ANTI-BCMA HEAVY CHAIN-ONLY ANTIBODIES

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority benefit of the filing date of US Provisional Patent Application Serial No. 62/437,588, filed on December 21, 2016, the disclosure of which application is herein incorporated by reference in its entirety.

FIELD OF THE INVENTION

[0002] The present invention concerns anti-BCMA heavy chain-only antibodies (HCAb). The invention further concerns methods of making such antibodies, compositions, including pharmaceutical compositions, comprising such antibodies, and their use to treat a B-cell disorder characterized by the expression of BCMA.

BACKGROUND OF THE INVENTION

B-Cell Maturation Antigen (BCMA)

[0003] BCMA, also known as tumor necrosis factor superfamily member 17 (TNFRSF17) (UniProt Q02223), is a cell surface receptor exclusively expressed on plasma cells and plasmablasts. BCMA is a receptor for two ligands in the tumor necrosis factor (TNF) superfamily: APRIL (a proliferation-inducing ligand, also known as TNFSF13; TALL-2 and TRDL-1; the high affinity ligand for BCMA) and B cell activation factor (BAFF) (also known as BLyS; TALL-1; THANK; zTNF4; TNFSF20; and D8Ertd387e; the low affinity ligand for BCMA). APRIL and BAFF are growth factors that bind BCMA and promote survival of plasma cells. BCMA is also highly expressed on malignant plasma cells in human multiple myeloma (MM). Antibodies binding to BCMA are described, for example, in Gras et al., 1995, *Int. Immunol*. 7:1093-1106, WO200124811 and WO200124812. Anti-BCMA antibodies that cross-react with TACI are described in WO2002/066516. Bispecific antibodies against BCMA and CD3 are described, for example, in US 2013/0156769 A1 and US 2015/0376287 A1. An anti-BCMA antibody-MMAE or -MMAF conjugate has been reported to selectively induce killing of multiple myeloma cells (Tai et al., *Blood* 2014, 123(20): 3128-38). Ali et al., *Blood* 2016, 128(13):1688-700, have reported that in a clinical trial (#NCT02215967) chimeric antigen receptor (CAR) T cells targeting BCMA resulted in remission of multiple myeloma in human patients.

Heavy Chain-Only Antibodies

[0004] In a conventional IgG antibody, the association of the heavy chain and light chain is due in part to a hydrophobic interaction between the light chain constant region and the CH1 constant domain of the heavy chain. There are additional residues in the heavy chain framework 2 (FR2) and framework 4 (FR4) regions that also contribute to this hydrophobic interaction between the heavy and light chains.

[0005] It is known, however, that sera of camelids (sub-order Tylopoda which includes camels, dromedaries and llamas) contain a major type of antibodies composed solely of paired H-chains (heavy-chain only antibodies or HCAbs). The HCAbs of *Camelidae* (*Camelus dromedarius, Camelus bactrianus, Lama glama, Lama guanaco, Lama alpaca* and *Lama vicugna*) have a unique structure consisting of a single variable domain (VHH), a hinge region and two constant domains (CH2 and CH3), which are highly homologous to the CH2 and CH3 domains of classical antibodies. ubtype. These HCAbs lack the first domain of the constant region (CH1) which is present in the genome, but is spliced out during mRNA processing. The absence of the CH1 domain explains the absence of the light chain in the HCAbs, since this domain is the anchoring place for the constant domain of the light chain. Such HCAbs naturally evolved to confer antigen-binding specificity and high affinity by three CDRs from conventional antibodies or fragments thereof (Muyldermans, 2001; *J Biotechnol* 74:277–302; Revets et al., 2005; *Expert Opin Biol Ther* 5:111–124). Cartilaginous fish, such as sharks, have also evolved a distinctive type of immunoglobulin, designated as IgNAR, which lacks the light polypeptide chains and is composed entirely by heavy chains. IgNAR molecules can be manipulated by molecular engineering to produce the variable domain of a single heavy chain polypeptide (vNARs) (Nuttall et al. *Eur. J. Biochem.* 270, 3543-3554 (2003); Nuttall et al. *Function and Bioinformatics* 55, 187-197 (2004); Dooley et al., *Molecular Immunology* 40, 25-33 (2003)).

[0006] The ability of heavy chain-only antibodies devoid of light chain to bind antigen was established in the 1960s (Jaton *et al.* (1968) *Biochemistry*, 7, 4185-4195). Heavy chain immunoglobulin physically separated from light chain retained 80% of antigen-binding activity relative to the tetrameric antibody. Sitia et al. (1990) *Cell*, 60, 781-790 demonstrated that removal of the CH1 domain from a rearranged mouse μ gene results in the production of a heavy chain-only antibody, devoid of light chain, in mammalian cell culture. The antibodies produced retained VH binding specificity and effector functions.

[0007] Heavy chain antibodies with a high specificity and affinity can be generated against a variety of antigens through immunization (van der Linden, R. H., et al. *Biochim. Biophys. Acta.* 1431, 37-46 (1999)) and the VHH portion can be readily cloned and expressed in yeast (Frenken, L. G. J., *et al. J. Biotechnol.* 78, 11-21 (2000)). Their levels of expression, solubility and stability are significantly higher than those of classical F(ab) or Fv fragments (Ghahroudi, M. A. et al. *FEBS Lett.* 414, 521-526 (1997)).

[0008] Mice in which the λ (lambda) light (L) chain locus and/or the λ and κ (kappa) L chain loci have been functionally silenced and antibodies produced by such mice are described in U.S. Patent Nos. 7,541,513 and 8,367,888. Recombinant production of heavy chain-only antibodies in mice and rats has been reported, for example, in WO2006008548; U.S. Application Publication No. 20100122358; Nguyen et al., 2003, *Immunology*; 109(1), 93-101; Brüggemann *et al.*, *Crit. Rev. Immunol.*; 2006, 26(5):377-90; and Zou *et al.,* 2007, *J Exp Med*; 204(13): 3271–3283. The production of knockout rats via embryo microinjections of zinc-finger nucleases is described in Geurts et al., 2009, *Science*, 325(5939):433. Soluble heavy chain-only antibodies and transgenic rodents comprising a heterologous heavy chain locus producing such antibodies are described in U. S. Patent Nos. 8,883,150 and 9,365,655. CAR-T structures comprising single-domain antibodies as binding (targeting) domain are described, for example, in Iri-Sofla *et al.*, 2011, *Experimental Cell Research* 317:2630-2641 and Jamnani *et al.*, 2014, *Biochim Biophys Acta*, 1840:378-386.

SUMMARY OF THE INVENTION

[0009] The present concerns anti-BCMA antibodies.

[0010] In one aspect, the invention concerns a heavy chain-only antibody binding to human B-Cell Maturation Antigen (BCMA) comprising a heavy chain variable region comprising:

(a) a CDR1 having at least 95% sequence identity to any of the sequences of SEQ ID NOs: 1 to 4; and/or

(b) a CDR2 having at least 95% sequence identity to any of the sequence of SEQ ID NOs: 5 to 18; and/or

(c) a CDR3 having at least 95% sequence identity to SEQ ID NO: 19.

[0011] In one embodiment, the CDR1, CDR2, and CDR3 sequences are present in a human framework.

[0012] In another embodiment, the anti-BCMAheavy chain-only antibody further comprises a heavy chain constant region sequence in the absence of a CH1 sequence.

[0013] In yet another embodiment, the heavy chain-only antibody comprises:

(a) a sequence selected from the group consisting of SEQ ID NOs: 1 to 4; and/or

(b) a CDR2 sequence sselected from the group consisting of SEQ ID NOs: 5 to 18; and/or

(c) a CDR3 of SEQ ID NO: 19.

