CHIMERIC ANTIGEN RECEPTORS TARGETING B-CELL MATURATION ANTIGEN

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This patent application claims the benefit of U.S. Provisional Patent Application No. 61/622,600 filed April 11, 2012 which is incorporated by reference in its entirety herein.

INCORPORATION-BY-REFERENCE OF MATERIAL SUBMITTED ELECTRONICALLY

[0002] Incorporated by reference in its entirety herein is a computer-readable nucleotide/amino acid sequence listing submitted concurrently herewith and identified as follows: One 42,589 Byte ASCII (Text) file named "712361_ST25.TXT," created on March 14, 2013.

BACKGROUND OF THE INVENTION

[0003] Multiple myeloma (MM) is a malignancy characterized by an accumulation of clonal plasma cells (see, e.g., Palumbo et al., *New England J. Med.*, *364*(11): 1046-1060 (2011), and Lonial et al., *Clinical Cancer Res.*, *17*(6): 1264-1277 (2011)). Current therapies for MM often cause remissions, but nearly all patients eventually relapse and die (see, e.g., Lonial et al., *supra*, and Rajkumar, *Nature Rev. Clinical Oncol.*, *8*(8): 479-491 (2011)). Allogeneic hematopoietic stem cell transplantation has been shown to induce immune-mediated elimination of myeloma cells; however, the toxicity of this approach is high, and few patients are cured (see, e.g., Lonial et al., *supra*, and Salit et al., *Clin. Lymphoma, Myeloma, and Leukemia*, *11*(3): 247-252 (2011)). Currently, there are no clinically effective, FDA-approved monoclonal antibody or autologous T-cell therapies for MM (see, e.g., Richardson et al., *British J. Haematology*, *154*(6): 745-754 (2011), and Yi, *Cancer Journal*, *15*(6): 502-510 (2009)).

[0004] Adoptive transfer of T-cells genetically modified to recognize malignancy-associated antigens is showing promise as a new approach to treating cancer (see, e.g., Morgan et al., *Science*, *314*(5796): 126-129 (2006); Brenner et al., *Current Opinion in Immunology*, *22*(2): 251-257 (2010); Rosenberg et al., *Nature Reviews Cancer*, *8*(4): 299-308 (2008), Kershaw et al., *Nature Reviews Immunology*, *5*(12): 928-940 (2005); and Pule et al., *Nature Medicine*, *14*(11): 1264-1270 (2008)). T-cells can be genetically modified to express

chimeric antigen receptors (CARs), which are fusion proteins comprised of an antigen recognition moiety and T-cell activation domains (see, e.g., Kershaw et al., *supra*, Eshhar et al., *Proc. Natl. Acad. Sci. USA*, *90*(2): 720-724 (1993), and Sadelain et al., *Curr. Opin. Immunol.*, *21*(2): 215-223 (2009)).

[0005] For B-cell lineage malignancies, extensive progress has been made in developing adoptive T-cell approaches that utilize anti-CD19 CARs (see, e.g., Jensen et al., *Biology of Blood and Marrow Transplantation*, *16*: 1245-1256 (2010); Kochenderfer et al., *Blood*, *116*(20): 4099-4102 (2010); Porter et al., *The New England Journal of Medicine*, *365*(8): 725-733 (2011); Savoldo et al., *Journal of Clinical Investigation*, *121*(5): 1822-1826 (2011), Cooper et al., *Blood*, *101*(4): 1637-1644 (2003); Brentjens et al., *Nature Medicine*, *9*(3): 279-286 (2003); and Kalos et al., *Science Translational Medicine*, *3*(95): 95ra73 (2011)). Adoptively transferred anti-CD19-CAR-transduced T-cells have cured leukemia and lymphoma in mice (see, e.g., Cheadle et al., *Journal of Immunology*, *184*(4): 1885-1896 (2010); Brentjens et al., *Clinical Cancer Research*, *13*(18 Pt 1): 5426-5435 (2007); and Kochenderfer et al., *Blood*, *116*(19): 3875-3886 (2010)). In early clinical trials, adoptively transferred T-cells transduced with anti-CD19 CARs eradicated normal and malignant B-cells in patients with leukemia and lymphoma (see, e.g., Kochenderfer et l., *Blood*, *116*(20): 4099-4102 (2010); Porter et al., *supra*, Brentjens et al., *Blood*, *118*(18): 4817-4828 (2011); and Kochenderfer et al., *Blood*, December 8, 2011 (epublication ahead of print (2012)). CD19, however, is only rarely expressed on the malignant plasma cells of multiple myeloma (see, e.g., Gupta et al., *Amer. J. Clin. Pathology*, *132*(5): 728-732 (2009); and Lin et al., *Amer. J. Clin. Pathology*, *121*(4): 482-488 (2004)).

[0006] Thus, there remains a need for compositions that can be used in methods to treat multiple myeloma. This invention provides such compositions and methods.

BRIEF SUMMARY

[0007] The present disclosure provides an isolated or purified nucleic acid sequence encoding a chimeric antigen receptor (CAR), wherein the CAR comprises an antigen recognition moiety and a T-cell activation moiety, and wherein the antigen recognition moiety is directed against B-cell Maturation Antigen (BCMA).

[0007a] In one aspect, there is provided an isolated or purified nucleic acid sequence encoding a chimeric antigen receptor (CAR), wherein the CAR comprises an antigen recognition

moiety and a T-cell activation moiety, and wherein the antigen recognition moiety is directed against B-cell Maturation Antigen (BCMA), and wherein a T cell or natural killer (NK) cell expressing the CAR secretes interferon-gamma in response to co-culture with a BCMA-positive target cell.

[0007b] In another aspect, there is provided an isolated or purified CAR encoded by the nucleic acid sequence as described herein.

[0007c] In yet another aspect, there is provided a vector comprising the isolated or purified nucleic sequence as described herein.

[0007d] In yet another aspect, there is provided an isolated host cell which expresses the nucleic acid sequence as described herein.

[0007e] In yet another aspect, there is provided a method of destroying cancer cells, which method comprises contacting cancer cells that express BCMA with the isolated or purified nucleic acid sequence as described herein, whereby the CAR is produced and binds to BCMA on the cancer cells and the cancer cells are destroyed, wherein the cancer cells are *in vitro*.

[0007f] In yet another aspect, there is provided a method of destroying cancer cells, which method comprises contacting cancer cells that express BCMA with the vector of the present disclosure, whereby the CAR is produced and binds to BCMA on the cancer cells and the cancer cells are destroyed, wherein the cancer cells are *in vitro*.

[0007g] In yet another aspect, there is provided a method of destroying cancer cells, which method comprises contacting cancer cells that express BCMA with one or more of the isolated T-cells of the present disclosure, whereby the CAR is produced and binds to BCMA on the cancer cells and the cancer cells are destroyed, wherein the cancer cells are *in vitro*.

[0007h] In yet another aspect, there is provided a method of destroying cancer cells, which method comprises contacting cancer cells that express BCMA with one or more of the isolated NK cells of the present disclosure, whereby the CAR is produced and binds to BCMA on the cancer cells and the cancer cells are destroyed, wherein the cancer cells are *in vitro*.

[0007i] In yet another aspect, there is provided a use of the nucleic acid sequence as described herein, the CAR as described herein, the vector as described herein, or the host cell as described herein, in the manufacture of a medicament for the destruction of BCMA-expressing cancer cells.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWING(S)

[0008] Figures 1A and 1B are graphs which depict experimental data illustrating the expression pattern of BCMA across a variety of human cell types, as determined using quantitative PCR. The results are expressed as the number of BCMA cDNA copies per 10^5 actin cDNA copies.

[0009] Figures 2A-2L are graphs which depict experimental data illustrating that cell-surface BCMA expression was detected on multiple myeloma cell lines, but not on other types of cells, as described in Example 1. For all plots, the solid line represents staining with anti-BCMA antibodies, and the dashed line represents staining with isotype-matched control antibodies. All plots were gated on live cells.

[0010] Figure 3A is a diagram which depicts a nucleic acid construct encoding an anti-BCMA CAR. From the N-terminus to the C-terminus, the anti-BCMA CAR includes an anti-BCMA scFv, the hinge and transmembrane regions of the CD8α molecule, the cytoplasmic portion of the CD28 molecule, and the cytoplasmic portion of the CD3ζ molecule.

[0011] Figures 3B-3D are graphs which depict experimental data illustrating that the anti-bcma1 CAR, the anti-bcma2 CAR, and the SP6 CAR (described in Example 2) are expressed on the surface of T-cells. Minimal anti-Fab staining occurred on untransduced (UT) cells. The plots are gated on $CD3^+$ lymphocytes. The numbers on the plots are the percentages of cells in each quadrant.

[0012] Figures 4A-4C are graphs which depict experimental data illustrating that T-cells expressing anti-BCMA CARs degranulate T-cells in a BCMA-specific manner, as described Example 3. The plots are gated on live CD3+ lymphocytes. The numbers on the plots are the percentages of cells in each quadrant.

[0013] Figures 5A-5D are graphs which depict experimental data illustrating that T-cells expressing anti-BCMA CARs degranulate T-cells in a BCMA-specific manner, as described Example 3. The plots are gated on live CD3+ lymphocytes. The numbers on the plots are the percentages of cells in each quadrant.

[0014] Figures 6A-6C are graphs which depict experimental data illustrating that T-cells expressing anti-BCMA CARs produce the cytokines IFNγ, IL-2, and TNF in a BCMA-specific manner, as described Example 3. The plots are gated on live CD3+ lymphocytes. The numbers on the plots are the percentages of cells in each quadrant.

[0015] Figure 7A is a graph which depicts experimental data illustrating that T-cells expressing the anti-bcma2 CAR proliferated specifically in response to BCMA. Figure 6B is a graph which depicts experimental data illustrating that T-cells expressing the SP6 CAR did not proliferate specifically in response to BCMA.

[0016] Figures 7C and 7D are graphs which depict experimental data illustrating that T-cells from Donor A expressing the anti-bcma2 CAR specifically killed the multiple myeloma cell lines H929 (Figure 6C) and RPMI8226 (Figure 6D) in a four-hour cytotoxicity assay at various effector:target cell ratios. T-cells transduced with the negative control SP6 CAR induced much lower levels of cytotoxicity at all effector:target ratios. For all effector:target ratios, the cytotoxicity was determined in duplicate, and the results are displayed as the mean +/- the standard error of the mean.

[0017] Figure 8A is a graph which depicts experimental data illustrating that BCMA is expressed on the surface of primary bone marrow multiple myeloma cells from Myeloma Patient 3, as described in Example 5. The plot is gated on $CD38^{high}$ $CD56^{+}$ plasma cells, which made up 40% of the bone marrow cells.

[0018] Figure 8B is a graph which depicts experimental data illustrating that allogeneic T-cells transduced with the anti-bcma2 CAR from Donor C produced IFNγ after co-culture with the unmanipulated bone marrow cells of Myeloma Patient 3, as described in Example 5. Figure 7B also illustrates that T-cells from the same allogeneic donor expressing the anti-bcma2 CAR produced much less IFNγ when they were cultured with peripheral blood mononuclear cell (PBMC) from Myeloma Patient 3. In addition, T-cells from Donor C expressing the SP6 CAR did not specifically recognize the bone marrow of Myeloma Patient 3.

[0019] Figure 8C is a graph which depicts experimental data illustrating that a plasmacytoma resected from Myeloma Patient 1 consisted of 93% plasma cells, and these primary plasma cells expressed BCMA, as revealed by flow cytometry for BCMA (solid line) and isotype-matched control staining (dashed line). The plot is gated on plasma cells.

[0020] Figure 8D is a graph which depicts experimental data illustrating that T-cells from Myeloma Patient 1 expressing the anti-bcma2 CAR produced IFNγ specifically in response to autologous plasmacytoma cells.

[0021] Figure 8E s a graph which depicts experimental data illustrating that T-cells from Myeloma Patient 1 expressing the anti-bcma2 CAR specifically killed autologous plasmacytoma cells at low effector to target ratios. In contrast, T-cells from Myeloma Patient

1 expressing the SP6 CAR exhibited low levels of cytotoxicity against autologous plasmacytoma cells. For all effector:target ratios, the cytotoxicity was determined in duplicate, and the results are displayed as the mean+/-the standard error of the mean.

