an immunosuppressant or a radioisotope. Cytotoxic agents include any agent that is detrimental to cells. Examples of suitable cytotoxic agents and chemotherapeutic agents for forming immunoconjugates are known in the art, (see for example, WO 05/103081).

Multispecific Antibodies

[0101] The antibodies of the present invention may be monospecific, bi-specific, or multispecific. Multispecific antibodies may be specific for different epitopes of one target polypeptide or may contain antigen-binding domains specific for more than one target polypeptide. See, e.g., Tutt et al., 1991, J. Immunol. 147:60-69; Kufer *et al.*, 2004, Trends Biotechnol. 22:238-244. The anti-IL-33 antibodies of the present invention can be linked to or co-expressed with another functional molecule, e.g., another peptide or protein. For example, an antibody or fragment thereof can be functionally linked (e.g., by chemical coupling, genetic

fusion, noncovalent association or otherwise) to one or more other molecular entities, such as another antibody or antibody fragment to produce a bi-specific or a multispecific antibody with a second binding specificity. For example, the present invention includes bi-specific antibodies wherein one arm of an immunoglobulin is specific for human IL-33 or a fragment thereof, and the other arm of the immunoglobulin is specific for a second therapeutic target or is conjugated to a therapeutic moiety.

[0102] An exemplary bi-specific antibody format that can be used in the context of the present invention involves the use of a first immunoglobulin (Ig) C_H3 domain and a second Ig C_H3 domain, wherein the first and second Ig C_H3 domains differ from one another by at least one amino acid, and wherein at least one amino acid difference reduces binding of the bispecific antibody to Protein A as compared to a bi-specific antibody lacking the amino acid difference. In one embodiment, the first Ig C_H3 domain binds Protein A and the second Ig C_H3 domain contains a mutation that reduces or abolishes Protein A binding such as an H95R modification (by IMGT exon numbering; H435R by EU numbering). The second C_H3 may further comprise a Y96F modification (by IMGT; Y436F by EU). Further modifications that may be found within the second C_H3 include: D16E, L18M, N44S, K52N, V57M, and V82I (by IMGT; D356E, L358M, N384S, K392N, V397M, and V422I by EU) in the case of IgG1 antibodies; N44S, K52N, and V82I (IMGT; N384S, K392N, and V422I by EU) in the case of IgG2 antibodies; and Q15R, N44S, K52N, V57M, R69K, E79Q, and V82I (by IMGT; Q355R, N384S, K392N, V397M, R409K, E419Q, and V422I by EU) in the case of IgG4 antibodies. Variations on the bi-specific antibody format described above are contemplated within the scope of the present invention.

[0103] Other exemplary bispecific formats that can be used in the context of the present invention include, without limitation, *e.g.*, scFv-based or diabody bispecific formats, IgG-scFv fusions, dual variable domain (DVD)-Ig, Quadroma, knobs-into-holes, common light chain (*e.g.*, common light chain with knobs-into-holes, etc.), CrossMab, CrossFab, (SEED)body, leucine zipper, Duobody, IgG1/IgG2, dual acting Fab (DAF)-IgG, and Mab^2 bispecific formats (*see*, *e.g.*, Klein *et al*. 2012, mAbs 4:6, 1-11, and references cited therein, for a review of the foregoing formats). Bispecific antibodies can also be constructed using peptide/nucleic acid conjugation, *e.g.*, wherein unnatural amino acids with orthogonal chemical reactivity are used to generate site-specific antibody-oligonucleotide conjugates which then self-assemble into multimeric complexes with defined composition, valency and geometry. (*See*, *e.g.*, Kazane *et al*., *J. Am. Chem. Soc*. [*Epub*: *Dec. 4, 2012*]).

pH-DEPENDENT BINDING

[0104] The present invention provides antibodies and antigen-binding fragments thereof that bind IL-33 in a pH-dependent manner. For example, an anti-IL-33 antibody of the invention may exhibit reduced binding to IL-33 at acidic pH as compared to neutral pH. Alternatively, an anti-IL-33 antibody of the invention may exhibit enhanced binding to its antigen at acidic pH as

compared to neutral pH.

[0105] In certain instances, "reduced binding to IL-33 at acidic pH as compared to neutral pH" is expressed in terms of a ratio of the K_D value of the antibody binding to IL-33 at acidic pH to the K_D value of the antibody binding to IL-33 at neutral pH (or vice versa). For example, an antibody or antigen-binding fragment thereof may be regarded as exhibiting "reduced binding to IL-33 at acidic pH as compared to neutral pH" for purposes of the present invention if the antibody or antigen-binding fragment thereof exhibits an acidic/neutral K_D ratio of about 3.0 or greater. In certain exemplary embodiments, the acidic/neutral K_D ratio for an antibody or antigen-binding fragment of the present invention can be about 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, 10.5, 11.0, 11.5, 12.0, 12.5, 13.0, 13.5, 14.0, 14.5, 15.0, 20.0. 25.0, 30.0, 40.0, 50.0, 60.0, 70.0, 100.0 or greater

[0106] Antibodies with pH-dependent binding characteristics may be obtained, *e.g.*, by screening a population of antibodies for reduced (or enhanced) binding to a particular antigen at acidic pH as compared to neutral pH. Additionally, modifications of the antigen-binding domain at the amino acid level may yield antibodies with pH-dependent characteristics. For example, by substituting one or more amino acids of an antigen-binding domain (*e.g.*, within a CDR) with a histidine residue, an antibody with reduced antigen-binding at acidic pH relative to neutral pH may be obtained. As used herein, the expression "acidic pH" means a pH of about 6.0 or less, about 5.5 or less, or about 5.0 or less. The expression "acidic pH" includes pH values of about 6.0, 5.95, 5.9, 5.85, 5.8, 5.75, 5.7, 5.65, 5.6, 5.55, 5.5, 5.45, 5.4, 5.35, 5.3, 5.25, 5.2, 5.15, 5.1, 5.05, 5.0, or less. As used herein, the expression "neutral pH" means a pH of about 7.0 to about 7.4. The expression "neutral pH" includes pH values of about 7.0, 7.05, 7.1, 7.15, 7.2, 7.25, 7.3, 7.35, and 7.4.

Therapeutic Formulation and Administration

[0107] The invention provides pharmaceutical compositions comprising the anti-IL-33 antibodies or antigen-binding fragments thereof of the present invention. The pharmaceutical compositions of the invention are formulated with suitable carriers, excipients, and other agents that provide improved transfer, delivery, tolerance, and the like. A multitude of appropriate formulations can be found in the formulary known to all pharmaceutical chemists: Remington's Pharmaceutical Sciences, Mack Publishing Company, Easton, PA. These formulations include, for example, powders, pastes, ointments, jellies, waxes, oils, lipids, lipid (cationic or anionic) containing vesicles (such as LIPOFECTIN™, Life Technologies, Carlsbad, CA), DNA conjugates, anhydrous absorption pastes, oil-in-water and water-in-oil emulsions, emulsions carbowax (polyethylene glycols of various molecular weights), semi-solid gels, and semi-solid mixtures containing carbowax. See also Powell et al. "Compendium of excipients for parenteral formulations" PDA (1998) J Pharm Sci Technol 52:238-311.

[0108] The dose of antibody administered to a patient may vary depending upon the age and the size of the patient, target disease, conditions, route of administration, and the like. The preferred dose is typically calculated according to body weight or body surface area. When an antibody of the present invention is used for treating a condition or disease associated with IL-33 activity in an adult patient, it may be advantageous to intravenously administer the antibody of the present invention normally at a single dose of about 0.01 to about 20 mg/kg body weight, more preferably about 0.02 to about 7, about 0.03 to about 5, or about 0.05 to about 3 mg/kg body weight. Depending on the severity of the condition, the frequency and the duration of the treatment can be adjusted. Effective dosages and schedules for administering anti-IL-33 antibodies may be determined empirically; for example, patient progress can be monitored by periodic assessment, and the dose adjusted accordingly. Moreover, interspecies scaling of dosages can be performed using well-known methods in the art (*e.g.*, Mordenti *et al.*, 1991, *Pharmaceut. Res. 8*:1351).

[0109] Various delivery systems are known and can be used to administer the pharmaceutical composition of the invention, *e.g.*, encapsulation in liposomes, microparticles, microcapsules, recombinant cells capable of expressing the mutant viruses, receptor mediated endocytosis (see, e.g., Wu et al., 1987, J. Biol. Chem. 262:4429-4432). Methods of introduction include, but are not limited to, intradermal, intramuscular, intraperitoneal, intravenous, subcutaneous, intranasal, epidural, and oral routes. The composition may be administered by any convenient route, for example by infusion or bolus injection, by absorption through epithelial or mucocutaneous linings (e.g., oral mucosa, rectal and intestinal mucosa, etc.) and may be administered together with other biologically active agents. Administration can be systemic or local.

[0110] A pharmaceutical composition of the present invention can be delivered subcutaneously or intravenously with a standard needle and syringe. In addition, with respect to subcutaneous delivery, a pen delivery device readily has applications in delivering a pharmaceutical composition of the present invention. Such a pen delivery device can be reusable or disposable. A reusable pen delivery device generally utilizes a replaceable cartridge that contains a pharmaceutical composition. Once all of the pharmaceutical composition within the cartridge has been administered and the cartridge is empty, the empty cartridge can readily be discarded and replaced with a new cartridge that contains the pharmaceutical composition. The pen delivery device can then be reused. In a disposable pen delivery device, there is no replaceable cartridge. Rather, the disposable pen delivery device comes prefilled with the pharmaceutical composition held in a reservoir within the device. Once the reservoir is emptied of the pharmaceutical composition, the entire device is discarded.

[0111] Numerous reusable pen and autoinjector delivery devices have applications in the subcutaneous delivery of a pharmaceutical composition of the present invention. Examples

include, but are not limited to AUTOPEN™ (Owen Mumford, Inc., Woodstock, UK), DISETRONIC™ pen (Disetronic Medical Systems, Bergdorf, Switzerland), HUMALOG MIX 75/25™ pen, HUMALOG™ pen, HUMALIN 70/30™ pen (Eli Lilly and Co., Indianapolis, IN), NOVOPEN™ I, II and III (Novo Nordisk, Copenhagen, Denmark), NOVOPEN JUNIOR™ (Novo Nordisk, Copenhagen, Denmark), BD™ pen (Becton Dickinson, Franklin Lakes, NJ), OPTIPEN™, OPTIPEN PRO™, OPTIPEN STARLET™, and OPTICLIK™ (sanofi-aventis, Frankfurt, Germany), to name only a few. Examples of disposable pen delivery devices having applications in subcutaneous delivery of a pharmaceutical composition of the present invention include, but are not limited to the SOLOSTAR™ pen (sanofi-aventis), the FLEXPEN™ (Novo Nordisk), and the KWIKPEN™ (Eli Lilly), the SURECLICK™ Autoinjector (Amgen, Thousand Oaks, CA), the PENLET™ (Haselmeier, Stuttgart, Germany), the EPIPEN (Dey, L.P.), and the HUMIRA™ Pen (Abbott Labs, Abbott Park IL), to name only a few.

[0112] In certain situations, the pharmaceutical composition can be delivered in a controlled release system. In one embodiment, a pump may be used (see Langer, supra; Sefton, 1987, CRC Crit. Ref. Biomed. Eng. 14:201). In another embodiment, polymeric materials can be used; see, Medical Applications of Controlled Release, Langer and Wise (eds.), 1974, CRC Pres., Boca Raton, Florida. In yet another embodiment, a controlled release system can be placed in proximity of the composition's target, thus requiring only a fraction of the systemic dose (see, *e.g.*, Goodson, 1984, in Medical Applications of Controlled Release, supra, vol. 2, pp. 115-138). Other controlled release systems are discussed in the review by Langer, 1990, Science 249:1527-1533.

