IL-1β Neutralizing Human Monoclonal Antibodies

Technical Field

The present invention relates to antigen binding proteins and in particular to IL-1β antigen binding proteins. More specifically, the present invention relates to sequences of the binding proteins and the heavy and light chains. Compositions comprising the antigen binding proteins, use of the antigen binding proteins and methods for production are also provided.

Background

Interleukin-1 beta (IL-1β) is a member of the Interleukin-1 cytokine family and is an important mediator of the inflammatory response. It is a pro-inflammatory cytokine and is involved in the proliferation, differentiation and apoptosis of cells.

Overexpression of IL-1β has been implicated in a number of inflammatory and autoimmune diseases such as cryopyrin-associated periodic syndromes and related disorders, diabetes, Crohn's disease, rheumatoid arthritis, renal cell carcinoma, gout and inflammatory acne.

It is an aim of the present invention to provide antigen binding proteins specific to IL-1β that are able to neutralize the activity of IL-1β to prevent or treat diseases associated with heightened IL-1β production.

To date, three biologicals targeting the IL-1β signalling pathway have been approved for clinical use: *anakinra (an IL-1 receptor antagonist)*, *rilonacept* (a fusion protein comprising the IL-1 receptor 1) and *canakinumab (a monoclonal antibody)*.

In addition to the three approved IL-1 blockers mentioned above, the humanized monoclonal antibody XOMA-052 (gevokizumab) is currently in clinical development. Each molecule exhibits unique mechanisms of action and displays different cross-reactivity and pharmacological profile.

Summary

According to a first example, there is provided an isolated IL-1β specific antigen binding protein comprising one or more binding units selected from the group consisting of the following binding units:

(i) a binding unit L1 comprising Kabat residues 23-35 of SEQ ID NO: 3 or Kabat residues 24-33 of SEQ ID NO: 4, 15 or 16, or a variant thereof which contains at least one amino acid substitution, insertion or deletion in the binding unit L1;

(ii) a binding unit L2 comprising Kabat residues 51-57 of SEQ ID NO: 3 or Kabat residues 49-55 of SEQ ID NO: 4, 15 or 16, or a variant thereof which contains at least one amino acid substitution, insertion or deletion in the binding unit L2;

(iii) a binding unit L3 comprising Kabat residues 92-102 of SEQ ID NO: 3 or Kabat residues 88-96 of SEQ ID NO: 4, 15 or 16, or a variant thereof which contains at least one amino acid substitution, insertion or deletion in the binding unit L3;

(iv) a binding unit H1 comprising Kabat residues 31-35 of SEQ ID NO: 1 or Kabat residues 31-35 of SEQ ID NO: 2 or 14, or a variant thereof which contains at least one amino acid substitution, insertion or deletion in the binding unit H1;

(v) a binding unit H2 comprising Kabat residues 50-66 of SEQ ID NO: 1 or Kabat residues 50-65 of SEQ ID NO: 2 or 14, or a variant thereof which contains at least one amino acid substitution, insertion or deletion in the binding unit H2; and

(vi) a binding unit H3 comprising Kabat residues 99-114 of SEQ ID NO: 1 or Kabat residues 98-108 of SEQ ID NO: 2 or 14, or a variant thereof which contains at least one amino acid substitution, insertion or deletion in the binding unit H3.

According to the second example, there is provided an isolated, IL-1β specific antigen binding protein that neutralizes IL-1β in a cell stimulation assay at an IC50 value of less than 20nM, less than 15nM, less than 10 nM, less than 5nM, less than 3nM, less than 1nM, less than 0.5nM or less than 0.2nM.

According to a third example, there is provided an isolated IL-1β specific antigen binding protein that inhibits IL-1β induced IL-6 production in a cell inhibition assay at an IC50 value of less than 20nM, less than 15nM, less than 10 nM, less than 5nM, less than 4nM, less than 3nM, less than 1nM, less than 0.5nM or less than 0.4nM.

According to a fourth example, there is provided an isolated, IL-1β specific antigen binding protein that binds IL-1β with a K_D value of less than 10nM, less than 5nM, less than 2nM, less than 1nM, less than 0.5nM, or less than 0.1nM.

According to a fifth example, there is provided an isolated, IL-1β specific antigen binding protein that neutralizes human IL-1β at an IC50 value of from 1pM to 100pM.

According to a sixth example, there is provided an isolated, IL-1β specific antigen binding protein that neutralizes murine IL-1β at an IC50 value of from 100pM to 1000pM.

According to a seventh example, there is provided an isolated, IL-1β specific antigen binding protein wherein said binding protein has an affinity (KD) to human IL-1β of from 1pM to 100pM.

According to an eighth example, there is provided an isolated, IL-1β specific antigen binding protein wherein said binding protein has an affinity (KD) to murine IL-1β of from 5pM to 200pM.

According to a ninth example, there is provided an isolated antigen binding protein of any one of the preceding claims, for use in treating cancer, an inflammatory disease or an autoimmune disease selected from the group consisting of arthritis, inflammatory bowel disease, Crohn's disease, rheumatoid arthritis, gout, diabetes, uveitis, cryopyrin-associated periodic syndromes and inflammatory acne.

According to a tenth example, there is provided a use of the isolated antigen binding protein as defined above, in the preparation of a medicament for the treatment of cancer, an inflammatory disease or an autoimmune disease selected from the

group consisting of arthritis, inflammatory bowel disease, Crohn's disease, rheumatoid arthritis, gout, diabetes, uveitis, cryopyrin-associated periodic syndromes and inflammatory acne.

According to an eleventh example, there is provided a composition comprising the antigen binding protein as defined above and a pharmaceutically acceptable carrier.

According to a twelfth example, there is provided an isolated cell line that is capable of producing the antigen binding protein as defined above.

According to a thirteenth example, there is provided an isolated nucleic acid molecule comprising or consisting of sequences selected from SEQ ID NO:1 or SEQ ID NO:2 or 14, or fragments thereof.

According to a fourteenth example, there is provided an isolated nucleic acid molecule comprising or consisting of sequences selected from SEQ ID NO:3 or SEQ ID NO:4, 15 or 16, or fragments thereof.

According to a fifteenth example, there is provided a vector comprising the nucleic acid molecule as defined above.

According to a sixteenth example, there is provided a host cell comprising the nucleic acid molecule as defined above.

According to a seventeenth example, there is provided a host cell comprising the vector as defined above.

According to an eighteenth example, there is provided a method of producing an antigen binding protein as defined above, comprising culturing the host cell as defined above under suitable conditions and recovering said protein therefrom.

According to a nineteenth example, there is provided a method of treating cancer, an inflammatory disease or an autoimmune disease selected from the group consisting of arthritis, inflammatory bowel disease, Crohn's disease, rheumatoid arthritis, gout, diabetes, uveitis, cryopyrin-associated periodic syndromes and inflammatory acne, wherein the isolated antigen binding protein as defined above is administered to a subject.

In one aspect, there is provided an isolated monoclonal antibody which specifically binds to IL-1β, or an antigen binding fragment thereof, wherein said antibody or fragment thereof comprises the following Complementarity Determining Regions (CDRs):

(i) a heavy chain variable region CDR H1 comprising the amino acid sequence DYYWS,

(ii) a heavy chain variable region CDR H2 comprising the amino acid sequence EIDHSGSTNYNPSLKS,

(iii) a heavy chain variable region CDR H3 comprising the amino acid sequence ASPSSGWTLDY,

(iv) a light chain variable region CDR L1 comprising the amino acid sequence GDKLGDKFAF,

(v) a light chain variable region CDR L2 comprising the amino acid sequence LDNKRPS, and

(vi) a light chain variable region CDR L3 comprising an amino acid sequence selected from the group consisting of: YAWADTYEV, QAWADSFEV, YAWDNAYEV, EAWDAAAEV, and EAWADTYEV.

In another aspect, there is provided an isolated monoclonal antibody which specifically binds to IL-1β, or an antigen binding fragment thereof, wherein said antibody or fragment thereof comprises:

(i) a light chain sequence comprising the amino acid sequence of SEQ ID NO: 17; and

(ii) a heavy chain sequence comprising the amino acid sequence of SEQ ID NO: 18 or SEQ ID NO:2.

In another aspect, there is provided a composition comprising the isolated antibody or fragment thereof as described herein and a pharmaceutically acceptable carrier.

In another aspect, there is provided an isolated nucleic acid encoding the isolated monoclonal antibody or fragment thereof as described herein, wherein the nucleic acid comprises: a first sequence encoding the light chain or the light chain variable region of said antibody or fragment, and a second sequence encoding the heavy chain or the heavy chain variable region of said antibody or fragment.