[0014] In a further embodiment, the nti-BCMA heavy chain-only antibody comprises:

(a) a CDR1 sequence selected from the group consisting of SEQ ID NOs: 1 to 4; and

(b) a CDR2 sequence selected from the group consisting of SEQ ID NOs: 5 to 18; and

(c) a CDR3 of SEQ ID NO: 19.

[0015] In a still further embodiment, the heavy chain-only anti-BCMA antibody comprises a heavy chain variable region having at least 95% sequence identity to any of the sequences of SEQ ID NOs: 20 to 53.

[0016] In another embodiment, the heavy chain-only anti-BCMA antibody comprises a heavy chain variable region sequence selected from the group consisting of SEQ ID NOs: 10 to 53.

[0017] In another aspect, the invention concerns a heavy chain-only antibody binding to human B-Cell Maturation Antigen (BCMA) comprising a heavy chain variable region comprising a heavy chain variable comprising

(a) a CDR1 sequence of the formula:

G F T F X1 X2 Y A

where

X1 is S or T; and

X2 is S, N or R; and

(b) CDR2 sequence of the formula:

X3 X4 X5 X6 G X7 X8 X9

where

X3 is I or L;

X4 is S, T, I or V;

X5 is G or E;

X6 is S, G, N or D;

X7 is G, D or A;

X8 is S, T or N;

X9 is T or S, and

(c) A CDR3 sequence of SEQ ID NO: 19

in a human VH framework.

[0018] In a further aspect, the invention concerns a heavy chain-only antibody binding to human B-Cell Maturation Antigen (BCMA) comprising a heavy chain variable region comprising CDR1, CDR2 and CDR3 sequences in a human VH framework wherein the CDR sequences are a sequence with at least 95% identity to a CDR sequence selected from the group consisting of SEQ ID NOs:1-19.

[0019] In one embodiment, such antibody comprises a heavy chain variable region comprising CDR1, CDR2 and CDR3 sequences in a human VH framework wherein the CDR sequences are selected from the group consisting of SEQ ID NOs:1-19.

[0020] In a further aspect, the invention concerns a heavy chain-only antibody binding to human B-Cell Maturation Antigen (BCMA) comprising a heavy chain variable region comprising

(a) a CDR1 of SEQ ID NO: 1, a CDR2 of SEQ ID NO: 5; and a CDR3 of SEQ ID NO: 19; or

(b) a CDR1 of SEQ ID NO: 2, a CDR2 of SEQ ID NO: 5; and a CDR3 of SEQ ID NO: 19 in a human VH framework.

[0021] In one embodiment, the heavy chain-only antibody is multi-specific, such as bispecific.

[0022] In another embodiment, the heavy chain-only antibody has binding affinity to two different BCMA proteins.

[0023] In yet another embodiment, the heavy chain-only antibody has binding affinity to two different epitopes on the same BCMA protein.

[0024] In a further embodiment, the heavy chain-only antibody has binding affinity to an effector cell.

[0025] In a still further embodiment, the heavy chain-only antibody has binding affinity to a T-cell antigen.

[0026] In another embodiment, the heavy chain-only antibody has binding affinity to CD3.

[0027] In a different aspect, the heavy chain-only antibody hereinabove described is in a CAR-T format.

[0028] In a further aspect, the invention concerns a pharmaceutical composition comprising an anti-BCMA heavy chain-only antibody herein.

[0029] In a still further aspect, the invention concerns a method for the treatment of a B-cell disorder characterized by the expression of BCMA comprising administering to a subject with such disorder an anti-BCMA heavy chain-only antibody herein, or a pharmaceutical composition comprising such antibody.

[0030] In various embodiments, the B-cell disorder may, for example, be multiple myeloma or systemic lupus erythematosus.

[0031] In a further aspect, the invention concerns a polynucleotide encoding an anti-BCMA heavy chain-only antibody herein.

[0032] In a still further aspect, the invention concerns a vector comprising a polynucleotide encoding an anti-BCMA heavy chain-only antibody herein.

[0033] In another aspect, the invention concerns a cell comprising a polynucleotide encoding an anti-BCMA heavy chain-only antibody herein, or a vector comprising such polynucleotide.

[0034] In yet another aspect, the invention concerns a method of producing an antibody herein, comprising growing a cell as hereinabove described under conditions permissive for expression of the antibody, and isolating the antibody from the cells.

[0035] In a further aspect, the invention concerns a method of making an anti-BCMA heavy chain-only antibody as described herein, comprising immunizing a UniRat animal with BCMA and identifying BCMA-binding heavy chain sequences.

[0036] These and further aspect will be further explained in the rest of the disclosure, including the Examples.

BRIEF DESCRIPTION OF THE DRAWINGS

[0037] FIG. 1 shows the CDR1, CDR2 and CDR3 amino acid sequences of 34 heavy chain-only anti-BCMA antibodies of the invention.

[0038] FIG. 2 shows the heavy chain variable region sequences of 34 heavy chain-only anti-BCMA antibodies of the invention.

[0039] FIG. 3: Heatmap summary of the antibody binding activities of 34 heavy chain-only anti-BCMA antibodies expressed in HEK 293 cells. Red indicates strong binding while blue represents weak or negative binding results. Cell binding assays were run on all 34 antibodies and were shown to bind H929 cells. Two antibodies encoding either VH sequence 308607 or VH sequence 308915 were tested for binding to an untagged human BCMA ECD fragment, and two off-target protein controls including human IgG1 and a baculovirus protein extract (BVP), and BCMA+ MM cell line RPMI8226. Two UniAbs were also evaluated for the ability to block APRIL (ligand)/BCMA (receptor) binding in a recombinant protein ELISA-style assay.

[0040] FIG. 4: Serum binding activity against the immunogen and other on- and off-target proteins. A single 1:500 dilution of d35 serum from a subset of the animals was assayed for binding activity to a series of proteins in a standard ELISA assay. On-target proteins include human BCMA Fc region (huBCMA-Fc), a cyno BCMA ECD fused to a human Fc sequence (cyBCMA), and huBCMA from two other sources that do not have the Fc fusion (*E. coli* and wheat germ). Human serum albumin and human IgG1were used to assess off-target reactivity.

[0041] FIG. 5: Serum binding activity against a BCMA+ cell line (NCI-H929). Titers were evaluated by testing for serum binding to NCI-H929 cells by flow cytometry using a PE-conjugated anti-rat IgG2a antibody. Percent of NCI-H929 cells showing significant staining was assessed.

[0042] FIG. 6: Representative CAR-T constructs comprising a human VH extracellular binding domain.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0043] The practice of the present invention will employ, unless otherwise indicated, conventional techniques of molecular biology (including recombinant techniques), microbiology, cell biology,

biochemistry, and immunology, which are within the skill of the art. Such techniques are explained fully in the literature, such as, "Molecular Cloning: A Laboratory Manual", second edition (Sambrook et al., 1989); "Oligonucleotide Synthesis" (M. J. Gait, ed., 1984); "Animal Cell Culture" (R. I. Freshney, ed., 1987); "Methods in Enzymology" (Academic Press, Inc.); "Current Protocols in Molecular Biology" (F. M. Ausubel et al., eds., 1987, and periodic updates); "PCR: The Polymerase Chain Reaction", (Mullis et al., ed., 1994); "A Practical Guide to Molecular Cloning" (Perbal Bernard V., 1988); "Phage Display: A Laboratory Manual" (Barbas et al., 2001); Harlow, Lane and Harlow, Using Antibodies: A Laboratory Manual: Portable Protocol No. I, Cold Spring Harbor Laboratory (1998); and Harlow and Lane, Antibodies: A Laboratory Manual, Cold Spring Harbor Laboratory; (1988).

[0044] Where a range of values is provided, it is understood that each intervening value, to the tenth of the unit of the lower limit unless the context clearly dictates otherwise, between the upper and lower limit of that range and any other stated or intervening value in that stated range is encompassed within the invention. The upper and lower limits of these smaller ranges may independently be included in the smaller ranges is also encompassed within the invention, subject to any specifically excluded limit in the stated range. Where the stated range includes one or both of the limits, ranges excluding either or both of those included limits are also included in the invention.

