



US 20250255905A1

(19) United States

(12) Patent Application Publication

Rezvani et al.

(10) Pub. No.: US 2025/0255905 A1

(43) Pub. Date: Aug. 14, 2025

(54) BCMA CHIMERIC ANTIGEN RECEPTORS AND USES THEREOF

A61K 40/11 (2025.01)

A61K 40/15 (2025.01)

A61K 40/42 (2025.01)

A61P 35/00 (2006.01)

C07K 14/54 (2006.01)

C07K 14/705 (2006.01)

C07K 14/725 (2006.01)

C07K 16/28 (2006.01)

C12N 15/62 (2006.01)

C12N 15/85 (2006.01)

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(52) U.S. Cl. (2025.01)

CPC

A61K 35/17 (2013.01); A61K 9/0019 (2013.01); A61K 40/11 (2025.01); A61K 40/15 (2025.01); A61K 40/4215 (2025.01); A61P 35/00 (2018.01); C07K 14/5443 (2013.01); C07K 14/7051 (2013.01); C07K 14/70521 (2013.01); C07K 16/2878 (2013.01); C12N 15/85 (2013.01); A61K 2239/13 (2023.05); A61K 2239/21 (2023.05); A61K 2239/22 (2023.05); C07K 2317/53 (2013.01); C07K 2317/565 (2013.01); C07K 2317/622 (2013.01); C07K 2319/03 (2013.01); C12N 15/62 (2013.01)

(21) Appl. No.: 19/193,206

(22) Filed: Apr. 29, 2025

Related U.S. Application Data

(62) Division of application No. 18/638,229, filed on Apr. 17, 2024, now Pat. No. 12,310,988.

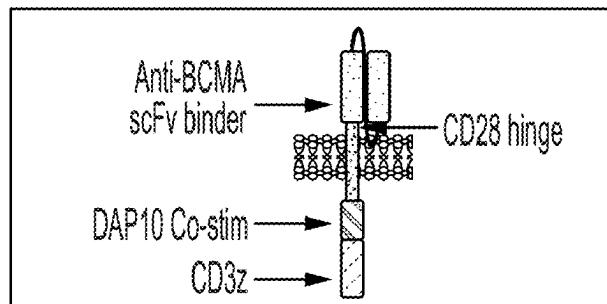
(60) Provisional application No. 63/496,823, filed on Apr. 18, 2023.

Publication Classification

(51) Int. Cl.

A61K 35/17 (2025.01)
A61K 9/00 (2006.01)**ABSTRACT**

The present application provides BCMA targeting chimeric antigen receptor (CAR) comprising a BCMA binding region and an intracellular costimulatory domain derived from DAP10. Further provided are engineered immune effector cells (such as NK cells) comprising the chimeric antigen receptors. Pharmaceutical compositions, kits and methods of treating cancer are also provided.

Specification includes a Sequence Listing.