In another aspect, there is provided a set of two isolated nucleic acids which together encode the isolated antibody or fragment thereof as described herein, wherein: the first nucleic acid comprises a sequence encoding the light chain or the light chain variable region of said antibody or fragment, and the second nucleic acid comprises a sequence encoding the heavy chain or the heavy chain variable region of said antibody or fragment.

In another aspect, there is provided a vector comprising the isolated nucleic acid molecule as described herein, or the set of two isolated nucleic acids as described hereni.

In another aspect, there is provided a host cell comprising the isolated nucleic acid as described herein, or the set of two isolated nucleic acids as described herein.

In another aspect, there is provided a method of producing the isolated monoclonal antibody or fragment thereof as described herein, comprising culturing the host cell as described herein under suitable conditions and recovering said antibody or fragment therefrom.

In another aspect, there is provided an isolated cell line that is capable of producing the isolated monoclonal antibody or fragment thereof as described herein.

In another aspect, there is provided an isolated monoclonal antibody or fragment thereof as described herein or the composition as described herein for use in therapy.

In another aspect, there is provided a use of the isolated monoclonal antibody or fragment thereof as described herein or the composition as described herein, in the preparation of a medicament for the treatment of an autoimmune disease.

In another aspect, there is provided a use of the isolated monoclonal antibody or fragment thereof as described herein or the composition as described herein, in the preparation of a medicament for the treatment of arthritis, inflammatory bowel disease, Crohn's disease, rheumatoid arthritis, gout, diabetes, uveitis, cryopyrin-associated periodic syndromes or inflammatory acne.

In another aspect, there is provided a use of the isolated monoclonal antibody or fragment thereof as described herein or the composition as described herein, in the preparation of a medicament for the treatment of an inflammatory disease.

In another aspect, there is provided a use of the isolated monoclonal antibody or fragment thereof as described herein or the composition as described herein, in the preparation of a medicament for the treatment of cancer.

In another aspect, there is provided a use of the isolated monoclonal antibody or fragment thereof as described herein or the composition as described herein, in the preparation of a medicament for reducing tumor growth.

Definitions

The following words and terms used herein shall have the meaning indicated:

The term "antigen binding protein" as used herein refers to antibodies, antibody fragments and other protein constructs, such as domains, which are capable of binding to IL-1β.

The term "antibody" as used herein in the broadest sense to refer to molecules with an immunoglobulin-like domain and includes monoclonal, recombinant, polyclonal, chimeric, humanised, bispecific, multispecific and heteroconjugate antibodies; a single variable domain, a domain antibody, antigen binding fragments, immunologically effective fragments, single chain Fv, diabodies, Tandabs™, etc (for a summary of alternative "antibody" formats see Holliger and Hudson, Nature Biotechnology, 2005, Vol 23, No. 9, 1126-1136).

The phrase "single variable domain" refers to an antigen binding protein variable domain (for example, V_H, V_{HH}, V_L) that specifically binds an antigen or epitope independently of a different variable region or domain.

A "domain antibody" or "dAb" may be considered the same as a "single variable domain" which is capable of binding to an antigen. A single variable domain may be a human antibody variable domain, but also includes single antibody variable domains from other species such as rodent (for example, as disclosed in WO 00/29004), nurse shark and *Camelid* V_{HH} dAbs. Camelid V_{HH} are immunoglobulin single variable domain polypeptides that are derived from species including camel, llama, alpaca, dromedary, and guanaco, which produce heavy chain antibodies naturally devoid of light chains. Such V_{HH} domains may be humanised according to standard techniques available in the art, and such domains are considered to be "domain antibodies". As used herein V_H includes camelid V_{HH} domains.

As used herein the term "domain" refers to a folded protein structure which has tertiary structure independent of the rest of the protein. Generally, domains are responsible for discrete functional properties of proteins, and in many cases may be added, removed or transferred to other proteins without loss of function of the remainder of the protein and/or of the domain. A "single variable domain" is a folded polypeptide domain comprising sequences characteristic of antibody variable domains. It therefore includes complete antibody variable domains and modified variable domains, for example, in which one or more loops have been replaced by sequences which are not characteristic of antibody variable domains, or antibody variable domains which have been truncated or comprise N- or C-terminal extensions, as well as folded fragments of variable domains which retain at least the binding activity and specificity of the full-length domain. A domain can bind an antigen or epitope independently of a different variable region or domain.

An antigen binding fragment may be provided by means of arrangement of one or more CDRs on non-antibody protein scaffolds such as a domain. The domain may be a domain antibody or may be a domain which is a derivative of a scaffold selected from the group consisting of CTLA-4 (Evibody); lipocalin; Protein A derived molecules such as Z-domain of Protein A (Affibody, SpA), A-domain (Avimer/Maxibody); Heat shock proteins such as GroEl and GroES; transferrin (trans-body); ankyrin repeat protein (DARPin); peptide aptamer; C-type lectin domain (Tetranectin); human γ-crystallin and human ubiquitin (affilins); PDZ domains; scorpion toxinkunitz type domains of human protease inhibitors; and fibronectin (adnectin); which has been subjected to protein engineering in order to obtain binding to a ligand other than its natural ligand.

CTLA-4 (Cytotoxic T Lymphocyte-associated Antigen 4) is a CD28-family receptor expressed on mainly CD4+ T-cells. Its extracellular domain has a variable domain-like Ig fold. Loops

corresponding to CDRs of antibodies can be substituted with heterologous sequence to confer different binding properties. CTLA-4 molecules engineered to have different binding specificities are also known as Evibodies. For further details see Journal of Immunological Methods 248 (1-2), 31-45 (2001)

Lipocalins are a family of extracellular proteins which transport small hydrophobic molecules such as steroids, bilins, retinoids and lipids. They have a rigid β-sheet secondary structure with a number of loops at the open end of the conical structure which can be engineered to bind to different target antigens. Anticalins are between 160-180 amino acids in size, and are derived from lipocalins. For further details see Biochim Biophys Acta 1482: 337-350 (2000), US7250297B1 and US20070224633

An affibody is a scaffold derived from Protein A of *Staphylococcus aureus* which can be engineered to bind to antigen. The domain consists of a three-helical bundle of approximately 58 amino acids. Libraries have been generated by randomisation of surface residues. For further details see Protein Eng. Des. Sel. 17, 455-462 (2004) and EP1641818A1

Avimers are multidomain proteins derived from the A-domain scaffold family. The native domains of approximately 35 amino acids adopt a defined disulphide bonded structure. Diversity is generated by shuffling of the natural variation exhibited by the family of A-domains. For further details see Nature Biotechnology 23(12), 1556 - 1561 (2005) and Expert Opinion on Investigational Drugs 16(6), 909-917 (June 2007)

A transferrin is a monomeric serum transport glycoprotein. Transferrins can be engineered to bind different target antigens by insertion of peptide sequences in a permissive surface loop. Examples of engineered transferrin scaffolds include the Trans-body. For further details see J. Biol. Chem 274, 24066-24073 (1999).

Designed Ankyrin Repeat Proteins (DARPins) are derived from Ankyrin which is a family of proteins that mediate attachment of

integral membrane proteins to the cytoskeleton. A single ankyrin repeat is a 33 residue motif consisting of two α-helices and a β-turn. They can be engineered to bind different target antigens by randomising residues in the first α-helix and a β-turn of each repeat. Their binding interface can be increased by increasing the number of modules (a method of affinity maturation). For further details see J. Mol. Biol. 332, 489-503 (2003), PNAS 100(4), 1700-1705 (2003) and J. Mol. Biol. 369, 1015-1028 (2007) and US20040132028A1.

Fibronectin is a scaffold which can be engineered to bind to antigen. Adnectins consists of a backbone of the natural amino acid sequence of the 10th domain of the 15 repeating units of human fibronectin type III (FN3). Three loops at one end of the β-sandwich can be engineered to enable an Adnectin to specifically recognize a therapeutic target of interest. For further details see Protein Eng. Des. Sel. 18, 435-444 (2005), US20080139791, WO2005056764 and US6818418B1.

Peptide aptamers are combinatorial recognition molecules that consist of a constant scaffold protein, typically thioredoxin (TrxA) which contains a constrained variable peptide loop inserted at the active site. For further details see Expert Opin. Biol. Ther.5, 783-797 (2005).