[0045] Unless indicated otherwise, antibody residues herein are numbered according to the Kabat numbering system (*e.g.*, Kabat *et al.*, Sequences of Immunological Interest. 5th Ed. Public Health Service, National Institutes of Health, Bethesda, Md. (1991)).

[0046] In the following description, numerous specific details are set forth to provide a more thorough understanding of the present invention. However, it will be apparent to one of skill in the art that the present invention may be practiced without one or more of these specific details. In other instances, well-known features and procedures well known to those skilled in the art have not been described in order to avoid obscuring the invention.

[0047] All references cited throughout the disclosure, including patent applications and publications, are incorporated by reference herein in their entirety.

I. Definitions

[0048] By "comprising" it is meant that the recited elements are required in the composition/method/kit, but other elements may be included to form the composition/method/kit etc. within the scope of the claim.

[0049] By "consisting essentially of", it is meant a limitation of the scope of composition or method described to the specified materials or steps that do not materially affect the basic and novel characteristic(s) of the subject invention.

[0050] By "consisting of", it is meant the exclusion from the composition, method, or kit of any element, step, or ingredient not specified in the claim.

[0051] The term "monoclonal antibody" as used herein refers to an antibody obtained from a population of substantially homogeneous antibodies, i.e., the individual antibodies comprising the population are identical except for possible naturally occurring mutations that may be present in minor amounts. Monoclonal antibodies are highly specific, being directed against a single antigenic site. Furthermore, in contrast to conventional (polyclonal) antibody preparations which typically include different antibodies directed against different determinants (epitopes), each monoclonal antibody is directed against a single determinant on the antigen.

[0052] The terms "heavy chain-only antibody," "heavy-chain antibody" and "HCAb" are used interchangeably, and refer, in the broadest sense, to antibodies lacking the light chain of a conventional antibody. Since the homodimeric HCAbs lack a light chain and thus a VL domain, the antigen is recognized by one single domain, i.e., the variable domain of the heavy chain of a heavy-chain antibody (VH). The term specifically includes, without limitation, homodimeric antibodies comprising the VH antigen-binding domain and the CH2 and CH3 constant domains, in the absence of the CH1 domain; functional (antigen-binding) variants of such antibodies, soluble VH variants, Ig-NAR comprising a homodimer of one variable domain (V-NAR) and five C-like constant domains (C-NAR) and functional fragments thereof; and soluble single domain antibodies (sdAbs). In one embodiment, the heavy chain-only antibody is composed of the variable region antigen-binding domain composed of framework 1, CDR1, framework 2, CDR2, framework 3, CDR3, and framework 4. In one embodiment, the heavy chain-only antibody is composed of an antigen-binding domain, at least part of a hinge region and CH2 and CH3 domains. In another embodiment, the heavy chain-only antibody is composed of an antigen-binding domain, at least part of a hinge region and a CH2 domain. In a further embodiment, the heavy chain-only antibody is composed of an antigen-binding domain, at least part of a hinge region and a CH3 domain. Heavy chain-only antibodies in which the CH2 and/or CH3 domain is truncated are also included herein. In a further embodiment the heavy chain is composed of an antigen binding domain, and at least one CH (CH1, CH2, CH3, or CH4) domain but no hinge region. The heavy chain-only antibody can be in the form of a dimer, in which two heavy chains are disulfide bonded other otherwise, covalently or non-covalently attached with each other. The heavy chain-only antibody may belong to the IgG subclass, but antibodies belonging to other subclasses, such as IgM, IgA, IgD and IgE subclass, are also included herein. In a particular embodiment, the heavy chain antibody is of the IgG1, IgG2, IgG3, or IgG4 subtype, in particular IgG1 subtype. In one embodiment, the heavy chain-only antibodies herein are used as a binding (targeting) domain of a chimeric antigen receptor (CAR).

[0053] The term "variable", as used in connection with antibodies, refers to the fact that certain portions of the antibody variable domains differ extensively in sequence among antibodies and are used in the binding and specificity of each particular antibody for its particular antigen. However, the variability is

not evenly distributed throughout the variable domains of antibodies. It is concentrated in three segments called hypervariable regions both in the light chain and the heavy chain variable domains. The more highly conserved portions of variable domains are called the framework regions (FRs). The variable domains of native heavy and light chains each comprise four FRs, largely adopting a β-sheet configuration, connected by three hypervariable regions, which form loops connecting, and in some cases forming part of, the β-sheet structure. The hypervariable regions in each chain are held together in close proximity by the FRs and, with the hypervariable regions from the other chain, contribute to the formation of the antigen-binding site of antibodies (see Kabat *et al., Sequences of Proteins of Immunological Interest*, 5th Ed. Public Health Service, National Institutes of Health, Bethesda, MD. (1991)). The constant domains are not involved directly in binding an antibody to an antigen, but exhibit various effector functions, such as participation of the antibody in antibody dependent cellular cytotoxicity (ADCC).

[0054] The term "hypervariable region" when used herein refers to the amino acid residues of an antibody which are responsible for antigen-binding. The hypervariable region generally comprises amino acid residues from a "complementarity determining region" or "CDR" (*e.g.* residues 31-35 (H1), 50-65 (H2) and 95-102 (H3) in the heavy chain variable domain; Kabat *et al., Sequences of Proteins of Immunological Interest*, 5th Ed. Public Health Service, National Institutes of Health, Bethesda, MD. (1991)) and/or those residues from a "hypervariable loop" residues 26-32 (H1), 53-55 (H2) and 96-101 (H3) in the heavy chain variable domain; Chothia and Lesk *J. Mol. Biol.* 196:901-917 (1987)). "Framework Region" or "FR" residues are those variable domain residues other than the hypervariable region residues as herein defined.

[0055] Exemplary CDR designations are shown herein, however one of skill in the art will understand that a number of definitions of the CDRs are commonly in use, including the Kabat definition (see "Zhao et al. A germline knowledge based computational approach for determining antibody complementarity determining regions." *Mol Immunol*. 2010;47:694–700), which is based on sequence variability and is the most commonly used. The Chothia definition is based on the location of the structural loop regions (Chothia et al. "Conformations of immunoglobulin hypervariable regions." *Nature*. 1989; 342:877–883). Alternative CDR definitions of interest include, without limitation, those disclosed by Honegger, "Yet another numbering scheme for immunoglobulin variable domains: an automatic modeling and analysis tool." *J Mol Biol*. 2001;309:657–670; Ofran et al. "Automated identification of complementarity determining regions (CDRs) reveals peculiar characteristics of CDRs and B cell epitopes." *J Immunol.* 2008;181:6230–6235; Almagro "Identification of differences in the specificity-determining residues of antibodies that recognize antigens of different size: implications for the rational design of antibody repertoires." *J Mol Recognit*. 2004;17:132–143; and Padlanet al. "Identification of specificity-determining

residues in antibodies." Faseb J. 1995;9:133–139., each of which is herein specifically incorporated by reference.

[0056] An "isolated" antibody is one which has been identified and separated and/or recovered from a component of its natural environment. Contaminant components of its natural environment are materials which would interfere with diagnostic or therapeutic uses for the antibody, and may include enzymes, hormones, and other proteinaceous or nonproteinaceous solutes. In preferred embodiments, the antibody will be purified (1) to greater than 95% by weight of antibody as determined by the Lowry method, and most preferably more than 99% by weight, (2) to a degree sufficient to obtain at least 15 residues of N-terminal or internal amino acid sequence by use of a spinning cup sequenator, or (3) to homogeneity by SDS-PAGE under reducing or nonreducing conditions using Coomassie blue or, preferably, silver stain. Isolated antibody includes the antibody *in situ* within recombinant cells since at least one component of the antibody's natural environment will not be present. Ordinarily, however, isolated antibody will be prepared by at least one purification step.