[0022] Figure 9A is a graph which depicts experimental data illustrating that T-cells transduced with the anti-bcma2 CAR can destroy established multiple myeloma tumors in mice. Figure 9B is a graph which depicts the survival of tumor-bearing mice treated with T-cells expressing the anti-bcma2 CAR as compared to controls.

DETAILED DESCRIPTION OF THE INVENTION

[0023] The invention provides an isolated or purified nucleic acid sequence encoding a chimeric antigen receptor (CAR), wherein the CAR comprises an antigen recognition moiety and a T-cell activation moiety. A chimeric antigen receptor (CAR) is an artificially constructed hybrid protein or polypeptide containing an antigen binding domain of an antibody (e.g., a single chain variable fragment (scFv)) linked to T-cell signaling or T-cell activation domains. CARs have the ability to redirect T-cell specificity and reactivity toward a selected target in a non-MHC-restricted manner, exploiting the antigen-binding properties of monoclonal antibodies. The non-MHC-restricted antigen recognition gives T-cells expressing CARs the ability to recognize an antigen independent of antigen processing, thus bypassing a major mechanism of tumor escape. Moreover, when expressed in T-cells, CARs advantageously do not dimerize with endogenous T-cell receptor (TCR) alpha and beta chains.

[0024] "Nucleic acid sequence" is intended to encompass a polymer of DNA or RNA, i.e., a polynucleotide, which can be single-stranded or double-stranded and which can contain non-natural or altered nucleotides. The terms "nucleic acid" and "polynucleotide" as used herein refer to a polymeric form of nucleotides of any length, either ribonucleotides (RNA) or deoxyribonucleotides (DNA). These terms refer to the primary structure of the molecule, and thus include double- and single-stranded DNA, and double- and single-stranded RNA. The terms include, as equivalents, analogs of either RNA or DNA made from nucleotide analogs and modified polynucleotides such as, though not limited to methylated and/or capped polynucleotides.

[0025] By "isolated" is meant the removal of a nucleic acid from its natural environment. By "purified" is meant that a given nucleic acid, whether one that has been removed from nature (including genomic DNA and mRNA) or synthesized (including cDNA) and/or

amplified under laboratory conditions, has been increased in purity, wherein "purity" is a relative term, not "absolute purity." It is to be understood, however, that nucleic acids and proteins may be formulated with diluents or adjuvants and still for practical purposes be isolated. For example, nucleic acids typically are mixed with an acceptable carrier or diluent when used for introduction into cells.

[0026] The inventive nucleic acid sequence encodes a CAR which comprises an antigen recognition moiety that is directed against B-cell Maturation Antigen (BCMA, also known as CD269). BCMA is a member of the tumor necrosis factor receptor superfamily (see, e.g., Thompson et al., *J. Exp. Medicine*, *192*(1): 129-135 (2000), and Mackay et al., *Annu. Rev. Immunol.*, *21*: 231-264 (2003)). BCMA binds B-cell activating factor (BAFF) and a proliferation inducing ligand (APRIL) (see, e.g., Mackay et al., *supra*, and Kalled et al., *Immunological Reviews*, *204*: 43-54 (2005)). Among nonmalignant cells, BCMA has been reported to be expressed mostly in plasma cells and subsets of mature B-cells (see, e.g., Laabi et al., *EMBO J.*, *11*(11): 3897-3904 (1992); Laabi et al., *Nucleic Acids Res.*, *22*(7): 1147-1154 (1994); Kalled et al., *supra*; O'Connor et al., *J. Exp. Medicine*, *199*(1): 91-97 (2004); and Ng et al., *J. Immunol.*, *173*(2): 807-817 (2004)). Mice deficient in BCMA are healthy and have normal numbers of B-cells, but the survival of long-lived plasma cells is impaired (see, e.g., O'Connor et al, *supra*; Xu et al., *Mol. Cell. Biol.*, *21*(12): 4067-4074 (2001); and Schiemann et al., *Science*, *293*(5537): 2111-2114 (2001)). BCMA RNA has been detected universally in multiple myeloma cells, and BCMA protein has been detected on the surface of plasma cells from multiple myeloma patients by several investigators (see, e.g., Novak et al., *Blood*, *103*(2): 689-694 (2004); Neri et al., *Clinical Cancer Research*, *13*(19): 5903-5909 (2007); Bellucci et al., *Blood*, *105*(10): 3945-3950 (2005); and Moreaux et al., *Blood*, *103*(8): 3148-3157 (2004)).

[0027] The inventive nucleic acid sequence encodes a CAR which comprises an antigen recognition moiety that contains a monoclonal antibody directed against BCMA, or an antigen-binding portion thereof. The term "monoclonal antibodies," as used herein, refers to antibodies that are produced by a single clone of B-cells and bind to the same epitope. In contrast, "polyclonal antibodies" refer to a population of antibodies that are produced by different B-cells and bind to different epitopes of the same antigen. The antigen recognition moiety of the CAR encoded by the inventive nucleic acid sequence can be a whole antibody or an antibody fragment. A whole antibody typically consists of four polypeptides: two identical copies of a heavy (H) chain polypeptide and two identical copies of a light (L) chain

polypeptide. Each of the heavy chains contains one N-terminal variable (VH) region and three C-terminal constant (CH1, CH2 and CH3) regions, and each light chain contains one N-terminal variable (VL) region and one C-terminal constant (CL) region. The variable regions of each pair of light and heavy chains form the antigen binding site of an antibody. The VH and VL regions have the same general structure, with each region comprising four framework regions, whose sequences are relatively conserved. The framework regions are connected by three complementarity determining regions (CDRs). The three CDRs, known as CDR1, CDR2, and CDR3, form the "hypervariable region" of an antibody, which is responsible for antigen binding.

[0028] The terms "fragment of an antibody," "antibody fragment," "functional fragment of an antibody," and "antigen-binding portion" are used interchangeably herein to mean one or more fragments or portions of an antibody that retain the ability to specifically bind to an antigen (see, generally, Holliger et al., *Nat. Biotech.*, *23*(9): 1126-1129 (2005)). The antigen recognition moiety of the CAR encoded by the inventive nucleic acid sequence can contain any BCMA-binding antibody fragment. The antibody fragment desirably comprises, for example, one or more CDRs, the variable region (or portions thereof), the constant region (or portions thereof), or combinations thereof. Examples of antibody fragments include, but are not limited to, (i) a Fab fragment, which is a monovalent fragment consisting of the VL, VH, CL, and CH1 domains; (ii) a F(ab')2 fragment, which is a bivalent fragment comprising two Fab fragments linked by a disulfide bridge at the hinge region; (iii) a Fv fragment consisting of the VL and VH domains of a single arm of an antibody; (iv) a single chain Fv (scFv), which is a monovalent molecule consisting of the two domains of the Fv fragment (i.e., VL and VH) joined by a synthetic linker which enables the two domains to be synthesized as a single polypeptide chain (see, e.g., Bird et al., *Science, 242*: 423-426 (1988); Huston et al., *Proc. Natl. Acad. Sci. USA*, *85*: 5879-5883 (1988); and Osbourn et al., *Nat. Biotechnol.*, *16*: 778 (1998)) and (v) a diabody, which is a dimer of polypeptide chains, wherein each polypeptide chain comprises a VH connected to a VL by a peptide linker that is too short to allow pairing between the VH and VL on the same polypeptide chain, thereby driving the pairing between the complementary domains on different VH -VL polypeptide chains to generate a dimeric molecule having two functional antigen binding sites. Antibody fragments are known in the art and are described in more detail in, e.g., U.S. Patent Application Publication 2009/0093024 A1. In a preferred embodiment, the antigen

recognition moiety of the CAR encoded by the inventive nucleic acid sequence comprises an anti-BCMA single chain Fv (scFv).

[0029] An antigen-binding portion or fragment of a monoclonal antibody can be of any size so long as the portion binds to BCMA. In this respect, an antigen binding portion or fragment of the monoclonal antibody directed against BCMA (also referred to herein as an "anti-BCMA monoclonal antibody") desirably comprises between about 5 and 18 amino acids (e.g., about 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, or a range defined by any two of the foregoing values).

[0030] In one embodiment, the inventive nucleic acid sequence encodes an antigen recognition moiety that comprises a variable region of an anti-BCMA monoclonal antibody. In this respect, the antigen recognition moiety comprises a light chain variable region, a heavy chain variable region, or both a light chain variable region and a heavy chain variable region of an anti-BCMA monoclonal antibody. Preferably, the antigen recognition moiety of the CAR encoded by the inventive nucleic acid sequence comprises a light chain variable region and a heavy chain variable region of an anti-BCMA monoclonal antibody. Heavy and light chain monoclonal antibody amino acid sequences that bind to BCMA are disclosed in, e.g., International Patent Application Publication WO 2010/104949.

[0031] In another embodiment, the inventive nucleic acid sequence encodes a CAR which comprises a signal sequence. The signal sequence may be positioned at the amino terminus of the antigen recognition moiety (e.g., the variable region of the anti-BCMA antibody). The signal sequence may comprise any suitable signal sequence. In one embodiment, the signal sequence is a human granulocyte-macrophage colony-stimulating factor (GM-CSF) receptor sequence or a CD8α signal sequence.

[0032] In another embodiment, the CAR comprises a hinge sequence. One of ordinary skill in the art will appreciate that a hinge sequence is a short sequence of amino acids that facilitates antibody flexibility (see, e.g., Woof et al., *Nat. Rev. Immunol.*, *4*(2): 89-99 (2004)). The hinge sequence may be positioned between the antigen recognition moiety (e.g., an anti-BCMA scFv) and the T-cell activation moiety. The hinge sequence can be any suitable sequence derived or obtained from any suitable molecule. In one embodiment, for example, the hinge sequence is derived from the human CD8α molecule or a CD28 molecule.

[0033] The inventive nucleic acid sequence encodes a CAR comprising a T-cell activation moiety . The T-cell activation moiety can be any suitable moiety derived or obtained from any suitable molecule. In one embodiment, for example, the T-cell activation

moiety comprises a transmembrane domain. The transmembrane domain can be any transmembrane domain derived or obtained from any molecule known in the art. For example, the transmembrane domain can be obtained or derived from a CD8α molecule or a CD28 molecule. CD8 is a transmembrane glycoprotein that serves as a co-receptor for the T-cell receptor (TCR), and is expressed primarily on the surface of cytotoxic T-cells. The most common form of CD8 exists as a dimer composed of a CD8α and CD8β chain. CD28 is expressed on T-cells and provides co-stimulatory signals required for T-cell activation. CD28 is the receptor for CD80 (B7.1) and CD86 (B7.2). In a preferred embodiment, the CD8α and CD28 are human.

[0034] In addition to the transmembrane domain, the T-cell activation moiety further comprises an intracellular (i.e., cytoplasmic) T-cell signaling domain. The intercellular T-cell signaling domain can be obtained or derived from a CD28 molecule, a CD3 zeta (ζ) molecule or modified versions thereof, a human Fc receptor gamma (FcRγ) chain, a CD27 molecule, an OX40 molecule, a 4-1BB molecule, or other intracellular signaling molecules known in the art. As discussed above, CD28 is a T-cell marker important in T-cell co-stimulation. CD3ζ associates with TCRs to produce a signal and contains immunoreceptor tyrosine-based activation motifs (ITAMs). 4-1BB, also known as CD137, transmits a potent costimulatory signal to T-cells, promoting differentiation and enhancing long-term survival of T lymphocytes. In a preferred embodiment, the CD28, CD3 zeta, 4-1BB, OX40, and CD27 are human.

[0035] The T-cell activation domain of the CAR encoded by the inventive nucleic acid sequence can comprise any one of aforementioned transmembrane domains and any one or more of the aforementioned intercellular T-cell signaling domains in any combination. For example, the inventive nucleic acid sequence can encode a CAR comprising a CD28 transmembrane domain and intracellular T-cell signaling domains of CD28 and CD3 zeta. Alternatively, for example, the inventive nucleic acid sequence can encode a CAR comprising a CD8α transmembrane domain and intracellular T-cell signaling domains of CD28, CD3 zeta, the Fc receptor gamma (FcRγ) chain, and/or 4-1BB.