Microbodies are derived from naturally occurring microproteins of 25-50 amino acids in length which contain 3-4 cysteine bridges - examples of microproteins include KalataB1 and conotoxin and knottins. The microproteins have a loop which can be engineered to include up to 25 amino acids without affecting the overall fold of the microprotein. For further details of engineered knottin domains, see WO2008098796.

Other binding domains include proteins which have been used as a scaffold to engineer different target antigen binding properties include human γ-crystallin and human ubiquitin (affilins), kunitz type domains of human protease inhibitors, PDZ-domains of the Ras-binding protein AF-6, scorpion toxins

(charybdotoxin), C-type lectin domain (tetranectins) are reviewed in Chapter 7 - Non-Antibody Scaffolds from Handbook of Therapeutic Antibodies (2007, edited by Stefan Dubel) and Protein Science 15:14-27 (2006). Binding domains of the present invention could be derived from any of these alternative protein domains.

An antigen binding fragment or an immunologically effective fragment may comprise partial heavy or light chain variable sequences. Fragments are at least 5, 6, 8 or 10 amino acids in length. Alternatively the fragments are at least 15, at least 20, at least 50, at least 75, or at least 100 amino acids in length.

The term "neutralises" as used throughout the present specification means that the biological activity of IL-1β is reduced in the presence of an antigen binding protein as described herein in comparison to the activity of IL-1β in the absence of the antigen binding protein, *in vitro* or *in vivo*. Neutralisation may be due to one or more of blocking IL-1β binding to its receptor, preventing IL-1β from activating its receptor, down regulating IL-1β or its receptor, or affecting effector functionality.

The reduction or inhibition in biological activity may be partial or total. A neutralising antigen binding protein may neutralise the activity of IL-1β by at least 20%, 30% 40%, 50%, 55%, 60%, 65%, 70%, 75%, 80%, 82%, 84%, 86%, 88%, 90%, 92%, 94%, 95%, 96%, 97%, 98%, 99% or 100% relative to IL-1β activity in the absence of the antigen binding protein.

Neutralisation may be determined or measured using one or more assays known to the skilled person or as described herein. For example, antigen binding protein binding to IL-1β can be assessed in a sandwich ELISA, by BIAcore™, FMAT, FORTEbio, or similar *in vitro* assays, but also in cell-based functional assays.

"CDRs" are defined as the complementarity determining region amino acid sequences of an antigen binding protein. These are the hypervariable regions of immunoglobulin heavy and light chains. There are three heavy chain and three ~~light chain~~ CDRs

(or CDR regions) in the variable portion of an immunoglobulin. Thus, "CDRs" as used herein refers to all three heavy chain CDRs, all three light chain CDRs, all heavy and light chain CDRs, or at least two CDRs.

Throughout this specification, amino acid residues in variable domain sequences and full length antibody sequences are numbered according to the Kabat numbering convention. Similarly, the terms "CDR", "CDRL1", "CDRL2", "CDRL3", "CDRH1", "CDRH2", "CDRH3" used in the Examples follow the Kabat numbering convention. For further information, see Kabat et al., Sequences of Proteins of Immunological Interest, 4th Ed., U.S. Department of Health and Human Services, National Institutes of Health (1987).

It will be apparent to those skilled in the art that there are alternative numbering conventions for amino acid residues in variable domain sequences and full length antibody sequences. There are also alternative numbering conventions for CDR sequences, for example those set out in Chothia et al. (1989) Nature 342: 877-883. The structure and protein folding of the antibody may mean that other residues are considered part of the CDR sequence and would be understood to be so by a skilled person.

Other numbering conventions for CDR sequences available to a skilled person include "AbM" (University of Bath) and "contact" (University College London) methods. The minimum overlapping region using at least two of the Kabat, Chothia, AbM and contact methods can be determined to provide the "minimum binding unit". The minimum binding unit may be a sub-portion of a CDR.

The table below represents one definition using each numbering convention for each CDR or binding unit. The Kabat numbering scheme is used in Table 1 to number the variable domain amino acid sequence. It should be noted that some of the CDR definitions may vary depending on the individual publication used.

	Kabat CDR	Chothia CDR	AbM CDR	Contact CDR	Minimum binding unit
H1	31-35/35A/35B	26-32/33/34	26-35/35A/35B	30-35/35A/35B	31-32
H2	50-65	52-56	50-58	47-58	52-56
H3	95-102	95-102	95-102	93-101	95-101
L1	24-34	24-34	24-34	30-36	30-34
L2	50-56	50-56	50-56	46-55	50-55
L3	89-97	89-97	89-97	89-96	89-96

For nucleotide and amino acid sequences, the term "identical" or "sequence identity" indicates the degree of identity between two nucleic acid or two amino acid sequences when optimally aligned and compared with appropriate insertions or deletions.

The percent identity between two sequences is a function of the number of identical positions shared by the sequences (i.e., % identity = number of identical positions/total number of positions times 100), taking into account the number of gaps, and the length of each gap, which need to be introduced for optimal alignment of the two sequences. The comparison of sequences and determination of percent identity between two sequences can be accomplished using a mathematical algorithm, as described below.

The percent identity between two nucleotide sequences can be determined using the GAP program in the GCG software package, using a NWSgapdna.CMP matrix and a gap weight of 40, 50, 60, 70, or 80 and a length weight of 1, 2, 3, 4, 5, or 6. The percent identity between two nucleotide or amino acid sequences can also be determined using the algorithm of E. Meyers and W. Miller (Comput. Appl. Biosci., 4:11-17 (1988)) which has been incorporated into the ALIGN program (version 2.0), using a PAM120 weight residue table, a gap length penalty of 12 and a gap

penalty of 4. In addition, the percent identity between two amino acid sequences can be determined using the Needleman and Wunsch (J. Mol. Biol. 48:444-453 (1970)) algorithm which has been incorporated into the GAP program in the GCG software package, using either a Blossum 62 matrix or a PAM250 matrix, and a gap weight of 16, 14, 12, 10, 8, 6, or 4 and a length weight of 1, 2, 3, 4, 5, or 6.

By way of example, a polynucleotide sequence may be identical to a reference polynucleotide sequence as described herein (see for example SEQ ID NO: X), that is be 100% identical, or it may include up to a certain integer number of nucleotide alterations as compared to the reference sequence, such as at least 50, 60, 70, 75, 80, 85, 90, 95, 98, or 99% identical. Such alterations are selected from at least one nucleotide deletion, substitution, including transition and transversion, or insertion, and wherein said alterations may occur at the 5' or 3' terminal positions of the reference nucleotide sequence or anywhere between those terminal positions, interspersed either individually among the nucleotides in the reference sequence or in one or more contiguous groups within the reference sequence. The number of nucleotide alterations is determined by multiplying the total number of nucleotides in a reference polynucleotide sequence, by the numerical percent of the respective percent identity (divided by 100) and subtracting that product from said total number of nucleotides in the reference polynucleotide sequence as follows:

$$n_n \leq x_n - (x_n \bullet y),$$

wherein n_n is the number of nucleotide alterations, x_n is the total number of nucleotides in the reference polynucleotide sequence and y is 0.50 for 50%, 0.60 for 60%, 0.70 for 70%, 0.75 for 75%, 0.80 for 80%, 0.85 for 85%, 0.90 for 90%, 0.95 for 95%, 0.98 for 98%, 0.99 for 99% or 1.00 for 100%, $\bullet$ is the symbol for the multiplication operator, and wherein any non-integer product

of x_n and y is rounded down to the nearest integer prior to subtracting it from x_n.

Similarly, a polypeptide sequence may be identical to a polypeptide reference sequence, that is be 100% identical, or it may include up to a certain integer number of amino acid alterations as compared to the reference sequence such that the % identity is less than 100%, such as at least 50, 60, 70, 75, 80, 85, 90, 95, 98, or 99% identical. Such alterations are selected from the group consisting of at least one amino acid deletion, substitution, including conservative and non-conservative substitution, or insertion, and wherein said alterations may occur at the amino- or carboxy-terminal positions of the reference polypeptide sequence or anywhere between those terminal positions, interspersed either individually among the amino acids in the reference sequence or in one or more contiguous groups within the reference sequence. The number of amino acid alterations for a given % identity is determined by multiplying the total number of amino acids in the polypeptide sequence encoded by the polypeptide reference sequence by the numerical percent of the respective percent identity (divided by 100) and then subtracting that product from said total number of amino acids in the polypeptide reference sequence as follows:

$$n_a \leq x_a - (x_a \bullet y),$$

wherein n_a is the number of amino acid alterations, x_a is the total number of amino acids in the reference polypeptide sequence and y is, 0.50 for 50%, 0.60 for 60%, 0.70 for 70%, 0.75 for 75%, 0.80 for 80%, 0.85 for 85%, 0.90 for 90%, 0.95 for 95%, 0.98 for 98%, 0.99 for 99%, or 1.00 for 100%, $\bullet$ is the symbol for the multiplication operator, and wherein any non-integer product of x_a and y is rounded down to the nearest integer prior to subtracting it from x_a. The % identity may be determined across the length of the sequence.