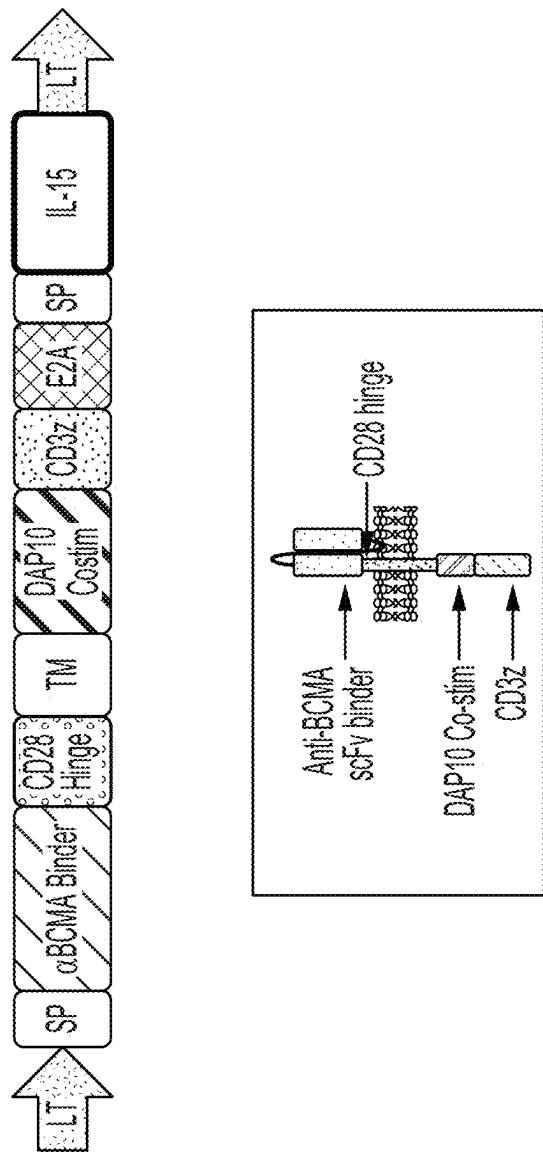


FIG. 1

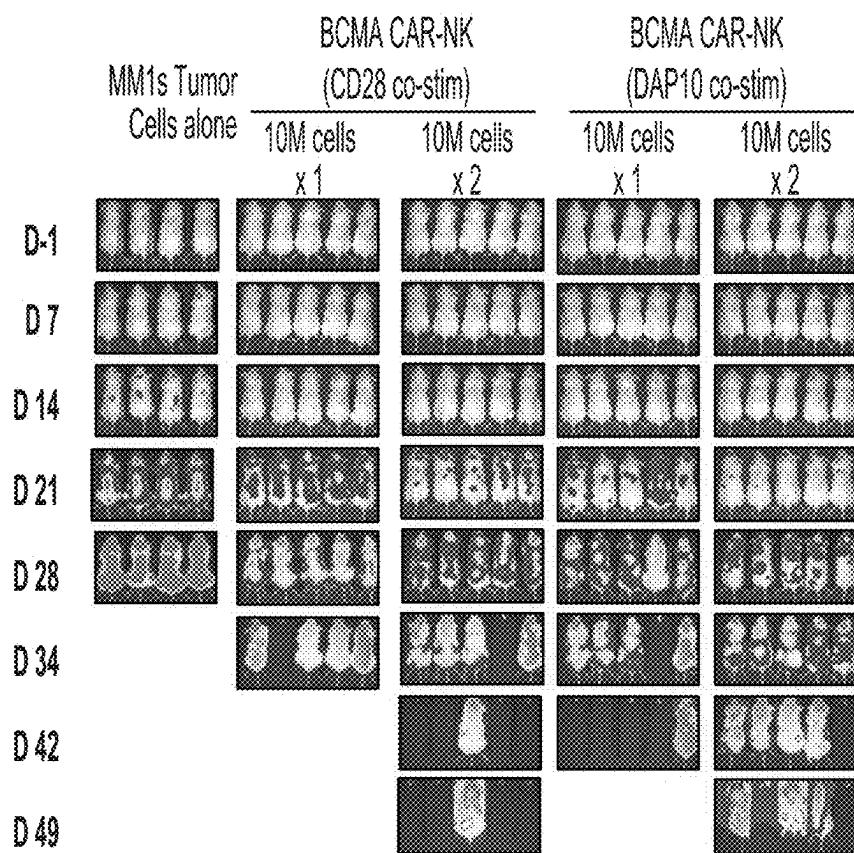


FIG. 2A

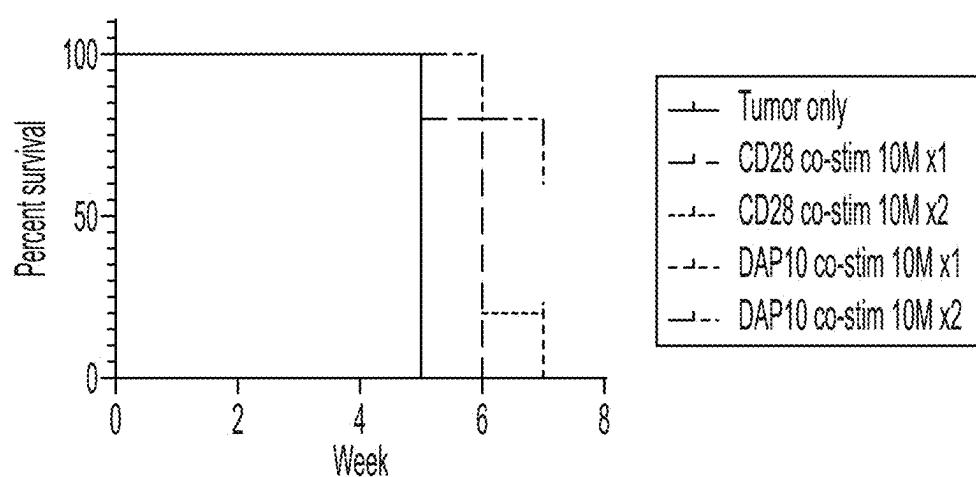


FIG. 2B

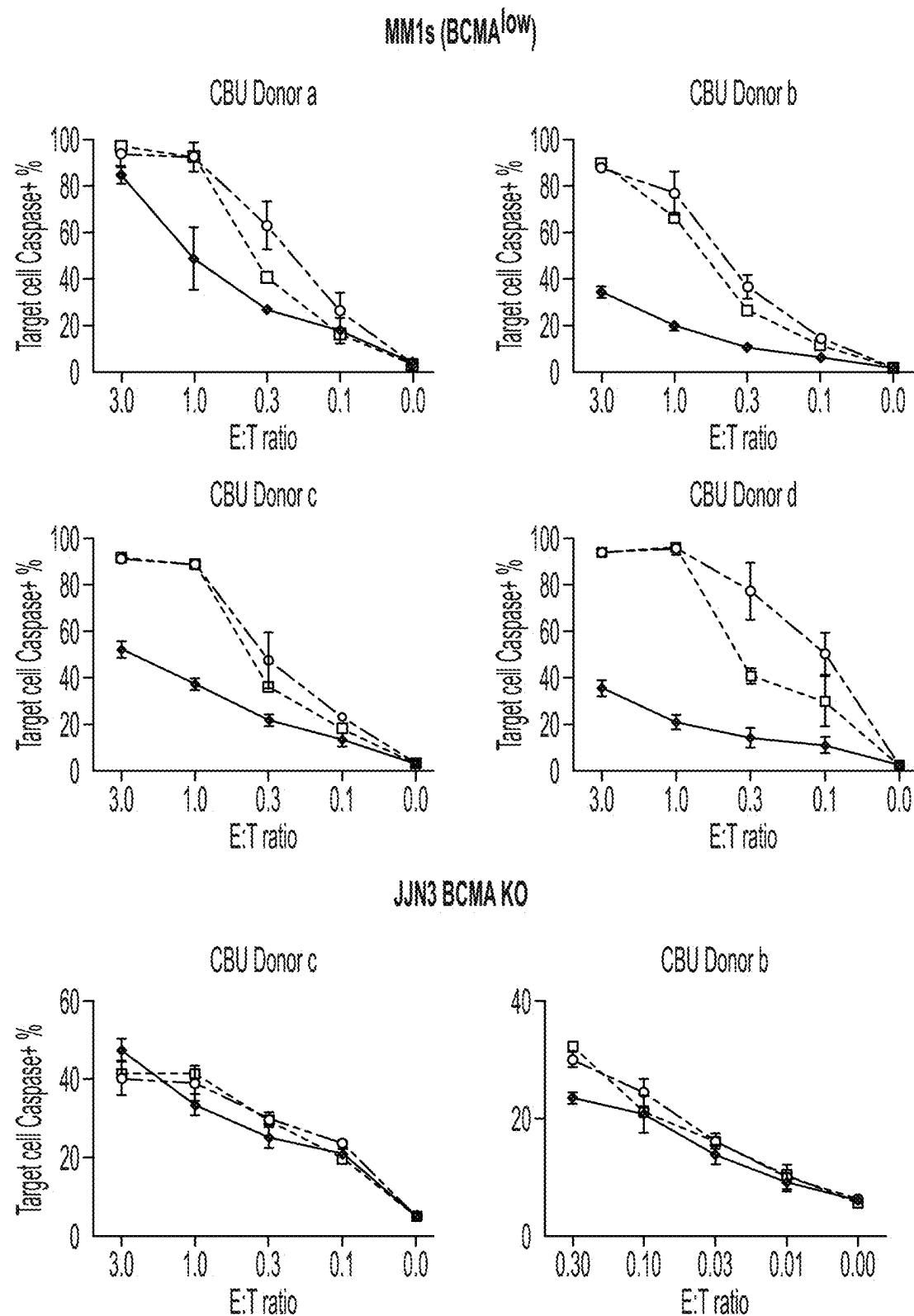


FIG. 3

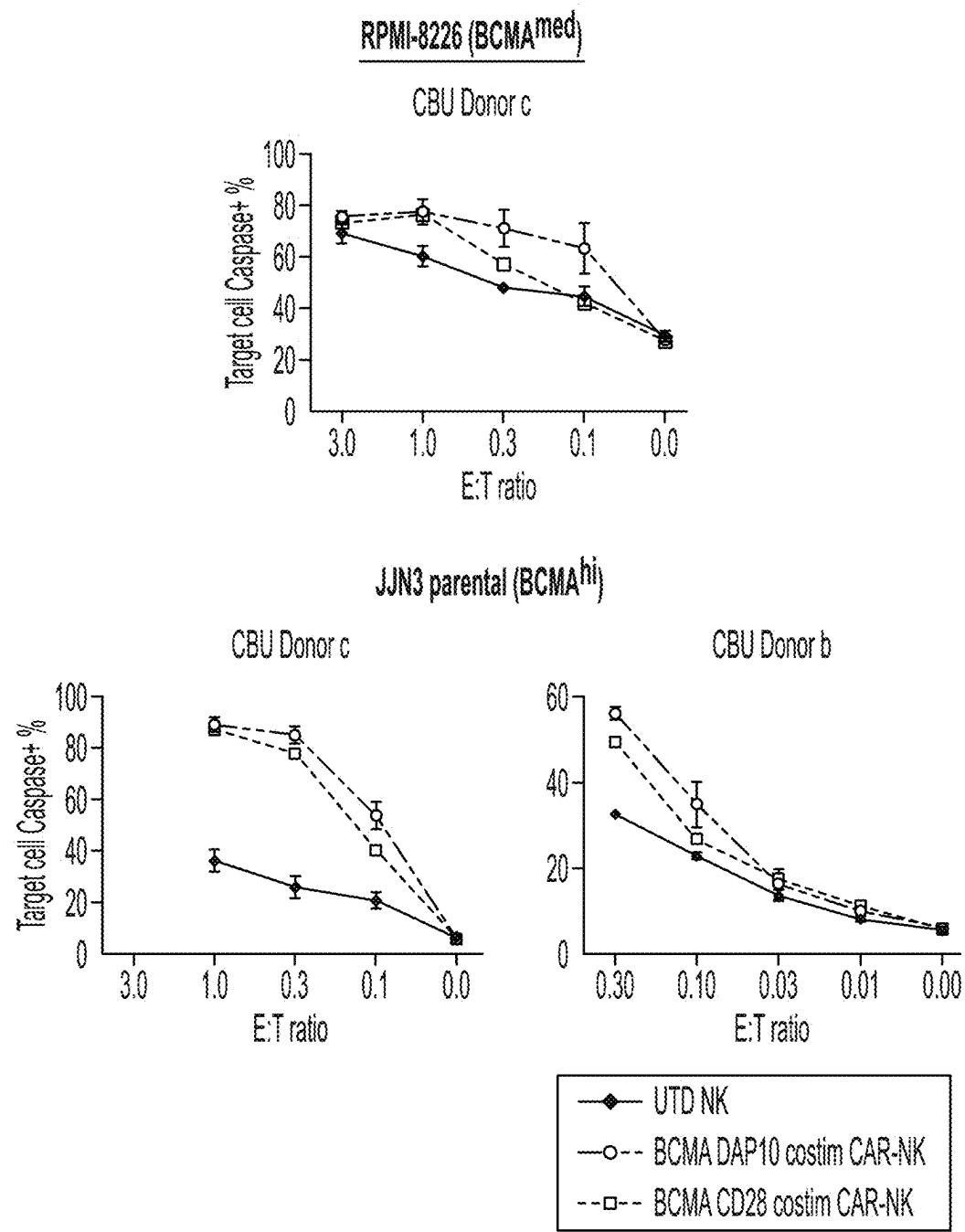


FIG. 3
CONTINUED

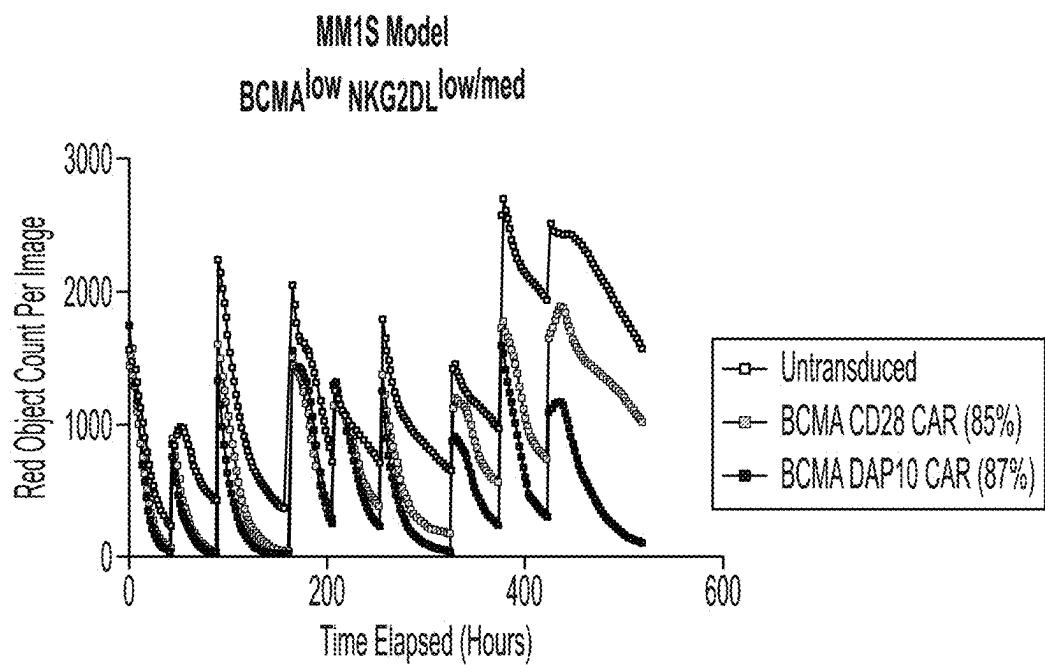


FIG. 4A

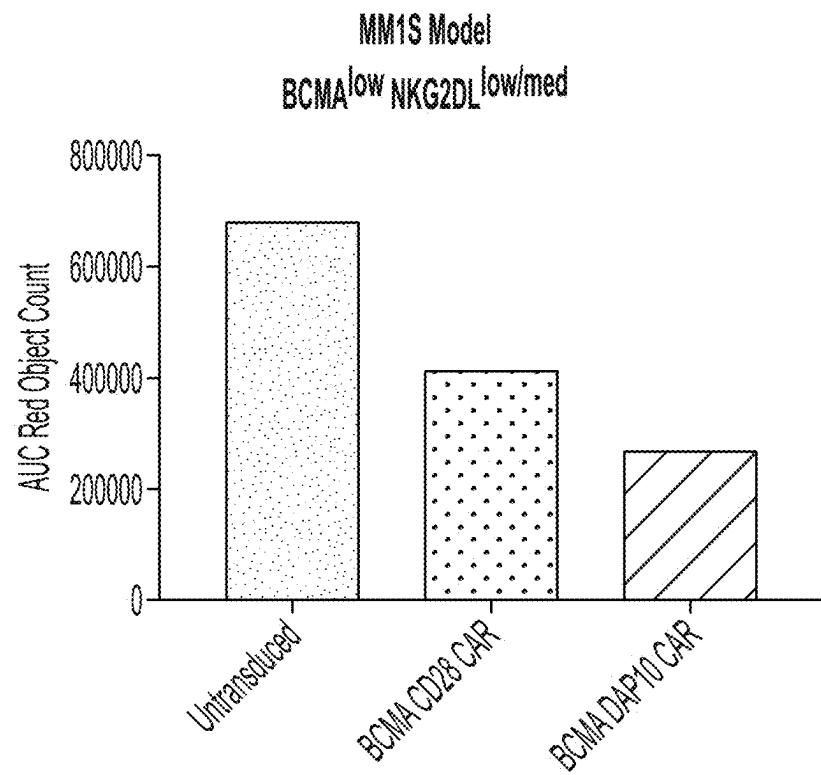


FIG. 4B

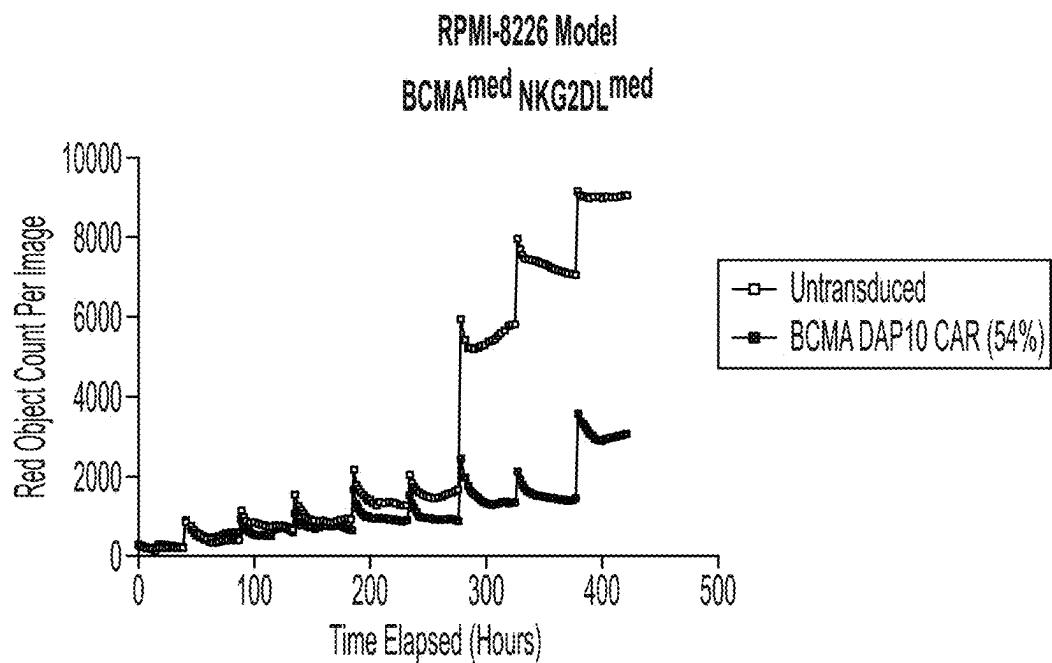


FIG. 5A

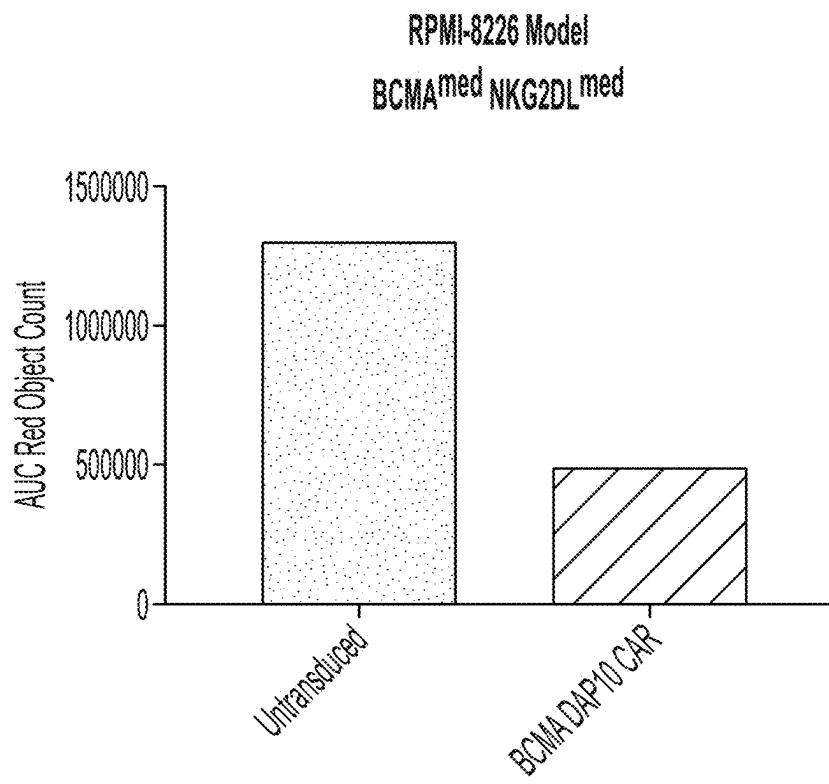


FIG. 5B

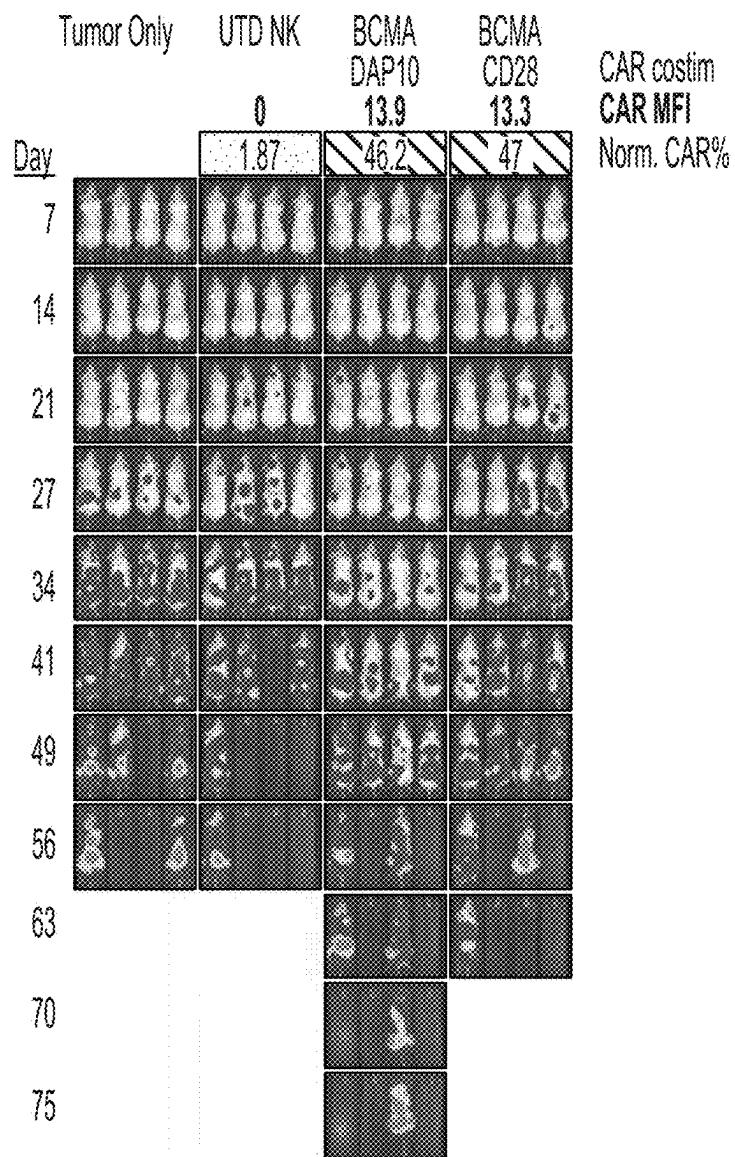


FIG. 6

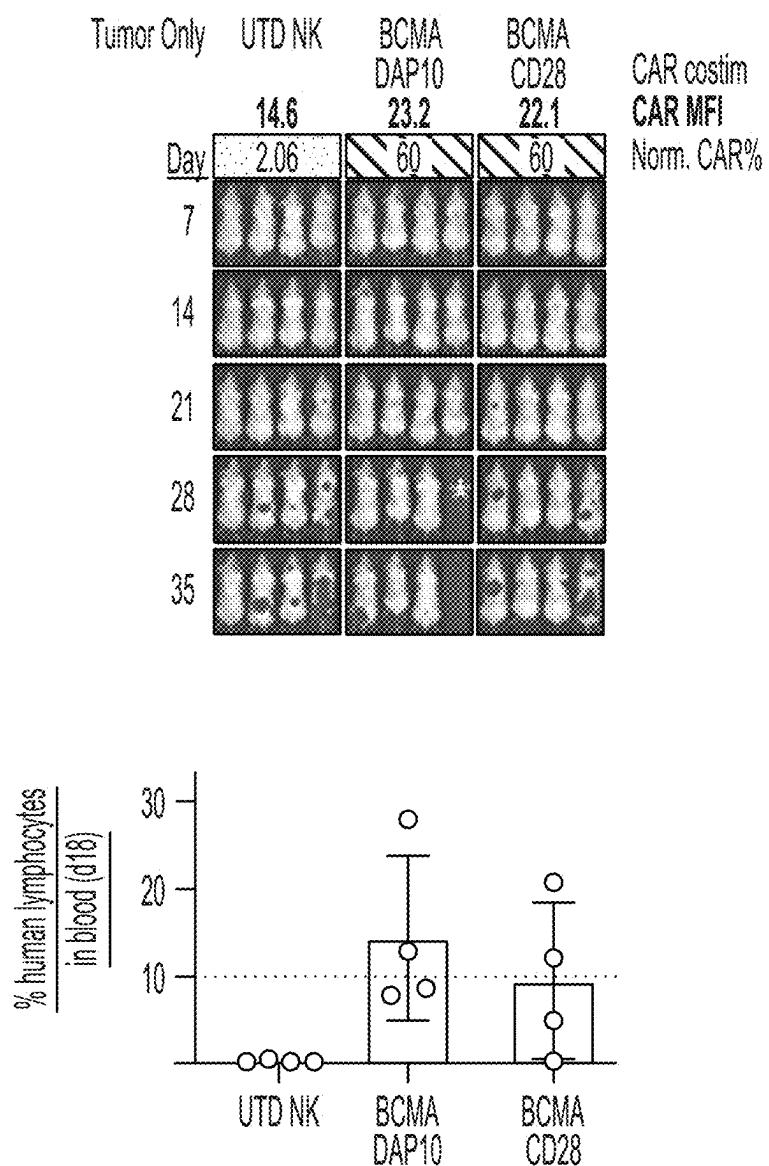


FIG. 7

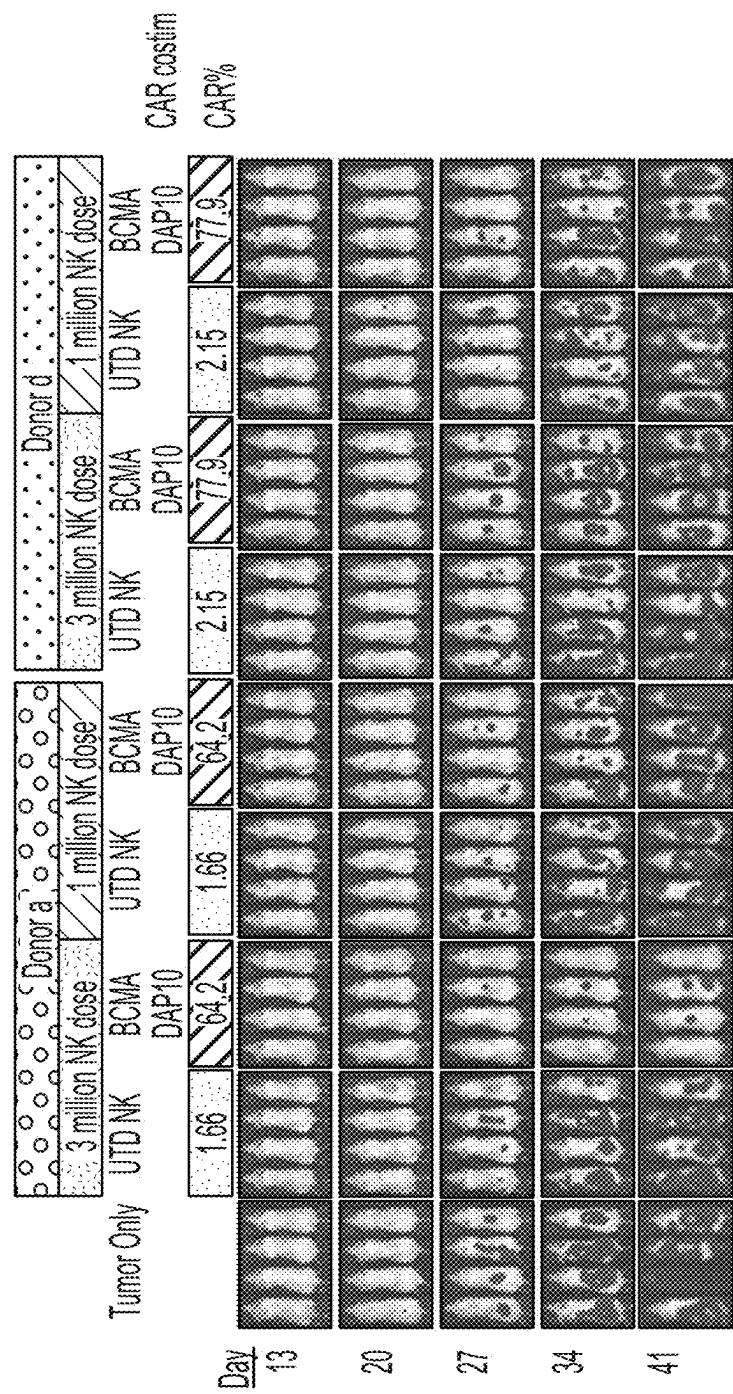


FIG. 8A

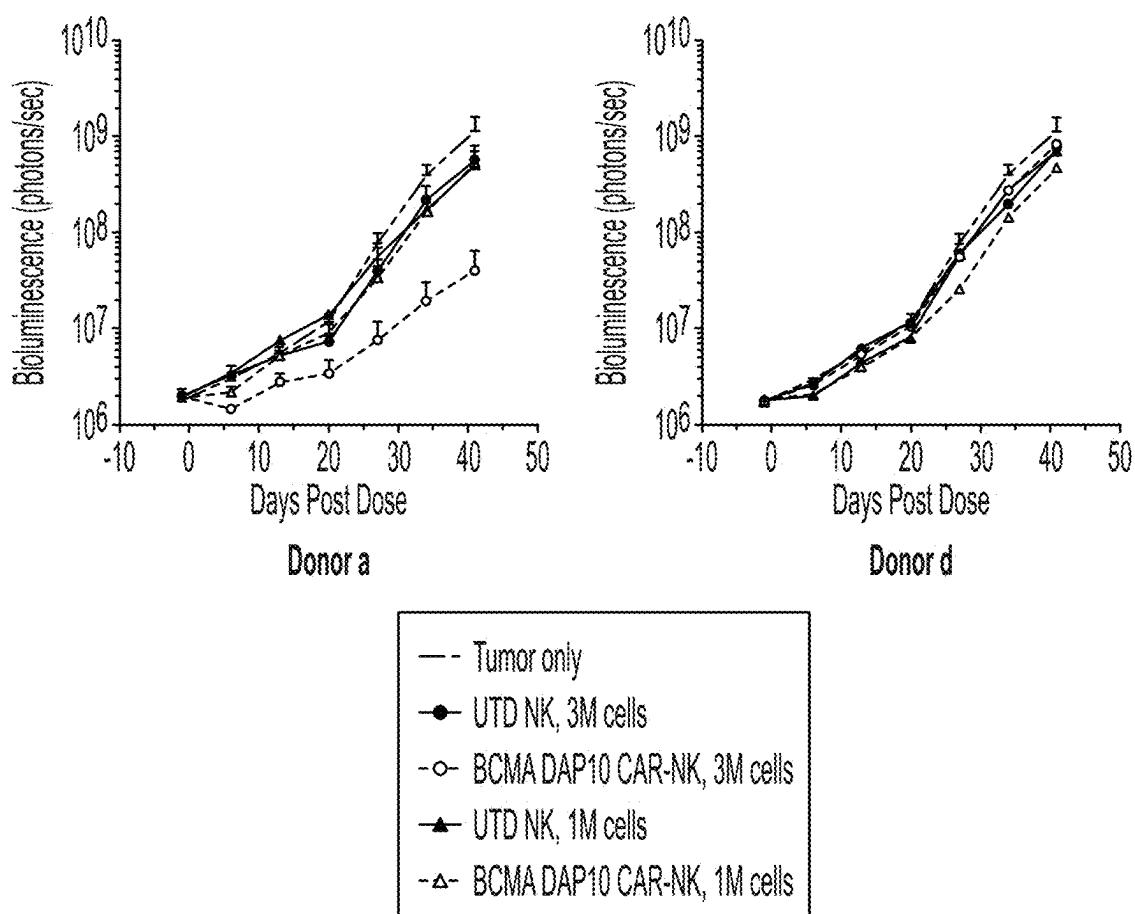


FIG. 8B

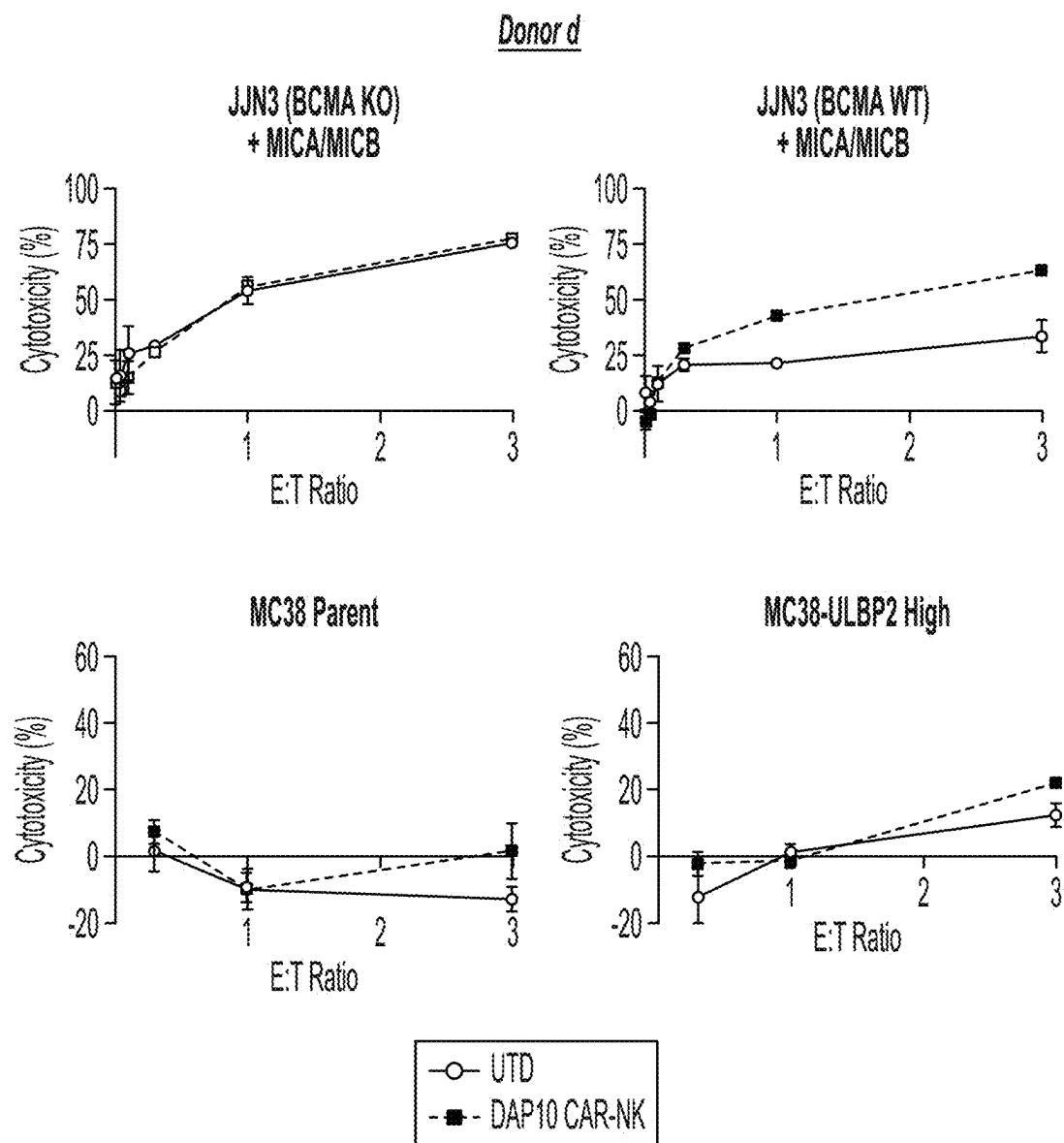


FIG. 9

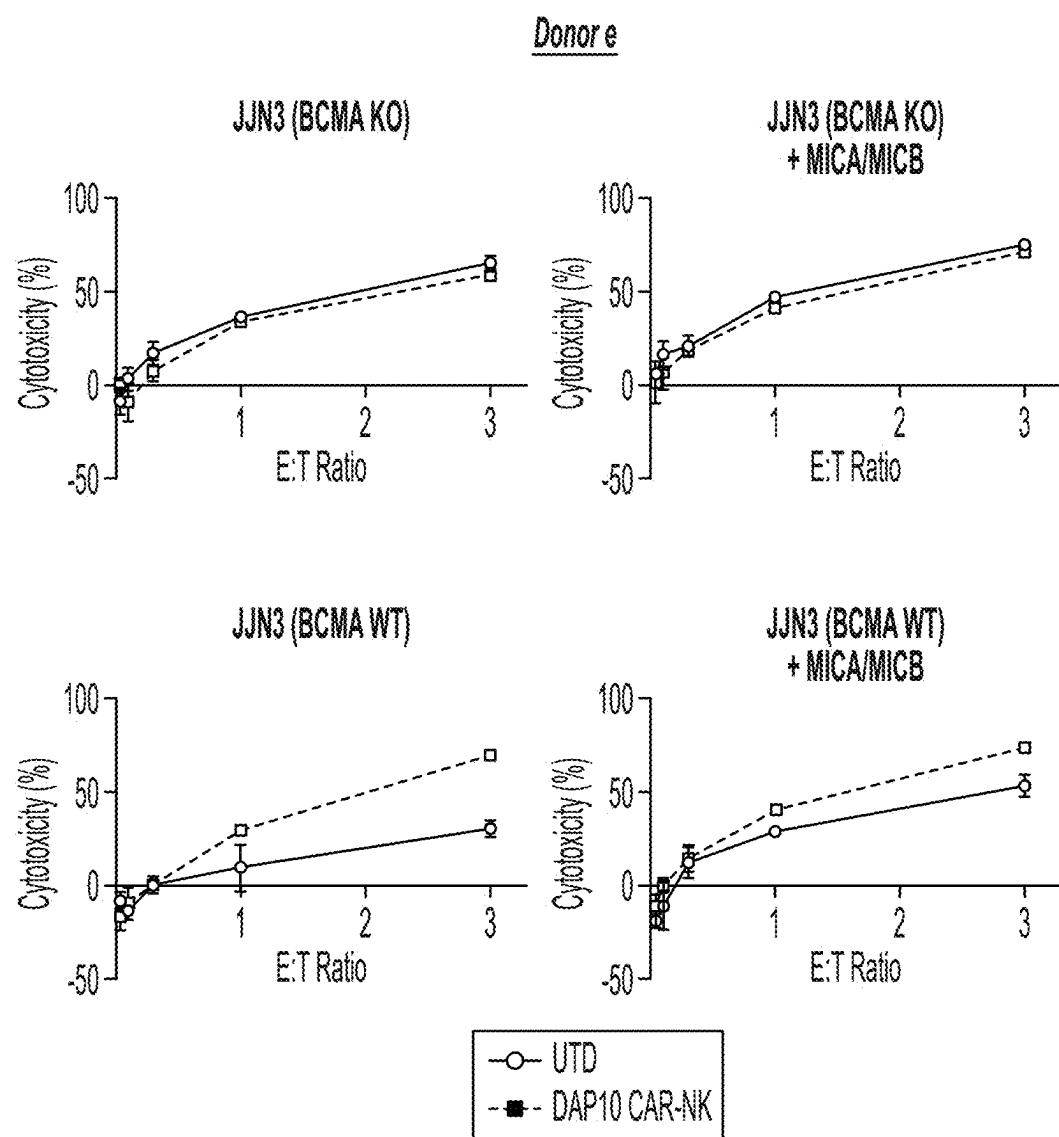


FIG. 10

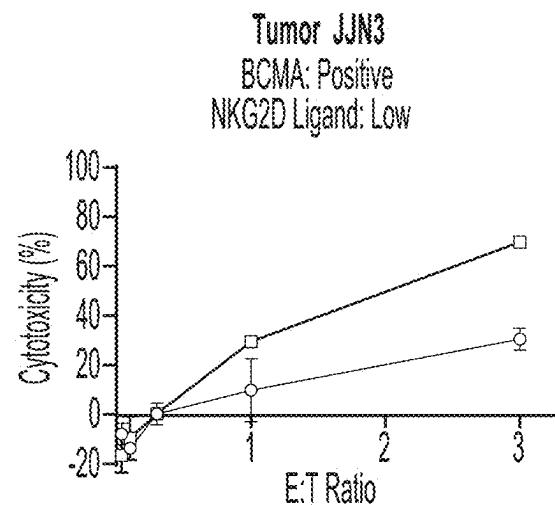


FIG. 11A

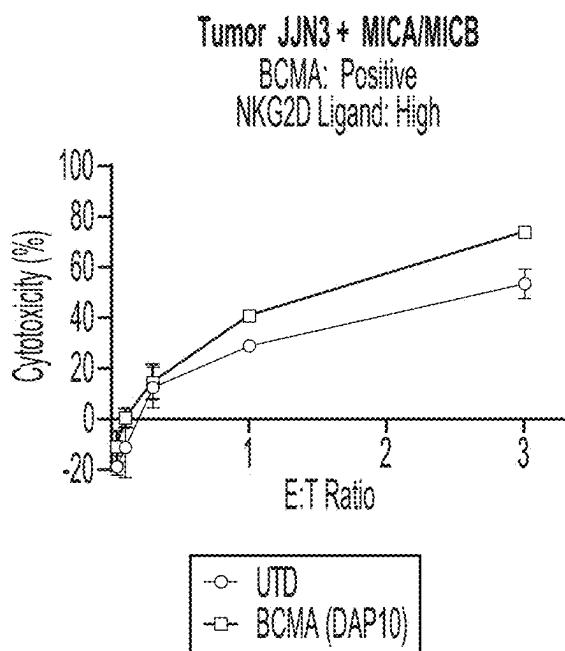


FIG. 11B

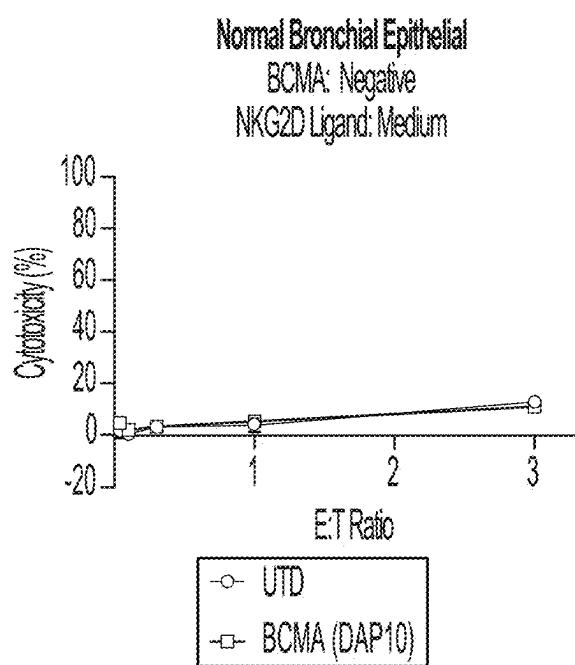


FIG. 11C

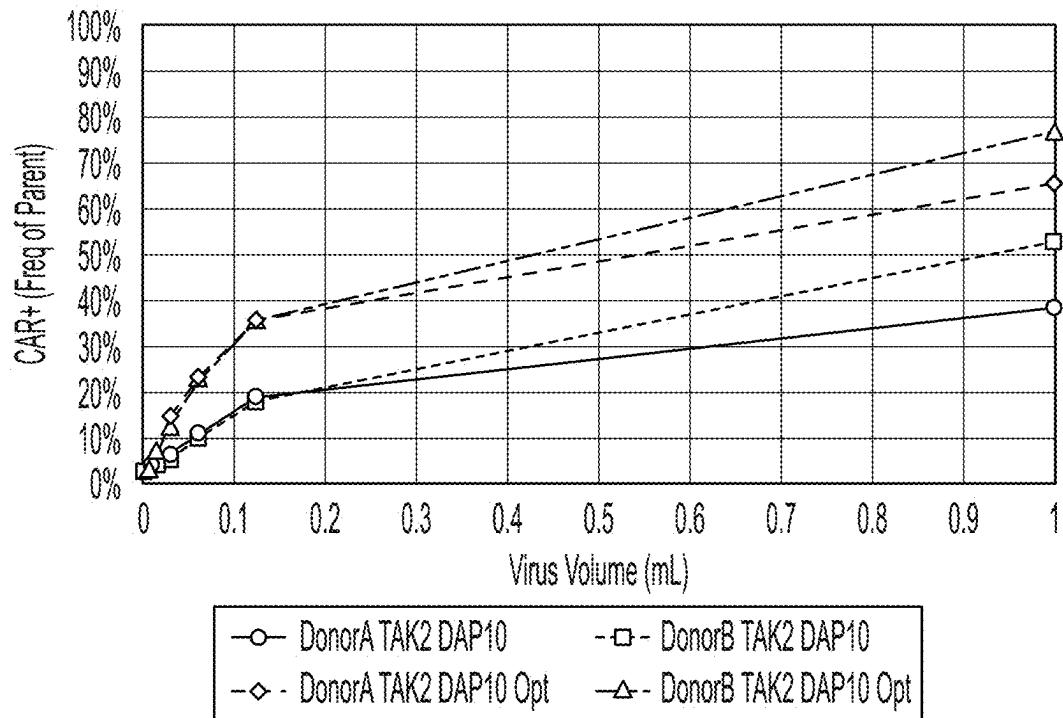


FIG. 12A

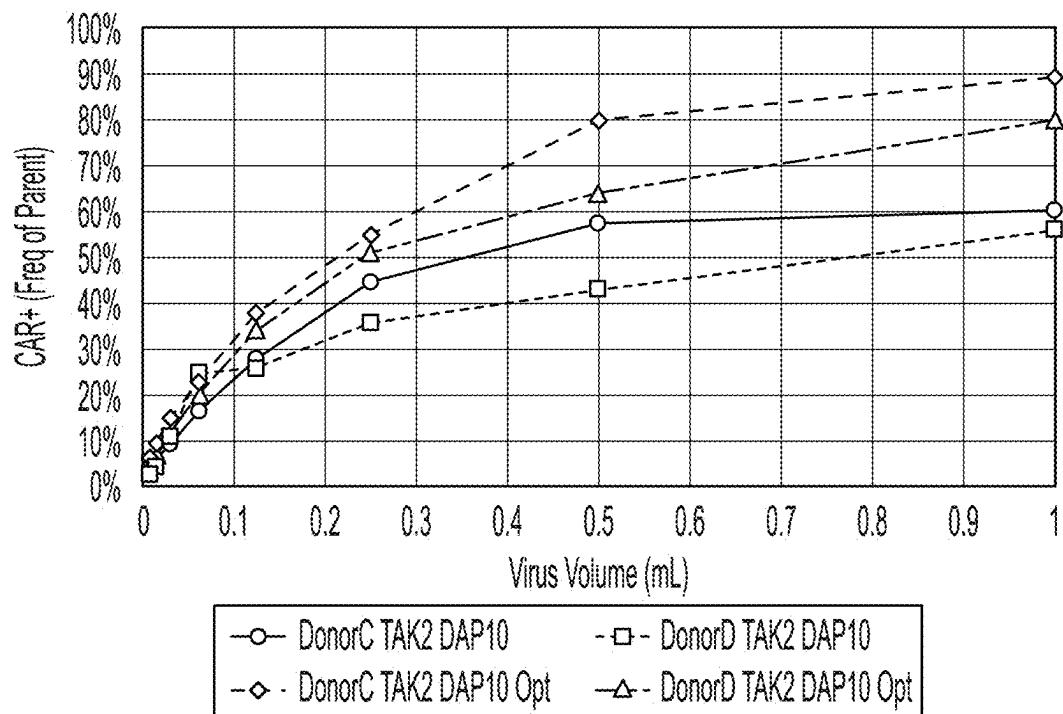


FIG. 12B

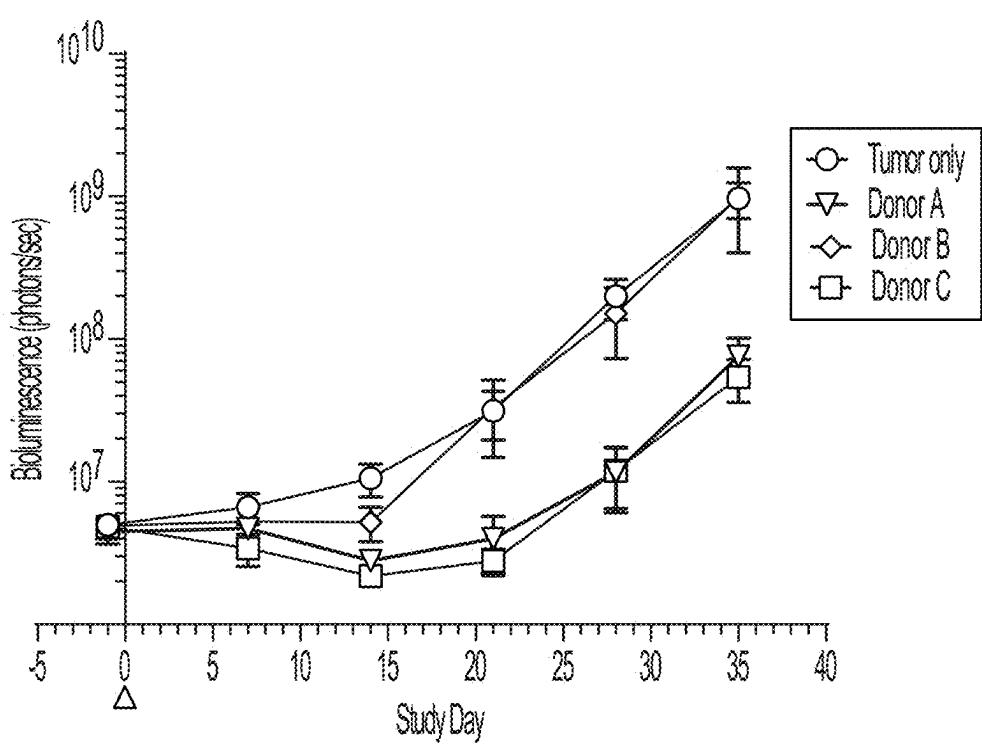


FIG. 13

**BCMA CHIMERIC ANTIGEN RECEPTORS
AND USES THEREOF****CROSS REFERENCE TO RELATED
APPLICATIONS**

[0001] This application is a divisional of U.S. patent application Ser. No. 18/638,229, filed on Apr. 17, 2024, which claims priority to, and the benefit of U.S. Provisional Patent Application No. 63/496,823 filed on Apr. 18, 2023; the contents of which are incorporated herein by reference in its entirety.

**INCORPORATION BY REFERENCE OF
SEQUENCE LISTING**

[0002] The instant application contains a sequence listing which has been submitted electronically in XML format and is hereby incorporated by reference in its entirety. The sequence listing file entitled MIL-021US1_SL.XML, was created on Oct. 4, 2024, which is 75 kilobytes in size.