[0036] In one embodiment, the inventive nucleic acid sequence encodes a CAR which comprises, from 5' to 3', a granulocyte-macrophage colony stimulating factor receptor (GM-CSF receptor) signal sequence, an anti-BCMA scFv, the hinge and transmembrane regions of the human CD8α molecule, the cytoplasmic T-cell signaling domain of the human CD28

molecule, and T-cell signaling domain of the human CD3ζ molecule. In another embodiment, the inventive nucleic acid sequence encodes a CAR which comprises, from 5' to 3', a human CD8α signal sequence, an anti-BCMA scFv, the hinge and transmembrane regions of the human CD8α molecule, the cytoplasmic T-cell signaling domain of the human CD28 molecule, and T-cell signaling domain of the human CD3ζ molecule. In another embodiment, the inventive nucleic acid sequence encodes a CAR which comprises, from 5' to 3', a human CD8α signal sequence, an anti-BCMA scFv, the hinge and transmembrane regions of the human CD8α molecule, the cytoplasmic T-cell signaling domain of the human 4-1BB molecule and/or the cytoplasmic T-cell signaling domain of the human OX40 molecule, and T-cell signaling domain of the human CD3ζ molecule. For example, the inventive nucleic acid sequence comprises or consists of the nucleic acid sequence of SEQ ID NO: 1, SEQ ID NO: 2, or SEQ ID NO: 3.

[0037] The invention further provides an isolated or purified chimeric antigen receptor (CAR) encoded by the inventive nucleic acid sequence.

[0038] The nucleic acid sequence of the invention can encode a CAR of any length, i.e., the CAR can comprise any number of amino acids, provided that the CAR retains its biological activity, e.g., the ability to specifically bind to antigen, detect diseased cells in a mammal, or treat or prevent disease in a mammal, etc. For example, the CAR can comprise 50 or more (e.g., 60 or more, 100 or more, or 500 or more) amino acids, but less than 1,000 (e.g., 900 or less, 800 or less, 700 or less, or 600 or less) amino acids. Preferably, the CAR is about 50 to about 700 amino acids (e.g., about 70, about 80, about 90, about 150, about 200, about 300, about 400, about 550, or about 650 amino acids), about 100 to about 500 amino acids (e.g., about 125, about 175, about 225, about 250, about 275, about 325, about 350, about 375, about 425, about 450, or about 475 amino acids), or a range defined by any two of the foregoing values.

[0039] Included in the scope of the invention are nucleic acid sequences that encode functional portions of the CAR described herein. The term "functional portion," when used in reference to a CAR, refers to any part or fragment of the CAR of the invention, which part or fragment retains the biological activity of the CAR of which it is a part (the parent CAR). Functional portions encompass, for example, those parts of a CAR that retain the ability to recognize target cells, or detect, treat, or prevent a disease, to a similar extent, the same extent, or to a higher extent, as the parent CAR. In reference to a nucleic acid sequence

encoding the parent CAR, a nucleic acid sequence encoding a functional portion of the CAR can encode a protein comprising, for example, about 10%, 25%, 30%, 50%, 68%, 80%, 90%, 95%, or more, of the parent CAR.

[0040] The inventive nucleic acid sequence can encode a functional portion of a CAR that contains additional amino acids at the amino or carboxy terminus of the portion, or at both termini, which additional amino acids are not found in the amino acid sequence of the parent CAR. Desirably, the additional amino acids do not interfere with the biological function of the functional portion, e.g., recognize target cells, detect cancer, treat or prevent cancer, etc. More desirably, the additional amino acids enhance the biological activity of the CAR, as compared to the biological activity of the parent CAR.

[0041] The invention also provides nucleic acid sequences encoding functional variants of the aforementioned CAR. The term "functional variant," as used herein, refers to a CAR, a polypeptide, or a protein having substantial or significant sequence identity or similarity to the CAR encoded by the inventive nucleic acid sequence, which functional variant retains the biological activity of the CAR of which it is a variant. Functional variants encompass, for example, those variants of the CAR described herein (the parent CAR) that retain the ability to recognize target cells to a similar extent, the same extent, or to a higher extent, as the parent CAR. In reference to a nucleic acid sequence encoding the parent CAR, a nucleic acid sequence encoding a functional variant of the CAR can be for example, about 10% identical, about 25% identical, about 30% identical, about 50% identical, about 65% identical, about 80% identical, about 90% identical, about 95% identical, or about 99% identical to the nucleic acid sequence encoding the parent CAR.

[0042] A functional variant can, for example, comprise the amino acid sequence of the CAR encoded by the inventive nucleic acid sequence with at least one conservative amino acid substitution. The phrase "conservative amino acid substitution" or "conservative mutation" refers to the replacement of one amino acid by another amino acid with a common property. A functional way to define common properties between individual amino acids is to analyze the normalized frequencies of amino acid changes between corresponding proteins of homologous organisms (Schulz, G. E. and Schirmer, R. H., *Principles of Protein Structure*, Springer-Verlag, New York (1979)). According to such analyses, groups of amino acids may be defined where amino acids within a group exchange preferentially with each other, and therefore resemble each other most in their impact on the overall protein structure (Schulz, G. E. and Schirmer, R. H., *supra*). Examples of conservative mutations include

amino acid substitutions of amino acids within the sub-groups above, for example, lysine for arginine and vice versa such that a positive charge may be maintained; glutamic acid for aspartic acid and vice versa such that a negative charge may be maintained; serine for threonine such that a free -OH can be maintained; and glutamine for asparagine such that a free -NH_2 can be maintained.

[0043] Alternatively or additionally, the functional variants can comprise the amino acid sequence of the parent CAR with at least one non-conservative amino acid substitution. "Non-conservative mutations" involve amino acid substitutions between different groups, for example, lysine for tryptophan, or phenylalanine for serine, etc. In this case, it is preferable for the non-conservative amino acid substitution to not interfere with, or inhibit the biological activity of, the functional variant. The non-conservative amino acid substitution may enhance the biological activity of the functional variant, such that the biological activity of the functional variant is increased as compared to the parent CAR.

[0044] The inventive nucleic acid sequence can encode a CAR (including functional portions and functional variants thereof) that comprises synthetic amino acids in place of one or more naturally-occurring amino acids. Such synthetic amino acids are known in the art, and include, for example, aminocyclohexane carboxylic acid, norleucine, α-amino n-decanoic acid, homoserine, S-acetylaminomethyl-cysteine, trans-3- and trans-4-hydroxyproline, 4-aminophenylalanine, 4- nitrophenylalanine, 4-chlorophenylalanine, 4-carboxyphenylalanine, β-phenylserine β-hydroxyphenylalanine, phenylglycine, α-naphthylalanine, cyclohexylalanine, cyclohexylglycine, indoline-2-carboxylic acid, 1,2,3,4-tetrahydroisoquinoline-3-carboxylic acid, aminomalonic acid, aminomalonic acid monoamide, N'-benzyl-N'-methyl-lysine, N',N'-dibenzyl-lysine, 6-hydroxylysine, ornithine, α-aminocyclopentane carboxylic acid, α-aminocyclohexane carboxylic acid, α-aminocycloheptane carboxylic acid, α-(2-amino-2-norbornane)-carboxylic acid, α,γ-diaminobutyric acid, α,β-diaminopropionic acid, homophenylalanine, and α-tert-butylglycine.

[0045] The inventive nucleic acid sequence can encode a CAR (including functional portions and functional variants thereof) which is glycosylated, amidated, carboxylated, phosphorylated, esterified, N-acylated, cyclized via, e.g., a disulfide bridge, or converted into an acid addition salt and/or optionally dimerized or polymerized, or conjugated.

[0046] In a preferred embodiment, the inventive nucleic acid sequence encodes a CAR that comprises or consists of the amino acid sequence of SEQ ID NO: 4, SEQ ID NO: 5, SEQ

ID NO: 6, SEQ ID NO: 8, SEQ ID NO: 9, SEQ ID NO: 10, SEQ ID NO: 11, or SEQ ID NO: 12.

[0047] The inventive nucleic acid sequence can be generated using methods known in the art. For example, nucleic acid sequences, polypeptides, and proteins can be recombinantly produced using standard recombinant DNA methodology (see, e.g., Sambrook et al., *Molecular Cloning: A Laboratory Manual*, 3rd ed., Cold Spring Harbor Press, Cold Spring Harbor, NY 2001; and Ausubel et al., *Current Protocols in Molecular Biology*, Greene Publishing Associates and John Wiley & Sons, NY, 1994). Further, a synthetically produced nucleic acid sequence encoding the CAR can be isolated and/or purified from a source, such as a plant, a bacterium, an insect, or a mammal, e.g., a rat, a human, etc. Methods of isolation and purification are well-known in the art. Alternatively, the nucleic acid sequences described herein can be commercially synthesized. In this respect, the inventive nucleic acid sequence can be synthetic, recombinant, isolated, and/or purified.

[0048] The invention also provides a vector comprising the nucleic acid sequence encoding the inventive CAR. The vector can be, for example, a plasmid, a cosmid, a viral vector (e.g., retroviral or adenoviral), or a phage. Suitable vectors and methods of vector preparation are well known in the art (see, e.g., Sambrook et al., *supra*, and Ausubel et al., *supra*).

[0049] In addition to the inventive nucleic acid sequence encoding the CAR, the vector preferably comprises expression control sequences, such as promoters, enhancers, polyadenylation signals, transcription terminators, internal ribosome entry sites (IRES), and the like, that provide for the expression of the nucleic acid sequence in a host cell. Exemplary expression control sequences are known in the art and described in, for example, Goeddel, *Gene Expression Technology: Methods in Enzymology*, Vol. 185, Academic Press, San Diego, Calif. (1990).

[0050] A large number of promoters, including constitutive, inducible, and repressible promoters, from a variety of different sources are well known in the art. Representative sources of promoters include for example, virus, mammal, insect, plant, yeast, and bacteria, and suitable promoters from these sources are readily available, or can be made synthetically, based on sequences publicly available, for example, from depositories such as the ATCC as well as other commercial or individual sources. Promoters can be unidirectional (i.e., initiate transcription in one direction) or bi-directional (i.e., initiate transcription in either a 3' or 5' direction). Non-limiting examples of promoters include, for example, the T7 bacterial

expression system, pBAD (araA) bacterial expression system, the cytomegalovirus (CMV) promoter, the SV40 promoter, and the RSV promoter. Inducible promoters include, for example, the Tet system (U.S. Patents 5,464,758 and 5,814,618), the Ecdysone inducible system (No et al., *Proc. Natl. Acad. Sci., 93*: 3346-3351 (1996)), the T-REX™ system (Invitrogen, Carlsbad, CA), LACSWITCH™ System (Stratagene, San Diego, CA), and the Cre-ERT tamoxifen inducible recombinase system (Indra et al., *Nuc. Acid. Res., 27*: 4324-4327 (1999); *Nuc. Acid. Res., 28*: e99 (2000); U.S. Patent 7,112,715; and Kramer & Fussenegger, *Methods Mol. Biol., 308*: 123-144 (2005)).

[0051] The term "enhancer" as used herein, refers to a DNA sequence that increases transcription of, for example, a nucleic acid sequence to which it is operably linked. Enhancers can be located many kilobases away from the coding region of the nucleic acid sequence and can mediate the binding of regulatory factors, patterns of DNA methylation, or changes in DNA structure. A large number of enhancers from a variety of different sources are well known in the art and are available as or within cloned polynucleotides (from, e.g., depositories such as the ATCC as well as other commercial or individual sources). A number of polynucleotides comprising promoters (such as the commonly-used CMV promoter) also comprise enhancer sequences. Enhancers can be located upstream, within, or downstream of coding sequences. The term "Ig enhancers" refers to enhancer elements derived from enhancer regions mapped within the immunoglobulin (Ig) locus (such enhancers include for example, the heavy chain (mu) 5' enhancers, light chain (kappa) 5' enhancers, kappa and mu intronic enhancers, and 3' enhancers (see generally Paul W.E. (ed), *Fundamental Immunology, 3rd Edition*, Raven Press, New York (1993), pages 353-363; and U.S. Patent 5,885,827).

[0052] The vector also can comprise a "selectable marker gene." The term "selectable marker gene," as used herein, refers to a nucleic acid sequence that allows cells expressing the nucleic acid sequence to be specifically selected for or against, in the presence of a corresponding selective agent. Suitable selectable marker genes are known in the art and described in, e.g., International Patent Application Publications WO 1992/08796 and WO 1994/28143; Wigler et al., *Proc. Natl. Acad. Sci. USA, 77*: 3567 (1980); O'Hare et al., *Proc. Natl. Acad. Sci. USA, 78*: 1527 (1981); Mulligan & Berg, *Proc. Natl. Acad. Sci. USA, 78*: 2072 (1981); Colberre-Garapin et al., *J. Mol. Biol., 150*: 1 (1981); Santerre et al., *Gene, 30*: 147 (1984); Kent et al., *Science, 237*: 901–903 (1987); Wigler et al., *Cell, 11*: 223 (1977);

Szybalska & Szybalski, *Proc. Natl. Acad. Sci. USA*, *48*: 2026 (1962); Lowy et al., *Cell*, *22*: 817 (1980); and U.S. Patents 5,122,464 and 5,770,359.