[0113] The injectable preparations may include dosage forms for intravenous, subcutaneous, intracutaneous and intramuscular injections, drip infusions, etc. These injectable preparations may be prepared by methods publicly known. For example, the injectable preparations may be prepared, *e.g.*, by dissolving, suspending or emulsifying the antibody or its salt described above in a sterile aqueous medium or an oily medium conventionally used for injections. As the aqueous medium for injections, there are, for example, physiological saline, an isotonic solution containing glucose and other auxiliary agents, etc., which may be used in combination with an appropriate solubilizing agent such as an alcohol (e.g., ethanol), a polyalcohol (e.g., propylene glycol, polyethylene glycol), a nonionic surfactant [e.g., polysorbate 80, HCO-50 (polyoxyethylene (50 mol) adduct of hydrogenated castor oil)], etc. As the oily medium, there are employed, e.g., sesame oil, soybean oil, etc., which may be used in combination with a solubilizing agent such as benzyl benzoate, benzyl alcohol, etc. The injection thus prepared is preferably filled in an appropriate ampoule.

[0114] Advantageously, the pharmaceutical compositions for oral or parenteral use described above are prepared into dosage forms in a unit dose suited to fit a dose of the active ingredients. Such dosage forms in a unit dose include, for example, tablets, pills, capsules,

injections (ampoules), suppositories, etc. The amount of the aforesaid antibody contained is generally about 5 to about 500 mg per dosage form in a unit dose; especially in the form of injection, it is preferred that the aforesaid antibody is contained in about 5 to about 100 mg and in about 10 to about 250 mg for the other dosage forms.

Therapeutic Uses of the Antibodies

[0115] Experiments using mouse model systems, conducted by the present inventors, have contributed to the identification of various diseases and conditions that can be treated, prevented and/or ameliorated by IL-33 antagonism. For example, hydrodynamic delivery of mouse IL-33 DNA resulted in the induction of lung mucus accumulation and increases in total serum IgE in mice. In addition, mIL-33 DNA delivery resulted in up-regulation of ST2 and various downstream cytokines as measured by microarray analysis. Experiments conducted by the present inventors using IL-33 knock-out mice also revealed various potential therapeutic benefits of IL-33 antagonism. For example, macroscopic scoring and skin infiltrates were found to be comparable between wild-type mice and IL-33$^{-/-}$ mice in a model of IMQ-induced psoriasis. Moreover, IL-33$^{-/-}$ mice showed reduced eosinophilia and residual mucus accumulation in an allergen-induced lung inflammation model.

[0116] The antibodies of the invention are useful, *inter alia*, for the treatment, prevention and/or amelioration of any disease or disorder associated with or mediated by IL-33 expression, signaling, or activity, or treatable by blocking the interaction between IL-33 and a IL-33 ligand (*e.g.*, ST2) or otherwise inhibiting IL-33 activity and/or signaling. For example, the present invention provides methods for treating, asthma (*e.g.*, allergic asthma, non-allergic asthma, severe refractory asthma, asthma exacerbations, steroid resistant asthma, steroid sensitive asthma, eosinophilic asthma or non-eosinophilic asthma, etc.), atopic dermatitis, psoriasis, other inflammatory disorders, allergy, anaphylaxis, cardiovascular disease, central nervous system disease, pain, arthritis (*e.g.*, rheumatoid arthritis, osteoarthritis, psoriatic arthritis, etc.), giant cell arteritis, vasculitis (behcet's disease and Churg Strauss syndrome), Henoch-Schonlein purpura., multiple sclerosis, inflammatory bowel disorder (*e.g.* Crohn's disease or ulcerative colitis), lupus, and sjogren's syndrome.

[0117] The antibodies of the present invention are also useful for the treatment, prevention and/or amelioration of one or more fibrotic diseases. Exemplary fibrotic diseases that are treatable by administering the anti-IL-33 antibodies of the invention include pulmonary fibrosis (*e.g.*, idiopathic pulmonary fibrosis, bleomycin-induced pulmonary fibrosis, asbestos-induced pulmonary fibrosis, and bronchiolitis obliterans syndrome), chronic asthma, fibrosis associated with acute lung injury and acute respiratory distress (*e.g.*, bacterial pneumonia induced fibrosis, trauma induced fibrosis, viral pneumonia induced fibrosis, ventilator induced fibrosis, non-pulmonary sepsis induced fibrosis and aspiration induced fibrosis), silicosis, radiation-induced fibrosis, chronic obstructive pulmonary disease (COPD, which may or may not be related to,

caused in part by, or resulting from, exposure to first or second hand cigarette smoke), scleroderma, ocular fibrosis, skin fibrosis (*e.g.*, scleroderma), hepatic fibrosis (*e.g.*, cirrhosis, alcohol-induced liver fibrosis, non-alcoholic steatohepatitis (NASH), bilary duct injury, primary bilary cirrhosis, infection- or viral-induced liver fibrosis, autoimmune hepatitis, kidney (renal) fibrosis, cardiac fibrosis, atherosclerosis, stent restenosis, and myelofibrosis.

[0118] In the context of the methods of treatment described herein, the anti-IL-33 antibody may be administered as a monotherapy (*i.e.*, as the only therapeutic agent) or in combination with one or more additional therapeutic agents (examples of which are described elsewhere herein).

Combination Therapies and Formulations

[0119] The present invention includes compositions and therapeutic formulations comprising any of the anti-IL-33 antibodies described herein in combination with one or more additional therapeutically active components, and methods of treatment comprising administering such combinations to subjects in need thereof.

[0120] The anti-IL-33 antibodies of the present invention may be co-formulated with and/or administered in combination with, *e.g.*, cytokine inhibitors, including small-molecule cytokine inhibitors and antibodies that bind to cytokines such as IL-1, IL-2, IL-3, IL-4, IL-5, IL-6, IL-8, IL-9, IL-11, IL-12, IL-13, IL-17, IL-18, IL-21, IL-23, IL-25, IL-26, or antagonists of their respective receptors.

[0121] The anti-IL-33 antibodies of the invention may also be administered and/or co-formulated in combination with antivirals, antibiotics, analgesics, corticosteroids, steroids, oxygen, antioxidants, metal chelators, IFN-gamma, and/or NSAIDs.

[0122] The additional therapeutically active component(s) may be administered just prior to, concurrent with, or shortly after the administration of an anti-IL-33 antibody of the present invention; (for purposes of the present disclosure, such administration regimens are considered the administration of an anti-IL-33 antibody "in combination with" an additional therapeutically active component). The present invention includes pharmaceutical compositions in which an anti-IL-33 antibody of the present invention is co-formulated with one or more of the additional therapeutically active component(s) as described elsewhere herein.

Administration Regimens

[0123] According to certain embodiments of the present invention, multiple doses of an anti-IL-33 antibody (or a pharmaceutical composition comprising a combination of an anti-IL-33 antibody and any of the additional therapeutically active agents mentioned herein) may be administered to a subject over a defined time course. The methods according to this aspect of the invention comprise sequentially administering to a subject multiple doses of an anti-IL-33

antibody of the invention. As used herein, "sequentially administering" means that each dose of anti-IL-33 antibody is administered to the subject at a different point in time, *e.g.*, on different days separated by a predetermined interval (*e.g.*, hours, days, weeks or months). The present invention includes methods which comprise sequentially administering to the patient a single initial dose of an anti-IL-33 antibody, followed by one or more secondary doses of the anti-IL-33 antibody, and optionally followed by one or more tertiary doses of the anti-IL-33 antibody.

[0124] The terms "initial dose," "secondary doses," and "tertiary doses," refer to the temporal sequence of administration of the anti-IL-33 antibody of the invention. Thus, the "initial dose" is the dose which is administered at the beginning of the treatment regimen (also referred to as the "baseline dose"); the "secondary doses" are the doses which are administered after the initial dose; and the "tertiary doses" are the doses which are administered after the secondary doses. The initial, secondary, and tertiary doses may all contain the same amount of anti-IL-33 antibody, but generally may differ from one another in terms of frequency of administration. In certain embodiments, however, the amount of anti-IL-33 antibody contained in the initial, secondary and/or tertiary doses varies from one another (*e.g.*, adjusted up or down as appropriate) during the course of treatment. In certain embodiments, two or more (*e.g.*, 2, 3, 4, or 5) doses are administered at the beginning of the treatment regimen as "loading doses" followed by subsequent doses that are administered on a less frequent basis (*e.g.*, "maintenance doses").

[0125] In certain exemplary embodiments of the present invention, each secondary and/or tertiary dose is administered 1 to 26 (*e.g.*, 1, 1½, 2, 2½, 3, 3½, 4, 4½, 5, 5½, 6, 6½, 7, 7½, 8, 8½, 9, 9½, 10, 10½, 11, 11½, 12, 12½, 13, 13½, 14, 14½, 15, 15½, 16, 16½, 17, 17½, 18, 18½, 19, 19½, 20, 20½, 21, 21½, 22, 22½, 23, 23½, 24, 24½, 25, 25½, 26, 26½, or more) weeks after the immediately preceding dose. The phrase "the immediately preceding dose," as used herein, means, in a sequence of multiple administrations, the dose of anti-IL-33 antibody which is administered to a patient prior to the administration of the very next dose in the sequence with no intervening doses.

[0126] The methods according to this aspect of the invention may comprise administering to a patient any number of secondary and/or tertiary doses of an anti-IL-33 antibody. For example, in certain embodiments, only a single secondary dose is administered to the patient. In other embodiments, two or more (*e.g.*, 2, 3, 4, 5, 6, 7, 8, or more) secondary doses are administered to the patient. Likewise, in certain embodiments, only a single tertiary dose is administered to the patient. In other embodiments, two or more (*e.g.*, 2, 3, 4, 5, 6, 7, 8, or more) tertiary doses are administered to the patient.

[0127] In embodiments involving multiple secondary doses, each secondary dose may be administered at the same frequency as the other secondary doses. For example, each secondary dose may be administered to the patient 1 to 2 weeks or 1 to 2 months after the

immediately preceding dose. Similarly, in embodiments involving multiple tertiary doses, each tertiary dose may be administered at the same frequency as the other tertiary doses. For example, each tertiary dose may be administered to the patient 2 to 12 weeks after the immediately preceding dose. In certain embodiments of the invention, the frequency at which the secondary and/or tertiary doses are administered to a patient can vary over the course of the treatment regimen. The frequency of administration may also be adjusted during the course of treatment by a physician depending on the needs of the individual patient following clinical examination.

[0128] The present invention includes administration regimens in which 2 to 6 loading doses are administered to a patient a first frequency (*e.g.*, once a week, once every two weeks, once every three weeks, once a month, once every two months, etc.), followed by administration of two or more maintenance doses to the patient on a less frequent basis. For example, according to this aspect of the invention, if the loading doses are administered at a frequency of once a month, then the maintenance doses may be administered to the patient once every six weeks, once every two months, once every three months, etc.).

Diagnostic Uses of the Antibodies

[0129] The anti-IL-33 antibodies of the present invention may also be used to detect and/or measure IL-33, or IL-33-expressing cells in a sample, *e.g.*, for diagnostic purposes. For example, an anti-IL-33 antibody, or fragment thereof, may be used to diagnose a condition or disease characterized by aberrant expression (*e.g.*, over-expression, under-expression, lack of expression, etc.) of IL-33. Exemplary diagnostic assays for IL-33 may comprise, *e.g.*, contacting a sample, obtained from a patient, with an anti-IL-33 antibody of the invention, wherein the anti-IL-33 antibody is labeled with a detectable label or reporter molecule. Alternatively, an unlabeled anti-IL-33 antibody can be used in diagnostic applications in combination with a secondary antibody which is itself detectably labeled. The detectable label or reporter molecule can be a radioisotope, such as ^{3}H, ^{14}C, ^{32}P, ^{35}S, or ^{125}I; a fluorescent or chemiluminescent moiety such as fluorescein isothiocyanate, or rhodamine; or an enzyme such as alkaline phosphatase, beta-galactosidase, horseradish peroxidase, or luciferase. Specific exemplary assays that can be used to detect or
measure IL-33 in a sample include enzyme-linked immunosorbent assay (ELISA), radioimmunoassay (RIA), and fluorescence-activated cell sorting (FACS).