FIELD OF THE INVENTION

[0003] The present invention provides BCMA targeting chimeric antigen receptors comprising a DAP10 costimulatory domain which have a high efficacy in killing tumor cells. Provided herein also include compositions, cells, and methods for treating diseases associated with expression of BCMA (e.g., cancer).

BACKGROUND

[0004] BCMA is a B-cell maturation antigen. BCMA (also known as TNFRSF17, BCM or CD269) is a member of the tumor necrosis receptor (TNFR) family and is predominantly expressed on terminally differentiated B cells, e.g., memory B cells, and plasma cells. BCMA protein is universally detected in multiple myeloma (MM) cells and in other lymphomas including non-Hodgkin's lymphoma (NHL). Patients having B cell malignancies, including non-Hodgkin's lymphoma (NHL) and multiple myeloma (MM), are significant contributors to cancer mortality.

[0005] The response of B cell malignancies to various forms of treatment is mixed. Traditional methods of treating B cell malignancies, including chemotherapy and radiotherapy, have limited utility due to toxic side effects. Immunotherapy with anti-CD19, anti-CD20, anti-CD22, anti-CD23, anti-CD52, anti-CD08, and anti-HLA-DR therapeutic antibodies have provided limited success, due in part to poor pharmacokinetic profiles, rapid elimination of antibodies by serum proteases and filtration at the glomerulus, and limited penetration into the tumor site and expression levels of the target antigen on cancer cells.

[0006] Attempts to use anti-BCMA antibody therapy and genetically modified cells expressing BCMA targeting chimeric antigen receptors (CARs) have made progression for immunotherapy of B cell malignancies.

SUMMARY OF THE INVENTION