[0053] In some embodiments, the vector is an "episomal expression vector" or "episome," which is able to replicate in a host cell, and persists as an extrachromosomal segment of DNA within the host cell in the presence of appropriate selective pressure (see, e.g., Conese et al., *Gene Therapy*, *11*: 1735-1742 (2004)). Representative commercially available episomal expression vectors include, but are not limited to, episomal plasmids that utilize Epstein Barr Nuclear Antigen 1 (EBNA1) and the Epstein Barr Virus (EBV) origin of replication (oriP). The vectors pREP4, pCEP4, pREP7, and pcDNA3.1 from Invitrogen (Carlsbad, CA) and pBK-CMV from Stratagene (La Jolla, CA) represent non-limiting examples of an episomal vector that uses T-antigen and the SV40 origin of replication in lieu of EBNA1 and oriP.

[0054] Other suitable vectors include integrating expression vectors, which may randomly integrate into the host cell's DNA, or may include a recombination site to enable the specific recombination between the expression vector and the host cell's chromosome. Such integrating expression vectors may utilize the endogenous expression control sequences of the host cell's chromosomes to effect expression of the desired protein. Examples of vectors that integrate in a site specific manner include, for example, components of the flp-in system from Invitrogen (Carlsbad, CA) (e.g., pcDNA™5/FRT), or the cre-lox system, such as can be found in the pExchange-6 Core Vectors from Stratagene (La Jolla, CA). Examples of vectors that randomly integrate into host cell chromosomes include, for example, pcDNA3.1 (when introduced in the absence of T-antigen) from Invitrogen (Carlsbad, CA), and pCI or pFN10A (ACT) FLEXI™ from Promega (Madison, WI).

[0055] Viral vectors also can be used. Representative viral expression vectors include, but are not limited to, the adenovirus-based vectors (e.g., the adenovirus-based Per.C6 system available from Crucell, Inc. (Leiden, The Netherlands)), lentivirus-based vectors (e.g., the lentiviral-based pLP1 from Life Technologies (Carlsbad, CA)), and retroviral vectors (e.g., the pFB-ERV plus pCFB-EGSH from Stratagene (La Jolla, CA)). In a preferred embodiment, the viral vector is a lentivirus vector.

[0056] The vector comprising the inventive nucleic acid encoding the CAR can be introduced into a host cell that is capable of expressing the CAR encoded thereby, including any suitable prokaryotic or eukaryotic cell. Preferred host cells are those that can be easily

and reliably grown, have reasonably fast growth rates, have well characterized expression systems, and can be transformed or transfected easily and efficiently.

[0057] As used herein, the term "host cell" refers to any type of cell that can contain the expression vector. The host cell can be a eukaryotic cell, e.g., plant, animal, fungi, or algae, or can be a prokaryotic cell, e.g., bacteria or protozoa. The host cell can be a cultured cell or a primary cell, i.e., isolated directly from an organism, e.g., a human. The host cell can be an adherent cell or a suspended cell, i.e., a cell that grows in suspension. Suitable host cells are known in the art and include, for instance, DH5α *E. coli* cells, Chinese hamster ovarian cells, monkey VERO cells, COS cells, HEK293 cells, and the like. For purposes of amplifying or replicating the recombinant expression vector, the host cell may be a prokaryotic cell, e.g., a DH5α cell. For purposes of producing a recombinant CAR, the host cell can be a mammalian cell. The host cell preferably is a human cell. The host cell can be of any cell type, can originate from any type of tissue, and can be of any developmental stage. In one embodiment, the host cell can be a peripheral blood lymphocyte (PBL), a peripheral blood mononuclear cell (PBMC), or a natural killer (NK). Preferably, the host cell is a natural killer (NK) cell. More preferably, the host cell is a T-cell. Methods for selecting suitable mammalian host cells and methods for transformation, culture, amplification, screening, and purification of cells are known in the art.

[0058] The invention provides an isolated host cell which expresses the inventive nucleic acid sequence encoding the CAR described herein. In one embodiment, the host cell is a T-cell. The T-cell of the invention can be any T-cell, such as a cultured T-cell, e.g., a primary T-cell, or a T-cell from a cultured T-cell line, or a T-cell obtained from a mammal. If obtained from a mammal, the T-cell can be obtained from numerous sources, including but not limited to blood, bone marrow, lymph node, the thymus, or other tissues or fluids. T-cells can also be enriched for or purified. The T-cell preferably is a human T-cell (e.g., isolated from a human). The T-cell can be of any developmental stage, including but not limited to, a $CD4^+/CD8^+$ double positive T-cell, a $CD4^+$ helper T-cell, e.g., Th_1 and Th_2 cells, a $CD8^+$ T-cell (e.g., a cytotoxic T-cell), a tumor infiltrating cell, a memory T-cell, a naïve T-cell, and the like. In one embodiment, the T-cell is a $CD8^+$ T-cell or a $CD4^+$ T-cell. T-cell lines are available from, e.g., the American Type Culture Collection (ATCC, Manassas, VA), and the German Collection of Microorganisms and Cell Cultures (DSMZ) and include, for example, Jurkat cells (ATCC TIB-152), Sup-T1 cells (ATCC CRL-1942), RPMI 8402 cells (DSMZ ACC-290), Karpas 45 cells (DSMZ ACC-545), and derivatives thereof.

[0059] In another embodiment, the host cell is a natural killer (NK) cell. NK cells are a type of cytotoxic lymphocyte that plays a role in the innate immune system. NK cells are defined as large granular lymphocytes and constitute the third kind of cells differentiated from the common lymphoid progenitor which also gives rise to B and T lymphocytes (see, e.g., *Immunobiology, 5th ed.*, Janeway et al., eds., Garland Publishing, New York, NY (2001)). NK cells differentiate and mature in the bone marrow, lymph node, spleen, tonsils, and thymus. Following maturation, NK cells enter into the circulation as large lymphocytes with distinctive cytotoxic granules. NK cells are able to recognize and kill some abnormal cells, such as, for example, some tumor cells and virus-infected cells, and are thought to be important in the innate immune defense against intracellular pathogens. As described above with respect to T-cells, the NK cell can be any NK cell, such as a cultured NK cell, e.g., a primary NK cell, or an NK cell from a cultured NK cell line, or an NK cell obtained from a mammal. If obtained from a mammal, the NK cell can be obtained from numerous sources, including but not limited to blood, bone marrow, lymph node, the thymus, or other tissues or fluids. NK cells can also be enriched for or purified. The NK cell preferably is a human NK cell (e.g., isolated from a human). NK cell lines are available from, e.g., the American Type Culture Collection (ATCC, Manassas, VA) and include, for example, NK-92 cells (ATCC CRL-2407), NK92MI cells (ATCC CRL-2408), and derivatives thereof.

[0060] The inventive nucleic acid sequence encoding a CAR may be introduced into a cell by "transfection," "transformation," or "transduction." "Transfection," "transformation," or "transduction," as used herein, refer to the introduction of one or more exogenous polynucleotides into a host cell by using physical or chemical methods. Many transfection techniques are known in the art and include, for example, calcium phosphate DNA co-precipitation (see, e.g., Murray E.J. (ed.), *Methods in Molecular Biology*, Vol. 7, Gene Transfer and Expression Protocols, Humana Press (1991)); DEAE-dextran; electroporation; cationic liposome-mediated transfection; tungsten particle-facilitated microparticle bombardment (Johnston, *Nature*, *346*: 776-777 (1990)); and strontium phosphate DNA co-precipitation (Brash et al., *Mol. Cell Biol.*, *7*: 2031-2034 (1987)). Phage or viral vectors can be introduced into host cells, after growth of infectious particles in suitable packaging cells, many of which are commercially available.

[0061] Without being bound to a particular theory or mechanism, it is believed that by eliciting an antigen-specific response against BCMA, the CARs encoded by the inventive nucleic acid sequence provide for one or more of the following: targeting and destroying

BCMA-expressing cancer cells, reducing or eliminating cancer cells, facilitating infiltration of immune cells to tumor site(s), and enhancing/extending anti-cancer responses. Thus, the invention provides a method of destroying multiple myeloma cells, which comprises contacting one or more of the aforementioned isolated T-cells or natural killer cells with a population of multiple myeloma cells that express BCMA, whereby the CAR is produced and binds to BCMA on the multiple myeloma cells and the multiple myeloma cells are destroyed. As discussed herein, multiple myeloma, also known as plasma cell myeloma or Kahler's disease, is a cancer of plasma cells, which are a type of white blood cell normally responsible for the production of antibodies (Raab et al., *Lancet*, *374*: 324-329 (2009)). Multiple myeloma affects 1-4 per 100,000 people per year. The disease is more common in men, and for yet unknown reasons is twice as common in African Americans as it is in Caucasian Americans. Multiple myeloma is the least common hematological malignancy (14%) and constitutes 1% of all cancers (Raab et al., *supra*). Treatment of multiple myeloma typically involves high-dose chemotherapy followed by hematopoietic stem cell transplanatation (allogenic or autologous); however, a high rate of relapse is common in multiple myeloma patients that have undergone such treatement. As discussed above, BCMA is highly expressed by multiple myeloma cells (see, e.g., Novak et al., *supra*; Neri et al., *supra*; Bellucci et al., *supra*; and Moreaux et al., *supra*).

[0062] One or more isolated T-cells expressing the inventive nucleic acid sequence encoding the anti-BCMA CAR described herein can be contacted with a population of multiple myeloma cells that express BCMA *ex vivo*, *in vivo*, or *in vitro*. "*Ex vivo*" refers to methods conducted within or on cells or tissue in an artificial environment outside an organism with minimum alteration of natural conditions. In contrast, the term "*in vivo*" refers to a method that is conducted within living organisms in their normal, intact state, while an "*in vitro*" method is conducted using components of an organism that have been isolated from its usual biological context. The inventive method preferably involves *ex vivo* and *in vivo* components. In this regard, for example, the isolated T-cells described above can be cultured *ex vivo* under conditions to express the inventive nucleic acid sequence encoding the anti-BCMA CAR, and then directly transferred into a mammal (preferably a human) affected by multiple myeloma. Such a cell transfer method is referred to in the art as "adoptive cell transfer (ACT)," in which immune-derived cells are passively transferred into a new recipient host to transfer the functionality of the donor immune-derived cells to the new host. Adoptive cell transfer methods to treat various types of cancers, including hematological

cancers such as myeloma, are known in the art and disclosed in, for example, Gattinoni et al., *Nat. Rev. Immunol.*, *6*(5): 383-393 (2006); June, CH, *J. Clin. Invest.*, *117*(6): 1466-76 (2007); Rapoport et al., *Blood*, *117*(3): 788-797 (2011); and Barber et al., *Gene Therapy*, *18*: 509-516 (2011)).

[0063] The invention also provides a method of destroying Hodgkin's lymphoma cells. Hodgkin's lymphoma (formerly known as Hodgkin's disease) is a cancer of the immune system that is marked by the presence of a multinucleated cell type called Reed-Sternberg cells. The two major types of Hodgkin's lymphoma include classical Hodgkin's lymphoma and nodular lymphocyte-predominant Hodgkin's lymphoma. Hodgkin's lymphoma currently is treated with radiation therapy, chemotherapy, or hematopoietic stem cell transplantation, with the choice of treatment depending on the age and sex of the patient and the stage, bulk, and histological subtype of the disease. BCMA expression has been detected on the surface of Hodgkin's lymphoma cells (see, e.g., Chiu et al., *Blood*, *109*(2): 729-739 (2007)).

[0064] When T-cells or NK cells are administered to a mammal, the cells can be allogeneic or autologous to the mammal. In "autologous" administration methods, cells (e.g., blood-forming stem cells or lymphocytes) are removed from a mammal, stored (and optionally modified), and returned back to the same mammal. In "allogeneic" administration methods, a mammal receives cells (e.g., blood-forming stem cells or lymphocytes) from a genetically similar, but not identical, donor. Preferably, the cells are autologous to the mammal.