[0130] Samples that can be used in IL-33 diagnostic assays according to the present invention include any tissue or fluid sample obtainable from a patient which contains detectable quantities of IL-33 protein, or fragments thereof, under normal or pathological conditions. Generally, levels of IL-33 in a particular sample obtained from a healthy patient (*e.g.*, a patient not afflicted with a disease or condition associated with abnormal IL-33 levels or activity) will be measured to initially establish a baseline, or standard, level of IL-33. This baseline level of IL-33 can then be

compared against the levels of IL-33 measured in samples obtained from individuals suspected of having a IL-33 related disease or condition.

EXAMPLES

[0131] The following examples are put forth so as to provide those of ordinary skill in the art with a complete disclosure and description of how to make and use the methods and compositions of the invention, and are not intended to limit the scope of what the inventors regard as their invention. Efforts have been made to ensure accuracy with respect to numbers used (e.g., amounts, temperature, etc.) but some experimental errors and deviations should be accounted for. Unless indicated otherwise, parts are parts by weight, molecular weight is average molecular weight, temperature is in degrees Centigrade, and pressure is at or near atmospheric.

Example 1. Generation of Human Antibodies to human IL-33

[0132] An immunogen comprising human IL-33 was administered directly, with an adjuvant to stimulate the immune response, to a VELOCIMMUNE® mouse comprising DNA encoding human Immunoglobulin heavy and kappa light chain variable regions. The antibody immune response was monitored by an IL-33-specific immunoassay. When a desired immune response was achieved splenocytes were harvested and fused with mouse myeloma cells to preserve their viability and form hybridoma cell lines. The hybridoma cell lines were screened and selected to identify cell lines that produce IL-33-specific antibodies. Using this technique several anti-IL-33 chimeric antibodies (*i.e.*, antibodies possessing human variable domains and mouse constant domains) were obtained; exemplary antibodies generated in this manner were designated as follows: H1M9559N, H1M9566N, H1M9568N and H1M9565N. The human variable domains from the chimeric antibodies were subsequently cloned onto human constant domains to make fully human anti-IL-33 antibodies as described herein.

[0133] Anti-IL-33 antibodies were also isolated directly from antigen-positive B cells without fusion to myeloma cells, as described in US 2007/0280945A1. Using this method, several fully human anti-IL-33 antibodies (*i.e.*, antibodies possessing human variable domains and human constant domains) were obtained; exemplary antibodies generated in this manner were designated as follows: H4H9629P, H4H9633P, H4H6940P, H4H9659P, H4H9660P, H4H9662P, H4H9663P, H4H9664P, H4H9665P, H4H9666P, H4H9667P, H4H9670P, H4H9671P, H4H9672P, H4H9675P, and H4H9676P.

[0134] Certain biological properties of the exemplary anti-IL-33 antibodies generated in accordance with the methods of this Example are described in detail in the Examples set forth below.

Example 2. Heavy and Light Chain Variable Region Amino Acid Sequences

[0135] Table 1 sets forth the heavy and light chain variable region amino acid sequence pairs, and CDR sequences, of selected anti-IL-33 antibodies and their corresponding antibody identifiers.

Table 1

	SEQ ID NOs:							
Antibody Designation	**HCVR**	**HCDR1**	**HCDR2**	**HCDR3**	**LCVR**	**LCDR1**	**LCDR2**	**LCDR3**
9559N	2	4	6	8	10	12	14	16
9566N	18	20	22	24	26	28	30	32
9568N	34	36	38	40	42	44	46	48
9629P	50	52	54	56	58	60	62	64
9633P	66	68	70	72	74	76	78	80
9640P	82	84	86	88	90	92	94	96
9659P	98	100	102	104	106	108	110	112
9660P	114	116	118	120	122	124	126	128
9662P	130	132	134	136	138	140	142	144
9663P	146	148	150	152	154	156	158	160
9664P	162	164	166	168	170	172	174	176
9665P	178	180	182	184	186	188	190	192
9666P	194	196	198	200	202	204	206	208
9667P	210	212	214	216	218	220	222	224
9670P	226	228	230	232	234	236	238	240
9671P	242	244	246	248	250	252	254	256
9672P	258	260	262	264	266	268	270	272
9675P	274	276	278	280	282	284	286	288
9676P	290	292	294	296	298	300	302	304
9565N	308	310	312	314	316	318	320	322

[0136] Antibodies are typically referred to herein according to the following nomenclature: Fc prefix (*e.g.* "H1M," or "H4H"), followed by a numerical identifier (*e.g.* "9559," "9566," or "9629" as shown in Table 1), followed by a "P," or "N" suffix. Thus, according to this nomenclature, an antibody may be referred to herein as, *e.g.*, "H1M9559N," "H1M9566N," "H4H9629P," etc. The H1M and H4H prefixes on the antibody designations used herein indicate the particular Fc region isotype of the antibody. For example, an "H1M" antibody has a mouse IgG1 Fc, whereas an "H4H" antibody has a human IgG4 Fc. As will be appreciated by a person of ordinary skill in the art, an antibody having a particular Fc isotype can be converted to an antibody with a different Fc isotype (*e.g.*, an antibody with a mouse IgG1 Fc can be converted to an antibody with a human IgG4, etc.), but in any event, the variable domains (including the CDRs) – which are indicated by the numerical identifiers shown in Table 1 – will remain the same, and the binding properties are expected to be identical or substantially similar regardless of the nature of the Fc domain.

Example 3. Antibody Binding to Human IL-33 as Determined by Surface Plasmon Resonance

[0137] Equilibrium dissociation constants (K_D values) for IL-33 binding to purified anti-IL-33 monoclonal antibodies were determined using a real-time surface plasmon resonance biosensor using a Biacore 4000 instrument. The Biacore sensor surface was first derivatized by amine coupling with either a polyclonal rabbit anti-mouse antibody (GE, # BR-1008-38) or with a monoclonal mouse anti-human Fc antibody (GE, # BR-1008-39) to capture anti-IL-33 monoclonal antibodies expressed with mouse or with human IgG4 constant regions, respectively. All Biacore binding studies were performed in 0.01M ADA pH 7.4, 0.15M NaCl, 3mM EDTA, and 0.05% v/v Surfactant Tween-20 (ABS-ET running buffer). Different concentrations of human IL-33 (hIL-33; R&D Systems, # 3625-IL-010/CF) or cynomolgus monkey IL-33 expressed with a C-terminal hexahistidine tag (MfIL-33-6His; SEQ ID NO:305 prepared in ABS-ET running buffer (ranging from 100nM to 3.7nM, 3-fold dilutions) were injected over the anti-IL-33 monoclonal antibody captured surface at a flow rate of 30µL/minute. Association of either hIL-33 or MfIL-33-6His to the captured monoclonal antibody was monitored for 4 minutes and their dissociation in ABS-ET running buffer was monitored for 10 minutes. The effect of reduced pH on the binding of each anti-IL-33 antibody to either hIL-33 or MfIL-33-6His was studied using an in-line pH chase assay format in 0.01M ADA pH 6.0, 0.15M NaCl, 3mM EDTA, and 0.05% v/v Surfactant Tween-20 (ABS-ET pH6 buffer). To achieve this, association of either hIL-33 or MfIL-33-6His to the captured monoclonal antibody was monitored for 4 minutes in ABS-ET running buffer. Following a 30 second dissociation of either hIL-33 or MfIL-33-6His in ABS-ET running buffer, ABS-ET pH6 buffer was injected for 3 minutes, and the analyte dissociation under the low-pH conditions was measured. All the binding kinetic experiments were performed at both 25°C and 37°C. Kinetic association (k_a) and dissociation (k_d) constants were determined by fitting the real-time sensorgrams to a 1:1 binding model using Scrubber 2.0c curve fitting software. Binding dissociation equilibrium constants (K_D) and dissociative half-lives ($t_{½}$) were calculated from the kinetic rate constants as:

[0138] K_D (M) = k_d/k_a and $t_{1/2}$ (min) = $\ln(2)/(60*k_d)$

[0139] Binding kinetic parameters for hl L-33 and Mfl L-33-6His binding to different anti-IL-33 monoclonal antibodies at 25°C and 37°C are shown in Tables 2 through 5. At 25°C, hl L-33 bound to the anti-I L-33 antibodies with K_D values ranging from 78pM to 757pM, as shown in Table 2. At 37°C, hl L-33 bound to the anti-I L-33 antibodies with K_D values ranging from 411pM to 2.03nM, as shown in Table 3. At both 25°C and 37°C, one anti-I L-33 antibody demonstrated weak binding and therefore its binding kinetic parameters could not be fit using an 1:1 binding model. At 25°C, Mfl L-33-6His bound to the anti-I L-33 antibodies with K_D values ranging from 333pM to 38nM, as shown in Table 4. At 37°C, Mfl L-33-6His bound to the anti-I L-33 antibodies

with K_D values ranging from 1nM to 48.6nM, as shown in Table 55.

Table 2: Binding kinetic parameters of anti-IL-33 monoclonal antibodies binding to human IL-33 at 25°C.

	Human IL-33 Binding Kinetics in ABS-ET Running Buffer				In-Line Chase in ABS-ET pH6 Buffer		
Antibody Captured	**k_a (1/Ms)**	**k_d (1/s)**	**K_D (M)**	**t½ (min)**	**k_d (1/s)**	**t½ (min)**	**t½ Ratio (pH7.4/ pH6.0)**
H4H9675P	1.02E+06	2.58E-04	2.54E-10	45	1.11E-03	10	4.3
H4H9662P	8.11E+05	2.50E-04	3.08E-10	46	8.26E-04	14	3.3
H4H9640P	9.12E+05	2.37E-04	2.60E-10	49	6.57E-04	18	2.8
H4H9629P	7.77E+05	2.26E-04	2.90E-10	51	1.28E-03	9	5.7
H4H9659P	5.26E+05	1.72E-04	3.27E-10	67	6.64E-04	17	3.9
H4H9660P	6.96E+05	2.24E-04	3.22E-10	52	7.08E-04	16	3.2
H4H9667P	6.37E+05	2.52E-04	3.95E-10	46	5.66E-04	20	2.2
H4H9670P	7.86E+05	2.89E-04	3.68E-10	40	8.25E-04	14	2.9
H4H9663P	1.36E+06	4.14E-04	3.05E-10	28	1.10E-03	11	2.7
H4H9666P	5.08E+05	2.80E-04	5.51E-10	41	1.34E-03	9	4.8
H4H9676P	1.03E+06	3.45E-04	3.34E-10	33	1.21E-03	10	3.5
H4H9633P	6.56E+05	2.83E-04	4.32E-10	41	8.10E-04	14	2.9
H4H9671P	7.71E+05	3.49E-04	4.53E-10	33	1.62E-03	7	4.6
H4H9672P	6.68E+05	3.52E-04	5.27E-10	33	1.41E-03	8	4.0
H4H9665P	8.88E+05	4.74E-04	5.33E-10	24	2.12E-03	5	4.5
H4H9664P	3.39E+05	2.57E-04	7.57E-10	45	8.23E-04	14	3.2
H1M9568N	7.02E+05	1.30E-04	1.84E-10	89	1.78E-04	65	1.4
H1M9566N	1.27E+05	1.00E-05**	7.88E-11**	1155**	1.10E-04	105	11.0
H1M9559N	4.04E+05	2.74E-04	6.78E-10	42	1.87E-04	62	0.7
H1M9565N	IC*	IC*	IC*	IC*	IC*	IC*	IC*

***IC**: inconclusive since very weak binding was observed under the experimental conditions and the real-time binding data could not be reliably fit into the 1:1 binding model.