[0007] The present invention in general relates to improved BCMA targeting CAR polypeptides and, among other things, compositions and cells comprising the improved BCMA-CAR polypeptides, and methods of use thereof for treatment of B cell associated diseases and disorders. The BCMA targeting CAR polypeptide comprises

a DAP10 costimulatory domain; the BCMA-DAP10 CAR polypeptide can increase expansion and therapeutic efficacy of immune effector cells (e.g., NK cells and T cells) genetically engineered to express BCMA targeting CAR polypeptides. In particular, NK cells that express the present BCMA targeting CAR polypeptides have higher efficacy in killing tumor cells in various tumors. In the present disclosure, the nucleic acid sequence encoding a BCMA targeting CAR polypeptide comprising a DAP10 co-stimulatory domain is codon optimized.

[0008] In one aspect, the present invention provides a chimeric antigen receptor (CAR) polypeptide comprising an antigen binding region that specifically binds to B-cell maturation antigen (BCMA), a hinge domain, a transmembrane domain, a DAP10 costimulatory domain, and at least one intracellular signaling domain. A polynucleotide encoding a chimeric antigen receptor polypeptide is also included.

[0009] In some embodiments, the BCMA binding domain of the CAR polypeptide is anti-BCMA antibody, an antigen binding domain thereof, a Fab fragment, a F(ab')2 fragment, a Fv fragment, a single chain variable fragment (scFv), a single domain antibody, or a nanobody.

[0010] In some embodiments, the BCMA binding region binds to BCMA with a K_D of less than about 1×10^{-6} M, less than about 1×10^{-7} M, less than about 1×10^{-8} M, or less than about 1×10^{-9} M, or less than about 1×10^{-10} M.

[0011] In some embodiments, the BCMA binding region comprises a heavy chain variable region complementarity determining region (HCDR) 1 comprising SYAIH (SEQ ID NO: 2), a HCDR2 comprising VTWHDGSNKYY-AESVMG (SEQ ID NO: 3), and a HCDR3 comprising AKFGEPQYFQH (SEQ ID NO: 4).