[0057] Antibodies of the invention include multi-specific antibodies. Multi-specific antibodies have more than one binding specificity. The term *"*multi-specific*"* specifically includes *"*bispecific*"* and *"*trispecific,*"* as well as higher-order independent specific binding affinities, such as higher-order polyepitopic specificity, as well as tetravalent antibodies and antibody fragments. "Multi-specific" antibodies specifically include antibodies comprising a combination of different binding entities as well as antibodies comprising more than one of the same binding entity. The terms *"*multi-specific antibody," multi-specific single chain-only antibody" and "multi-specific HCAb" are used herein in the broadest sense and cover all antibodies with more than one binding specificity.

[0058] The term "valent" as used herein refers to a specified number of binding sites in an antibody molecule.

[0059] A "multi-valent" antibody has two or more binding sites. Thus, the terms "bivalent", "trivalent", and "tetravalent" refers to the presence of two binding sites, three binding sites, and four binding sites, respectively. Thus, a bispecific antibody according to the invention is at least bivalent and may be trivalent, tetravalent, or otherwise multi-valent.

[0060] A large variety of methods and protein configurations are known and used for the preparation of bispecific monoclonal antibodies (BsMAB), tri-specific antibodies, and the like.

[0061] The term "bispecific three-chain antibody like molecule" or "TCA" is used herein to refer to antibody-like molecules comprising, consisting essentially of, or consisting of three polypeptide subunits, two of which comprise, consist essentially of, or consist of one heavy and one light chain of a monoclonal antibody, or functional antigen-binding fragments of such antibody chains, comprising an antigen-binding region and at least one CH domain. This heavy chain/light chain pair has binding specificity for a first

antigen. The third polypeptide subunit comprises, consists essentially of, or consists of a heavy chain only antibody comprising an Fc portion comprising CH2 and/or CH3 and/or CH4 domains, in the absence of a CH1 domain, and an antigen binding domain that binds an epitope of a second antigen or a different epitope of the first antigen, where such binding domain is derived from or has sequence identity with the variable region of an antibody heavy or light chain. Parts of such variable region may be encoded by V_H and/or V_L gene segments, D and J_H gene segments, or J_L gene segments. The variable region may be encoded by rearranged V_HDJ_H, V_LDJ_H, V_HJ_L, or V_LJ_L gene segments. A TCA protein makes use of a heavy chain-only antibody as hereinabove defined.

[0062] The term "chimeric antigen receptor" or "CAR" is used herein in the broadest sense to refer to an engineered receptor, which grafts a desired binding specificity (e.g. the antigen-binding region of a monoclonal antibody or other ligand) to membrane-spanning and intracellular-signaling domains. Typically, the receptor is used to graft the specificity of a monoclonal antibody onto a T cell to create a chimeric antigen receptos (CAR). (*J Natl Cancer Inst,* 2015; 108(7):dvj439; and Jackson et al., *Nature Reviews Clinical Oncology*, 2016; 13:370–383.) A representative CAR-T construct comprising a human VH extracellular binding domain is shown in FIG. 6.

[0063] By "human idiotype" is meant a polypeptide sequence epitope present on a human antibody in the immunoglobulin heavy and/or light chain variable region. The term "human idiotype" as used herein includes both naturally occurring sequences of a human antibody, as well as synthetic sequences substantially identical to the polypeptide found in naturally occurring human antibodies. By "substantially" is meant that the degree of amino acid sequence identity is at least about 85%-95%. Preferably, the degree of amino acid sequence identity is greater than 90%, more preferably greater than 95%.

[0064] By a "chimeric antibody" or a "chimeric immunoglobulin" is meant an immunoglobulin molecule comprising amino acid sequences from at least two different Ig loci, e.g., a transgenic antibody comprising a portion encoded by a human Ig locus and a portion encoded by a rat Ig locus. Chimeric antibodies include transgenic antibodies with non-human Fc-regions or artificial Fc-regions, and human idiotypes. Such immunoglobulins can be isolated from animals of the invention that have been engineered to produce such chimeric antibodies.

[0065] Antibody "effector functions" refer to those biological activities attributable to the Fc region (a native sequence Fc region or amino acid sequence variant Fc region) of an antibody. Examples of antibody effector functions include C1q binding; complement dependent cytotoxicity; Fc receptor binding; antibody-dependent cell-mediated cytotoxicity (ADCC); phagocytosis; down regulation of cell surface receptors (*e.g.* B cell receptor; BCR), etc.

[0066] "Antibody-dependent cell-mediated cytotoxicity" and "ADCC" refer 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 subsequently cause lysis of the target cell. The primary cells for mediating ADCC, NK cells, express FcγRIII only, whereas monocytes express FcγRI, FcγRII and FcγRIII. FcR expression on hematopoietic cells in summarized is Table 3 on page 464 of Ravetch and Kinet, *Annu. Rev. Immunol* 9:457-92 (1991). To assess ADCC activity of a molecule of interest, an *in vitro* ADCC assay, such as that described in US Patent No. 5,500,362 or 5,821,337 may be performed. Useful effector cells for such assays include peripheral blood mononuclear cells (PBMC) and Natural Killer (NK) cells. Alternatively, or additionally, ADCC activity of the molecule of interest may be *assessed in vivo*, *e.g.*, in an animal model such as that disclosed in Clynes *et al. PNAS (USA)* 95:652-656 (1998).

[0067] "Human effector cells" are leukocytes which express one or more FcRs and perform effector functions. Preferably, the cells express at least FcγRIII and perform ADCC effector function. Examples of human leukocytes which mediate ADCC include peripheral blood mononuclear cells (PBMC), natural killer (NK) cells, monocytes, cytotoxic T cells and neutrophils; with PBMCs and NK cells being preferred. The effector cells may be isolated from a native source thereof, *e.g.* from blood or PBMCs as described herein.

[0068] "Complement dependent cytotoxicity" or "CDC" refers to the ability of a molecule to lyse a target in the presence of complement. The complement activation pathway is initiated by the binding of the first component of the complement system (C1q) to a molecule (*e.g.* an antibody) complexed with a cognate antigen. To assess complement activation, a CDC assay, *e.g.* as described in Gazzano-Santoro *et al.*, *J. Immunol. Methods* 202:163 (1996), may be performed.

[0069] "Binding affinity" refers to the strength of the sum total of noncovalent interactions between a single binding site of a molecule (*e.g.*, an antibody) and its binding partner (*e.g.*, an antigen). Unless indicated otherwise, as used herein, "binding affinity" refers to intrinsic binding affinity which reflects a 1:1 interaction between members of a binding pair (*e.g.*, antibody and antigen). The affinity of a molecule X for its partner Y can generally be represented by the dissociation constant (Kd). Affinity can be measured by common methods known in the art. Low-affinity antibodies generally bind antigen slowly and tend to dissociate readily, whereas high-affinity antibodies generally bind antigen faster and tend to remain bound.

[0070] As used herein, the "Kd" or "Kd value" refers to a dissociation constant determined by BioLayer Interferometry, using an Octet QK384 instrument (Fortebio Inc., Menlo Park, CA) in kinetics mode. For example, anti-mouse Fc sensors are loaded with mouse-Fc fused antigen and then dipped into antibody-containing wells to measure concentration dependent association rates (kon). Antibody dissociation rates

(koff) are measured in the final step, where the sensors are dipped into wells containing buffer only. The Kd is the ratio of koff/kon. (For further details see, Concepcion, J, et al., *Comb Chem High Throughput Screen*, 12(8), 791-800, 2009).

[0071] An *"epitope"* is the site on the surface of an antigen molecule to which a single antibody molecule binds. Generally an antigen has several or many different epitopes and reacts with many different antibodies. The term specifically includes linear epitopes and conformational epitopes.