** Under the experimental conditions no dissociation of IL33 from the captured monoclonal antibody was observed' therefore the value of k_d was fixed to 1.00E-05, and the derived t½ and K_D values represent lower and upper limits, respectively.

Table 3: Binding kinetic parameters of anti-IL-33 monoclonal antibodies binding to human IL-33 at 37°C.

	Human IL-33 Binding Kinetics in ABS-ET Running Buffer				In-Line Chase in ABS-ET pH6 Buffer		
Antibody Captured	**k_a (1/Ms)**	**k_d (1/s)**	**K_D (M)**	**t½ (min)**	**k_d (1/s)**	**t½ (min)**	**t½ Ratio (pH7.4/ pH6.0)**
H4H9675P	2.12E+06	8.72E-04	4.11E-10	13	4.63E-03	2	5.3
H4H9662P	1.40E+06	6.20E-04	4.43E-10	19	3.83E-03	3	6.2

H4H9640P	1.15E+06	5.73E-04	4.98E-10	20	2.65E-03	4	4.6
H4H9629P	1.27E+06	6.46E-04	5.08E-10	18	5.82E-03	2	9.0
H4H9659P	7.07E+05	4.03E-04	5.70E-10	29	2.99E-03	4	7.4
H4H9660P	8.03E+05	4.79E-04	5.96E-10	24	3.23E-03	4	6.8
H4H9667P	9.76E+05	6.03E-04	6.18E-10	19	2.44E-03	5	4.0
H4H9670P	1.16E+06	7.83E-04	6.76E-10	15	3.83E-03	3	4.9
H4H9663P	1.83E+06	1.24E-03	6.77E-10	9	4.62E-03	3	3.7
H4H9666P	1.13E+06	7.70E-04	6.81E-10	15	6.80E-03	2	8.8
H4H9676P	1.38E+06	1.28E-03	9.22E-10	9	5.24E-03	2	4.1
H4H9633P	7.40E+05	6.89E-04	9.31E-10	17	2.40E-03	5	3.5
H4H9671P	1.21E+06	1.14E-03	9.38E-10	10	5.85E-03	2	5.1
H4H9672P	1.09E+06	1.15E-03	1.05E-09	10	5.41E-03	2	4.7
H4H9665P	1.21E+06	1.44E-03	1.19E-09	8	9.65E-03	1	6.7
H4H9664P	5.19E+05	7.21E-04	1.39E-09	16	2.79E-03	4	3.9
H1M9568N	6.72E+05	9.61E-04	1.43E-09	12	1.10E-03	10	1.1
H1M9566N	1.66E+05	2.83E-04	1.70E-09	41	9.67E-04	12	3.4
H1M9559N	4.73E+05	9.62E-04	2.03E-09	12	9.92E-04	12	1.0
H1M9565N	IC*	IC*	IC*	IC*	IC*	IC*	IC*

***IC**: inconclusive since very weak binding was observed under the experimental conditions and the real-time binding data could not be reliably fit into the 1:1 binding model.

Table 4: Binding kinetic parameters of anti-IL-33 monoclonal antibodies binding to MfIL-33-6His at 25°C.

	MfIL-33-6His Binding Kinetics in ABS-ET Running Buffer				**In-Line Chase in ABS-ET pH6 Buffer**		
Antibody Captured	**k_a (1/Ms)**	**k_d (1/s)**	**K_D (M)**	**t½ (min)**	**k_d (1/s)**	**t½ (min)**	**t½ Ratio (pH7.4/ pH6.0)**
H4H9675P	5.06E+05	1.29E-03	2.55E-09	9	1.56E-03	7	1.2
H4H9662P	3.53E+05	4.42E-04	1.25E-09	26	1.17E-04	99	0.3
H4H9640P	4.50E+05	1.37E-03	3.06E-09	8	5.01E-04	23	0.4
H4H9629P	5.62E+05	1.35E-02	2.39E-08	0.9	3.58E-02	0.3	2.7
H4H9659P	3.25E+05	4.86E-04	1.50E-09	24	1.23E-04	94	0.3
H4H9660P	4.26E+05	1.49E-03	3.49E-09	8	1.08E-03	11	0.7
H4H9667P	3.43E+05	9.91E-04	2.89E-09	12	6.96E-04	17	0.7
H4H9670P	4.40E+05	2.10E-03	4.77E-09	6	3.93E-04	29	0.2
H4H9663P	8.69E+05	9.25E-04	1.06E-09	12	6.83E-04	17	0.7
H4H9666P	2.22E+05	3.54E-03	1.59E-08	3.3	8.09E-03	1.4	2.3
H4H9676P	8.52E+05	4.12E-03	4.84E-09	2.8	1.45E-03	8	0.4
H4H9633P	2.62E+05	9.97E-03	3.80E-08	1.2	2.87E-03	4	0.3
H4H9671P	5.87E+05	1.50E-03	2.55E-09	8	1.61E-03	7	1.1
H4H9672P	4.37E+05	3.60E-03	8.22E-09	3.2	2.67E-03	4	0.7
H4H9665P	5.57E+05	5.66E-04	1.02E-09	20	7.53E-04	15	1.3
H4H9664P	1.40E+05	1.65E-03	1.18E-08	7	4.80E-04	24	0.3
H1M9568N	2.44E+05	2.61E-04	1.07E-09	44	3.02E-04	38	1.2
H1M9566N	2.93E+05	9.75E-05	3.33E-10	119	1.26E-04	91	1.3
H1M9559N	3.21E+05	1.23E-03	3.82E-09	9	1.52E-03	8	1.2
H1M9565N	4.06E+04	7.20E-05	1.77E-09	160	1.43E-04	81	2.0

Table 5: Binding kinetic parameters of anti-IL-33 monoclonal antibodies binding to MfIL-33-6His at 37°C.

	MfIL-33-6His Binding Kinetics in ABS-ET Running Buffer				In-Line Chase in ABS-ET pH6 Buffer		
Antibody Captured	**k_a (1/Ms)**	**k_d (1/s)**	**K_D (M)**	**t½ (min)**	**k_d (1/s)**	**t½ (min)**	**t½ Ratio (pH7.4/ pH6.0)**
H4H9675P	1.02E+06	4.91E-03	4.81E-09	2.4	7.35E-03	1.6	1.5
H4H9662P	7.07E+05	1.58E-03	2.24E-09	7	1.68E-03	7	1.1
H4H9640P	8.10E+05	4.36E-03	5.38E-09	2.6	2.26E-03	5	0.5
H4H9629P	1.07E+06	3.47E-02	3.24E-08	0.3	FT*	FT*	FT*
H4H9659P	5.98E+05	1.86E-03	3.11E-09	6	1.02E-03	11	0.5
H4H9660P	6.80E+05	4.44E-03	6.53E-09	2.6	4.63E-03	2.5	1.0
H4H9667P	6.81E+05	3.17E-03	4.66E-09	4	2.68E-03	4	0.8
H4H9670P	7.35E+05	5.03E-03	6.84E-09	2.3	1.65E-03	7	0.3
H4H9663P	1.62E+06	3.61E-03	2.22E-09	3.2	3.54E-03	3.3	1.0
H4H9666P	4.32E+05	1.41E-02	3.27E-08	0.8	FT*	FT*	FT*
H4H9676P	1.87E+06	1.44E-02	7.70E-09	0.8	FT*	FT*	FT*
H4H9633P	4.68E+05	2.27E-02	4.86E-08	0.5	FT*	FT*	FT*
H4H9671P	1.20E+06	6.07E-03	5.08E-09	1.9	8.19E-03	1.4	1.3
H4H9672P	9.46E+05	1.30E-02	1.37E-08	0.9	FT*	FT*	FT*
H4H9665P	1.10E+06	2.10E-03	1.91E-09	5	4.00E-03	2.9	1.9
H4H9664P	3.61E+05	5.84E-03	1.62E-08	2.0	1.93E-03	6	0.3
H1M9568N	3.89E+05	1.73E-03	4.46E-09	7	2.24E-03	5	1.3
H1M9566N	3.99E+05	4.00E-04	1.00E-09	29	1.15E-03	10	2.9
H1M9559N	4.93E+05	3.47E-03	7.04E-09	3.3	3.07E-03	4	0.9
H1M9565N	7.82E+04	2.02E-04	2.59E-09	57	2.28E-04	51	1.1

*FT: fast t½ such that MfIL-33-6His bound to the captured anti-IL-33 monoclonal antibody was

Example 4. Anti-IL-33 Antibodies Block Binding of IL-33 to the Human ST2 Receptor

[0140] The ability of anti-IL-33 antibodies to block either human IL-33 (hIL-33) or cynomologus monkey IL-33 binding to the human ST2 receptor was measured using a competition sandwich ELISA. A portion of human ST2 protein ecto domain that was expressed with a C-terminal human IgG1 Fc tag (hST2-hFc; SEQ ID NO:306), was coated at a concentration of 1 μg/mL in PBS buffer on a 96-well microtiter plate overnight at 4°C. Nonspecific binding sites were subsequently blocked using a 0.5% (w/v) solution of BSA in PBS. Constant concentrations of either 30 pM biotinylated hIL-33 protein (R&D systems, Cat #3625-IL/CF) (biotin-hIL-33) or 150 pM cynomologus monkey IL-33 expressed with hexahistidine tag (MfIL-33-6His; SEQ ID NO:305) were separately added to serial dilutions of antibodies so that the final concentrations of antibodies ranged from 0 to 100 nM. The antibody/IL-33 mixtures were incubated for 1 hour at room temperature before they were transferred to the hST2-hFc-coated microtiter plates. After incubating for 1 hour at room temperature, the wells were then washed, and plate-bound

biotin-hIL-33 was detected with streptavidin conjugated with horse-radish peroxidase (HRP) (Thermo Scientific, Cat # N200), and plate-bound MfIL-33-6His was detected with a HRP conjugated anti-His monoclonal antibody (Qiagen, #34460). All samples were developed with a TMB solution (BD biosciences, # 51-2607KC) to produce a colorimetric reaction and then quenched by acidification with 1M sulfuric acid before measuring absorbance at 450nm on a Victor X5 plate reader. Data analysis was performed using a sigmoidal dose-response model within Prism™ software. The calculated IC_{50} value, defined as the concentration of antibody required to reduce by 50% from maximal signal the biotin-hIL-33 or MfIL-33-6His binding to plate-coated hST2-hFc, was used as an indicator of blocking potency. Percent blockade was calculated as the ratio of the reduction in signal observed in the presence of antibody relative to the difference between the signal with IL-33 alone and background (signal from HRP-conjugated secondary antibody or streptavidin alone). The absorbance measured for the constant concentration of biotin-hIL-33 or MfIL-33-6His alone is defined as 0% blocking and the absorbance measured for no added IL-33 is defined as 100% blocking. The absorbance values of the wells containing the highest concentration for each antibody were used to determine the percent maximum blocking.