[0012] In some embodiments, the BCMA binding region comprises a light chain variable region complementarity determining region (LCDR) 1 comprising RASQGINNYLA (SEQ ID NO: 6), a LCDR2 comprising AASTLQS (SEQ ID NO: 7), and a LCDR3 comprising QQLKSYPFT (SEQ ID NO: 8).

[0013] In some embodiments, the BCMA binding region comprises a heavy chain variable region (VH) that comprises three complementarity determining regions: HCDR1 comprising SYAIH (SEQ ID NO: 2), HCDR2 comprising VTWHDGSNKYYAESVMG (SEQ ID NO: 3), and HCDR3 comprising AKFGEPQYFQH (SEQ ID NO: 4), and a light chain variable region (VL) that comprises three complementarity determining regions: LCDR1 comprising RASQGINNYLA (SEQ ID NO: 6), LCDR2 comprising AASTLQS (SEQ ID NO: 7), and LCDR3 comprising QQLKSYPFT (SEQ ID NO: 8).

[0014] In some embodiments, the BCMA binding region comprises a heavy chain variable region (VH) comprising an amino acid sequence represented by SEQ ID NO: 1, or an amino acid sequence that is at least about 75%, 80%, 85%, 90%, 95%, 96%, 97%, 97%, 98%, or 99% identical to SEQ ID NO: 1.

[0015] In some embodiments, the BCMA binding region comprises a light chain variable region (VL) comprising an amino acid sequence represented by SEQ ID NO: 5, or an amino acid sequence that is at least about 75%, 80%, 85%, 90%, 95%, 96%, 97%, 97%, 98%, or 99% identical to SEQ ID NO: 5.

[0016] In some embodiments, the BCMA binding region comprises a heavy chain variable region (VH) comprising

the amino acid sequence of SEQ ID NO: 1 and a light chain variable region (VL) comprising the amino acid sequence of SEQ ID NO: 5.