[0072] *"Epitope mapping"* is the process of identifying the binding sites, or epitopes, of antibodies on their target antigens. Antibody epitopes may be linear epitopes or conformational epitopes. Linear epitopes are formed by a continuous sequence of amino acids in a protein. Conformational epitopes are formed of amino acids that are discontinuous in the protein sequence, but which are brought together upon folding of the protein into its three-dimensional structure.

[0073] "Polyepitopic specificity" refers to the ability to specifically bind to two or more different epitopes on the same or different target(s).

[0074] An antibody binds *"essentially the same epitope"* as a reference antibody, when the two antibodies recognize identical or sterically overlapping epitopes. The most widely used and rapid methods for determining whether two epitopes bind to identical or sterically overlapping epitopes are competition assays, which can be configured in all number of different formats, using either labeled antigen or labeled antibody. Usually, the antigen is immobilized on a 96-well plate, and the ability of unlabeled antibodies to block the binding of labeled antibodies is measured using radioactive or enzyme labels.

[0075] The terms "treatment", "treating" and the like are used herein to generally mean obtaining a desired pharmacologic and/or physiologic effect. The effect may be prophylactic in terms of completely or partially preventing a disease or symptom thereof and/or may be therapeutic in terms of a partial or complete cure for a disease and/or adverse effect attributable to the disease. "Treatment" as used herein covers any treatment of a disease in a mammal, and includes: (a) preventing the disease from occurring in a subject which may be predisposed to the disease but has not yet been diagnosed as having it; (b) inhibiting the disease, i.e., arresting its development; or (c) relieving the disease, i.e., causing regression of the disease. The therapeutic agent may be administered before, during or after the onset of disease or injury. The treatment of ongoing disease, where the treatment stabilizes or reduces the undesirable clinical symptoms of the patient, is of particular interest. Such treatment is desirably performed prior to complete loss of function in the affected tissues. The subject therapy may be administered during the symptomatic stage of the disease, and in some cases after the symptomatic stage of the disease.

[0076] A "therapeutically effective amount" is intended for an amount of active agent which is necessary to impart therapeutic benefit to a subject. For example, a "therapeutically effective amount" is an amount which induces, ameliorates or otherwise causes an improvement in the pathological symptoms, disease

progression or physiological conditions associated with a disease or which improves resistance to a disorder.

[0077] The terms "subject," "individual," and "patient" are used interchangeably herein to refer to a mammal being assessed for treatment and/or being treated. In an embodiment, the mammal is a human. The terms "subject," "individual," and "patient" encompass, without limitation, individuals having cancer, individuals with autoimmune diseases, with pathogen infections, and the like. Subjects may be human, but also include other mammals, particularly those mammals useful as laboratory models for human disease, *e.g.* mouse, rat, *etc.*

II. Detailed Description

Anti-BCMA Antibodies

[0078] The present invention provides a family of closely related heavy chain-only antibodies that bind to human BCMA. The antibodies of this family comprise a set of CDR sequences as defined herein and shown in FIG. 1, and are exemplified by the provided heavy chain variable region (VH) sequences of SEQ ID NOs 20 to 53 set forth in FIG. 2. The families of antibodies provide a number of benefits that contribute to utility as clinically therapeutic agent(s). The antibodies include members with a range of binding affinities, allowing the selection of a specific sequence with a desired binding affinity.

[0079] A suitable antibody may be selected from those provided herein for development and therapeutic or other use, including without limitation use as a bispecific or tri-specific antibody, or part of a CAR-T structure. Determination of affinity for a candidate protein can be performed using methods known in the art, such as Biacore measurements. Members of the antibody family may have an affinity for BCMA with a Kd of from about 10^{-6} to around about 10^{-11}, including without limitation: from about 10^{-6} to around about 10^{-10}; from about 10^{-6} to around about 10^{-9}; from about 10^{-6} to around about 10^{-8}; from about 10^{-8} to around about 10^{-11}; from about 10^{-8} to around about 10^{-10}; from about 10^{-8} to around about 10^{-9}; from about 10^{-9} to around about 10^{-11}; from about 10^{-9} to around about 10^{-10}; or any value within these ranges. The affinity selection may be confirmed with a biological assessment for modulating, e.g. blocking, a BCMA biological activity, including *in vitro* assays, pre-clinical models, and clinical trials, as well as assessment of potential toxicity.

[0080] Members of the antibody family herein are not cross-reactive with the BCMA protein of *Cynomolgus* macaque but can be engineered to provide cross-reactivity if desired.

[0081] The family of BCMA specific antibodies herein comprises a VH domain, comprising CDR1, CDR2 and CDR3 sequences in a human VH framework. The CDR sequences may be situated, as an example, in the region of around amino acid residues 26-35; 53-59; and 98-117 for CDR1, CDR2 and CDR3, respectively, of the provided exemplary variable region sequences set forth in SEQ ID NO: 20-53.

It will be understood by one of skill in the art that the CDR sequences may be in different position if a different framework sequence is selected, although generally the order of the sequences will remain the same.

[0082] The antibodies of the present invention share the CDR3 amino acid sequence of SEQ ID NO: 19. The CDR1 and CDR2 sequences of the anti-BCMA antibodies of the present invention may be encompassed by the following structural formulas, where an X indicates a variable amino acid, which may be specific amino acids as indicated below.

CDR1

G F T F X1 X2 Y A

where

X1 is S or T;

X2 is S, N or R

CDR2

X3 X4 X5 X6 G X7 X8 X9

where

X3 is I or L;

X4 is S, T, I or V;

X5 is G or E;

X6 is S, G, N or D;

X7 is G, D or A;

X8 is S, T or N;

X9 is T or S.

[0083] Representative CDR1, CDR2, and CDR3 sequences are shown in FIG. 1.

[0084] In some embodiments the anti-BCMA antibody of the invention comprises a CDR1 sequence of SEQ ID NO: 1, 2, 3, or 4. In a particular embodiment, the CDR1 sequence is SEQ ID NO: 1 or SEQ ID NO: 2.

[0085] In some other embodiments the anti-BCMA antibody of the invention comprises a CDR2 sequence of any one of SEQ ID NOs: 5-18. In a particular embodiment, the CDR2 sequence is SEQ ID NO: 5.

[0086] In another embodiment, the anti-BCMA antibody of the present invention comprises a CDR1 sequence of SEQ ID NO: 1, a CDR2 sequence of SEQ ID NO: 5 and a CDR3 sequence of SEQ ID NO: 19.

[0087] In a further embodiment, the anti-BCMA antibody of the present invention comprises a CDR1 sequence of SEQ ID NO: 2, a CDR2 sequence of SEQ ID NO: 5 and a CDR3 sequence of SEQ ID NO: 19.

[0088] In further embodiments, the the anti-BCMA antibody of the present invention comprises any of the heavy chain amino acid sequences of SEQ ID NOs: 20 to 53 (FIG. 2).

[0089] In some embodiments a CDR sequence of the invention comprises one, two, three or more amino acid substitutions relative to a CDR1, CDR2 an/dor CDR3 sequence or set of CDR1, CDR2 and CDR3 sequences in any one of SEQ ID NOs:1 to 19 (FIG. 1). In some embodiments said amino acid substitution(s) are one or more of amino acid positions 5 and 6 of CDR1, and/or one or more of the amino acid positions of 1-4 and 6-8 of CDR2, relative to the formulas provided above. In some embodiments the CDR sequences of an anti-BCMA antibody herein have a sequence with at least 85% identity, at least 90% identity, at least 95% identity, at least 98% identify, or at least 99% identity relative to a CDR1, CDR2 and/or CD3 sequence or set of CDR1, CDR2, and CDR3 sequences in any one of SEQ ID NO: 1 to 19 (FIG. 1). In some other embodiment, the single chain-only anti-BCMA antibodies herein will comprise a heavy chain variable region sequence with at least 85% identity, at least 90% identity, at least 95% identity, at least 98% identify, or at least 99% identity to the heavy chain variable region sequences shown in FIG. 2.