The term "specifically binds" as used throughout the present specification in relation to antigen binding proteins

means that the antigen binding protein binds to a target epitope on IL-1β with a greater affinity than that which results when bound to a non-target epitope. In certain embodiments, specific binding refers to binding to a target with an affinity that is at least 10, 50, 100, 250, 500, or 1000 times greater than the affinity for a non-target epitope. For example, binding affinity may be as measured by routine methods, e.g., by competition ELISA or by measurement of Kd with BIACORE™, KINEXA™ or PROTEON™.

The term "IC50" as used herein means the molar concentration of a substance (antagonist) that reduces the efficacy of a reference agonist or the constitutive activity of a biological target by 50% of an antagonist curve (Top-Bottom) for a particular test substance.

The term "EC50" as used herein means the molar concentration of a substance (agonist) that induces a response by 50% of the maximal effect of a dose-response curve.

Throughout this specification, amino acid residues in variable domain sequences and full length antibody sequences are numbered according to the Kabat numbering convention. For further information, see Kabat et al., Sequences of Proteins of Immunological Interest, 4th Ed., U.S. Department of Health and Human Services, National Institutes of Health (1987).

It will be apparent to those skilled in the art that there are alternative numbering conventions for amino acid residues in variable domain sequences and full length antibody sequences. There are also alternative numbering conventions for CDR sequences, for example those set out in Chothia et al. (1989) Nature 342: 877-883. The structure and protein folding of the antibody may mean that other residues are considered part of the CDR sequence and would be understood to be so by a skilled person.

Other numbering conventions for CDR sequences available to a skilled person include "AbM" (University of Bath) and "contact" (University College London) methods. The minimum overlapping region using at least two of the Kabat, Chothia, AbM and contact

methods can be determined to provide the "minimum binding unit". The minimum binding unit may be a sub-portion of a CDR.

The term "pharmaceutically acceptable carrier" is intended to include solvents, dispersion media, coatings, anti-bacterial and anti-fungal agents, isotonic and absorption delaying agents, and the like. The use of such media and agents for pharmaceutically active substances is well known in the art. Except insofar as any conventional media or agent is incompatible with the compound, use thereof in the therapeutic compositions and methods of treatment and prophylaxis is contemplated. Supplementary active compounds may also be incorporated into the compositions according to the present invention. It is especially advantageous to formulate parenteral compositions in dosage unit form for ease of administration and uniformity of dosage.

Nucleic acid as used herein means any single or double-stranded RNA or DNA molecule, such as mRNA, cDNA, and genomic DNA.

As used herein, the term "about", in the context of concentrations of components of the formulations, typically means +/- 5% of the stated value, more typically +/- 4% of the stated value, more typically +/- 3% of the stated value, more typically, +/- 2% of the stated value, even more typically +/- 1% of the stated value, and even more typically +/- 0.5% of the stated value.

Throughout this disclosure, certain embodiments may be disclosed in a range format. It should be understood that the description in range format is merely for convenience and brevity and should not be construed as an inflexible limitation on the scope of the disclosed ranges. Accordingly, the description of a range should be considered to have specifically disclosed all the possible sub-ranges as well as individual numerical values within that range. For example, description of a range such as from 1 to 6 should be considered to have specifically disclosed sub-ranges such as from 1 to 3, from 1 to 4, from 1 to 5, from 2 to 4, from 2 to 6, from 3 to 6 etc., as well as individual numbers within

that range, for example, 1, 2, 3, 4, 5, and 6. This applies regardless of the breadth of the range.

Disclosure of Optional Embodiments

Exemplary, non-limiting embodiments of an isolated IL-1β specific antigen binding protein will now be disclosed.

In one embodiment the isolated IL-1β specific antigen binding protein comprises one or more binding units selected from the group consisting of the following binding units:

(i) a binding unit L1 comprising Kabat residues 23-35 of SEQ ID NO: 3 or Kabat residues 24-33 of SEQ ID NO: 4, 15 or 16, or a variant thereof which contains at least one amino acid substitution, insertion or deletion in the binding unit L1;

(ii) a binding unit L2 comprising Kabat residues 51-57 of SEQ ID NO: 3 or Kabat residues 49-55 of SEQ ID NO: 4, 15 or 16, or a variant thereof which contains at least one amino acid substitution, insertion or deletion in the binding unit L2;

(iii) a binding unit L3 comprising Kabat residues 92-102 of SEQ ID NO: 3 or Kabat residues 88-96 of SEQ ID NO: 4, 15 or 16, or a variant thereof which contains at least one amino acid substitution, insertion or deletion in the binding unit L3;

(iv) a binding unit H1 comprising Kabat residues 31-35 of SEQ ID NO: 1 or Kabat residues 31-35 of SEQ ID NO: 2 or 14, or a variant thereof which contains at least one amino acid substitution, insertion or deletion in the binding unit H1;

(v) a binding unit H2 comprising Kabat residues 50-66 of SEQ ID NO: 1 or Kabat residues 50-65 of SEQ ID NO: 2 or 14, or a variant thereof which contains at least one amino acid substitution, insertion or deletion in the binding unit H2; and

(vi) a binding unit H3 comprising Kabat residues 99-114 of SEQ ID NO: 1 or Kabat residues 98-108 of SEQ ID NO: 2 or 14, or a variant thereof which contains at least one amino acid substitution, insertion or deletion in the binding unit H3.

In one embodiment the isolated IL-1β specific antigen binding protein comprises a heavy chain and/or a light chain in

which the heavy chain comprises or consists of an amino acid sequence encoded by the nucleotide sequence selected from SEQ ID NO:1 or SEQ ID NO: 2 or 14 and in which the light chain comprises or consists of an amino acid sequence encoded by the nucleotide sequence selected from SEQ ID NO:3 or SEQ ID NO: 4, 15 or 16.

The heavy chain may be selected from the group consisting of α, δ, ε, γ and μ heavy chains. Preferably the heavy chain is γ.

The light chain is preferably selected from λ or κ light chains. Preferably the light chain is λ.

In one embodiment, the Kabat residues 88-96 of SEQ ID NO: 4, 15 or 16 may be selected from residues consisting of the group selected from amino acids 1-9 of SEQ ID NO: 9, SEQ ID NO: 10, SEQ ID NO: 11, SEQ ID NO: 12 or SEQ ID NO: 13.

In one embodiment, the isolated IL-1β specific antigen binding protein neutralizes IL-1β in a cell function neutralization assay at an IC50 value of less than about 20nM.

In another embodiment the isolated IL-1β specific antigen binding protein neutralizes IL-1β in a cell stimulation assay at an IC50 value of less than about 15nM, less than about 10nM, less than about 5nM, less than about 3nM, less than about 1nM, less than about 0.5nM, less than about 0.2nM, less than about 100pM, less than 50pM, less than 10pM, less than 5pM or about 1pM.

In some embodiments, the isolated IL-1β specific antigen binding protein is selected from human IL-1β and cross-reacts with murine or simian IL-1β.

In one embodiment, the isolated IL-1β specific antigen binding protein as described herein inhibits IL-1β induced IL-6 production in a cell inhibition assay at an IC50 value selected from less than about 20nM. In another embodiment, the isolated IL-1β specific antigen binding protein described herein inhibits IL-1β induced IL-6 production in a cell inhibition assay at an IC50 value selected from less than about 15nM, less than about 10nM, less than about 5nM, less than about 4nM, less than about 3nM, less than about 1nM, less than about 0.5nM or less than

about 0.4nM, less than about 300pM, less than about 200pM, less than about 100pM, less than about 50pM, less than about 10pM or less than about 5pM.

In one embodiment the isolated IL-1β specific antigen binding protein binds IL-1β with a K_D value of less than about 10nM. In another embodiment, the isolated IL-1β specific antigen binding protein binds IL-1β with a K_D value of less than less than about 5nM, less than about 2nM, less than about 1nM, less than about 0.5nM, less than about 200pM, less than about 100pM, less than about 5pM or less than about 1pM.