[0017] In one preferred embodiment, the BCMA binding region is a single chain variable fragment (scFv). One exemplary scFv that can bind to BCMA comprises the sequence of SEQ ID NO: 20. The BCMA binding domain may also comprise an amino acid sequence at least about 75%, at least about 80%, at least about 85%, at least about 90%, at least about 95%, at least about 96%, at least about 97%, at least about 98%, or at least about 99% identical to SEQ ID NO: 20.

[0018] In some embodiments, the BCMA binding domain is encoded by a nucleic acid sequence of SEQ ID NO: 35, or SEQ ID NO: 51.

[0019] In accordance with the present invention, the BCMA targeting CAR polypeptide comprises an intracellular DAP10 costimulatory domain. In some embodiments, the DAP10 co-stimulatory domain comprises the amino acid sequence of SEQ ID NO: 24, or an amino acid sequence at least about 75%, at least about 80%, at least about 85%, at least about 90%, at least about 95%, at least about 96%, at least about 97%, at least about 98%, or at least about 99% identical to SEQ ID NO: 24. In some embodiments, the DAP10 co-stimulatory domain is encoded by a nucleic acid sequence comprising the sequence of SEQ ID NO: 39, or SEQ ID NO: 57.

[0020] In some embodiments, the BCMA targeting CAR comprises one or more additional intracellular costimulatory domain.

[0021] In accordance with the present invention, the BCMA targeting CAR polypeptide comprises an intracellular signaling domain. In some embodiments, the intracellular signaling domain is a CD3 ζ signaling domain. The intracellular CD3 ζ signaling domain comprises the amino acid sequence of SEQ ID NO: 23, or an amino acid sequence at least about 75%, at least about 80%, at least about 85%, at least about 90%, at least about 95%, at least about 96%, at least about 97%, at least about 98%, or at least about 99% identical to SEQ ID NO: 23. In some embodiments, the CD3 ζ signaling domain is encoded by a nucleic acid sequence comprising the sequence of SEQ ID NO: 40, or SEQ ID NO: 58.