[0065] The T-cells or NK cells desirably are administered to a human in the form of a composition, such as a pharmaceutical composition. Alternatively, the inventive nucleic acid sequence encoding the CAR, or a vector comprising the CAR-encoding nucleic acid sequence, can be formulated into a composition, such as a pharmaceutical composition, and administered to a human. The inventive pharmaceutical composition can comprise a population of T-cells of NK cells that express the inventive CAR. In addition to the inventive nucleic acid sequence, or host cells which express the inventive CAR, the pharmaceutical composition can comprise other pharmaceutically active agents or drugs, such as chemotherapeutic agents, e.g., asparaginase, busulfan, carboplatin, cisplatin, daunorubicin, doxorubicin, fluorouracil, gemcitabine, hydroxyurea, methotrexate, paclitaxel, rituximab, vinblastine, vincristine, etc. In a preferred embodiment, the pharmaceutical composition comprises an isolated T-cell or NK cell which expresses the inventive CAR, more preferably a population of T-cells or NK cells which express the inventive CAR.

[0066] The inventive T-cells or NK cells can be provided in the form of a salt, e.g., a pharmaceutically acceptable salt. Suitable pharmaceutically acceptable acid addition salts include those derived from mineral acids, such as hydrochloric, hydrobromic, phosphoric, metaphosphoric, nitric, and sulphuric acids, and organic acids, such as tartaric, acetic, citric, malic, lactic, fumaric, benzoic, glycolic, gluconic, succinic, and arylsulphonic acids, for example, *p*-toluenesulphonic acid.

[0067] The choice of carrier will be determined in part by the particular inventive nucleic acid sequence, vector, or host cells expressing the CAR, as well as by the particular method used to administer the inventive nucleic acid sequence, vector, or host cells expressing the CAR. Accordingly, there are a variety of suitable formulations of the pharmaceutical composition of the invention. For example, the pharmaceutical composition can contain preservatives. Suitable preservatives may include, for example, methylparaben, propylparaben, sodium benzoate, and benzalkonium chloride. A mixture of two or more preservatives optionally may be used. The preservative or mixtures thereof are typically present in an amount of about 0.0001% to about 2% by weight of the total composition.

[0068] In addition, buffering agents may be used in the composition. Suitable buffering agents include, for example, citric acid, sodium citrate, phosphoric acid, potassium phosphate, and various other acids and salts. A mixture of two or more buffering agents optionally may be used. The buffering agent or mixtures thereof are typically present in an amount of about 0.001% to about 4% by weight of the total composition.

[0069] Methods for preparing administrable (e.g., parenterally administrable) compositions are known to those skilled in the art and are described in more detail in, for example, *Remington: The Science and Practice of Pharmacy*, Lippincott Williams & Wilkins; 21st ed. (May 1, 2005).

[0070] The composition comprising the inventive nucleic acid sequence encoding the CAR, or host cells expressing the CAR, can be formulated as an inclusion complex, such as cyclodextrin inclusion complex, or as a liposome. Liposomes can serve to target the host cells (e.g., T-cells or NK cells) or the inventive nucleic acid sequence to a particular tissue. Liposomes also can be used to increase the half-life of the inventive nucleic acid sequence. Many methods are available for preparing liposomes, such as those described in, for example, Szoka et al., *Ann. Rev. Biophys. Bioeng.*, 9: 467 (1980), and U.S. Patents 4,235,871, 4,501,728, 4,837,028, and 5,019,369.

[0071] The composition can employ time-released, delayed release, and sustained release delivery systems such that the delivery of the inventive composition occurs prior to, and with sufficient time to cause, sensitization of the site to be treated. Many types of release delivery systems are available and known to those of ordinary skill in the art. Such systems can avoid repeated administrations of the composition, thereby increasing convenience to the subject and the physician, and may be particularly suitable for certain composition embodiments of the invention.

[0072] The composition desirably comprises the host cells expressing the inventive nucleic acid sequence encoding a CAR, or a vector comprising the inventive nucleic acid sequence, in an amount that is effective to treat or prevent multiple myeloma or Hodgkin's lymphoma. As used herein, the terms "treatment," "treating," and the like refer to obtaining a desired pharmacologic and/or physiologic effect. Preferably, the effect is therapeutic, i.e., the effect partially or completely cures a disease and/or adverse symptom attributable to the disease. To this end, the inventive method comprises administering a "therapeutically effective amount" of the composition comprising the host cells expressing the inventive nucleic acid sequence encoding a CAR, or a vector comprising the inventive nucleic acid sequence. A "therapeutically effective amount" refers to an amount effective, at dosages and for periods of time necessary, to achieve a desired therapeutic result. The therapeutically effective amount may vary according to factors such as the disease state, age, sex, and weight of the individual, and the ability of the CAR to elicit a desired response in the individual. For example, a therapeutically effective amount of CAR of the invention is an amount which binds to BCMA on multiple myeloma cells and destroys them.

[0073] Alternatively, the pharmacologic and/or physiologic effect may be prophylactic, i.e., the effect completely or partially prevents a disease or symptom thereof. In this respect, the inventive method comprises administering a "prophylactically effective amount" of the composition comprising the host cells expressing the inventive nucleic acid sequence encoding a CAR, or a vector comprising the inventive nucleic acid sequence, to a mammal that is predisposed to multiple myeloma or Hodgkin's lymphoma. A "prophylactically effective amount" refers to an amount effective, at dosages and for periods of time necessary, to achieve a desired prophylactic result (e.g., prevention of disease onset).

[0074] A typical amount of host cells administered to a mammal (e.g., a human) can be, for example, in the range of one million to 100 billion cells; however, amounts below or above this exemplary range are within the scope of the invention. For example, the daily

dose of inventive host cells can be about 1 million to about 50 billion cells (e.g., about 5 million cells, about 25 million cells, about 500 million cells, about 1 billion cells, about 5 billion cells, about 20 billion cells, about 30 billion cells, about 40 billion cells, or a range defined by any two of the foregoing values), preferably about 10 million to about 100 billion cells (e.g., about 20 million cells, about 30 million cells, about 40 million cells, about 60 million cells, about 70 million cells, about 80 million cells, about 90 million cells, about 10 billion cells, about 25 billion cells, about 50 billion cells, about 75 billion cells, about 90 billion cells, or a range defined by any two of the foregoing values), more preferably about 100 million cells to about 50 billion cells (e.g., about 120 million cells, about 250 million cells, about 350 million cells, about 450 million cells, about 650 million cells, about 800 million cells, about 900 million cells, about 3 billion cells, about 30 billion cells, about 45 billion cells, or a range defined by any two of the foregoing values).

[0075] Therapeutic or prophylactic efficacy can be monitored by periodic assessment of treated patients. For repeated administrations over several days or longer, depending on the condition, the treatment is repeated until a desired suppression of disease symptoms occurs. However, other dosage regimens may be useful and are within the scope of the invention. The desired dosage can be delivered by a single bolus administration of the composition, by multiple bolus administrations of the composition, or by continuous infusion administration of the composition.

[0076] The composition comprising the host cells expressing the inventive CAR-encoding nucleic acid sequence, or a vector comprising the inventive CAR-encoding nucleic acid sequence, can be administered to a mammal using standard administration techniques, including oral, intravenous, intraperitoneal, subcutaneous, pulmonary, transdermal, intramuscular, intranasal, buccal, sublingual, or suppository administration. The composition preferably is suitable for parenteral administration. The term "parenteral," as used herein, includes intravenous, intramuscular, subcutaneous, rectal, vaginal, and intraperitoneal administration. More preferably, the composition is administered to a mammal using peripheral systemic delivery by intravenous, intraperitoneal, or subcutaneous injection.

[0077] The composition comprising the host cells expressing the inventive CAR-encoding nucleic acid sequence, or a vector comprising the inventive CAR-encoding nucleic acid sequence, can be administered with one or more additional therapeutic agents, which can be coadministered to the mammal. By "coadministering" is meant administering one or more additional therapeutic agents and the composition comprising the inventive host cells or the

inventive vector sufficiently close in time such that the inventive CAR can enhance the effect of one or more additional therapeutic agents, or *vice versa*. In this regard, the composition comprising the inventive host cells or the inventive vector can be administered first, and the one or more additional therapeutic agents can be administered second, or *vice versa*. Alternatively, the composition comprising the inventive host cells or the inventive vector and the one or more additional therapeutic agents can be administered simultaneously. An example of a therapeutic agent that can be co-administered with the composition comprising the inventive host cells or the inventive vector is IL-2.

[0078] Once the composition comprising host cells expressing the inventive CAR-encoding nucleic acid sequence, or a vector comprising the inventive CAR-encoding nucleic acid sequence, is administered to a mammal (e.g., a human), the biological activity of the CAR can be measured by any suitable method known in the art. In accordance with the inventive method, the CAR binds to BCMA on the multiple myeloma cells, and the multiple myeloma cells are destroyed. Binding of the CAR to BCMA on the surface of multiple myeloma cells can be assayed using any suitable method known in the art, including, for example, ELISA and flow cytometry. The ability of the CAR to destroy multiple myeloma cells can be measured using any suitable method known in the art, such as cytotoxicity assays described in, for example, Kochenderfer et al., *J. Immunotherapy*, *32*(7): 689-702 (2009), and Herman et al. *J. Immunological Methods*, 285(1): 25-40 (2004). The biological activity of the CAR also can be measured by assaying expression of certain cytokines, such as CD107a, IFNγ, IL-2, and TNF.

[0079] One of ordinary skill in the art will readily appreciate that the inventive CAR-encoding nucleic acid sequence can be modified in any number of ways, such that the therapeutic or prophylactic efficacy of the CAR is increased through the modification. For instance, the CAR can be conjugated either directly or indirectly through a linker to a targeting moiety. The practice of conjugating compounds, e.g., the CAR, to targeting moieties is known in the art. See, for instance, Wadwa et al., *J. Drug Targeting* 3: 111 (1995), and U.S. Patent 5,087,616.

[0080] The following examples further illustrate the invention but, of course, should not be construed as in any way limiting its scope.

EXAMPLE 1

[0081] This example demonstrates the expression pattern of BCMA in human cells.

[0082] Quantitative polymerase chain reaction (qPCR) was performed on a panel of cDNA samples from a wide range of normal tissues included in the Human Major Tissue qPCR panel II (Origine Technologies, Rockville, MD) using a BCMA-specific primer and probe set (Life Technologies, Carlsbad, CA). cDNA from cells of a plasmacytoma that was resected from a patient with advanced multiple myeloma was analyzed as a positive control. RNA was extracted from the plasmacytoma cells with an RNeasy mini kit (Qiagen, Inc., Valencia, CA), and cDNA was synthesized using standard methods. A standard curve for the BCMA qPCR was created by diluting a plasmid that encoded the full-length BCMA cDNA (Origine Technologies, Rockville, MD) in carrier DNA. The qPCR accurately detected copy numbers from 10^2 to 10^9 copies of BCMA per reaction. The number of β-actin cDNA copies in the same tissues was quantitated with a Taqman β-actin primer and probe kit (Life Technologies, Carlsbad, CA). A β-actin standard curve was created by amplifying serial dilutions of a β-actin plasmid. All qPCR reactions were carried out on the Roche LightCycler480 machine (Roche Applied Sciences, Indianapolis, IN).

[0083] The results of the qPCR analysis are depicted in Figures 1A and 1B. 93% percent of the cells from the plasmacytoma sample were plasma cells as determined by flow cytometry. BCMA expression in the plasmacytoma sample was dramatically higher than BCMA expression in any other tissue. BCMA cDNA was detected in several hematologic tissues, such as peripheral blood mononuclear cells (PBMC), bone marrow, spleen, lymph node, and tonsil. Low levels of BCMA cDNA were detected in most gastrointestinal organs, such as duodenum, rectum, and stomach. BCMA expression in gastrointestinal organs may be the result of plasma cells and B-cells present in gut-associated lymphoid tissues such as the lamina propria and Peyer's Patches (see, e.g., Brandtzaeg, *Immunological Investigations, 39*(4-5): 303-355 (2010)). Low levels of BCMA cDNA also were detected in the testis and the trachea. The low levels of BCMA cDNA detected in the trachea may be due to the presence of plasma cells in the lamina propria of the trachea (see, e.g., Soutar, *Thorax, 31*(2):158-166 (1976)).