In one embodiment, the isolated, IL-1β specific antigen binding protein neutralizes human IL-1β at an IC50 value of from 1pM to 5nM.

In one embodiment, the isolated, IL-1β specific antigen binding protein neutralizes murine IL-1β at an IC50 value of from 100pM to 15nM.

In one embodiment, the isolated antigen binding protein is capable of specifically binding to IL-1β.

In some embodiments, the isolated antigen binding protein comprises or consists of:

(i) a heavy chain encoded by the nucleotide sequence of SEQ ID NO:1 and a light chain encoded by the nucleotide sequence of SEQ ID NO:3; or

(ii) a heavy chain encoded by the nucleotide sequence of SEQ ID NO:2 or 14 and a light chain encoded by the nucleotide sequence of SEQ ID NO:4, 15 or 16.

In one embodiment the Kabat residues 88-96 of SEQ ID NO: 4, 15 or 16 may be selected from residues consisting of the group selected from amino acids 1-9 of SEQ ID 9, SEQ ID 10, SEQ ID 11, SEQ ID 12 or SEQ ID NO: 13.

In one embodiment, the isolated antigen binding protein or fragment thereof comprises or consists of a amino acid sequence having an identity selected from the group consisting of from at least 50%, at least 60%, at least 70%, at least 80% and at least 90% to SEQ ID NO: 1, 2, 14, 3, 4, 15 or 16.

In one embodiment, the isolated antigen binding protein is an antibody. Preferably, the antibody is monoclonal, polyclonal, bispecific or heteroconjugate.

In one embodiment, the antibody may be fully human.

In one embodiment the isolated antigen binding protein is an antibody selected from the subtype IgG1, IgG2, IgG4 or IgG3.

In one embodiment the isolated antigen binding protein is a single variable domain, a domain antibody, an antigen binding fragment, an immunologically effective fragment, a single chain Fv, a diabody or a tetravalent bispecific antibody (Tandab). In one embodiment, the antigen binding fragment may comprise an arrangement of one or more CDRs on non-antibody protein scaffolds such as a domain.

In one embodiment, the isolated antigen binding protein is recombinant.

In one embodiment, the isolated antigen binding protein comprises an agent selected from the group consisting of an immunoadhesion molecule, an imaging agent, a therapeutic agent and a cytotoxic agent.

The immunoadhesion molecules may comprise one or more of the immunoglobulin (Ig) superfamily of cell adhesion molecules (CAMs), integrins, cadherins, and selectins.

In one embodiment, the imaging agent may be selected from the group consisting of a radiolabel, an enzyme, a fluorescent label, a luminescent label, a bioluminescent label, a magnetic label and biotin.

Suitable examples of radiolabels include but are not limited to 32-Phosphorus or tritium in the form of tritiated thymidine.

Examples of suitable fluorescent labels include cyanine, fluorescein, rhodamine, Alexa Fluors, Dylight fluors, ATTO Dyes and BODIPY Dyes.

Examples of suitable luminescent labels include chemiluminescent labels including but not limited to luminol and

Ruthenium probes and bioluminescent labels including but not limited to luciferin.

In one embodiment, the agent is a therapeutic or cytotoxic agent. The therapeutic or cytotoxic agent may be selected from the group consisting of an anti-metabolite, an alkylating agent, an antibiotic, a growth factor, a cytokine, an anti-angiogenic agent, an anti-mitotic agent, an anthracycline, toxin and an apoptotic agent.

In one embodiment, the isolated antigen binding protein is used in treating cancer, an inflammatory disease or an autoimmune disease selected from the group consisting or arthritis, inflammatory bowel disease, Crohn's disease, rheumatoid arthritis, gout, diabetes, uveitis, cryopyrin-associated periodic syndromes and inflammatory acne.

In one embodiment, the isolated antigen binding protein is used in the preparation of a medicament for the treatment of cancer, an inflammatory disease or an autoimmune disease selected from the group consisting of arthritis, inflammatory bowel disease, Crohn's disease, rheumatoid arthritis, gout, diabetes, uveitis, cryopyrin-associated periodic syndromes and inflammatory acne.

In one embodiment the cryopyrin-associated periodic syndromes may be selected from familial cold autoinflammatory syndrome (FCAS), Muckle-Wells syndrome (MWS), and neonatal-onset multisystem inflammatory disease (NOMID, also called chronic infantile neurologic cutaneous and articular syndrome or CINCA).

In one embodiment, there is provided a composition comprising the antigen binding protein as described herein and a pharmaceutically acceptable carrier.

In one embodiment, the antigen binding protein may be administered by injection. In the case of injectable solutions, the carrier can be a solvent or dispersion medium containing, for example, water, ethanol, polyol (for example, glycerol, propylene glycol, and liquid polyetheylene glycol, and the like), suitable mixtures thereof, and vegetable oils. The proper fluidity can be

maintained, for example, by the use of a coating such as lecithin, by the maintenance of the required particle size in the case of dispersion and by the use of surfactants. Prevention of the action of microorganisms can be achieved by including various anti-bacterial and/or anti-fungal agents. Suitable agents are well known to those skilled in the art and include, for example, parabens, chlorobutanol, phenol, benzyl alcohol, ascorbic acid, thimerosal, and the like. In many cases, it may be preferable to include isotonic agents, for example, sugars, polyalcohols such as mannitol, sorbitol and sodium chloride in the composition. Prolonged absorption of the injectable compositions can be brought about by including in the composition an agent which delays absorption, for example, aluminium monostearate and gelatin.

Sterile injectable solutions can be prepared by incorporating the analogue in the required amount in an appropriate solvent with one or a combination of ingredients enumerated above, as required, followed by filtered sterilisation. Generally, dispersions are prepared by incorporating the analogue into a sterile vehicle which contains a basic dispersion medium and the required other ingredients from those enumerated above.

Preferably, the pharmaceutical composition may further include a suitable buffer to minimise acid hydrolysis. Suitable buffer agent agents are well known to those skilled in the art and include, but are not limited to, phosphates, citrates, carbonates and mixtures thereof.

Single or multiple administrations of the pharmaceutical compositions, according to the invention may be carried out. One skilled in the art would be able, by routine experimentation, to determine effective, non-toxic dosage levels of the compound and/or composition of the invention and an administration pattern which would be suitable for treating the diseases and/or infections to which the compounds and compositions are applicable.

Further, it will be apparent to one of ordinary skill in the art that the optimal course of treatment, such as the number of doses of the compound or composition of the invention given per day for a defined number of days, can be ascertained using convention course of treatment determination tests.

Generally, an effective dosage per 24 hours may be in the range of about 0.0001 mg to about 1000 mg per kg body weight; suitably, about 0.001 mg to about 750 mg per kg body weight; about 0.01 mg to about 500 mg per kg body weight; about 0.1 mg to about 500 mg per kg body weight; about 0.1 mg to about 250 mg per kg body weight; or about 1.0 mg to about 250 mg per kg body weight. More suitably, an effective dosage per 24 hours may be in the range of about 1.0 mg to about 200 mg per kg body weight; about 1.0 mg to about 100 mg per kg body weight; about 1.0 mg to about 50 mg per kg body weight; about 1.0 mg to about 25 mg per kg body weight; about 5.0 mg to about 50 mg per kg body weight; about 5.0 mg to about 20 mg per kg body weight; or about 5.0 mg to about 15 mg per kg body weight.

Alternatively, an effective dosage may be up to about 500mg/m^2. For example, generally, an effective dosage is expected to be in the range of about 25 to about 500mg/m^2, about 25 to about 350mg/m^2, about 25 to about 300mg/m^2, about 25 to about 250mg/m^2, about 50 to about 250mg/m^2, and about 75 to about 150mg/m^2.

In one embodiment, the composition further comprises one or more therapeutic agents as described herein.

There is also provided an isolated cell line that is capable of producing the antigen binding protein as described herein.

Examples of cell lines capable of producing the antigen binding protein include HEK293 and CHO.

There is also provided an isolated nucleic acid molecule comprising or consisting of sequences selected from SEQ ID NO:1 or SEQ ID NO:2 or 14, or fragments thereof.

There is also provided an isolated nucleic acid molecule comprising or consisting of sequences selected from SEQ ID NO:3 or SEQ ID NO:4, 15 or 16, or fragments thereof.

In one embodiment, the isolated nucleic acid molecule or fragment thereof comprises or consists of a nucleotide sequence having an identity selected from the group consisting of from at least 50%, at least 60%, at least 70%, at least 80% and at least 90% to SEQ ID NO: 1, 2, 14, 3, 4, 15 or 16.