[0090] In some embodiments, bispecific or multispecific antibodies are provided, which may have any of the configurations discussed herein, including without limitation a three chain bispecific antibody. Bispecific antibodies comprise at least the heavy chain variable region of an antibody specific for a protein other than BCMA.

[0091] Where a protein of the invention is a bispecific antibody, one binding moiety is specific for human BCMA while the other arm may be specific for target cells, tumor associated antigens, targeting antigens, *e.g.* integrins, *etc.*, pathogen antigens, checkpoint proteins, and the like. Target cells specifically include cancer cells, such as hematologic tumors, e.g. B-cell tumors.

[0092] Various formats of bispecific antibodies are within the ambit of the invention, including without limitation single chain polypeptides, two chain polypeptides, three chain polypeptides, four chain polypeptides, and multiples thereof. The bispecific antibodies herein specifically include T-cell bispecific

antibodies binding to BCMA, which is selectively expressed on plasma cells (PCs) and multiple myeloma (MM), and CD3 (anti-BCMA × Anti-CD3 antibodies) Such antibodies induce potent T-cell mediated killing of cells carrying BCMA.

Pharmaceutical Compositions

[0093] It is another aspect of the present invention to provide pharmaceutical compositions comprising one or more antibodies of the present invention in admixture with a suitable pharmaceutically acceptable carrier. Pharmaceutically acceptable carriers as used herein are exemplified, but not limited to, adjuvants, solid carriers, water, buffers, or other carriers used in the art to hold therapeutic components, or combinations thereof.

[0094] Pharmaceutical composition of the antibodies used in accordance with the present invention are prepared for storage by mixing proteins having the desired degree of purity with optional pharmaceutically acceptable carriers, excipients or stabilizers (see, e.g. Remington's Pharmaceutical Sciences 16th edition, Osol, A. Ed. (1980)), such as in the form of lyophilized formulations or aqueous solutions. Acceptable carriers, excipients, or stabilizers are nontoxic to recipients at the dosages and concentrations employed, and include buffers such as phosphate, citrate, and other organic acids; antioxidants including ascorbic acid and methionine; preservatives (such as octadecyldimethylbenzyl ammonium chloride; hexamethonium chloride; benzalkonium chloride, benzethonium chloride; phenol, butyl or benzyl alcohol; alkyl parabens such as methyl or propyl paraben; catechol; resorcinol; cyclohexanol; 3-pentanol; and m-cresol); low molecular weight (less than about 10 residues) polypeptides; proteins, such as serum albumin, gelatin, or immunoglobulins; hydrophilic polymers such as polyvinylpyrrolidone; amino acids such as glycine, glutamine, asparagine, histidine, arginine, or lysine; monosaccharides, disaccharides, and other carbohydrates including glucose, mannose, or dextrins; chelating agents such as EDTA; sugars such as sucrose, mannitol, trehalose or sorbitol; salt-forming counter-ions such as sodium; metal complexes (e.g. Zn-protein complexes); and/or non-ionic surfactants such as TWEEN™, PLURONICS™ or polyethylene glycol (PEG).

[0095] Anti-BCMA antibody formulations are disclosed, for example, in U.S. Patent No. 9,034,324. Similar formulations can be used for the proteins of the present invention.

Methods of Use

[0096] The pharmaceutical compositions herein can be used for the treatment of B-cell related disorders characterized by the expression of BCMA.

[0097] Such B-cell related disorders include B-cell and plasma cell malignancies and autoimmune disorders, including, without limitation, plasmacytoma, Hodgkins' lymphoma, follicular lymphomas,

small non-cleaved cell lymphomas, endemic Burkitt's lymphoma, sporadic Burkitt's lymphoma, marginal zone lymphoma, extranodal mucosa-associated lymphoid tissue lymphoma, nodal monocytoid B cell lymphoma, splenic lymphoma, mantle cell lymphoma, large cell lymphoma, diffuse mixed cell lymphoma, immunoblastic lymphoma, primary mediastinal B cell lymphoma, pulmonary B cell angiocentric lymphoma, small lymphocytic lymphoma, B cell proliferations of uncertain malignant potential, lymphomatoid granulomatosis, post-transplant lymphoproliferative disorder, an immunoregulatory disorder, rheumatoid arthritis, myasthenia gravis, idiopathic thrombocytopenia purpura, anti-phospholipid syndrome, Chagas' disease, Grave's disease, Wegener's granulomatosis, poly-arteritis nodosa, Sjogren's syndrome, pemphigus vulgaris, scleroderma, multiple sclerosis, anti-phospholipid syndrome, ANCA associated vasculitis, Goodpasture's disease, Kawasaki disease, autoimmune hemolytic anemia, and rapidly progressive glomerulonephritis, heavy-chain disease, primary or immunocyte-associated amyloidosis, or monoclonal gammopathy.

[0098] The plasma cell disorders characterized by the expression of BCMA include Multiple Myeloma (MM). MM is a B-cell malignancy characterized by a monoclonal expansion and accumulation of abnormal plasma cells in the bone marrow compartment. Current therapies for MM often cause remissions, but nearly all patients eventually relapse and die. There is substantial evidence of an immune-mediated elimination of myeloma cells in the setting of allogeneic hematopoietic stem cell transplantation; however, the toxicity of this approach is high, and few patients are cured. Although some monoclonal antibodies have shown promise for treating MM in preclinical studies and early clinical trials, consistent clinical efficacy of any monoclonal antibody therapy for MM has not been conclusively demonstrated. There is therefore a great need for new therapies, including immunotherapies for MM (see, e.g.Carpenter et al., *Cliln Cancer Res* 2013, 19(8):2048-2060).

[0099] Another B-cell disorder involving plasma cells i.e. expressing BCMA is systemic lupus erythematosus (SLE), also known as lupus. SLE is a systemic, autoimmune disease that can affect any part of the body and is represented with the immune system attacking the body's own cells and tissue, resulting in chronic inflammation and tissue damage. It is a Type III hypersensitivity reaction in which antibody-immune complexes precipitate and cause a further immune response (Inaki & Lee, *Nat Rev Rheumatol* 2010; 6: 326-337).

[0100] The antibodies of the present invention can be used to develop therapeutic agents for the treatment of MM, SLE, and other B-cell disorders characterized by the expression of BCMA, such as those listed above.

[0101] In one embodiment, the antibodies herein can be in the form of heavy chain-only anti-BCMA antibody-CAR structures, i.e. heavy chain-only anti-BCMA antibody-CAR-transduced T cell structures.

[0102] Effective doses of the compositions of the present invention for the treatment of disease vary depending upon many different factors, including means of administration, target site, physiological state of the patient, whether the patient is human or an animal, other medications administered, and whether treatment is prophylactic or therapeutic. Usually, the patient is a human, but nonhuman mammals may also be treated, e.g. companion animals such as dogs, cats, horses, *etc*., laboratory mammals such as rabbits, mice, rats, *etc*., and the like. Treatment dosages can be titrated to optimize safety and efficacy.

[0103] Dosage levels can be readily determined by the ordinarily skilled clinician, and can be modified as required, e.g., as required to modify a subject's response to therapy. The amount of active ingredient that can be combined with the carrier materials to produce a single dosage form varies depending upon the host treated and the particular mode of administration. Dosage unit forms generally contain between from about 1 mg to about 500 mg of an active ingredient.