[0084] The expression of BCMA on the surface of various cell types was further characterized using flow cytometry (see Figures 2A-2L), including multiple myeloma cell lines H929, U266, and RPMI8226. The multiple myeloma cell lines H929, U266, and RPMI8226 all expressed cell surface BCMA. In contrast, the sarcoma cell line TC71, the T-cell leukemia line CCRF-CEM, and the kidney cell line 293T-17 did not express cell surface BCMA. Primary $CD34^+$ hematopoietic cells, primary small airway epithelial cells, primary

bronchial epithelial cells, and primary intestinal epithelial cells all lacked cell surface BCMA expression.

[0085] The results of this example demonstrate that BCMA is expressed on the surface of multiple myeloma cells, and it has a restricted expression pattern in normal tissues.

EXAMPLE 2

[0086] This example describes the construction of the inventive nucleic acid sequence encoding anti-BCMA chimeric antigen receptors (CARs).

[0087] Antibody sequences of two mouse-anti-human-BCMA antibodies designated as "C12A3.2" and "C11D5.3" were obtained from International Patent Application Publication WO 2010/104949 (Kalled et al.). The amino acid sequences of the heavy chain variable regions and light chain variable regions of these antibodies were used to design single chain variable fragments (scFvs) having the following general structure:

light chain variable region – linker – heavy chain variable region.

[0088] The linker had the following amino acid sequence: GSTSGSGKPGSGEGSTKG (SEQ ID NO: 7) (see, e.g., Cooper et al., *Blood*, *101*(4): 1637-1644 (2003)).

[0089] DNA sequences encoding two chimeric antigen receptors were designed, each of which contained the following elements from 5' to 3': the CD8α signal sequence, the aforementioned anti-BCMA scFv, hinge and transmembrane regions of the human CD8α molecule, the cytoplasmic portion of the CD28 molecule, and the cytoplasmic portion of the CD3ζ molecule. A schematic of these CAR-encoding nucleic acid sequences is set forth in Figure 3A. The CARs incorporating variable regions from C12A3.2 and C11D5.3 were designated anti-bcma1 and anti-bcma2, respectively.

[0090] DNA sequences encoding five additional chimeric antigen receptors based on the above-described anti-bcma2 CAR were designed, each of which contained different signal sequences and T-cell activation domains. In this respect, 8ss-anti-bcma2 CAR contained the following elements from 5' to 3: the CD8α signal sequence, scFv, hinge and transmembrane regions of the human CD8α molecule, the cytoplasmic portion of the CD28 molecule, and the cytoplasmic portion of the CD3ζ molecule. The G-anti-bcma2 CAR contained the following elements from 5' to 3': the human GM-CSF receptor signal sequence, scFv, hinge and transmembrane regions of the human CD8α molecule, the cytoplasmic portion of the CD28 molecule, and the cytoplasmic portion of the CD3ζ molecule. The anti-bcma2-BB

CAR contained the following elements from 5' to 3': the CD8α signal sequence, scFv, hinge and transmembrane regions of the human CD8α molecule, the cytoplasmic portion of the 4-1BB molecule, and the cytoplasmic portion of the CD3ζ molecule. The anti-bcma2-OX40 CAR contained the following elements from 5' to 3': the CD8α signal sequence, scFv, hinge and transmembrane regions of the human CD8α molecule, the cytoplasmic portion of the OX40 molecule (see, e.g., Latza et al., *European Journal of Immunology*, *24*: 677-683 (1994)), and the cytoplasmic portion of the CD3ζ molecule. The anti-bcma2-BBOX40 contained the following elements from 5' to 3': the CD8α signal sequence, scFv, hinge and transmembrane regions of the human CD8α molecule, the cytoplasmic portion of the 4-1BB molecule, the cytoplasmic region of the OX40 molecule, and the cytoplasmic portion of the CD3ζ molecule. The elements present in each of the seven CAR sequences are set forth in Table 1.

Table 1

CAR	SEQ ID NO (amino acid)	Signal Sequence	Hinge and Transmembrane Regions	Intracellular T-cell Signaling Domain
anti-bcma1	4	Human CD8α	Human CD8α	CD28 CD3ζ
anti-bcma2	5	Human CD8α	Human CD8α	CD28 CD3ζ
G-Anti-bcma2	8	GM-CSF receptor	Human CD8α	CD28 CD3ζ
8ss-anti-bcma2	9	Human CD8α	Human CD8α	CD28 CD3ζ
anti-bcma2-BB	10	Human CD8α	Human CD8α	4-1BB CD3ζ
anti-bcma2-OX40	11	Human CD8α	Human CD8α	OX40 CD3ζ
anti-bcma2-BBOX40	12	Human CD8α	Human CD8α	4-1BB OX40 CD3ζ

[0091] The sequences used for CD8α, CD28, CD3ζ, 4-1BB (CD137), and OX40 (CD134) were obtained from the publicly available National Center for Biotechnology Information (NCBI) database.

[0092] The CAR-encoding nucleic acid sequences were generated using methods known in the art, such as those described in, for example, Kochenderfer et al., *J. Immunology*, *32*(7): 689-702 (2009), and Zhao et al., *J. Immunology*, *183*(9): 5563-5574 (2009). The nucleic acid

sequence encoding each CAR was codon optimized and synthesized using GeneArt™ technology (Life Technologies, Carlsbad, CA) with appropriate restriction sites.

[0093] The sequences encoding the anti-bcma1 and anti-bcma2 CARs were ligated into a lentiviral vector plasmid designated pRRLSIN.cPPT.MSCV.coDMF5.oPRE (see, e.g., Yang et al., *J. Immunotherapy*, *33*(6): 648-658 (2010)). The coDMF5 portion of this vector was replaced with the CAR-encoding nucleic acid sequences using standard methods. The two resulting anti-BCMA CAR vectors were denoted pRRLSIN.cPPT.MSCV.anti-bcma1.oPRE and pRRLSIN.cPPT.MSCV.anti-bcma2.oPRE. A negative-control CAR containing the SP6 scFv that recognizes the hapten 2,4,6-trinitrophenyl also was constructed (see, e.g., Gross et al., *Proc. Natl. Acad. Sci. USA*, *86*(24): 10024-10028 (1989)). This CAR was referred to as SP6. The SP6 CAR was cloned into the same lentiviral vector as the anti-BCMA CARs and contained the same signaling domains as anti-bcma1 and anti-bcma2. Supernatant containing lentiviruses encoding each CAR was produced by the protocol described in Yang et al., *supra*. Specifically, 293T-17 cells (ATCC CRL-11268) were transfected with the following plasmids: pMDG (encoding the vesicular stomatitis virus envelope protein), pMDLg/pRRE (encoding HIV Gag and Pol proteins), pRSV-Rev (encoding RSV Rev protein), and plasmids encoding the anti-bcma CARs (see, e.g., Yang et al., *supra*).

[0094] The sequences encoding the G-anti-bcma2, 8ss-anti-bcma2, anti-bcma2-BB, anti-bcma2-OX40, and anti-bcma2-BBOX40 CARs were each ligated into a gammaretroviral vector plasmid designated MSGV (mouse stem cell virus-based splice-gag vector) using standard methods, such as those described in, e.g., Hughes et al., *Human Gene Therapy*, *16*: 457-472 (2005). After the CAR-encoding gammaretroviral plasmids were generated, replication incompetent retroviruses with the RD114 envelope were produced by transient transfection of 293-based packaging cells as described in Kochenderfer et al., *J. Immunotherapy*, *32*(7): 689-702 (2009).

[0095] The replication-incompetent lentiviruses and retroviruses encoding the above-described CARs were used to transduce human T-cells. For anti-bcma1 and anti-bcma2, T-cells were cultured as described previously (see, e.g., Kochenderfer et al., *J. Immunotherapy*, *32*(7): 689-702 (2009)) and were stimulated with the anti-CD3 monoclonal antibody OKT3 (Ortho-Biotech, Horsham, PA) in AIM V™ medium (Life Technologies, Carlsbad, CA) containing 5% human AB serum (Valley Biomedical, Winchester, VA) and 300 international units (IU)/mL of interleukin-2 (Novartis Diagnostics, Emeryville, CA). Thirty-six hours after the cultures were started, the activated T-cells were suspended in lentiviral supernatant with

protamine sulfate and 300 IU/mL IL-2. The cells were centrifuged for 1 hour at 1200xg. The T-cells were then cultured for three hours at 37 °C. The supernatant was then diluted 1:1 with RPMI medium (Mediatech, Inc., Manassas, VA) +10% fetal bovine serum (Life Technologies, Carlsbad, CA) and IL-2. The T-cells were cultured in the diluted supernatant overnight, and then returned to culture in AIM V™ medium (Life Technologies, Carlsbad, CA) plus 5% human AB serum with IL-2. T-cells were stained with biotin-labeled polyclonal goat anti-mouse-F(ab)$_2$ antibodies (Jackson Immunoresearch Laboratories, Inc., West Grove, PA) to detect the anti-BCMA CARs. High levels of cell surface expression of the anti-bcma1 CAR, the anti-bcma2 CAR, and the SP6 CAR on the transduced T-cells were observed, as shown in Figures 3B-3D.

[0096] For the G-anti-bcma2, 8ss-anti-bcma2, anti-bcma2-BB, anti-bcma2-OX40, and anti-bcma2-BBOX40 CARs, peripheral blood mononuclear cells were suspended at a concentration of 1x10^6 cell per mL in T-cell medium containing 50 ng/mL of the anti-CD3 monoclonal antibody OKT3 (Ortho, Bridgewater, NJ) and 300 IU/mL of IL-2. RETRONECTIN™ polypeptide (Takara Bio Inc., Shiga, Japan), which is a recombinant polypeptide of human fibronectin fragments that binds viruses and cell surface proteins, was dissolved at a concentration of 11 μg/mL in phosphate buffered saline (PBS) solution, and two mL of the RETRONECTIN ™ polypeptide in PBS solution were added to each well of nontissue-culture-coated 6 well plates (BD Biosciences, Franklin Lakes, New Jersey). The plates were incubated for two hours at room temperature (RT). After the incubation, the RETRONECTIN ™ solution was aspirated, and 2 mL of a blocking solution consisting of Hanks' balanced salt solution (HBSS) plus 2% bovine serum albumin (BSA) were added to each RETRONECTIN ™-coated well. The plates were incubated for 30 minutes at room temperature (RT). The blocking solution was aspirated, and the wells were rinsed with a solution of HBSS+2.5% (4-(2-hydroxyethyl)-1-piperazineethanesulfonic acid) (HEPES). Retroviral supernatant was rapidly thawed and diluted 1:1 in T-cell media, and two mL of the diluted supernatant were then added to each RETRONECTIN ™-coated well. After addition of the supernatants, the plates were centrifuged at 2000xg for 2 hours at 32 °C. The supernatant was then aspirated from the wells, and 2x10^6 T-cells that had been cultured with OKT3 antibody and IL-2 for 2 days were added to each well. When the T-cells were added to the retrovirus-coated plates, the T-cells were suspended at a concentration of 0.5x10^6 cells per mL in T-cell medium plus 300 IU/mL of IL-2. After the T-cells were added to each well, the plates were centrifuged for 10 minutes at 1000xg. The plates were incubated at 37 °C

overnight. The transduction was repeated the next day. After an 18-24 hour incubation, the T-cells were removed from the plates and suspended in fresh T-cell medium with 300 IU/mL of IL-2 at a concentration of $0.5x10^6$ cells per mL and cultured at 37 °C and 5% CO_2. High levels of cell surface expression of anti-bcma2-BBOX40, anti-bcma2-BB, and 8ss-anti-bcma2 on the transduced T-cells were observed.

[0097] The results of this example demonstrate a method of producing the inventive CAR-encoding nucleic acid sequence, and methods of expressing the CAR on the surface of T-cells.

EXAMPLE 3

[0098] This example describes a series of experiments used to determine the specificity of the inventive CAR for BCMA.