There is also provided a vector comprising the nucleic acid molecule as defined herein.

In one embodiment, the vector may be a plasmid or a virus. It will be appreciated by the person of skill in the art that many suitable vectors exist and are included in the scope of the present disclosure.

Preferably, the vector comprises an expression control sequence operably linked to said nucleic acid molecule.

The expression control sequence may be a nucleic acid fragment that promotes, enhances or represses expression of a gene or protein of interest.

There is also provided a host cell comprising the nucleic acid molecule as defined above.

The host cell may be a cultured cell line, an *in vivo* cell or an *ex vivo* cell.

In one embodiment, the host cell comprises the vector as described herein.

There is also provided a method of producing an antigen binding protein as described herein comprising culturing the host cell according as described herein under suitable conditions and recovering said protein therefrom.

There is also provided a method of treating cancer, an inflammatory disease or an autoimmune disease selected from the group consisting of arthritis, inflammatory bowel disease, Crohn's disease, rheumatoid arthritis, gout, diabetes, uveitis, cryopyrin-associated periodic syndromes and inflammatory acne,

wherein the isolated antigen binding protein as described herein is administered to a subject.

Brief Description of Drawings

The accompanying drawings illustrate a disclosed embodiment and serve to explain the principles of the disclosed embodiment. It is to be understood, however, that the drawings are designed for purposes of illustration only, and not as a definition of the limits of the invention.

Figure 1 shows the neutralization of IL-1β by Fab clones 1H and 2H. IL-1β neutralization was measured based on the optical density (OD) read at 655nm and the concentration of Fab. The results show that clones 1H and 2H block the activation of IL-1β with an IC50 of 1.31 and 0.21 respectively.

Figure 2 shows the sequencing results of the heavy and light chains of the 1H and 2H Fab clones.

Figure 3 shows the neutralization of human IL-1β by IgG1 1H and 2H. IL-1β neutralization was measured based on the optical density (OD) read at 655nm and the concentration of IgG. The results show that clones 1H and 2H neutralize human IL-1β with a potency (EC50) of 2.6 nM and 0.17 nM respectively.

Figure 4 shows the neutralization of mouse IL-1β by IgG1 1H and 2H. IL-1β neutralization was measured based on the optical density (OD) read at 655nm and the concentration of IgG. The results show that clones 1H and 2H neutralized mouse IL-1β with a potency (EC50) of 11.5 nM and 1.5 nM respectively.

Figure 5 shows that IgG 1H and 2H inhibit human IL-1β-induced IL-6 production in MRC5 cells. Human IL-1β neutralizing potency was determined by measuring the level of IL-6 produced in the presence of IgG 1H and 2H. MRC5 cells were stimulated by 4 pM of IL-1β together with various concentrations of IgG 1H and 2H. The results show that IgG 1H and 2H have an inhibition potency (EC50) of 3.92 nM and 0.35 nM respectively.

Figure 6 shows that IgG 2H inhibits the human IL-1β induced IL-6 production in vivo in Balb/c mice. Neutralizing potency of IgG 2H was assessed by injecting mice intraperitoneally with 4 or 20 mg/kg of 2H or 400 µL of PBS and human IL-1β or PBS the following day. The blood was collected and IL-6 measured by ELISA. The results show that IgG 2H was able to inhibit human IL-1β induced production of IL-6 in mice in a dose dependent manner.

Figure 7 shows that IgG 2H is specific for IL-1β and does not recognize IL-1α. Binding specificity of IgG 2H was determined based on the optical density (OD) at 460 nm and the concentration of IgG 2H. The results show that while IgG 2H bound to both human and mouse IL-1β in a dose dependent manner, it failed to bind to either human or mouse IL-1α.

Figures 8 and 9 show the neutralization potency of 5 IgG clones obtained from the affinity maturation of IgG 2H. Neutralization potency was determined based on the concentration of secreted IL-6 against the concentration of each of the IgG clones. The results show that all matured IgG clones presented high neutralization potency for both mouse and human IL-1β. The results also show that matured clones were 2 to 8-fold more effective in neutralizing mouse IL-1β (Figure 8) and 3 to 23-fold more effective in neutralizing human IL-1β (Figure 9) than the non-matured IgG 2H.

Figure 10 shows the sequence of P2D7KK. P2D7KK was derived from P2D7 by changing one arginine and one serine residue by lysine residues (bold and underlined) at positions 75 and 81 of the heavy chain variable region.

Figure 11 shows arthritic scores in DBA mice after induction of arthritis with anti-collagen antibodies. Mice were injected either with 5 mg/kg isotype, 5 mg/kg P2D7KK or 15 mg/kg P2D7KK. The results show that mice treated with P2D7KK had much lower arthritic scores than mice injected with the isotype control.

Figure 12 shows a representative front (top) and hind (bottom) paw swelling after arthritis induction and administration of isotype control (left), P2D7KK 5mg/kg (middle) ~~or P2D7KK 15mg/kg~~

(right). The results show that P2D7KK clearly contained inflammation as mice treated with P2D7KK did not experience swelling of the paws as compared to mice injected with the isotype control.

Figure 13 shows a representative histological analysis of front (top) and hind (bottom) paws joints from mice injected with the isotype antibody (left) or treated with either 5mg/kg (middle) or 15mg/kg (right) of P2D7KK. The results show that in mice treated with P2D7KK, joints remain virtually free of immune cell infiltration while joints of isotype-injected mice were the site of a highly inflammatory reaction.

Figure 14 shows infiltration of immune cells in the peritoneal cavity after injection of PBS (1) or monosodium urate crystals followed by administration of PBS (2), Anakinra 30mg/kg (3), isotype human antibody 15mg/kg (4), P2D7KK 5mg/kg (5) or P2D7KK 15mg/kg (6). Shown are means±s.e.m. Unpaired t-test: * $p<0.05$; ** $p<0.01$; *** $p<0.001$; n.s. not significant.

Figure 15 shows tumour growth between days 7 and 17 post carcinoma cell inoculation in mice treated with P2D7KK or with the isotype control. Shown are means±SD, 2-way ANOVA test (Turkey's multiple comparison) * = $p<0.05$.

Figure 16 shows absolute numbers of cells in mice auricular draining lymph nodes. Graph 1 represents mice not infected with *P. acnes;* graph 4 represents mice infected with *P. acnes* and injected with PBS; graph 3 represents mice infected with *P. acnes* and injected with isotype control; graph 2 represents mice infected with *P. acnes* and treated with P2D7KK.

Figure 17 shows the number of lymphocytes in epidermis of mice not infected with *P. acnes* (first bar from the left of each group), infected with *P. acnes* and injected with PBS (second bar from the left of each group), infected with *P. acnes* and injected with isotype control (third bar from the left of each group), or infected with *P. acnes* and treated with P2D7KK (fourth bar from the left of each group). p-values refer to an unpaired t-test.

Examples

Non-limiting examples of the invention, including the best mode, and a comparative example will be further described in greater detail by reference to specific Examples, which should not be construed as in any way limiting the scope of the invention.

Example 1 - Isolation of the anti-human IL-1β antibodies and characterization of the IL-1β neutralization capacity in cell-based assays

Anti-IL-1β antibodies were isolated from a human antibody phage display library (Humanyx HX-02 library) via *in vitro* selection. IL-1β specific monoclonal antibodies in the Fab format were initially identified by ELISA. These ELISA-positive Fabs were added to HEK-Blue™ IL-1β cells (InvivoGen, USA) which is an engineered HEK293 cell line that overexpresses recombinant human IL-1 receptor.

Binding of IL-1β to its receptor IL-1R on the surface of HEK-Blue™ IL-1β cells triggers a signaling cascade leading to the activation of NF-kB and the subsequent production of secreted alkaline phosphatase (SEAP). Detection of SEAP in the supernatant of HEK-Blue™ IL-1β cells can be readily assessed using QUANTI-Blue™, a colorimetric SEAP substrate. The HEK-Blue cells are sensitive to both human and mouse IL-1β, but are insensitive to human IL-1α or TNF-α.

Of the 22 ELISA-positive Fabs, two clones, 1H and 2H, were found to block the activation of the HEK-Blue IL-1β cells by IL-1β stimulation with IC_{50} (concentration inhibiting 50% of IL-1β activity) of 1.31 and 0.21 nM, respectively (Fig. 1). Sequencing results revealed that both clones possessed λ light chain. Sequences of the heavy and light chains of clones 1H and 2H are shown in Fig. 2.