Table 6: ELISA blocking of biotin-hIL-33 or MfIL-33-6His binding to hST2-hFc by anti-IL-33 antibodies

Ab ID	Blocking 30pM biotin-hIL-33 on hST2-hFc, IC_{50} (M)	% Maximum blocking biotin-hIL-33 on hST2-hFc	Blocking 150pM Mf-IL-33-6His on hST2-hFc, IC_{50} (M)	% Maximum blocking Mf-IL-33-6His on hST2-hFc
H1M9559N*	1.4E-10	88	1.0E-08	53
H1M9566N*	3.2E-10	69	2.2E-10	41
H1M9565N*	2.2E-08	68	1.2E-08	86
H1M9568N*	1.9E-10	55	8.4E-10	38
H4H9629P	4.5E-10	80	N/A	NBI
H4H9633P	4.4E-10	66	N/A	NBI
H4H9640P	3.5E-10	78	3.5E-09	73
H4H9659P	4.0E-10	78	6.0E-10	92
H4H9660P	3.1E-10	57	4.2E-09	68
H4H9662P	1.0E-09	77	8.6E-10	87
H4H9663P	5.0E-10	74	1.2E-09	81
H4H9664P	3.0E-10	73	3.8E-09	67
H4H9665P	8.7E-10	55	4.2E-10	81
H4H9666P	6.0E-10	71	1.3E-08	40
H4H9667P	4.1E-10	78	4.1E-09	72
H4H9670P	4.8E-10	69	3.5E-09	69
H4H9671P	4.6E-10	46	5.8E-10	62

H4H9672P	4.4E-10	63	5.5E-09	48
H4H9675P	4.4E-10	58	1.5E-09	72
H4H9676P	4.6E-10	54	3.2E-09	57

N/A= not applicable
NBI= non-blocker
*= Experiment performed on a separate day

[0141] Binding experiments for 20 antibodies were performed on two separate days, as indicated in Table 6. All 20 of the anti-IL-33 antibodies blocked biotin-hIL-33 binding to hST2-hFc with IC_{50} values ranging from 140pM to 22nM and percent maximum blocking ranging from 46% to 88%. Eighteen of the 20 anti-IL-33 antibodies blocked MfIL-33-6His binding to hST2-hFc with IC_{50} values ranging from 220pM to 13nM and percent maximum blocking ranging from 38% to 92%, as shown in Table 6. Two of the antibodies tested, H4H9629P and H4H9633P, did not demonstrate measurable blockade of MfIL-33-6His binding to hST2-hFc.

Example 5. Inhibition of IL-33 binding to anti-IL-33 monoclonal antibody by ST2 as shown by Biacore Analysis

[0142] The ability of anti-IL-33 antibodies to bind to a pre-formed complex of IL-33 with ST2 was tested using Biacore T-200 instrument equipped with a real-time surface plasmon resonance biosensor. The experiment was performed at 25°C with a running buffer composed of 0.01M HEPES pH 7.4, 0.15M NaCl, 3mM EDTA, and 0.05% v/v Surfactant Tween-20 (HBS-ET). The Biacore sensor surface was first derivatized by amine coupling an anti-myc tag-specific monoclonal antibody (Clone# 9E10), and on this derivatized sensor was captured approximately 160 response units (RU) of human ST2 protein expressed with a C-terminal myc-myc-hexahistadine tag (hST2-MMH; SEQ ID NO: 323**).** The captured hST2-MMH surface was then saturated by injecting 100nM of human IL-33 (hIL-33; R&D Systems, # 3625-IL-010/CF) for 3 minutes followed by a 3 minute injection of a 100nM solution of the anti-IL-33 monoclonal antibody. The real-time binding response was monitored during the entire course of the experiment, and the observed binding response at 3 minutes after injection of anti-IL-33 antibody to the pre-formed complex of hIL-33 and captured hST2-MMH was recorded and tabulated and shown in Table 7. No non-specific binding of anti-IL-33 monoclonal antibody to the anti-myc tag capture surface was observed. As shown in Table 7, 17 of the tested antibodies did not show measurable binding to hIL-33 after it was pre-complexed with hST2-MMH, while three antibodies (H1M9565N, H1M9566N, and H1M9568N) bound to hIL-33 after it was pre-complexed with hST2-MMH.

Table 7: Binding of anti-IL-33 antibodies to a pre-formed complex of hIL-33 and hST2-MMH

Antibody	Antibody Binding Response (RU)
H4H9629P	-1
H4H9633P	-1
H4H9640P	-1
H4H9659P	-1
H4H9660P	-1
H4H9662P	0
H4H9663P	-1
H4H9664P	-1
H4H9665P	0
H4H9666P	-1
H4H9667P	-1
H4H9670P	-1
H4H9671P	-1
H4H9672P	-1
H4H9675P	-1
H4H9676P	-1
H1M9559N	-4
H1M9565N	11
H1M9566N	13
H1M9568N	131

Example 6. Inhibition of IL-33-Mediated Receptor Signaling by Anti-IL-33 Antibodies

[0143] Interleukin-33 (IL-33) is a ligand for ST2, a toll-like/interleukin-1 receptor super-family member that associates with an accessory protein, IL-1RAcP (for review, see Kakkar and Lee, 2008). Upon activation of ST2/ IL-1RAcP by IL-33, a signaling cascade is triggered through downstream molecules such as MyD88 (myeloid differentiation factor 88) and TRAF6 (TNF receptor associated factor 6), leading to activation of NFκB (nuclear factor –κB), among others. To develop a biologically relevant bioassay system to test anti-IL-33 antibodies, human embryonic kidney cells (HEK293) were stably transfected to express human ST2 (amino acids 1-556 of accession number NP_057316) along with a luciferase reporter [NFκB response element (5x)-luciferase-IRES-GFP] (HEK293/hST2/NFkB-luciferase cell line). The HEK293 cell line expresses IL-1RAcP endogenously and NFκB activation by IL-33 in HEK293 cells has been shown previously (Schmitz *et al.*, *Immunity 23*:479-490 (2005)). The stable cell line was isolated and maintained in 10% FBS, DMEM, NEAA, penicillin/streptomycin, and G418.

[0144] For the bioassay, HEK293/hST2/NFkB-luciferase cells were seeded onto 96-well assay plates at 10,000 cells per well in low serum media containing 0.1% w/v FBS and OPTIMEM (Invitrogen, #31985-070) and then incubated at 37°C in 5% CO_2 overnight. The next day, to determine the dose response of IL-33, either human IL-33 (hIL-33; R&D Systems, #3625-IL) or cynomolgus monkey IL-33 expressed with a C-terminal hexahistidine tag (MfIL-33-6His; SEQ ID NO:305) were serially diluted at 1:3 and added to the cells starting from 10 nM and ranging down to 0.0002 nM, plus a control sample containing no IL-33. To measure inhibition, antibodies were serially diluted and added to the cells followed by addition of constant concentrations of IL-33 (10 pM hIL-33 for the human assay and 5 pM MfIL-33-6His for the monkey assay). Three-fold antibody serial dilutions were performed before adding to the cells, starting from 100 pM and ranging down to 0.002 nM or starting from 10 nM and ranging down to 0.0002 nM. In addition to the antibody dilution series, a well containing the constant concentration of IL-33 but without any antibody was also included. After 5.5 hours of incubation at 37°C in 5% CO_2, luciferase activity was detected using a Victor X (Perkin Elmer) plate reader, and the results were analyzed using nonlinear regression (4-parameter logistics) with Prism 5. Results are shown in Table 8.

Table 8: Inhibition of human IL-33 and monkey IL-33 activation of HEK293/hST2/NFkB-luciferase cells by anti-IL33 antibodies

Species	**Human**				**Monkey**		
EC_{50} [M]	**2.2E-12**		**3.5E-12**	**2.4E-11**	**8.2E-13**		**3.5E-12**
Constant IL-33	**10pM hIL-33**				**5pM MfIL-33-6His**		
AbPID	**IC_{50} [M]**	**Notes**	**IC_{50} [M]**	**IC_{50} [M]**	**IC_{50} [M]**	**Notes**	**IC_{50} [M]**
H1M9559N	2.0E-09				4.9E-08		
H1M9566N	9.5E-10	Partial Inhibition (Max at 66%)			1.5E-09	Partial Inhibition (Max at 61%)	
H1M9565N	2.9E-08				1.7E-08		
H1M9568N	2.5E-10	Partial Inhibition (Max at 48%)			3.5E-09	Partial Inhibition (Max at 34%)	
H4H9629P				1.3E-11			5.5E-08
H4H9633P			2.2E-10				1.3E-07
H4H9640P			3.0E-11				1.4E-08
H4H9659P			4.7E-11				3.3E-09
H4H9660P			3.5E-11				1.9E-08
H4H9662P				2.0E-11			1.5E-09
H4H9663P			1.3E-10				2.7E-09
H4H9664P			5.0E-11				2.6E-08

H4H9665P			9.0E-11				6.6E-10
H4H9666P			3.5E-11				7.8E-08
H4H9667P			7.1E-11				1.2E-08
H4H9670P			1.2E-10				1.7E-08
H4H9671P				2.5E-11			4.8E-09
H4H9672P			2.5E-11				2.0E-08
H4H9675P				7.5E-12			4.1E-09
H4H9676P			3.5E-11				8.4E-09

[0145] Eighteen of the 20 anti-IL33 antibodies blocked human IL-33 stimulation of the HEK293/hST2/NFkB-luciferase cells with IC_{50} values ranging from 7.5pM to 29nM, as shown in Table 8. Two of the antibodies tested, H1 M9566N and H1 M9568N, partially inhibited hlL-33 with a maximum inhibition of 48% and 66%, with IC_{50} values of 950 pM and 250 pM, respectively. Eighteen of the 20 anti-IL33 antibodies blocked MflL-33-6His stimulation of HEK293/hST2/NFkB-luciferase cells with IC_{50} values ranging from 660pM to 130nM as shown in Table 8. Two of the antibodies tested, H1 M9566N and H1 M9568N, partially inhibited MflL-33-6His with a maximum inhibition of 61 % and 34%, with IC_{50} values of 1.5 nM and 3.5 nM, respectively.

Example 7. Inhibition of IL-33-lnduced Degranulation of Human Basophils by Anti-IL-33 Antibodies

[0146] To further assess the in vitro characteristics of select anti-IL-33 antibodies of the invention, their ability to block IL-33-induced basophil degranulation was measured. Peripheral blood mononuclear cells (PBMC) were purified from fresh whole blood from two different human donors by density gradient centrifugation. K2 EDTA whole blood was diluted 1 :1 in RPMI 1640, carefully layered over Ficoll-Paque (GE Healthcare, # 17-1440-03) and centrifuged to separate PBMC. The interphase layer containing the PBMC was aspirated, transferred to a new tube, and washed twice with MACS buffer that was comprised of a 1 :20 dilution of the MACS BSA solution (Militenyi Biotec, #130-091-376) in MACS rinsing solution (Militenyi Biotec, #130-091 -222). The purified PBMC were then plated in a v-bottom 96-well plate at a final concentration of -$3.0x10^6$ cells/mL in 100 μI_ of MACS buffer. To prime the basophils contained within the PBMC population, 1 ng of IL-3 (Sigma, # H7166-10UG) in 50 μI_ Dulbecco's Phosphate-Buffered Saline without Ca^{++} or Mg^{++} (DPBS) was added to the cell suspension, and then incubated at 37°C for 10 minutes.

[0147] Serial dilutions (1:3) of two different exemplary anti-IL-33 antibodies of the invention (H4H9675P and H4H9659P) or an isotype control antibody were made, ranging from 10 nM to 4.6 pM, plus a control with no antibody. The solutions were mixed with a fixed concentration of 100 pM (final concentration) of human IL-33 (R&D Systems, # 3625-IL/CF) or no IL-33 negative control prior to adding to the PBMC. All conditions were tested in duplicate.

[0148] After addition of the human IL-33 and antibodies to the cells, the cells were incubated at 37°C for 20 minutes to facilitate basophil degranulation. Degranulation was then stopped by cooling the assay plates on wet ice for 5 minutes. To enable analysis of the basophil population used to measure degranulation, 20 µL each (as per the manufacturer's instructions) of anti-HLA-DR-FITC (Beckman Coulter, # IM0463U), anti-CD123-APC (BD, # 560087), and anti-CD203c-PE (Beckman Coulter, # IM3575) were added to each sample, and the samples were held at 4°C for 20 minutes in the dark. The cells were then centrifuged, washed with DPBS, and then resuspended in 2% formaldehyde (fixation buffer) at 4°C. The next day, fixed cells were analyzed on a BD FACSCanto II to determine levels of basophil degranulation. Results are summarized in Tables 9 and 10.