[0022] In some embodiments, the present BCMA targeting CAR polypeptide may comprise one or more additional costimulatory domains and/or, one or more signaling domains. In some aspects, the costimulatory domains are derived from OX-40, 4-1B B/CD137, C D 2, C D 7, C D 27, CD28, CD30, CD40, programmed death-1 (PD-1), inducible T cell costimulator (ICOS), CDS gamma, CD3 delta, CD3 epsilon, CD247, CD276 (B7-H3), LIGHT (tumor necrosis factor superfamily member 14; TNFSF1.4), NKG2C, 2B4, Ig alpha (CD79a), DAP12, Fc gamma receptor, MHC class I molecule, TN F receptor proteins, Immunoglobulin-like proteins, cytokine receptors, integrins, signaling lymphocytic activation molecules (SLAM proteins), activating NK cell receptors, BTLA, a Toll ligand receptor, ICAM-1, B7-H3, CDS, ICAM-1, GITR, BAFFR, LIGHT, HVEM (LIGHTR), KIRDS2, SLAM F7, NKP80 (KLRF1), NKP44, NKP30, NKP46, CD 19, CD4, CDSalpha, CDSbeta, 11.2 beta, IL2R gamma, IL7R alpha, ITGA4, VLA1, CD49a, ITGA4, IA4, CD49D, ITGA6, VLA-6, CD49f, ITGAD, ITGAE, CD103, ITGAL, LFA-1, ITGAM, ITGAX, ITGB1, CD29, ITGB2, ICOS, CD18, LFA-1, ITGB7, NKG2D,

TNFR2, TRANCE RANKL, DNAM1(CD226), SLAMF4 (CD244, 2B4), CD84, CD96(Tactile), CEACAM 1, CRT AM, Ly9 (CD229), CD160 (BY 55), PSGLI, CDIOO (SEMA4D), CD69, SLAM F6 (NTB-A, Ly108), BLAME (SLAM F8), SELPLG (CD 162), LTBR, LAT, GADS, SLP-76, PAG/Cbp, CD 19a, a ligand that specifically binds with CD83, or any combination thereof. In some aspects, the signaling domains are derived from C D 28, CD137 (4-IBB), CD134 (OX 40), FcR γ , FcR β , Fc ϵ RI, CD3 zeta, CD3 epsilon, CD3 gamma, CD3 delta, CD27, CD2, CD5, CD22, CD79a, CD79b, CD66d, CD278 (ICOS), ICAM-1, LFA-1 (CD1 la/CD18), Lck, TNFR-I, TNFR-II, Fas, CD30, CD40 DAP10, DAP12, or combinations thereof.

[0023] In accordance with the present invention, the BCMA targeting CAR polypeptide comprises a hinge domain and a transmembrane domain that link the extracellular BCMA binding region and the cytoplasmic region of the CAR (i.e., the costimulatory domain and signaling domain).

[0024] In some embodiments, the hinge domain is selected from hinge domains and/or extracellular domains of IgG, CD8a, CD4 and CD28. In some examples, the hinge domain is a CD28 hinge domain; the CD28 hinge domain comprises the amino acid sequence of SEQ ID NO: 21, or an amino acid sequence at least about 75%, at least about 80%, at least about 85%, at least about 90%, at least about 95%, at least about 96%, at least about 97%, at least about 98%, or at least about 99% identical to SEQ ID NO: 21.

[0025] In some embodiments, the CD28 hinge domain is encoded by a nucleic acid sequence comprising the sequence of SEQ ID NO: 37, or SEQ ID NO: 54.

[0026] In some embodiments, the transmembrane domain is a transmembrane domain derived from CD8, CD 16, CD27, CD28, NKG2D, NKP44, NKP46, NKP30, NKP80, DNAM-1, CD3 zeta, CD3 epsilon, CD3 gamma, CD3 delta, CD45, CD4, CD5, CD9, CD22, CD33, CD37, CD64, CD80, CD86, CD134, CD137, CD154, ICOS/CD278, GITR/CD357, DAP10, DAP12, or variant thereof. In some examples, the transmembrane domain is a CD28 transmembrane domain; the CD28 transmembrane domain comprises the amino acid sequence of SEQ ID NO: 22, or an amino acid sequence at least about 75%, at least about 80%, at least about 85%, at least about 90%, at least about 95%, at least about 96%, at least about 97%, at least about 98%, or at least about 99% identical to SEQ ID NO: 22.

[0027] In some embodiments, the CD28 transmembrane domain is encoded by a nucleic acid sequence comprising the sequence of SEQ ID NO: 38, or SEQ ID NO: 56.

[0028] In some embodiments, the BCMA targeting CAR polypeptide further comprises one or more additional polypeptides. In some examples, the polypeptide is a cytokine such as IL-15. As a non-limiting example, the BCMA targeting CAR polypeptide further comprises an IL-15 having the amino acid sequence of SEQ ID NO: 26. In some embodiments, the IL-15 is encoded by a nucleic acid sequence comprising the sequence of SEQ ID NO: 52, or SEQ ID NO: 53.

[0029] In some embodiments, the BCMA targeting CAR polypeptide of the present invention comprises a signal peptide and one or more linker sequences such as a cleavable 2A peptide (e.g., E2A). For example, the E2A peptide may locate between the CAR polypeptide and IL-15 as shown in FIG. 1. The E2A peptide, in one example, comprises the

amino acid sequence of SEQ ID NO: 27. A n exemplary signal peptide sequence is presented by SEQ ID NO: 28, or SEQ ID NO: 59.

[0030] A n exemplary BCMA targeting CAR polypeptide of the present invention comprises the amino acid sequence of SEQ ID NO: 29. In some examples, the BCMA targeting CAR polypeptide comprises an amino acid sequence at least about 75%, at least about 80%, at least about 85%, at least about 90%, at least about 95%, at least about 96%, at least about 7, at least about 98%, or at least about 99% identical to SEQ ID NO: 29.

[0031] In another aspect of the present invention, a polynucleotide encoding a BCMA targeting CAR polypeptide contemplated herein is provided. The polynucleotide is mRNA or DNA. In some embodiments, the polynucleotide is codon optimized. In some embodiments, the polynucleotide comprises at least one modified nucleotide. In other embodiments, the polynucleotide comprises unmodified nucleotides.

[0032] A n exemplary polynucleotide encoding the BCMA targeting CAR polypeptide comprises the nucleotide sequence of SEQ ID NO: 44. In some aspects, the polynucleotide comprises a nucleotide sequence at least about 75%, at least about 80%, at least about 85%, at least about 90%, at least about 95%, at least about 96%, at least about 97%, at least about 98%, at least 99%, or 100% identical to SEQ ID NO: 44.

[0033] In one embodiment, the polynucleotide encoding the BCMA targeting CAR polypeptide comprises the nucleotide sequence of SEQ ID NO: 60. In some aspects, the polynucleotide comprises a nucleotide sequence at least about 75%, at least about 80%, at least about 85%, at least about 90%, at least about 95%, at least about 96%, at least about 97%, at least about 98%, at least 99%, or 100% identical to SEQ ID NO: 60.

[0034] Another exemplary BCMA targeting CAR polypeptide of the present invention comprises the amino acid sequence of SEQ ID NO: 13. In some examples, the BCMA targeting CAR polypeptide comprises an amino acid sequence at least about 75%, at least about 80%, at least about 85%, at least about 90%, at least about 95%, at least about 96%, at least about 97%, at least about 98%, at least 99%, or 100% identical to SEQ ID NO: 13.

[0035] In one embodiment, the polynucleotide encoding the BCMA targeting CAR (e.g., signal sequence 1-BCMA binder-linker-CD28(hinge)-linker-CD28(TM)-DAP10 (costim)-CD3z-E 2A-Signal sequence 2-sIL15) comprises the nucleotide sequence of SEQ ID NO: 25. In some aspects, the polynucleotide comprises a nucleotide sequence at least about 75%, at least about 80%, at least about 85%, at least about 90%, at least about 95%, at least about 96%, at least about 97%, at least about 98%, at least 99%, or 100% identical to SEQ ID NO: 25.

[0036] In one embodiment, the polynucleotide encoding the BCMA targeting CAR comprises a codon optimized sequence of SEQ ID NO: 55. In some aspects, the polynucleotide comprises a nucleotide sequence at least about 75%, at least about 80%, at least about 85%, at least about 90%, at least about 95%, at least about 96%, at least about 97%, at least about 98%, at least 99%, or 100% identical to SEQ ID NO: 55.

[0037] In some embodiments, a vector comprises any polynucleotide encoding the BCMA targeting CAR of the present invention is provided. The vector may be a non-viral

vector such as plasmid, or a viral vector such as an adenoviral vector, an adenovirus associated viral (AAV) vector, a lentiviral vector, and a retroviral vector. As non-limiting examples, the vector may comprise a polynucleotide having the nucleic acid sequence selected from the group consisting of SEQ ID NOS: 25, 44, 55 and 60.

[0038] In another aspect, the present invention provides immune effector cells that are genetically engineered to express at least one BCMA targeting CAR polypeptide described herein. The immune effector cell includes but is not limited to natural killer (NK) cell, natural killer T (NKT) cell, T cell, B cell, macrophage, mesenchymal stromal cell, dendritic cell, tumor-infiltrating lymphocyte (TIL), cytotoxic T lymphocyte (CTL), or any combination thereof.

[0039] In some embodiments, the immune effector cell is T cell, such as mature T cell, T helper cell, tumor infiltrating T cell, autologous T cell, engineered autologous T cell (eACT), allogeneic T cell, or any combination thereof.

[0040] In some embodiments, the immune effector cell is NK cell derived from cord blood, peripheral blood, induced pluripotent stem cells, hematopoietic stem cells, bone marrow, from a cell line, or a mixture thereof.

[0041] In some embodiments, the immune effector cells are engineered to express the BCMA targeting CAR for immunotherapy, e.g., cancer treatment. In some embodiments, the immune cells are autologous, allogeneic, or a mixture thereof.

[0042] Accordingly, pharmaceutical compositions comprising the BCMA targeting CAR polypeptides, polynucleotides encoding the BCMA targeting CAR and immune effector cells engineered to express the BCMA targeting CAR polypeptide are provided. The compositions may be formulated for cell-based therapy.

[0043] In another aspect of the present invention, methods for treating cancer in a subject in need using the BCMA targeting CARs, compositions and cells expressing the BCMA targeting CAR contemplated herein are provided. The BCMA targeting CARs, compositions and cells expressing the BCMA targeting CAR of the present invention can be used to induce an immune response against a disorder or disease associated with BCMA expression in a subject.