Example 2 - Neutralization of IL-1β by IgG1 1H and 2H in the HEK-Blue cell assay

The two Fab clones 1H and 2H were converted into full length IgG by amplifying the heavy and light chains of each clone separately by PCR and cloning into the mammalian cell expression vector. The resulting plasmids, with human IgG1 subtype, were subsequently used for full length antibody expression by transient transfection into mammalian cells. Antibodies were purified by Protein G column.

Human IL-1β

The neutralizing potency of the IgG clone 1H and 2H on human IL-1β was then assayed using HEK-Blue cells as described above. Cells were stimulated with 4 pM human IL-1β together with various concentrations of the antibody. The dose-response curve was fitted by the sigmoidal non-linear regression (variable slope) equation from which the EC_{50} (the half maximal effective concentration) is calculated. In this assay clones 1H and 2H neutralized human IL-1β with potency (EC_{50}) of 2.6 nM and 0.17 nM, respectively (Fig. 3).

Mouse IL-1β

The neutralizing potency of the IgG clone 1H and 2H on mouse IL-1β was examined using HEK-Blue cells as described above. However, cells were stimulated with mouse IL-1β together with various concentrations of the antibody. In this assay clones 1H and 2H neutralized mouse IL-1β with potency (EC_{50}) of 11.5 nM and 1.5 nM, respectively (Fig. 4).

Example 3 - Inhibition of human IL-1β induced IL-6 production IgG 1H and 2H

In vitro

Inhibition of human IL-1β induced IL-6 production by IgG 1H and 2H was examined in vitro using the human fibroblast cell line, MRC5. Stimulation of the human lung fibroblast cell, MRC5, by IL-1β results in IL-6 production.

The human IL-1β neutralizing potency of IgG 1H and 2H was examined by measuring the level of IL-6 produced in the presence of the antibodies. Cells were stimulated with human IL-1β together with various concentrations of the antibodies, and the IL-6 was quantified by ELISA. In this assay, IgG 1H and 2H showed inhibition potency (EC_{50}) of 3.92 and 0.35 nM, respectively (Fig. 5).

In vivo

Inhibition of human IL-1β induced IL-6 production by IgG 1H and 2H was examined in vivo in Balb/C mice. Administration of human IL-1β into Balb/c mice is followed by a rapid secretion of mouse IL-6 that is detectable in the serum by ELISA.

To assess the neutralizing potency of IgG 2H, mice were injected intraperitoneally with 4 or 20 mg/kg of 2H or with 400 µL of PBS. The following day, mice received human IL-1β or PBS (negative control). Two hours after IL-1β injection, blood was collected and IL-6 was measured in the serum by ELISA.

The results showed that 2H was able to inhibit the human IL-1β-induced production of IL-6 in mice in a dose-dependent manner (Fig. 6).

Example 4 - Specificity of IgG 2H

The binding specificity of IgG 2H was examined against the two subtypes of IL-1, α and β, by direct ELISA. The results show that while IgG 2H bound to both human and mouse IL-1β in a dose

dependent manner, it failed to bind to either human or mouse IL-1α at the concentration range tested (Fig. 7). Thus, IgG 2H displayed strong selectivity for IL-1β over IL-1α. Accordingly, IgG 2H is specific for IL-1β and does not recognize IL-1α.

Example 5 – Affinity maturation of IgG 2H

IgG 2H was affinity matured using the phage-display method and 5 matured clones with mutations in the CDR3 region of the light chain were selected after IL-1β neutralization assay on MRC5 cells.

All matured IgG clones presented high neutralization potency for both mouse and human IL-1β in this assay. Matured clones were 2 to 8-fold more effective in neutralizing mouse IL-1β and 3 to 23-fold more effective in neutralizing human IL-1β than the initial IgG 2H, with potency ranging from EC_{50} of 158.4 to 623.2pM for the mouse cytokine (Fig. 8) and EC_{50} from 6.5 to 45.3pM for its human counterpart (Fig. 9)

Matured clones (except P1E8) were tested for affinity towards mouse and human IL-1β using the ProteOn bioanalyzer (BioRad, Hercules, USA).

The results showed that affinities for mouse IL-1β were 3 to 13-fold higher for matured clones compared to IgG 2H and 8 to 25-fold higher regarding human IL-1β (Table 1).

	142	78.3
	10.9	3.1
	16.6	4.57

[redacted]	23.6	6.73
[redacted]	48.9	10.1

Table 1: Affinities of matured clones towards mouse and human IL-1β compared to IgG 2H.

Sequences of affinity matured clones

The matured clones were sequenced and the amino acid sequences of their light chain CDR3 region are presented in the Table 2.

[redacted]	QAWDSNIEV
[redacted]	YAWDNAYEV
[redacted]	EAWDAAAEV
[redacted]	QAWADSFEV
[redacted]	YAWADTYEV
[redacted]	EAWADTYEV

Table 2: Amino acid sequences of the light chain CD3 region of each of the matured clones.

The corresponding nucleotide sequences of the light chain CDR3 regions after reverse translation are presented below:

```
>2H
CAGGCGTGGGACAGCAACATTGAAGTA  (original 2H sequence)
  A  T     TTCT  T  C  G  T  (sequences encoding
     A        A     A     C   the same amino-acids)
     C        G           G

>P1D9
TATGCTTGGGATAATGCTTATGAAGTT
  C  C     C  C  C  C  G  C
```

```
     A          A          A
     G          G          G

>P1E8
GAAGCTTGGGATGCTGCTGCTGAAGTT
  G  C     C  C  C  C  G  C
     A        A  A  A     A
     G        G  G  G     G

>P1H8
CAAGCTTGGGCTGATTCTTTTGAAGTT
  G  C     C  CAGC  C  G  C
     A     A     A        A
     G     G     G        G

>P2D7
TATGCTTGGGCTGATACTTATGAAGTT
  C  C     C  C  C  C  G  C
     A     A     A        A
     G     G     G        G

>P2D8
GAAGCTTGGGCTGATACTTATGAAGTT
  G  C     C  C  C  C  G  C
     A     A     A        A
     G     G     G        G
```

Example 6 - In vivo efficacy of P2D7KK

Derivation of P2D7KK

Out of the 5 affinity matured clones, P2D7 was selected and engineered to be a germline-like antibody, named P2D7KK. P2D7KK was derived from P2D7 by changing one arginine and one serine

residues by lysine residues in positions 75 and 81 of the heavy chain variable region (Fig. 10).

P2D7KK was then tested for preliminary in vivo efficacy in 4 different animal models of disease (1) CAIA: collagen antibody-induced arthritis, a model of rheumatoid arthritis, (2) MSU: monosodium urate crystals-induced inflammation, a model mimicking gout, (3) RCC: renal cell carcinoma growth, to evaluate the use of IL-1β antibody in the tumour microenvironment to inhibit tumour growth and (4) P. acnes: a model of inflammatory acne using Propionibacterium acnes.

CAIA - collagen antibody-induced arthritis

Arthritis was induced in Balb/c mice by intraperitoneal injection of 1.5 mg/mouse of anti-collagen antibody cocktail at day 0, followed by injection of 25 µg of lipopolysaccharide (LPS) at day 3.

A group of 8 mice received 5 mg/kg of P2D7KK intraperitoneally at days 2, 5 and 9. Another group received 15 mg/kg of P2D7KK and one control group received 5 mg/kg of the isotype control following the same schedule.

The results showed that mice treated with P2D7KK have much lower arthritic scores than mice injected with the isotype control (Fig. 11). Accordingly, administration of P2D7KK inhibited the development of arthritis.

The results also showed that P2D7KK clearly contained inflammation as mice treated with P2D7KK did not experience swelling of the paws as did the mice injected with an isotype antibody (Fig. 12).

Histological analyses of hind paws showed that in mice treated with P2D7KK, joints remains virtually free of immune cells infiltration while joints of isotype-injected mice were the site of a highly inflammatory reaction (Fig. 13).

MSU - monosodium urate crystals-triggered inflammation

Six groups of C57/BL6 mice were injected intraperitoneally with 3mg of monosodium urate in 200µL of PBS, or PBS alone for the control group. Mice were then injected with:

- P2D7KK 5mg/kg in 300µL of PBS (n=5)
- P2D7KK 15mg/kg in 300µL of PBS (n=4)
- Isotype antibody 15mg/kg in 300µL of PBS (n=5)
- Anakinra 30mg/kg in 300µL of PBS 9n=5)
- 300µL of PBS (n=3, vehicle control group)
- 300µL of PBS (n=5, no MSU control group)

Six hours after antibody administration, mice were culled and peritoneum lavaged with 5mL of cold complete media. Neutrophils and monocytes were counted in lavage fluid by flow cytometry.