Table 9: Percent degranulation of human basophils induced by human IL-33 challenge

Donor	100pM IL-33		No IL-33	
	Mean	SD	Mean	SD
655687	68.800	2.263	10.295	0.856
655688	61.600	0.849	9.915	0.969

Table 10: Anti-IL-33 antibody blocking human IL-33 induced degranulation of human basophils

	Donor 655687	Donor 655688
Antibody	IC_{50} (M)	IC_{50} (M)
H4H9675P	1.329E-10	9.712E-11
H4H9659P	5.786E-10	4.465E-10
Isotype Control	non-blocking	non-blocking

[0149] As shown in Table 9, at 100 pM, human IL-33 induced basophil degranulation in two different donors with a mean percent degranulation of 68.8% for donor 655687 and 61.6% for donor 655688.

[0150] As shown in Table 10, one anti-IL33 antibody, H4H9675P, blocked basophil degranulation induced by 100 pM human IL-33 challenge with an IC_{50} value of 132.9 pM for donor 655687, and an IC_{50} value of 97.12 pM for donor 655688. Another anti-IL33 antibody, H4H9659P, blocked basophil degranulation induced by 100 pM human IL-33 challenge with an IC_{50} value of 578.6 pM for donor 655687, and an IC_{50} value of 446.5 pM for donor 655688. In contrast, the isotype control did not block basophil degranulation from any of the tested donors.

Example 8. Inhibition of IL-33-Induced IFN-gamma From Human PBMCs by Anti-IL-33 Antibodies

[0151] To further characterize anti-IL-33 antibodies of the invention, a primary cell based assay using peripheral blood mononuclear cells (PBMCs) was utilized. The assay used in this Example was based on the results published by Smithgall *et al.* in *International Immunology*, 2008, vol. 20 (8) pp. 1019-1030. For this assay, PBMCs were purified from fresh whole blood

from three different donors by density gradient centrifugation. Briefly, K2 EDTA whole blood was diluted two-fold in RPMI 1640, carefully layered over Ficoll-Paque (GE Healthcare, #17-1440-03) and centrifuged for 20 minutes. The interphase layer containing the PBMCs was aspirated, transferred to a new tube, and washed twice with PBS. The isolated PBMCs were plated in round-bottom 96-well plates at a final concentration of $5x10^5$ cells/mL in RPMI 1640 supplemented with 10% FBS, 2 mM L-glutamine, 100 U/mL penicillin, and 100 µg/mL streptomycin. Cells were then incubated with 50 g/mL of human IL-12 (hIL-12; R&D Systems, #219-IL-025/CF) and a serial dilution of human IL-33 (hIL-33; R&D Systems, #3625-IL-010/CF) alone from 10 nM to 0.64 pM, or with 260 pM of hIL-33 in combination with serial dilutions of antibodies from 100 nM to 6.4 pM. The final volume was 200 µL per well. Each condition was tested in triplicate. When antibodies were present, they were added to the cells after 30 minutes of pre-incubation with hIL-33.

[0152] The cells were incubated overnight at 37°C in a humidified incubator with 5% CO_2, and then IFNγ levels in the culture supernatant were measured by ELISA (R&D Systems, #DY285). For the ELISA, 96-well flat-bottom plates were coated with the capture antibody, according to the manufacturer's instructions. After washing and blocking, 100 µL of undiluted culture supernatant was added to the plates and incubated for 2 hours. Subsequent washes and detection were done following the manufacturer's instructions.

[0153] Human IL-33, in the presence of hIL-12, induced the release of IFNγ from human total PBMC from the three different donors tested, with EC_{50} values between 274pM to 39pM as shown in Table 11. Eleven anti-IL-33 antibodies were tested using PBMCs from donors #603486 and #603487, while 3 anti-IL-33 antibodies were tested with PBMCs from donor #603491. All 11 of the anti-IL-33 antibodies tested on donors #603486 and #603487 blocked the release of IFNγ from human PBMC induced by 260pM IL-33, with IC_{50} values ranging from 175 pM to 22 nM, as shown in Table 12. None of the three IL-33 antibodies tested on donor #603491 blocked the release of IFNγ from human PBMC induced by 260pM hIL-33 and instead caused an increase of IFNγ release with EC_{50} values between 56.1pM and 189nM.

Table 11: hIL-33 induced IFNγ release from human PBMC from three donors.

[IL-33]	Donor 603486	Donor 603487	Donor 603491
EC_{50} (M)	1.101E-10	3.878E-11	2.739E-10

Table 12: Anti-IL-33 antibodies blocking IL-33 induced IFN-γ release from human PBMC from donor #603486 and #603487

Antibody	Donor #603486 IC_{50} (M)	Donor #603487 IC_{50} (M)
H4H9629P	8.154E-10	5.205E-09
H4H9640P	4.419E-09	1.224E-08
H4H9659P	1.252E-09	2.710E-09

H4H9660P	6.669E-10	2.913E-09
H4H9662P	9.640E-10	3.021E-09
H4H9663P	1.236E-08	2.203E-08
H4H9664P	3.984E-09	6.081E-09
H4H9665P	1.044E-08	2.337E-08
H4H9667P	8.066E-09	1.876E-08
H4H9671P	2.968E-09	8.622E-09
H4H9675P	1.754E-10	4.715E-10

Table 13: Anti-IL-33 antibodies blocking IL-33 induced IFN-γ release from human PBMC from donor #603491.

Antibody	Donor #603491 IC_{50} (M)
H1M9559N	Non-blocking
H1M9566N	Non-blocking
H1M9568N	Non-blocking

[0154] The present invention is not to be limited in scope by the specific embodiments described herein. Indeed, various modifications of the invention in addition to those described herein will become apparent to those skilled in the art from the foregoing description and the accompanying figures. Such modifications are intended to fall within the scope of the appended claims.

Example 9. Human IL-33 cross-competition using bio-layer interferometry

[0155] Binding competition between a panel of different anti-IL-33 monoclonal antibodies was determined using a real time, label-free bio-layer interferometry assay on an Octet® HTX biosensor (ForteBio, A Division of Pall Life Sciences). The experiment was performed at 25°C using a buffer of 0.01M HEPES pH7.4, 0.15M NaCl, 0.05% v/v Surfactant Tween-20, and 0.1mg/ml BSA (HBS-ET kinetics buffer) with the plate shaking at a speed of 1000rpm. To assess whether two antibodies were able to compete with one another for binding to human IL-33, a pre-mix assay format was used where 100nM of human IL-33 (R&D Systems; # 3625-IL-010/CF) was pre-mixed with 500nM of different anti-IL-33 monoclonal antibodies (subsequently referred to as mAb-2) for at least 2 hours prior to running the binding competition assay. Octet biosensors coated with either an anti-mouse Fc polyclonal antibody (Pall ForteBio Corp., # 18-5088; subsequently referred as AMC) or with an anti-human Fc polyclonal antibody (Pall ForteBio Corp., # 18-5060; subsequently referred as AHC) were first submerged into wells containing 20µg/mL of individual anti-IL-33 monoclonal antibodies for 3 minutes to capture anti-IL-33 monoclonal antibodies expressed either a with mouse Fc or with a human Fc, respectively (subsequently referred to as mAb-1). Following the capture step, unoccupied anti-mouse Fc polyclonal antibody and anti-human Fc polyclonal antibody on the Octet biosensors were saturated by submerging them for 4 minutes into wells containing 200µg/mL of a non-specific

monoclonal antibody with a mouse Fc or with a human Fc, respectively. Finally, the Octet biosensors were immersed for 4 minutes into wells containing the pre-mixed samples of 100nM of human IL-33 and 500nM of mAb-2. At the end of each cycle, the non-covalently captured anti-IL-33 antibodies along with the bound pre-complex of human IL-33 and mAb-2 were removed from the biosensors using three alternate 20 second immersions into 10mM HCI followed by submerging into HBS-ET kinetics buffer. The biosensors were washed in HBS-ET kinetics buffer in between every step of the experiment. The real-time binding response was monitored during the binding events, and the binding response (in units of nm) at the end of every step was recorded. During the analysis, the self-self background binding signal for a given mAb-2 (where mAb-1 = mAb-2, i.e., along the diagonal of the matrix) was subtracted from the observed signal for all mAb-2 binding events (across a column in the cross-competition matrix), and the background-corrected results are shown in Figure 1. The response of mAb-1 binding to the pre-complex of human IL-33 and each of the different mAb-2 samples was measured to determine the competitive/non-competitive behavior of different anti-IL-33 monoclonal antibodies with respect to each other.

[0156] As shown in Figure 1 light grey boxes with black font represent binding response for self-competition. Antibodies competing with each other in both directions, independent of the order of binding, are represented with black boxes and white font. Cells highlighted in dark grey with black font represent the anti-IL-33 monoclonal antibody that binds weakly to human IL-33, resulting in an observed unidirectional cross-competition. The isotype controls used in the experiment are represented by dark grey boxes with white font. White boxes with black font represent no competition between antibodies, which suggests each antibody has a distinct binding epitope.

Example 10. Monkey IL-33 cross-competition using bio-layer interferometry

[0157] Binding competition between a panel of different anti-IL-33 monoclonal antibodies was determined using a real time, label-free bio-layer interferometry assay on an Octet® HTX biosensor (ForteBio, A Division of Pall Life Sciences). The experiment was performed at 25°C using a buffer of 0.01M HEPES pH7.4, 0.15M NaCl, 3mM EDTA, 0.05% v/v Surfactant Tween-20, and 0.1mg/ml BSA (HBS-ET kinetics buffer) with the plate shaking at a speed of 1000rpm. To assess whether two antibodies were able to compete with one another for binding to recombinant monkey IL-33 expressed with a C-terminal hexahistidine tag (MfIL-33-6His; SEQ ID NO: 305, approximately 0.15nm binding units of MfIL-33-6His was first captured onto anti-penta-His antibody coated Octet biosensors (Fortebio Inc, # 18-5079) by submerging the biosensors for 85 seconds into wells containing 2µg/mL of MfIL-33-6His. The antigen-captured biosensors were then saturated with a first anti-IL-33 monoclonal antibody (subsequently referred to as mAb-1) by immersion into wells containing 50µg/mL solution of mAb-1 for 5 minutes. The

biosensors were then dipped into wells containing a 50µg/mL solution of a second anti-IL-33 monoclonal antibody (subsequently referred to as mAb-2) for 4 minutes. The biosensors were washed in HBS-ET kinetics buffer in between every step of the experiment. The real-time binding response was monitored during the experiment, and the maximum binding response for each binding step was recorded. The response of mAb-2 binding to MfIL-33-6His pre-complexed with mAb-1 was measured, and competitive/non-competitive behavior of different anti-IL-33 monoclonal antibodies with respect to each other was determined.

[0158] As shown in Figure 2, light grey boxes with black font (along a diagonal) represent self-competition (where mAb-1=mAb-2). Antibodies competing in both directions, independent of the order of binding, are represented with black boxes and white font. White boxes with black font represent no competition between antibodies, which suggests each antibody has a distinct binding epitope. Dark grey boxes with white font represent the isotype control used in the experiment.

EXAMPLE 11. mAb testing in In vivo model; Acute HDM-induced lung inflammation model to study role of IL-33 in lung inflammation

[0159] To determine the effect of an anti-IL-33 antibody, H4H9675P, in a relevant *in vivo* model, an acute HDM-induced lung inflammation study was conducted in mice that were homozygous for the expression of human IL-33 in place of mouse IL-33 (IL-33 HumIn mice).