[0104] In some embodiments, the therapeutic dosage the agent may range from about 0.0001 to 100 mg/kg, and more usually 0.01 to 5 mg/kg, of the host body weight. For example dosages can be 1 mg/kg body weight or 10 mg/kg body weight or within the range of 1-10 mg/kg. An exemplary treatment regime entails administration once every two weeks or once a month or once every 3 to 6 months. Therapeutic entities of the present invention are usually administered on multiple occasions. Intervals between single dosages can be weekly, monthly or yearly. Intervals can also be irregular as indicated by measuring blood levels of the therapeutic entity in the patient. Alternatively, therapeutic entities of the present invention can be administered as a sustained release formulation, in which case less frequent administration is required. Dosage and frequency vary depending on the half-life of the polypeptide in the patient.

[0105] Typically, compositions are prepared as injectables, either as liquid solutions or suspensions; solid forms suitable for solution in, or suspension in, liquid vehicles prior to injection can also be prepared. The preparation also can be emulsified or encapsulated in liposomes or micro particles such as polylactide, polyglycolide, or copolymer for enhanced adjuvant effect, as discussed above. Langer, Science 249: 1527, 1990 and Hanes, Advanced Drug Delivery Reviews 28: 97-119, 1997. The agents of this invention can be administered in the form of a depot injection or implant preparation which can be formulated in such a manner as to permit a sustained or pulsatile release of the active ingredient. The pharmaceutical compositions are generally formulated as sterile, substantially isotonic and in full compliance with all Good Manufacturing Practice (GMP) regulations of the U.S. Food and Drug Administration.

[0106] Toxicity of the antibodies and antibody structures described herein can be determined by standard pharmaceutical procedures in cell cultures or experimental animals, *e.g.*, by determining the LD_{50} (the dose lethal to 50% of the population) or the LD_{100} (the dose lethal to 100% of the population). The dose

ratio between toxic and therapeutic effect is the therapeutic index. The data obtained from these cell culture assays and animal studies can be used in formulating a dosage range that is not toxic for use in humans. The dosage of the antibodies described herein lies preferably within a range of circulating concentrations that include the effective dose with little or no toxicity. The dosage can vary within this range depending upon the dosage form employed and the route of administration utilized. The exact formulation, route of administration and dosage can be chosen by the individual physician in view of the patient's condition.

[0107] The compositions for administration will commonly comprise an antibody or other ablative agent dissolved in a pharmaceutically acceptable carrier, preferably an aqueous carrier. A variety of aqueous carriers can be used, e.g., buffered saline and the like. These solutions are sterile and generally free of undesirable matter. These compositions may be sterilized by conventional, well known sterilization techniques. The compositions may contain pharmaceutically acceptable auxiliary substances as required to approximate physiological conditions such as pH adjusting and buffering agents, toxicity adjusting agents and the like, e.g., sodium acetate, sodium chloride, potassium chloride, calcium chloride, sodium lactate and the like. The concentration of active agent in these formulations can vary widely, and will be selected primarily based on fluid volumes, viscosities, body weight and the like in accordance with the particular mode of administration selected and the patient's needs (e.g., Remington's Pharmaceutical Science (15th ed., 1980) and Goodman & Gillman, The Pharmacological Basis of Therapeutics (Hardman et al., eds., 1996)).

[0108] Also within the scope of the invention are kits comprising the active agents and formulations thereof, of the invention and instructions for use. The kit can further contain a least one additional reagent, e.g. a chemotherapeutic drug, *etc*. Kits typically include a label indicating the intended use of the contents of the kit. The term label includes any writing, or recorded material supplied on or with the kit, or which otherwise accompanies the kit.

[0109] The invention now being fully described, it will be apparent to one of ordinary skill in the art that various changes and modifications can be made without departing from the spirit or scope of the invention.

EXAMPLES

Example 1

Genetically Engineered Rats Expressing Heavy Chain-Only Antibodies

[0110] A 'human – rat' IgH locus was constructed and assembled in several parts. This involved the modification and joining of rat C region genes downstream of human J_Hs and subsequently, the upstream

addition of the human V_H6 –D-segment region. Two BACs with separate clusters of human V_H genes [BAC6 and BAC3] were then co-injected with the BAC termed Georg, encoding the assembled and modified region comprising human V_H6 , all Ds, all J_Hs , and modified rat Cγ2a/1/2b (ΔC_H1).

[0111] Transgenic rats carrying artificial heavy chain immunoglobulin loci in unrearranged configuration were generated. The IgG2a(ΔC_H1)., igG1(ΔC_H1)., IgG2b(ΔC_H1) genes lacked the C_H1 segment. The constant region genes IgE, IgA and 3' enhancer were included in Georg BAC. RT-PCR and serum analysis (ELISA) of transgenic rats revealed productive rearrangement of transgenic immunoglobulin loci and expression of heavy chain only antibodies of various isotypes in serum. Transgenic rats were cross-bred with rats with mutated endogenous heavy chain and light chain loci previously described in US patent publication 2009/0098134 A1. Analysis of such animals demonstrated inactivation of rat immunoglobulin heavy and light chain expression and high level expression of heavy chain antibodies with variable regions encoded by human V, D, and J genes. Immunization of transgenic rats resulted in production of high titer serum responses of antigen-specific heavy chain antibodies. These transgenic rats expressing heavy chain antibodies with a human VDJ region were called UniRats.

Example 2

Immunization

Immunization with recombinant extracellular domain of BCMA.

[0112] Twelve UniRat animals (6 HC27, 6 HC28) were immunized with recombinant human BCMA protein. The animals were immunized according to standard protocol using a Titermax/Alhydrogel adjuvant. Recombinant extracellular domain of BCMA was purchased from R&D Systems and was diluted with sterile saline and combined with adjuvant. The immunogen was combined with Titermax and Alhydrogel adjuvants. The first immunization (priming) with immunogen in Titermax was administered in the left and right legs. Subsequent boosting immunizations were done in the presence of Alhydrogel and three days before harvest boosts were performed with immunogens in PBS. Serum was collected from rats at the final bleed to determine serum titers.

Serum titer results

[0113] Serum titer summary information is shown in FIGs. 4 and 5. For half of the animals, binding activity for a single 1:500 serum titer dilution was tested by ELISA against a huBCMA+Fc protein and a cynoBCMA+Fc protein produced in eukaryotic cells and two human BCMA proteins from E. coli and wheat germ, respectively. In addition, serum samples were tested against two off-target proteins, HSA and human IgG1. In addition, serum from all 12 animals was assayed for binding to NCI-H929 cells (BCMA+, lambda-).

[0114] Among this group of animals, we observed a significant spread in serum reactivity levels to NCI-H929 cells (BCMA+, lambda-). The relevance of these results is confirmed by the ELISA binding data generated for a subset of the animals. Some general Fc-specific reactivity is observed for a number of the animals, but those that look the most promising also show high apparent titer in the assays against untagged human BCMA from alternative sources (*E. coli*, wheat germ) indicating significant BCMA ECD-specific binding activity. Positive signal for binding to the cynoBCMA+Fc protein may reflect binding to either the ECD or the Fc portion of the molecule that is also included on the human immunogen. In both assay types, analysis of serum taken from these animals prior to immunization showed no reactivity to the immunogen or off target protein.

Example 3

Gene Assembly, Expression and Binding Assays

[0115] 309 cDNAs encoding heavy chain only antibodies highly expressed in lymph node cells were selected for gene assembly and cloned into an expression vector. Subsequently, these 309 heavy chain sequences were expressed in HEK cells as UniAb heavy chain only antibodies (CH1 deleted, no light chain). Binding results including amino acid sequences for 34 VH regions tested can be found in the BCMA_FAM2_DATA.

[0116] Supernatants of two antibodies were tested for binding in a standard ELISA assay to a human BCMA. Binding to recombinant BCMA protein was determined by ELISA using human BCMA ECD obtained from Abcam (ab50089). The BCMA ECD protein was used at a concentration of 2 µg/mL to capture UniAbs at 50 ng/mL. Binding of UniAbs was detected with a goat anti-human IgG HRP conjugated antibody (ThermoFisher 31413). All antibodies were diluted in 1X TBS with 0.05% Tween-20 and 1% dry milk powder.