Cells

[0099] NCI-H929, U266, and RPMI8226 are all BCMA+ multiple myeloma cell lines that were obtained from ATCC (ATCC Nos. CRL-9068, TIB-196, and CCL-155, respectively). A549 (ATCC No. CCL-185) is a BCMA-negative lung cancer cell line. TC71 is a BCMA-negative sarcoma cell line. CCRF-CEM is a BCMA-negative T-cell line (ATCC No. CCL-119). BCMA-K562 are K562 cells (ATCC No. CCL-243) that have been transduced with a nucleic acid sequence encoding full-length BCMA. NGFR-K562 are K562 cells that have been transduced with the gene encoding low-affinity nerve growth factor (see, e.g., Kochenderfer et al., *J. Immunotherapy.*, 32(7):689-702 (2009)). Peripheral blood lymphocytes (PBL) from three patients with multiple myeloma (i.e., Myeloma Patient 1 through 3) were used, as were PBL from three other subjects: Donor A, Donor B, and Donor C. Donors A through C all had melanoma. CD34+ primary cells were obtained from three normal healthy donors. A sample of plasmacytoma cells was obtained from Myeloma patient 1, and a sample of bone marrow was obtained from Myeloma Patient 3. All of the human samples mentioned above were obtained from patients enrolled in IRB-approved clinical trials at the National Cancer Institute. The following primary human epithelial cells were obtained from Lonza, Inc. (Basel, Switzerland): small airway epithelial cells, bronchial epithelial cells, and intestinal epithelial cells.

Interferon-γ and TNF ELISA

[0100] BCMA-postivie or BCMA-negative cells were combined with CAR-transduced T-cells in duplicate wells of a 96 well round bottom plate (Corning Life Sciences, Lowell, MA) in AIM V™ medium (Life Technologies, Carlsbad, CA) + 5% human serum. The plates were incubated at 37 °C for 18-20 hours. Following the incubation, ELISAs for IFNγ and TNF were performed using standard methods (Pierce, Rockford, IL).

[0101] T-cells transduced with the anti-bcma1 or anti-bcma2 CARs produced large amounts of IFNγ when they were cultured overnight with the BCMA-expressing cell line BCMA-K562, but the CAR-transduced T-cells only produced background levels of IFNγ when they were cultured with the negative control cell line NGFR-K562, as indicated in Table 2 (all units are pg/mL IFNγ).

Table 2

	BCMA-Expressing Targets**			**BCMA-Negative Targets**					
	BCMA-K562	H929	RPMI-8226	NGFR-K562	CCRF-CEM	A549	TC71	293T	T-cells Alone
Effector Cells*									
anti-bcma1	15392	11306	5335	76	76	52	65	54	112
anti-bcma2	25474	23120	10587	62	67	32	31	28	41
SP6	32	60	149	27	28	21	361	73	27
Untransduced	<12	<12	<12	<12	<12	<12	<12	12	<12
Targets Alone	<12	<12	<12	<12	<12	<12	<12	13	

* Effector cells were T-cells from a patient with multiple myeloma (Myeloma Patient 2). The T-cells were transduced with the indicated CAR or left untransduced.

** The indicated target cells were combined with the effector cells for an overnight incubation and an IFNγ ELISA was performed.

[0102] T-cells expressing the 8ss-anti-bcma2, anti-bcma2-BB, and anti-bcma2-OX40 CARs produced IFNγ specifically in response to BCMA+ target cells when T-cells and target cells were cocultured overnight, as indicated in Table 3 (all units are pg/mL of IFNγ).

Table 3

	BCMA-Positive Targets		BCMA-Negative Targets			
	BCMA-K562	RPMI-8226	NGFR-K562	CCRF-CEM	A549	T-cells Alone
Effector Cells						
anti-bcma2-OX40	17704	4875	42	44	24	40
anti-bcma2-BB	25304	8838	404	602	350	706
8ss-anti-bcma2	9671	2168	100	120	49	171
Untransduced	<12	57	15	17	<12	20

[0103] T-cells transduced with anti-BCMA CARs produced large amounts of IFNγ when they were cultured overnight with BCMA-expressing multiple myeloma cell lines. In contrast, the anti-BCMA CARs produced much lower amounts of IFNγ when they were cultured with a variety of BCMA-negative cell lines. Compared with T-cells transduced with the anti-bcma1 CAR, T-cells transduced with the anti-bcma2 CAR and variants thereof (i.e., 8ss-anti-bcma2, anti-bcma2-BB, and anti-bcma2-OX40) produced more IFNγ when cultured with BCMA-positive cells and less IFNγ when cultured with BCMA-negative cells.

[0104] T-cells transduced with the anti-bcma2 CAR variants produced TNF specifically in response to BCMA+ target cells when T-cells and target cells were cocultured overnight, as indicated in Table 4 (all units are pg/mL of tumor necrosis factor (TNF)).

Table 4

	BCMA-Positive Targets		BCMA-Negative Targets			
	BCMA-K562	RPMI-8226	NGFR-K562	CCRF-CEM	A549	T-cells Alone
Effector Cells						
anti-bcma2-OX40	4913	3406	<40	47	<40	74
anti-bcma2-BB	6295	2723	56	164	89	252
8ss-anti-bcma2	5340	1354	<40	121	<40	191
Untransduced	<40	<40	47	<40	<40	<40

[0105] Because the T-cells transduced with the anti-bcma2 CAR and variants thereof exhibited slightly stronger and more specific recognition of BCMA-expressing cells than T-cells transduced with the anti-bcma1 CAR, only the anti-bcma2 CAR and anti-bcma2 CAR variants were used in the following experiments.

CD107a assay

[0106] Two populations of T-cells were prepared in two separate tubes. One tube contained BCMA-K562 cells, and the other tube contained NGFR-K562 cells. Both tubes also contained T-cells transduced with the anti-bcma2 CAR and anti-bcma2 CAR variants, 1 mL of AIM V ™ medium (Life Technologies, Carlsbad, CA) + 5% human serum, a titrated concentration of an anti-CD107a antibody (eBioscience, Inc., San Diego, CA; clone eBioH4A3), and 1 μL of Golgi Stop (BD Biosciences, Franklin Lakes, NJ). All tubes were incubated at 37 °C for four hours and then stained for expression of CD3, CD4, and CD8.

[0107] *CAR-transduced T-cells from three different subjects upregulated CD107a* specifically in response to stimulation with BCMA-expressing target cells (see Figures 4A-4C). This indicates the occurrence of BCMA-specific degranulation of the T-cells, which is a prerequisite for perforin-mediated cytotoxicity (see, e.g., Rubio et al., *Nature Medicine*, *9*(11): 1377-1382 (2003)). In addition, T-cells expressing the anti-bcma2 CAR variants 8ss-anti-bcma2, anti-bcma2-BB, anti-bcma2-OX40 degranulated in a BCMA-specific manner when stimulated with target cells *in vitro* as shown in Figures 5A-5D.

Intracellular cytokine staining assay (ICCS)

[0108] A population of BCMA-K562 cells and a population of NGFR-K562 cells were prepared in two separate tubes as described above. Both tubes also contained T-cells transduced with the anti-bcma2 CAR from Myeloma Patient 2, 1 mL of AIM V medium (Life Technologies, Carlsbad, CA) + 5% human serum, and 1 μL of Golgi Stop (BD Biosciences, Franklin Lakes, NJ). All tubes were incubated at 37 °C for six hours. The cells were surface-stained with anti-CD3, anti-CD4, and anti-CD8 antibodies. The cells were permeabilized, and intracellular staining was conducted for IFNγ (BD Biosciences, Franklin Lakes, NJ, clone B27), IL-2 (BD Biosciences, Franklin Lakes, NJ, clone MQ1-17H12), and TNF (BD Biosciences, Franklin Lakes, NJ, clone MAb11) by following the instructions of the Cytofix/Cytoperm kit (BD Biosciences, Franklin Lakes, NJ).

[0109] Large populations of T-cells transduced with the anti-bcma2 CAR from Myeloma Patient 2 specifically produced the cytokines IFNγ, IL-2, and TNF in a BCMA-specific manner after the six-hour stimulation with BCMA-expressing target cells, as shown in Figures 6A-6C.

Proliferation assays

[0110] The ability of T-cells transduced with the anti-bcma2 CAR to proliferate when stimulated with BCMA-expressing target cells was assessed. Specifically, $0.5x10^6$ irradiated BCMA-K562 cells or $0.5x10^6$ irradiated NGFR-K562 cells were co-cultured with $1x10^6$ total T-cells that had been transduced with either the anti-bcma2 CAR or the SP6 CAR. The T-cells were labeled with carboxyfluorescein diacetate succinimidyl ester (CFSE) (Life Technologies, Carlsbad, CA) as described in Mannering et al., J. *Immunological Methods*, *283*(1-2): 173-183 (2003). The medium used in the co-cultures was AIM V™ medium (Life Technologies, Carlsbad, CA) + 5% human AB serum. IL-2 was not added to the medium. Four days after initiation, the live cells in each co-culture were counted with trypan blue for dead cell exclusion. Flow cytometry was then performed by staining T-cells with polyclonal biotin-labeled goat-anti-human BCMA antibodies (R&D Systems, Minneapolis, MN) followed by streptavidin (BD Biosciences, Franklin Lakes, NJ), anti-CD38 antibody (eBioscience, Inc., San Diego, CA), and anti-CD56 antibody (BD Biosciences, Franklin Lakes, NJ). Flow cytometry data analysis was performed by using FlowJo software (Tree Star, Inc., Ashland, OR).

[0111] T-cells that expressed the anti-bcma2 CAR exhibited a greater dilution of CFSE when cultured with the BCMA-K562 cells than when cultured with negative control NGFR-K562 cells, as shown in Figure 7A. These results indicate that T-cells transduced with the anti-bcma2 CAR specifically proliferated when stimulated with BCMA-expressing target cells. In contrast, there was no significant difference in CFSE dilution when T-cells expressing the SP6 CAR were cultured with either BCMA-K562 target cells or NGFR-K562 target cells (see Figure 7B), which demonstrates a lack of BCMA-specific proliferation by T-cells expressing the SP6 CAR.

[0112] At the beginning of the proliferation assays, $0.8x10^6$ T-cells expressing the anti-bcma2 CAR were cultured with either BCMA-K562 cells or NGFR-K562 cells. After 4 days of culture, $2.7x10^6$ T-cells expressing the anti-bcma2 CAR were present in the cultures containing BCMA-K562 cells while only $0.6x10^6$ T-cells expressing the anti-bcma2 CAR were present in the cultures containing NGFR-K562 cells. This BCMA-specific increase in the absolute number of T-cells expressing the anti-bcma2 CAR indicates that these T-cells proliferated in response to BCMA.

[0113] The results of this example demonstrate that T-cells expressing the inventive CAR exhibit BCMA-specific cytokine production, degranulation, and proliferation.

EXAMPLE 4

[0114] This example demonstrates that T-cells expressing the inventive anti-BCMA CAR can destroy multiple myeloma cell lines.

[0115] Cytotoxicity assays were performed to determine whether T-cells transduced with the anti-bcma2 CAR described in Examples 2 and 3 could destroy BCMA-expressing multiple myeloma (MM) cell lines. Specifically, the cytotoxicity of target cells was measured by comparing the survival of BCMA-expressing target cells (i.e., multiple myeloma cell lines *H929* and *RPMI8226*) relative to the survival of negative control CCRF-CEM cells using an assay described in, e.g., Kochenderfer et al., *J. Immunotherapy*, *32*(7): 689-702 (2009), and Hermans et al., *J. Immunological Methods*, *285*(1): 25-40 (2004).

[0116] Approximately 50,000 BCMA-expressing target cells and 50,000 CCRF-CEM cells were combined in the same tubes with different numbers of CAR-transduced T-cells. CCRF-CEM negative control cells were labeled with the fluorescent dye 5-(and-6)-(((4-chloromethyl)benzoyl)amino)tetramethylrhodamine (CMTMR) (Life Technologies, Carlsbad, CA), and BCMA-expressing target cells were labeled with CFSE. In all experiments, the cytotoxicity of effector T-cells that were transduced with the anti-bcma2 CAR was compared to the cytotoxicity of negative control effector T-cells from the same subject that were transduced with the SP6 CAR. Co-cultures were established in sterile 5 mL test tubes (BD Biosciences, Franklin Lakes, NJ) in duplicate at the following T-cell:target cell ratios: 20.0:1, 7:1, 2:1, and 0.7:1. The cultures were incubated for four hours at 37 °C. Immediately after the incubation, 7-amino-actinomycin D (7AAD; BD Biosciences, Franklin Lakes, NJ) was added. The percentages of live BCMA-expressing target cells and live CCRF-CEM negative control cells were determined for each T-cell/target cell co-culture.