[0160] IL-33 HumIn mice were intranasally administered either 50µg of house dust mite extract (HDM; Greer, #XPB70D3A2.5) diluted in 20µL of 1X phosphate buffered saline (PBS) (n=17) or 20µL of 1X PBS (n=3) for 5 days per week for 2 weeks. A subset of the HDM challenged mice were injected subcutaneously with either 25 mg/kg of an anti-IL-33 antibody, H4H9675, (n=6) or an isotype control antibody (n=6) starting at three days prior to the first HDM administration and then twice weekly until the end of the HDM challenge. On day 15 after the first intranasal HDM, all mice were sacrificed and their lungs were harvested. Experimental dosing and treatment protocol for groups of mice are shown in Table 14.

Table 14: Experimental dosing and treatment protocol for groups of mice

Group	Mice	Intranasal challenge	Length of intranasal challenge	Antibody
1	IL-33 HumIn mice	1X PBS	2 weeks	None
2	IL-33 HumIn mice	50µg HDM in 20µL 1X PBS	2 weeks	None
3	IL-33 HumIn mice	50µg HDM in 20µL 1X PBS	2 weeks	Isotype control

4	IL-33 HumIn mice	50µg HDM in 20µL 1X PBS	2 weeks	Anti-IL-33 antibody (H4H9675)

Lung harvest for cytokine analysis:

[0161] After exsanguination, the cranial and middle lobes of the right lung from each mouse were removed and placed into tubes containing a solution of tissue protein extraction reagent (1X T-PER reagent; Pierce, #78510) supplemented with 1X Halt Protease inhibitor cocktail (Pierce, #78430). All further steps were performed on ice. The volume of T-PER Reagent (containing the protease inhibitor cocktail) was adjusted for each sample to match a 1:8 (w/v) tissue to T-PER ratio. Lung samples were manually homogenized in the tubes, using disposable pestles (Kimble Chase, # 749625-0010). The resulting lysates were centrifuged to pellet debris. The supernatants containing the soluble protein extracts were transferred to fresh tubes and stored at 4°C until further analysis.

[0162] Total protein content in the lung protein extracts was measured using a Bradford assay. For the assay, 10µL of diluted extract samples were plated into 96 well plates in duplicates and mixed with 200µL of 1X Dye Reagent (Biorad, #500-0006). Serial dilutions of bovine serum albumin (Sigma, #A7979), starting at 700µg/mL in 1X T-Per reagent were used as a standard to determine the exact protein concentration of the extracts. After a 5-minute incubation at room temperature, absorbance at 595nm was measured on a Molecular Devices SpectraMax M5 plate reader. Data analysis to determine total protein content was performed using GraphPad Prism™ software.

[0163] Cytokine concentrations in the lung protein extracts were measured using a Proinflammatory Panel 1 (mouse) multiplex immunoassay kit (MesoScale Discovery, # K15048D-2), according to the manufacturer's instructions. Briefly, 50 µL/well of calibrators and samples (diluted in Diluent 41) were added to plates pre-coated with capture antibodies and incubated at room temperature while shaking at 700 rpm for 2 hours. The plates were then washed 3 times with 1X PBS containing 0.05% (w/v) Tween-20, followed by the addition of 25µL of Detection Antibody Solution diluted in Diluent 45. After another 2-hour incubation at room temperature while shaking, the plate was washed 3 times, and 150 µL of 2X Read Buffer was added to each well. Electrochemiluminescence was immediately read on a MSD Spector® instrument. Data analysis was performed using GraphPad Prism™ software.

[0164] Each cytokine concentration in lung total protein extracts from all mice in each group was normalized to the total protein content of the extracts measured by the Bradford assay and expressed for each group as average pg of cytokine per mg of total lung proteins (pg/mg lung protein, ± SD) as shown in Table 15.

Lung harvest for cytokine analysis:

[0165] The level of the cytokines IL-4 and IL-5 released in the lungs of IL-33 HumIn mice receiving HDM for 2 weeks was significantly higher than in IL-33 HumIn mice challenged with saline buffer. In contrast, there was a trend towards reduced IL-4 and IL-5 levels in the lungs of IL-33 HumIn mice treated with anti-IL-33 antibody during the course of the acute HDM challenge as compared to IL-33 HumIn mice administered HDM without treatment or with isotype control.

Table 15: Cytokine concentration in lung protein extracts

Experimental group	Mean [IL-4] in lung protein extracts (pg/mg lung protein) (±SD)	Mean [IL-5] in lung protein extracts (pg/mg lung protein) (±SD)
1. 1X PBS challenge (n=3)	0.01 (±0.01)	0.03 (±0.01)
2. HDM challenge (n=5)	1.77 (±1.63) *	4.72 (±4.14) **
3. HDM challenge + Isotype control Antibody (n=6)	0.79 (±0.52) *	2.03 (±1.05) *
4. HDM challenge + H4H9675P (n=6)	0.30 (±0.18)	0.81 (±0.67)

Note: Statistical significance determined by Kruskal-Wallis One-way ANOVA with Dunn's multiple comparison post-hoc test is indicated (*= $p<0.05$, **= $p<0.01$, compared to Group 1: IL33 HumIn mice, Saline challenge).

Lung harvest for pulmonary cell infiltrate analysis

[0166] After exsanguination, the caudal lobe of the right lung from each mouse was removed, chopped into cubes that were approximately 2 to 3 mm in size, and then placed into a tube containing a solution of 20 µg/mL DNAse (Roche, #10104159001) and 0.7 U/mL Liberase TH (Roche, #05401151001) diluted in Hank's Balanced Salt Solution (HBSS) (Gibco, #14025), which was incubated in a 37°C water bath for 20 minutes and vortexed every 5 minutes. The reaction was stopped by adding ethylenediaminetetraacetic acid (Gibco, #15575) at a final concentration of 10mM. Each lung was subsequently dissociated using a gentleMACS dissociator® (Miltenyi Biotec, #130-095-937), then filtered through a 70 µm filter and centrifuged. The resulting lung pellet was resuspended in 1 mL of 1X red blood cell lysing buffer (Sigma, #R7757) to remove red blood cells. After incubation for 3 minutes at room temperature, 3 mL of 1X DMEM was added to deactivate the red blood cell lysing buffer. The cell suspensions were then centrifuged, and the resulting cell pellets were resuspended in 5 mL of MACS buffer (autoMACS Running Buffer; Miltenyi Biotec, #130-091-221). The resuspended samples were filtered through a 70 µm filter and $1x10^6$ cells per well were plated in a 96-well V-bottom plate.

Cells were then centrifuged and the pellets were washed in 1X PBS. After a second centrifugation, the cell pellets were resuspended in 100µL of LIVE/DEAD® Fixable Aqua Dead Cell Stain (Life Technologies, #L34957) diluted at 1:1000 in 1X PBS to determine cell viability and incubated for 20 minutes at room temperature while protected from light. After one wash in 1X PBS, cells were incubated in a solution of MACS buffer containing 10µg/mL of purified rat anti-mouse CD16/CD32 Fc Block, (Clone: 2.4G2; BD Biosciences, #553142) for 10 minutes at 4°C. The cells were washed once and then incubated in the appropriate antibody mixture (described in Table 16) diluted in MACS buffer for 30 minutes at 4°C while protected from light. After antibody incubation, the cells were washed twice in MACS buffer, resuspended in BD cytofix (BD Biosciences, #554655) and then incubated for 15 minutes at 4°C while protected from light. The cells were subsequently washed, resuspended in MACS buffer, and then transferred to BD FACS tubes (BD Biosciences, #352235) for analysis of eosinophils, innate lymphoid cell type 2 (ILC2) and lymphocytes by flow cytometry.

[0167] Activated CD4 T cells were defined as cells that were live, $CD45^{+}$, SSC^{Lo}, FSC^{Lo}, $CD3^{+}$, $CD19^{-}$, $CD4^{+}$, $CD8^{-}$, and $CD69^{+}$. Activated B cells were defined as cells that were live, $CD45^{+}$, SSC^{Lo}, FSC^{Lo}, $CD3^{-}$, $CD19^{+}$, and $CD69^{+}$. Eosinophils were defined as live, $CD45^{+}$, $GR1^{-}$, $CD11c^{lo}$, $SiglecF^{hi}$. ILC2 cells were defined as live, $CD45^{+}$, Lineage- (Lineage: CD19, CD3, CD11b, CD11c, F4/80), CD127+, $Sca^{-}1^{+}$, $ST2^{+}$. Data for activated CD4 cells, expressed as frequency of activated cells ($CD69^{+}$) within the parent population (CD4, ± SD), are shown in Table 17.

Table 16: Antibodies Used for Flow Cytometry Analysis

Antibody	Fluorochrome	Manufacturer	Catalog Number	Final dilution
CD11c	APC	BD Biosciences	550261	1/100
CD45	PerCP Cy5.5	eBiosciences	45-0454-82	1/800
F4/80	Pacific Blue	eBiosciences	48-4801-82	1/200
Siglec-F	PE	BD Biosciences	552126	1/100
Ly6G (Gr-1)	APC-eFluor780	eBiosciences	47-5931-82	1/200
CD3	PE-Cy7	BD Biosciences	552774	1/200
CD19	eFluor 450	eBiosciences	48-0193-82	1/200
CD4	APC-H7	BD Biosciences	560181	1/200
CD8	APC	eBiosciences	17-0081-82	1/200
CD69	PE	eBiosciences	12-0691-82	1/200
CD3	eFluor 450	eBiosciences	48-0031-82	1/200
CD11b	eFluor450	eBiosciences	40-0112-82	1/100

Antibody	Fluorochrome	Manufacturer	Catalog Number	Final dilution
CD11c	eFluor450	eBiosciences	48-0114-82	1/100
CD127	APC-eFluor780	eBiosciences	47-1271-82	1/200
Sca-1	FITC	BD Biosciences	557405	1/200
ST2	APC	Biolegend	145306	1/200

Pulmonary cell infiltrate analysis:

[0168] As shown in Table 17, the frequency of activated $CD4^+$ T cells, eosinophils, and ILC2 in the lungs of IL-33 HumIn mice receiving HDM for 2 weeks was significantly higher than in IL-33 HumIn mice challenged with 1X PBS control. In contrast, a trend towards a reduced frequency of these infiltrates was observed in IL-33 HumIn mice when treated with the anti-IL-33 antibody during the course of the acute HDM challenge as compared to IL-33 HumIn mice administered HDM without treatment or with isotype control.

[0169] A trend towards an increase in the frequency of activated B cells was observed in the lungs of IL33 HumIn mice challenged with HDM for 2 weeks compared to IL33 Humin mice challenged with 1X PBS control. Upon anti-IL-33 antibody treatment, a significant reduction in the frequency of pulmonary activated B cells in the lungs of IL33 HumIn mice challenged with HDM was observed, as compared to IL-33 HumIn mice administered HDM without treatment or with isotype control.

Table 17: Frequency of pulmonary cell infiltrate as determined by flow cytometry

Experimental group	Mean Frequency of activated CD4+ T cells in CD4+ population (±SD)	Mean Frequency of activated B cells in the B cell population (±SD)	Mean Frequency of eosinophils in CD45+ population (±SD)	Mean Frequency of ILC2 in Lymphoid population (±SD)
1. 1X PBS challenge (n=3)	6.17 (±0.59)	6.85 (±3.09)	2.55 (±0.79)	0.33 (±0.05)
2. HDM challenge (n=5)	29.52 (±8.57) *	10.13 (±3.30)	17.28 (±3.97) *	1.15 (±0.37) *
3. HDM challenge + Isotype control Antibody (n=6)	29.68 (±9.84) *	11.01 (±2.31)	19.19 (±11.55)*	1.57 (±0.78) *

4. HDM challenge + H4H9675P (n=6)	16.38 (±3.30)	4.88 (±1.70) †	10.32 (±4.63)	0.53 (±0.12)

Note: Statistical significance determined by Kruskal-Wallis One-way ANOVA with Dunn's multiple comparison post-hoc test is indicated (*= $p<0.05$, **= $p<0.01$, compared to groups 1: IL33 HumIn mice, Saline challenge; †$p<0.05$, compared to group 3: IL33 Humin mice, HDM challenge 2 weeks + Isotype control antibody).