[0117] Off-target binding to Baculo Virus Protein Extract (BVP) was conducted by ELISA as above, with the modification of using 1X PBS and 1% dry milk powder for the diluent. BVP extract was obtained from INSERM (Nantes, France). Binding to baculovirus particles (>5x over background in our assay) is thought to indicate low-affinity interactions with human tissues which correlates with reduced half-lives of antibodies in humans and monkeys (Hotzel et al., mAbs 4:6, p753-760, 2012). Off-target binding of human IgG1 was assessed by ELISA using the UniAbs to capture human IgG1 kappa followed by detection of the kappa chain with a goat anti-human kappa HRP conjugated antibody (Southern Biotech 2060-05).

[0118] Supernatants of all antibodies were also tested by flow cytometry for binding to RPMI-8226 cells (BCMA+, lambda +) and H929 cells (BCMA+, lambda-). The samples were measured by flow cytometry using a Guava easyCyte 8HT instrument from EMD Millipore and analyzed using guavaSoft. Bound

antibodies were detected with goat anti-human IgG $F(ab')_2$ conjugated to PE (Southern Biotech 2042-09). All antibodies were diluted in PBS with 1% BSA. Positive staining was determined by comparison to staining with a human IgG1 isotype control. The NCI-H929 and RPMI-8226 cell lines are human multiple myeloma lines expressing human BCMA, which were obtained from the American Type Culture Collection (ATCC) and cultured according to ATCC recommendations.

[0119] Two UniAbs were also evaluated for the ability to block APRIL (ligand)/BCMA (receptor) binding in a recombinant protein ELISA-style assay. To evaluate blocking of the receptor/ligand interaction between BCMA and APRIL, recombinant human BCMA (Sino Biological 10620-H03H) was directly coated on plates followed by incubation with a dilution series of each UniAb. HA-tagged recombinant APRIL protein (RnD Systems 5860-AP-010) was then incubated with the BCMA/antibody complexes and binding of APRIL to BCMA was detected using a chicken anti-HA antibody conjugated to HRP (Abcam ab1190). A RnD systems anti-BCMA antibody (AF193) was used as a positive control for BCMA/APRIL blocking.

[0120] An additional off-target binding assay was run on intact baculovirus particles (BVPs) though none of the tested UniAbs showed positive binding.

[0121] While preferred embodiments of the present invention have been shown and described herein, it will be obvious to those skilled in the art that such embodiments are provided by way of example only. Numerous variations, changes, and substitutions will now occur to those skilled in the art without departing from the invention. It should be understood that various alternatives to the embodiments of the invention described herein may be employed in practicing the invention. It is intended that the following claims define the scope of the invention and that methods and structures within the scope of these claims and their equivalents be covered thereby.

CLAIMS:

1. A heavy chain-only antibody binding to human B-Cell Maturation Antigen (BCMA) comprising a heavy chain variable region comprising:

(a) a CDR1 having at least 95% sequence identity to any of the sequences of SEQ ID NOs: 1 to 4; and/or

(b) a CDR2 having at least 95% sequence identity to any of the sequence of SEQ ID NOs: 5 to 18; and/or

(c) a CDR3 having at least 95% sequence identity to SEQ ID NO: 19.

2. The heavy chain-only antibody of claim 1, wherein said CDR1, CDR2, and CDR3 sequences are present in a human framework.

3. The heavy chain-only antibody of claim 1 further comprising a heavy chain constant region sequence in the absence of a CH1 sequence.

4. The heavy chain-only antibody of any one of claims 1-3, comprising:

(a) a CDR1 sequence selected from the group consisting of SEQ ID NOs: 1 to 4; and/or

(b) a CDR2 sequence sselected from the group consisting of SEQ ID NOs: 5 to 18; and/or

(c) a CDR3 of SEQ ID NO: 19.

5. The heavy chain-only antibody of claim 4, comprising:

(a) a CDR1 sequence selected from the group consisting of SEQ ID NOs: 1 to 4; and

(b) a CDR2 sequence selected from the group consisting of SEQ ID NOs: 5 to 18; and

(c) a CDR3 of SEQ ID NO: 19.

6. The heavy chain-only antibody of any one of claims 1-3, comprising a heavy chain variable region having at least 95% sequence identity to any of the sequences of SEQ ID NOs: 20 to 53.

7. The heavy chain-only antibody of claim 6 comprising a heavy chain variable region sequence selected from the group consisting of SEQ ID NOs: 10 to 53.

8. A heavy chain-only antibody binding to human B-Cell Maturation Antigen (BCMA) comprising a heavy chain variable region comprising a heavy chain variable comprising

(a) a CDR1 sequence of the formula:

G F T F X1 X2 Y A

where

X1 is S or T; and

X2 is S, N or R; and

(b) CDR2 sequence of the formula:

X3 X4 X5 X6 G X7 X8 X9

where

X3 is I or L;

X4 is S, T, I or V;

X5 is G or E;

X6 is S, G, N or D;

X7 is G, D or A;

X8 is S, T or N;

X9 is T or S, and

(c) A CDR3 sequence of SEQ ID NO: 19

in a human VH framework.

9. A heavy chain-only antibody binding to human B-Cell Maturation Antigen (BCMA) comprising a heavy chain variable region comprising CDR1, CDR2 and CDR3 sequences in a human VH framework wherein the CDR sequences are a sequence with at least 95% identity to a CDR sequence selected from the group consisting of SEQ ID NOs:1-19.

10. The heavy chain-only antibody of claim 9, comprising a heavy chain variable region comprising CDR1, CDR2 and CDR3 sequences in a human VH framework wherein the CDR sequences are selected from the group consisting of SEQ ID NOs:1-19.

11. A heavy chain-only antibody binding to human B-Cell Maturation Antigen (BCMA) comprising a heavy chain variable region comprising

(a) a CDR1 of SEQ ID NO: 1, a CDR2 of SEQ ID NO: 5; and a CDR3 of SEQ ID NO: 19; or

(b) a CDR1 of SEQ ID NO: 2, a CDR2 of SEQ ID NO: 5; and a CDR3 of SEQ ID NO: 19 in a human VH framework.

12. The heavy chain-only antibody of any one of claims 1 to 11, which is multi-specific.

13. The heavy chain-only antibody of claim 12, which is bispecific.

14. The heavy chain-only antibody of claim 13, which has binding affinity to two different BCMA proteins.

15. The heavy chain-only antibody of claim 13, which has binding affinity to two different epitopes on the same BCMA protein.

16. The heavy chain-only antibody of claim 12, having binding affinity to an effector cell.

17. The heavy chain-only antibody of claim 12, having binding affinity to a T-cell antigen.

18. The heavy chain-only antibody of claim 17, having binding affinity to CD3.

19. The heavy chain-only antibody of any one of claims 1 to 15, which is in a CAR-T format.

20. A pharmaceutical composition comprising a heavy chain-only antibody of any one of claims 1 to 19.

21. A method for the treatment of a B-cell disorder characterized by the expression of BCMA comprising administering to a subject with said disorder an antibody of any one of claims 1 to 19 or a pharmaceutical composition of claim 20.

22. The method of claim 21, wherein the B-cell disorder is multiple myeloma.

23. The method of claim 21, wherein the B-cell disorder is systemic lupus erythematosus.

24. A polynucleotide encoding an antibody of any of claims 1 to 19.

25. A vector comprising the polynucleotide of claim 23.

26. A cell comprising the vector of claim 25.

27. A method of producing an antibody of any of claims 1 to 19, comprising growing a cell according to claim 26 under conditions permissive for expression of the protein, and isolating the antibody from the cells.

28. A method of making antibody of any one of claims 1 to 19 comprising immunizing a UniRat animal with BCMA and identifying BCMA-binding heavy chain sequences.