[0117] For each T-cell/target cell co-culture, the percent survival of BCMA-expressing target cells relative to the CCRF-CEM negative control cells was determined by dividing the percent BCMA-expressing cells by the percent CCRF-CEM negative control cells. The corrected percent survival of BCMA-expressing target cells was calculated by dividing the percent survival of BCMA-expressing target cells in each T-cell/target cell co-culture by the ratio of the percent BCMA-expressing target cells:percent CCRF-CEM negative control cells in tubes containing only BCMA-expressing target cells and CCRF-CEM negative control cells without effector T-cells. This correction was necessary to account for variation in the starting cell numbers and for spontaneous target cell death. Cytotoxicity was calculated as follows:

% cytotoxicity of BCMA-expressing target cells = 100-corrected % survival of BCMA-expressing target cells

[0118] The results of the cytotoxicity assay are shown in Figures 7C and 7D. T-cells transduced with the anti-bcma2 CAR specifically killed the BCMA-expressing multiple myeloma cell lines H929 and RPMI8226. In contrast, T-cells transduced with the SP6 CAR exhibited much lower levels of cytotoxicity against these cell lines.

[0119] The results of this example demonstrate that the inventive nucleic acid sequence encoding an anti-BCMA CAR can be used in a method of destroying multiple myeloma cell lines.

EXAMPLE 5

[0120] This example demonstrates that T-cells expressing the inventive anti-BCMA CAR can destroy primary multiple myeloma cells.

[0121] The primary multiple myeloma cells described in Example 2 were evaluated for BCMA expression, as well as BCMA-specific cytokine production, degranulation, and proliferation using the methods described above.

[0122] Cell surface BCMA expression was detected on four primary multiple myeloma samples, as well as on primary bone marrow multiple myeloma cells from Myeloma Patient 3 (see Figure 8A). BCMA-expressing plasma cells made up 40% of the cells in the bone marrow sample from Myeloma Patient 3. Allogeneic T-cells transduced with the anti-bcma2 CAR from Donor C produced IFNγ after co-culture with the unmanipulated bone marrow cells of Myeloma Patient 3, as shown in Figure 8B. Anti-bcma2 CAR-transduced T-cells from the same allogeneic donor produced much less IFNγ when they were cultured with peripheral blood mononuclear cell (PBMC) from Myeloma Patient 3. In addition, SP6-CAR-transduced T-cells from Donor C did not specifically recognize the bone marrow of Myeloma Patient 3. It has been previously reported that normal PBMC does not contain cells that express BCMA (see, e.g., Ng et al., *J. Immunology*, *173*(2): 807-817 (2004)). To confirm this observation, PBMC of Patient 3 was assessed for BCMA expression by flow cytometry. PBMC of Patient 3 did not contain BCMA-expressing cells, aside from a small population of $CD56+CD38^{high}$ cells that made up approximately 0.75% of the PBMC. This population possibly consisted of circulating multiple myeloma cells.

[0123] A plasmacytoma resected from Myeloma Patient 1 consisted of 93% plasma cells, and these primary plasma cells expressed BCMA, as shown in Figure 8C. T-cells from

Myeloma Patient 2 produced IFNγ when cultured with the allogeneic, unmanipulated plasmacytoma cells of Myeloma Patient 1. T-cells from Myeloma Patient 2 did not produce significant amounts of IFNγ when cultured with PBMC from Myeloma patient 1. T-cells from Myeloma Patient 2 that were transduced with the SP6 CAR did not produce significant amounts of IFNγ when they were cultured with either plasmacytoma cells or PBMC from Myeloma Patient 1. The PBMC of Myeloma Patient 1 did not express BCMA as measured by flow cytometry.

[0124] T-cells of Myeloma Patient 1, who had received eight prior cycles of myeloma therapy, were successfully cultured and transduced with a lentivirus vector encoding the anti-bcma2 CAR. Eight days after the cultures were initiated, expression of the anti-bcma2 CAR was detected on 65% of the T-cells. The T-cells from Myeloma Patient 1 expressing the anti-bcma2 CAR produced IFNγ specifically in response to autologous plasmacytoma cells (Figure 8D). T-cells from Myeloma Patient 1 expressing the SP6 CAR did not recognize autologous plasmacytoma cells. T-cells expressing the anti-bcma2 CAR and T-cells expressing the SP6 CAR did not recognize autologous PBMC. T-cells from Myeloma Patient 1 expressing the anti-bcma2 CAR also specifically killed autologous plasmacytoma cells at low effector to target ratios. In contrast, T-cells from Myeloma Patient 1 expressing the SP6 CAR exhibited low levels of cytotoxicity against autologous plasmacytoma cells (Figure 8E).

[0125] The results of this example demonstrate that the inventive anti-BCMA CAR can be used in a method of destroying primary multiple myeloma cells.

EXAMPLE 6

[0126] This example demonstrates that T-cells expressing the inventive anti-BCMA CARs can destroy established tumors in mice.

[0127] Immunodeficient NSG mice (NOD.Cg-Prkdcscid Il2rgtm1Wjl/SzJ, Jackson Laboratory) were injected intradermally with $8x10^6$ RPMI8226 cells. Tumors were allowed to grow for 17 to 19 days, and then the mice received intravenous infusions of $8x10^6$ human T-cells that were transduced with either the anti-bcma2 CAR or the SP6 CAR. Tumors were measured with calipers every 3 days. The longest length and the length perpendicular to the longest length were multiplied to obtain the tumor size (area) in mm^2. When the longest length reached 15 mm, mice were sacrificed. Animal studies were approved by the National Cancer Institute Animal Care and Use Committee.

[0128] The results of this example are shown in Figures 9A and 9B. At around day 6, mice treated with anti-bcma2-transduced T-cells showed a reduction in tumor size, and tumors were eradicated at day 15. In addition, all mice treated with anti-bcma2-transduced T-cells survived out to 30 days post T-cell infusion.

[0129] The results of this example demonstrate that the inventive anti-BMCA CAR can destroy multiple myeloma cells *in vivo*.

[0130] All references, including publications, patent applications, and patents, cited herein are hereby incorporated by reference to the same extent as if each reference were individually and specifically indicated to be incorporated by reference and were set forth in its entirety herein.

[0131] The use of the terms "a" and "an" and "the" and similar referents in the context of describing the invention (especially in the context of the following claims) are to be construed to cover both the singular and the plural, unless otherwise indicated herein or clearly contradicted by context. The terms "comprising," "having," "including," and "containing" are to be construed as open-ended terms (i.e., meaning "including, but not limited to,") unless otherwise noted. Recitation of ranges of values herein are merely intended to serve as a shorthand method of referring individually to each separate value falling within the range, unless otherwise indicated herein, and each separate value is incorporated into the specification as if it were individually recited herein. All methods described herein can be performed in any suitable order unless otherwise indicated herein or otherwise clearly contradicted by context. The use of any and all examples, or exemplary language (e.g., "such as") provided herein, is intended merely to better illuminate the invention and does not pose a limitation on the scope of the invention unless otherwise claimed. No language in the specification should be construed as indicating any non-claimed element as essential to the practice of the invention.

[0132] Preferred embodiments of this invention are described herein, including the best mode known to the inventors for carrying out the invention. Variations of those preferred embodiments may become apparent to those of ordinary skill in the art upon reading the foregoing description. The inventors expect skilled artisans to employ such variations as appropriate, and the inventors intend for the invention to be practiced otherwise than as specifically described herein. Accordingly, this invention includes all modifications and equivalents of the subject matter recited in the claims appended hereto as permitted by

applicable law. Moreover, any combination of the above-described elements in all possible variations thereof is encompassed by the invention unless otherwise indicated herein or otherwise clearly contradicted by context.

CLAIMS:

1. An isolated or purified nucleic acid sequence encoding a chimeric antigen receptor (CAR), wherein the CAR comprises an antigen recognition moiety and a T-cell activation moiety, and wherein the antigen recognition moiety is directed against B-cell Maturation Antigen (BCMA), and wherein a T cell or natural killer (NK) cell expressing the CAR secretes interferon-gamma in response to co-culture with a BCMA-positive target cell.

2. The isolated or purified nucleic acid sequence of claim 1, wherein the antigen recognition moiety comprises a monoclonal antibody directed against BCMA, or an antigen-binding portion thereof.

3. The isolated or purified nucleic acid sequence of claim 2, wherein the antigen recognition moiety comprises a variable region of a monoclonal antibody directed against BCMA.

4. The isolated or purified nucleic acid sequence of any one of claims 1-3, wherein the T-cell activation moiety comprises a T-cell signaling domain of any one of the following proteins: a human CD8-alpha protein, a human CD28 protein, a human CD3-zeta protein, a human FcRγ protein, a CD27 protein, an OX40 protein, a human 4-1BB protein, modified versions of any of the foregoing, or any combination of the foregoing.

5. The isolated or purified nucleic acid sequence of any one of claims 1-4, wherein the antigen recognition moiety comprises the (i) heavy chain complementarity determining region (CDR)1, (ii) heavy chain CDR2, (iii) heavy chain CDR3, (iv) light chain CDR1, (v) light chain CDR2, and (vi) light chain CDR3 of an amino acid sequence selected from the group consisting of SEQ ID NO: 4, SEQ ID NO: 5, SEQ ID NO: 6, SEQ ID NO: 8, SEQ ID NO: 9, SEQ ID NO: 10, SEQ ID NO: 11, and SEQ ID NO: 12.

6. The isolated or purified nucleic acid sequence of any one of claims 1-5, wherein the antigen recognition moiety comprises the (i) heavy chain variable region and (ii) light chain variable region of an amino acid sequence selected from the group consisting of SEQ ID NO: 4,

SEQ ID NO: 5, SEQ ID NO: 6, SEQ ID NO: 8, SEQ ID NO: 9, SEQ ID NO: 10, SEQ ID NO: 11, and SEQ ID NO: 12.

7. The isolated or purified nucleic acid sequence of any one of claims 1-46, which comprises the nucleic acid sequence of SEQ ID NO: 1, SEQ ID NO: 2, or SEQ ID NO: 3

8. An isolated or purified CAR encoded by the nucleic acid sequence of any one of claims 1-7.

9. The isolated or purified CAR of claim 8, which comprises the amino acid sequence of SEQ ID NO: 4, SEQ ID NO: 5, SEQ ID NO: 6, SEQ ID NO: 8, SEQ ID NO: 9, SEQ ID NO: 10, SEQ ID NO: 11, or SEQ ID NO: 12.

10. A vector comprising the isolated or purified nucleic acid sequence of any one of claims 1-7.

11. An isolated host cell which expresses the nucleic acid sequence of any one of claims 1-7.

12. The isolated host cell of claim 11, which expresses a CAR comprising an amino acid sequence of SEQ ID NO: 4, SEQ ID NO: 5, SEQ ID NO: 6, SEQ ID NO: 8, SEQ ID NO: 9, SEQ ID NO: 10, SEQ ID NO: 11, or SEQ ID NO: 12.

13. The isolated host cell of claim 11 or claim 12, which is a T-cell.

14. The isolated host cell of claim 11 or claim 12, which is a natural killer (NK) cell.

15. A method of destroying cancer cells, which method comprises contacting cancer cells that express BCMA with the isolated or purified nucleic acid sequence of any one of claims 1-7, whereby the CAR is produced and binds to BCMA on the cancer cells and the cancer cells are destroyed, wherein the cancer cells are *in vitro*.

16. A method of destroying cancer cells, which method comprises contacting cancer cells that express BCMA with the vector of claim 10, whereby the CAR is produced and binds to

BCMA on the cancer cells and the cancer cells are destroyed, wherein the cancer cells are *in vitro*.

17. A method of destroying cancer cells, which method comprises contacting cancer cells that express BCMA with one or more of the isolated T-cells of claim 13, whereby the CAR is produced and binds to BCMA on the cancer cells and the cancer cells are destroyed, wherein the cancer cells are *in vitro*.

18. A method of destroying cancer cells, which method comprises contacting cancer cells that express BCMA with one or more of the isolated NK cells of claim 14, whereby the CAR is produced and binds to BCMA on the cancer cells and the cancer cells are destroyed, wherein the cancer cells are *in vitro*.

19. Use of the nucleic acid sequence of any one of claims 1-7, the CAR of claim 8 or 9, the vector of claim 10, or the host cell of any one of claims 11-14, in the manufacture of a medicament for the destruction of BCMA-expressing cancer cells.

20. The method of any one of claims 15-18 or the use of claim 19, wherein the cancer cells are multiple myeloma or Hodgkin's lymphoma cells.