EXAMPLE 12: mAb testing in In vivo model; Chronic HDM-induced fibrosis and severe lung inflammation model to study role of IL-33 in lung inflammation

[0170] To determine the effect of an anti-IL-33 antibody, H4H9675P, in a relevant *in vivo* model, a chronic HDM-induced fibrosis and severe lung inflammation study was conducted in mice that were homozygous for the expression of human IL-33 in place of mouse IL-33 (IL-33 HumIn mice).

[0171] IL-33 HumIn mice were intranasally administered either 50µg house dust mite extract (HDM; Greer, #XPB70D3A2.5) diluted in 20µL of 1X phosphate buffered saline (PBS) or 20µL of 1X PBS for 5 days per week for 12 weeks. A second control group of IL33 HumIn mice were administered 50µg HDM extract diluted in 20µL of 1X PBS for 5 days per week for 4 weeks, to assess the severity of the disease at the onset of antibody treatment. Two groups of HDM challenged mice were injected subcutaneously with 25 mg/kg of either an anti-IL-33 antibody, H4H9675P, or an isotype control antibody starting after 4 weeks of HDM challenge and then twice per week until the end of the HDM challenge (8 weeks of antibody treatment). On day 85 of the study, all mice were sacrificed and their lungs were harvested. Experimental dosing and treatment protocol for groups of mice are shown in Table 18.

Table 18: Experimental dosing and treatment protocol for groups of mice

Group	Mice	Intranasal challenge	Length of intranasal challenge	Antibody
1	IL-33 HumIn mice	1X PBS	12 weeks	None
2	IL-33 HumIn mice	50µg HDM in 20µL 1X PBS	4 weeks	None
3	IL-33 HumIn mice	50µg HDM in 20µL 1X PBS	12 weeks	None
4	IL-33 HumIn mice	50µg HDM in 20µL 1X PBS	12 weeks	Isotype control antibody
5	IL-33 HumIn	50µg HDM in	12 weeks	Anti-IL-33 antibody

	mice	20µL 1X PBS		(H4H9675P)

Lung harvest for cytokine analysis:

[0172] After exsanguination, the cranial and middle lobes of the right lung from each mouse were removed and placed into tubes containing a solution of tissue protein extraction reagent (1X T-PER reagent; Pierce, #78510) supplemented with 1X Halt Protease inhibitor cocktail (Pierce, #78430). All further steps were performed on ice. The volume of T-PER Reagent (containing the protease inhibitor cocktail) was adjusted for each sample to match a 1:8 (w/v) tissue to T-PER ratio. Lung samples were manually homogenized in the tubes, using disposable pestles (Kimble Chase, # 749625-0010). The resulting lysates were centrifuged to pellet debris. The supernatants containing the soluble protein extracts were transferred to fresh tubes and stored at 4°C until further analysis.

[0173] Total protein content in the lung protein extracts was measured using a Bradford assay. For the assay, 10µL of diluted extract samples were plated into 96 well plates in duplicates and mixed with 200µL of 1X Dye Reagent (Biorad, #500-0006). Serial dilutions of bovine serum albumin (BSA; Sigma, #A7979), starting at 700µg/mL in 1X T-Per reagent were used as a standard to determine the protein concentration of the extracts. After a 5-minute incubation at room temperature, absorbance at 595nm was measured on a Molecular Devices SpectraMax M5 plate reader. Data analysis to determine total lung extract protein content based on the BSA standard was performed using GraphPad Prism™ software.

[0174] Cytokine concentrations in the lung protein extracts were measured using a Proinflammatory Panel 1 (mouse) multiplex immunoassay kit (MesoScale Discovery, # K15048D-2), according to the manufacturer's instructions. Briefly, 50 µL/well of calibrators and samples (diluted in Diluent 41) were added to plates pre-coated with capture antibodies and incubated at room temperature while shaking at 700 rpm for 2 hours. The plates were then washed 3 times with 1X PBS containing 0.05% (w/v) Tween-20, followed by the addition of 25µL of Detection Antibody Solution diluted in Diluent 45. After another 2 hour incubation at room temperature while shaking, the plate was washed 3 times, and 150µL of 2X Read Buffer was added to each well. Electrochemiluminescence was immediately read on a MSD Spector® instrument. Data analysis was performed using GraphPad Prism software.

[0175] Each cytokine concentration in lung total protein extracts from all mice in each group was normalized to the total protein content of the extracts measured by the Bradford assay, and expressed for each group as average pg of cytokine per mg of total lung proteins (pg/mg lung protein, ± SD) as shown in Table 19.

Table 19: Cytokine concentration in lung protein extracts

Experimental group	Mean [IL-4] in lung protein	Mean [IL-5] in lung protein

	extracts (pg/mg lung protein) (±SD)	extracts (pg/mg lung protein) (±SD)
1. 1X PBS challenge, 12 weeks (n=5)	0.03 (±0.01)	0.08 (±0.05)
2. HDM challenge, 4 weeks (n=6)	2.84 (±2.22) *	4.44 (±4.00) **
3. HDM challenge, 12 weeks (n=3)	7.31 (±3.94) **	6.23 (±3.81) *
4. HDM challenge, 12 weeks + Isotype control antibody (n=2)	2.28 (±1.94)	3.39 (±3.29)
5. HDM challenge, 12 weeks + H4H9675P (n=5)	0.38 (±0.21)	0.48 (±0.17)

Note: Statistical significance determined by Kruskal-Wallis One-way ANOVA with Dunn's multiple comparison post-hoc test is indicated (*= $p<0.05$, **= $p<0.01$, compared to groups 1: IL33 HumIn mice, Saline challenge).

Lung cytokines analysis:

[0176] The level of the cytokines IL-4 and IL-5 released in the lungs of IL-33 HumIn mice receiving HDM for 4 and 12 weeks was significantly higher than in IL-33 HumIn mice challenged with 1X PBS. In contrast, there was a trend towards reduced IL-4 and IL-5 levels in the lungs of IL-33 HumIn mice treated with anti-IL-33 antibody during the course of the chronic HDM challenge as compared to IL-33 HumIn mice administered HDM without treatment or with isotype control.

What is claimed is:

1. An isolated human monoclonal antibody or antigen-binding fragment thereof that binds human interleukin 33 (IL-33), wherein the antibody or antigen-binding fragment thereof inhibits or attenuates IL-33-mediated signaling and comprises the complementarity determining regions, HCDR1-HCDR2-HCDR3-LCDR1-LCDR2-LCDR3, respectively, of SEQ ID NOs: 276-278-280-284-286-288.

2. The isolated antibody or antigen-binding fragment of claim 1, wherein the antibody or antigen-binding fragment thereof blocks the interaction of IL-33 and ST2.

3. The isolated antibody or antigen-binding fragment of claim 2, wherein the antibody or antigen-binding fragment thereof blocks the interaction of IL-33 and ST2 with an IC_{50} value of less than about 10 nM, or blocks greater than about 50% of the interaction of IL-33 and ST2 as measured in an *in vitro* receptor/ligand binding assay at 25ºC.

4. The isolated antibody or antigen-binding fragment of any one of claims 1 to 3, wherein the antibody or antigen-binding fragment thereof binds human IL-33 with a binding dissociation equilibrium constant (K_D) of less than about 1 nM as measured in a surface plasmon resonance assay at 37ºC.

5. The isolated antibody or antigen-binding fragment of any one of claims 1 to 4, wherein the antibody or antigen-binding fragment thereof binds human IL-33 with a dissociative half-life (t½) of greater than about 8 minutes as measured in a surface plasmon resonance assay at 37ºC.

6. The antibody or antigen-binding fragment of any one of claims 1 to 5, wherein the antibody or antigen-binding fragment thereof inhibits IL-33-mediated degranulation of human basophils.

7. The antibody or antigen-binding fragment of claim 6, wherein the antibody or antigen-binding fragment thereof inhibits IL-33-mediated degranulation of human basophils with an IC_{50} of less than about 600 pM as measured in an *in vitro* basophil activation test (BAT).

8. The antibody or antigen-binding fragment of any one of claims 1 to 7, wherein the antibody or antigen-binding fragment thereof inhibits IL-33-mediated IFN-gamma production from human PBMCs.

9. The antibody or antigen-binding fragment of claim 8, wherein the antibody or antigen-binding fragment thereof inhibits IL-33-mediated IFN-gamma production from human PBMCs with an IC_{50} of less than about 25 nM as measured in an *in vitro* PBMC IFN-gamma production assay.

10. The antibody or antigen-binding fragment of claim 9, wherein the antibody or antigen-binding fragment thereof inhibits IL-33-mediated IFN-gamma production from human PBMCs with an IC_{50} of less than about 3 nM as measured in an *in vitro* PBMC IFN-gamma production assay.

11. The antibody or antigen-binding fragment of claim 10, wherein the antibody or antigen-binding fragment thereof inhibits IL-33-mediated IFN-gamma production from human PBMCs with an IC_{50} of less than about 0.5 nM as measured in an *in vitro* PBMC IFN-gamma production assay.

12. The antibody or antigen-binding fragment of any one of claims 1 to 11, comprising a heavy chain variable region comprising the amino acid sequence of SEQ ID NO: 274 and a light chain variable region comprising the amino acid sequence of SEQ ID NO: 282.

13. The antibody of any one of claims 1 to 12, wherein the antibody has a human IgG1 or human IgG4 constant region.

14. An isolated nucleic acid molecule encoding an antibody or antigen-binding fragment of any of claims 1 through 13.

15. An expression vector comprising the nucleic acid molecule of claim 14.

16. A host cell comprising the expression vector of claim 15.

17. A pharmaceutical composition comprising the antibody or antigen-binding fragment of any one of claims 1 to 13, and a pharmaceutically acceptable carrier or diluent.

18. Use of an antibody or antigen-binding fragment of any one of claims 1 to 13 in the manufacture of a medicament for treating an inflammatory disease or disorder, wherein the inflammatory disease or disorder is an IL-33-mediated inflammatory disease or disorder selected from the group consisting of asthma, atopic dermatitis, chronic obstructive pulmonary disease (COPD), inflammatory bowel disease, multiple sclerosis, arthritis, allergic rhinitis, eosinophilic esophagitis and psoriasis.

19. The use of claim 18, wherein the inflammatory disease or disorder is asthma.

20. The use of claim 19, wherein the asthma is eosinophilic or non-eosinophilic asthma.

21. The use of any of claims 18-20, wherein the asthma is steroid resistant or steroid sensitive asthma.

22. The use of claim 19, wherein the asthma includes an asthma exacerbation.

23. The use of claim 18, wherein the inflammatory disease or disorder is atopic dermatitis.

24. The use of claim 18, wherein the inflammatory disease or disorder is chronic obstructive pulmonary disease (COPD).

25. The use of claim 24, wherein the chronic obstructive pulmonary disease results from, or is caused in part by cigarette smoke.

26. Use of an antibody or antigen-binding fragment of any one of claims 1 to 13 in the manufacture of a medicament for treating an allergy.

27. The use of any of claims 18-26, wherein the medicament is to be combined with a second therapeutic agent useful for alleviating the inflammatory disease or disorder, or for diminishing an allergic response to an allergen.

28. The use of claim 27, wherein the second therapeutic agent is selected from the group consisting of a non-steroidal anti-inflammatory (NSAID), a corticosteroid, a bronchial dilator, an antihistamine, epinephrine, a decongestant, a thymic stromal lymphopoietin (TSLP)

antagonist, an IL-13 antagonist, an IL-4 antagonist, an IL-4/IL-13 dual antagonist, an IL-5 antagonist, an IL-6 antagonist, an IL-12/23 antagonist, an IL-22 antagonist, an IL-25 antagonist, an IL-17 antagonist, an IL-31 antagonist, an oral PDE4 inhibitor and another IL-33 antagonist or a different antibody to IL-33.