The results showed that injection of MSU in the peritoneum induces recruitment of neutrophils and monocytes. Like Anakinra, P2D7KK was able to significantly reduce infiltration of neutrophils (at both 15 and 5mg/kg) and monocytes (only at 15mg/kg) in the peritoneal cavity (Fig. 14).

RCC - human renal cell carcinoma xenograft

Female SCID mice aged 6-8 weeks were injected intramuscularly with $2x10^6$ RCC4 cells. One group of 6 mice then received 100µg/mouse of P2D7KK injected in the tumour site, on days 1, 3, 5, 7 and 9 post-tumour inoculation. Another group of 6 mice received the isotype control antibody.

Tumour growth was monitored every 2 days between days 7 and 17.

The results showed that P2D7KK significantly reduced tumour growth in the treated mice (Fig. 15).

P. acnes - inflammatory acne

C57/BL6 mice were injected intraperitoneally with 400µg of either P2D7KK or the isotype control at day -1 and at day 1. At day 0, mice were infected with 10^8 colony-forming units of *Propionibacterium acnes* in the right ear and received PBS in the left ear. Some control mice were not infected, some were infected but did not receive any antibody.

Immune parameters in the dermis and in the epidermis were assessed on days 2, 5 and 9.

The results showed that at day 9, P2D7KK reduced the inflammation as observed by the cell number decrease in the lymph nodes (Fig. 16). Without being bound by theory, it is likely that P2D7KK reduces lymphocytes infiltration in the epidermis (Fig. 17).

Accordingly, P2D7KK showed *in vivo* efficacy in 4 different models of human disease, namely rheumatoid arthritis, gout, renal cell carcinoma and inflammatory acne.

Applications

It will be apparent that various other modifications and adaptations of the invention will be apparent to the person skilled in the art after reading the foregoing disclosure without departing from the spirit and scope of the invention and it is intended that all such modifications and adaptations come within the scope of the appended claims.

Claims

1. An isolated monoclonal antibody which specifically binds to IL-1β, or an antigen binding fragment thereof, wherein said antibody or fragment thereof comprises the following Complementarity Determining Regions (CDRs):

(i) a heavy chain variable region CDR H1 comprising the amino acid sequence DYYWS,

(ii) a heavy chain variable region CDR H2 comprising the amino acid sequence EIDHSGSTNYNPSLKS,

(iii) a heavy chain variable region CDR H3 comprising the amino acid sequence ASPSSGWTLDY,

(iv) a light chain variable region CDR L1 comprising the amino acid sequence GDKLGDKFAF,

(v) a light chain variable region CDR L2 comprising the amino acid sequence LDNKRPS, and

(vi) a light chain variable region CDR L3 comprising an amino acid sequence selected from the group consisting of: YAWADTYEV, QAWADSFEV, YAWDNAYEV, EAWDAAAEV, and EAWADTYEV.

2. The isolated monoclonal antibody or fragment thereof of claim 1, wherein the light chain variable region CDR L3 comprises the amino acid sequence YAWADTYEV.

3. The isolated monoclonal antibody or fragment thereof of claim 1, wherein the light chain variable CDR3 comprises the amino acid sequence QAWADSFEV.

4. The isolated monoclonal antibody or fragment thereof of claim 1, wherein the light chain variable CDR3 comprises the amino acid sequence YAWDNAYEV.

5. The isolated monoclonal antibody or fragment thereof of claim 1, wherein the light chain variable CDR3 comprises the amino acid sequence EAWDAAAEV.

6. The isolated monoclonal antibody or fragment thereof of claim 1, wherein the light chain variable CDR3 comprises the amino acid sequence EAWADTYEV.

7. An isolated monoclonal antibody which specifically binds to IL-1β, or an antigen binding fragment thereof, wherein said antibody or fragment thereof comprises:

(i) a light chain sequence comprising the amino acid sequence of SEQ ID NO: 17; and

(ii) a heavy chain sequence comprising the amino acid sequence of SEQ ID NO: 18 or SEQ ID NO:2.

8. The isolated monoclonal antibody or fragment thereof of claim 7, wherein the heavy chain sequence comprises the amino acid sequence of SEQ ID NO: 18.

9. The isolated monoclonal antibody or fragment thereof of claim 8, wherein the heavy chain sequence comprises the amino acid sequence of SEQ ID NO: 14.

10. The isolated monoclonal antibody or fragment thereof of claim 7, wherein the heavy chain sequence comprises the amino acid sequence of SEQ ID NO:2.

11. The isolated monoclonal antibody or fragment thereof of any one of claims 1-10, which is fully human.

12. The isolated monoclonal antibody or fragment thereof of any one of claims 1-11, wherein the IL-1β is human.

13. The isolated monoclonal antibody or fragment thereof of any one of claims 1-12, which is the antibody of the subtype IgG1, IgG2, IgG3 or IgG4.

14. The isolated monoclonal antibody or fragment thereof of claim 13, wherein the antibody is of the subtype IgG4.

15. A composition comprising the isolated antibody or fragment thereof of any one of claims 1-14 and a pharmaceutically acceptable carrier.

16. An isolated nucleic acid encoding the isolated monoclonal antibody or fragment thereof of any one of claims 1-14, wherein the nucleic acid comprises: a first sequence encoding the light chain or the light chain variable region of said antibody or fragment, and a second sequence encoding the heavy chain or the heavy chain variable region of said antibody or fragment.

17. A set of two isolated nucleic acids which together encode the isolated antibody or fragment thereof of any one of claims 1-14, wherein: the first nucleic acid comprises a sequence encoding the light chain or the light chain variable region of said antibody or fragment, and the second nucleic acid comprises a sequence encoding the heavy chain or the heavy chain variable region of said antibody or fragment.

18. A vector comprising the isolated nucleic acid molecule of claim 16, or the set of two isolated nucleic acids of claim 17.

19. A host cell comprising the isolated nucleic acid of claim 16, or the set of two isolated nucleic acids of claim 17.

20. A method of producing the isolated monoclonal antibody or fragment thereof of any one of claims 1-14, comprising culturing the

host cell of claim 19 under suitable conditions and recovering said antibody or fragment therefrom.

21. An isolated cell line that is capable of producing the isolated monoclonal antibody or fragment thereof of any one of claims 1-14.

22. The isolated monoclonal antibody or fragment thereof of any one of claims 1-14 or the composition of claim 15 for use in therapy.

23. Use of the isolated monoclonal antibody or fragment thereof of any one of claims 1-14 or the composition of claim 15, in the preparation of a medicament for the treatment of an autoimmune disease.

24. Use of the isolated monoclonal antibody or fragment thereof of any one of claims 1-14 or the composition of claim 15, in the preparation of a medicament for the treatment of arthritis, inflammatory bowel disease, Crohn’s disease, rheumatoid arthritis, gout, diabetes, uveitis, cryopyrin-associated periodic syndromes or inflammatory acne.

25. Use of the isolated monoclonal antibody or fragment thereof of any one of claims 1-14 or the composition of claim 15, in the preparation of a medicament for the treatment of an inflammatory disease.

26. The use of claim 25, wherein the inflammatory disease is arthritis, gout or inflammatory acne.

27. Use of the isolated monoclonal antibody or fragment thereof of any one of claims 1-14 or the composition of claim 15, in the preparation of a medicament for the treatment of cancer.

28. Use of the isolated monoclonal antibody or fragment thereof of any one of claims 1-14 or the composition of claim 15, in the preparation of a medicament for reducing tumor growth.

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Arg Ala Ser Pro Ser Ser Gly Trp Thr Leu Asp Tyr Trp Gly Gln Gly
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Asn Ser Gly Ala Leu Thr Ser Gly Val His Thr Phe Pro Ala Val Leu
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Gln Ser Ser Gly Leu Tyr Ser Leu Ser Ser Val Val Thr Val Pro Ser
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Phe Gly Gly Gly Thr Lys Leu Thr Val Leu Gly Gln Pro Lys Ala Ala
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Thr Leu

IL-1β Neutralizing Human Monoclonal Antibodies

Abstract

The present invention is directed to antigen binding proteins and in particular to IL-1β antigen binding proteins. The present invention further provides compositions comprising the antigen binding proteins, use of the antigen binding proteins and methods for production.

No Suitable Figure