[0044] In some embodiments, the immune effector cells of the invention are administered at an amount from about 1×10^6 to 10×10^8 , or about 5×10^6 to about 9.5×10^8 , or about 1×10^7 to 9×10^8 , or about 5×10^7 to 8.5×10^8 , or about 1×10^8 to 8.0×10^8 , or about 2.0×10^8 to 8.0×10^8 , or about 1.0×10^8 to 2.0×10^9 .

[0045] In some embodiments, the cells are administered at an amount of 1.0×10^8 .

[0046] In some embodiments, the cells are administered at an amount of 5.0×10^8 .

[0047] In some embodiments, the cells are administered at an amount of 1.5×10^9 .

[0048] In some embodiment, the BCMA targeting CAR s, composition and/or engineered immune cells are administered by infusion, injection, intravenously, intraarterially, intraperitoneally, intratracheally, intratumorally, intramuscularly, endoscopically, intralesionally, intracranially, percutaneously, subcutaneously, regionally, by perfusion, or any combination thereof.

[0049] In some embodiments, BCMA targeting CARs, composition and/or engineered immune cells are administered intravenously.

[0050] In some embodiments, the BCMA targeting CARs, composition and/or engineered immune cells may be used alone for treating a cancer or in combination with one or more other cancer therapies including chemotherapy, radiation, immunotherapy, cancer vaccine, and/or targeted therapy.

[0051] In some embodiments, the subject receives immunodepleting chemotherapy.

[0052] In some embodiments, the method of the present invention may be used to treat B cell malignancy, multiple myeloma (e.g., relapsed and refractory multiple myeloma), lymphoma, and/or leukemia.

BRIEF DESCRIPTION OF THE DRAWINGS

[0053] FIG. 1 is an exemplary diagram of the BCMA-DAP10-CAR construct.

[0054] FIG. 2A shows the representative images of mice which were inoculated with tumor cells, after receiving one (10M×1) or two doses (10M×2) of BCMA-CAR expressing NK cells.

[0055] FIG. 2B demonstrates in vivo efficacy of BCMA-DAP10 and BCMA-CD28 CAR constructs against MM1S tumor.

[0056] FIG. 3 shows in vivo efficacy of BCMA-DAP10 and BCMA-CD28 CAR constructs against multiple tumor cell lines.

[0057] FIG. 4A-4B show the ability of BCMA-DAP10-CAR and BCMA-CD28-CAR NK cells to kill tumor cells in MM1S tumor model in vitro with multiple rounds of Restimulation.

[0058] FIG. 5A-5B show the ability of BCMA-DAP10-CAR and BCMA-CD28-CAR NK cells to kill tumor cells in RPMI-8226 model in vitro with multiple rounds of Restimulation.

[0059] FIG. 6 shows in vivo efficacy of BCMA-DAP10 CAR and BCMA-CD28 CAR constructs against RPMI-8226 tumor.

[0060] FIG. 7 shows in vivo expansion of BCMA-DAP10 CAR NK cells and BCMA-CD28 CAR NK cells in RPMI-8226 tumor model.

[0061] FIG. 8A-8B show in vivo efficacy of BCMA-DAP10 CAR in RPMI-8226 tumor model at multiple doses.

[0062] FIG. 9 shows in vitro efficacy of BCMA-DAP10 CAR against tumor lines expressing different levels of stress ligands (Donor d)

[0063] FIG. 10 shows In vitro efficacy of BCMA DAP10 CAR against tumor cell lines expressing different levels of stress ligands (Donor e)

[0064] FIG. 11A-11C show in vitro efficacy of BCMA-DAP10-CAR against tumor cell lines expressing different levels of stress ligands and normal cells.

[0065] FIG. 12A-12B demonstrates CAR protein expression using codon-optimized nucleic acid sequence. The codon-optimized BCMA-DAP10 CAR construct (SEQ ID NO: 25) yielded higher transduction efficiency against the BCMA-DAP10 CAR (SEQ ID NO: 55) across all four Cord blood NK donors.

[0066] FIG. 13 demonstrates in vivo efficacy of NK cell expressing BCMA CAR (expressed using codon-optimized nucleic acid sequence) at a low CAR+ dose.

DETAILED DESCRIPTION

[0067] The present invention provides, among other things, chimeric antigen receptor (CAR) targeting B-cell maturation antigen (BCMA), compositions and cells expressing BCMA targeting CAR, and methods of use thereof for the treatment of a disease such as cancer. The present BCMA targeting CAR construct incorporates a DAP10 derived costimulatory signaling domain which increases expansion in vivo and functionality of immune effector cells that express the BCMA-DAP10 CAR (e.g., NK cells). The present BCMA-DAP10 CAR polypeptides demonstrate a higher efficacy in killing tumor cells and inhibiting tumor growth. In some embodiments, the BCMA-DAP10 CAR of the present invention further comprises IL-15, which is cleavable from the CAR polypeptide. The polynucleotide encoding a BCMA-DAP10 CAR polypeptide may be codon optimized.

Definitions

[0068] Unless defined otherwise, all technical and scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art to which the invention pertains. Although any methods and materials similar or equivalent to those described herein can be used in the practice for testing of the present invention, the preferred materials and methods are described herein. In describing and claiming the present invention, the following terminology will be used. It is also to be understood that the terminology used herein is for the purpose of describing particular embodiments only, and is not intended to be limiting.

[0069] The articles “a” and “an” are used herein to refer to one or to more than one (i.e., to at least one) of the grammatical object of the article. By way of example, “an element” means one element or more than one element.

[0070] “About” as used herein when referring to a measurable value such as an amount, a temporal duration, and the like, is meant to encompass variations of $\pm 20\%$ or $\pm 10\%$, more preferably $\pm 5\%$, even more preferably $\pm 1\%$, and still more preferably $\pm 0.1\%$ from the specified value, as such variations are appropriate to perform the disclosed methods.

[0071] Antigen binding domain: as used herein, the term “antigen binding domain” refers to one or more extracellular domains of the chimeric antigen receptor which have specificity for a particular antigen, e.g., BCMA.

[0072] Antibody: as used herein, the term “antibody,” refers to an immunoglobulin molecule which specifically binds with an antigen. For example, in one aspect, the antigen is B7-H6. In another aspect, the antigen is M ICA. Antibodies can be intact immunoglobulins derived from natural sources or from recombinant sources and can be immunoreactive portions of intact immunoglobulins. The term is used in the broadest sense and includes polyclonal and monoclonal antibodies, including intact antibodies and functional (antigen-binding) antibody fragments, including fragment antigen binding (Fab) fragments, $F(ab')_2$ fragments, Fab' fragments, Fv fragments, recombinant IgG (rIgG) fragments, single chain antibody fragments, including single chain variable fragments (scFv), diabodies, and single domain antibodies (e.g., sdAb, sdFv, nanobody) fragments. The term encompasses genetically engineered and/or otherwise modified forms of immunoglobulins, such as intrabodies, peptibodies, chimeric antibodies, fully human

antibodies, humanized antibodies, and heteroconjugate antibodies, multispecific (e.g., bispecific) antibodies, diabodies, triabodies, and tetrabodies, tandem di-scFv, tandem tri-scFv. Unless otherwise stated, the term “antibody” should be understood to encompass functional antibody fragments thereof. The term also encompasses intact or full-length antibodies, including antibodies of any class or sub-class, including IgG and sub-classes thereof, IgM, IgE, IgA, and IgD.

[0073] An “antibody heavy chain,” as used herein, refers to the larger of the two types of polypeptide chains present in all antibody molecules in their naturally occurring conformations. An “antibody light chain,” as used herein, refers to the smaller of the two types of polypeptide chains present in all antibody molecules in their naturally occurring conformations. Kappa and lambda light chains refer to the two major antibody light chain isotypes.

[0074] The term “antibody fragment” refers to a portion of an intact antibody and refers to the antigenic determining variable regions of an intact antibody. Examples of antibody fragments include, but are not limited to, fragment antigen binding (Fab) fragments, F(ab')₂ fragments, Fab' fragments, Fv fragments, recombinant IgG (rlgG) fragments, single chain antibody fragments, including single chain variable fragments (scFv), single domain antibodies (e.g., sdAb, sdFv, nanobody) fragments, diabodies, and multispecific antibodies formed from antibody fragments. In a specific embodiment, the antibody fragment may be an scFv.

[0075] Chimeric antigen receptor (CAR): As used herein, the term “chimeric antigen receptor” or “CAR” means a protein that when expressed on the surface of a cell allows a CAR expressing cell to recognize its specific protein (antigen), such as on tumor cells, infected cells or cells mediating autoimmune or inflammatory diseases or disorders. Such receptors are also known as chimeric T cell receptors, chimeric immunoreceptors, or artificial T cell receptors. Upon transduction of a cell with a nucleic acid construct encoding a CAR, the cell will recognize the antigen specified by the CAR. A CAR is typically comprised of an ectodomain (extracellular domain) and an endodomain (cytoplasmic domain), separated by a transmembrane domain. The ectodomain, expressed on the surface of the cell, comprises an antigen binding domain or receptor domain, optionally a signal peptide that directs the antigen binding domain into the endoplasmic reticulum for processing, and optionally a spacer (or hinge) region. The antigen binding domain (or receptor domain) comprises peptides that specifically recognize a target antigen. As a non-limiting example, the antigen binding domain can be a single chain antibody, such as an scFv. The spacer region links the antigen binding domain to the transmembrane domain and is designed to be sufficiently flexible to allow the antigen binding domain to orient in a manner that allows antigen recognition. Examples of spacer domains include, but are not limited to, the hinge region from IgG, the CH₂CH₃ region of an immunoglobulin, CD28 hinge, Dap10 hinge, CD8 hinge, and portions of CD3 molecules. The transmembrane domain is a hydrophobic alpha helix, typically, that spans across the lipid bilayer of the cell membrane. The endodomain of the CAR is composed of a signal transmitting peptide that transmits an activation signal intracellularly to the cell cytoplasm, thereby stimulating the cell expressing the CAR. The endodomain may include multiple such signaling domains, as explained, infra. In some embodi-

ments, a CAR comprises at least an extracellular antigen binding domain, a transmembrane domain and a cytoplasmic signaling domain (also referred to herein as “an intracellular signaling domain”) comprising a functional signaling domain derived from a stimulatory molecule and/or costimulatory molecule as defined below. In some aspects, the set of polypeptides encoding the CAR are contiguous with each other. In some embodiments, the set of polypeptides include a dimerization switch that, upon the presence of a dimerization molecule, can couple the polypeptides to one another, e.g., can couple an antigen binding domain to an intracellular signaling domain. In one aspect, the stimulatory molecule is the zeta chain associated with the T cell receptor complex. In one aspect, the cytoplasmic signaling domain further comprises one or more functional signaling domains derived from at least one costimulatory molecule as defined below. In one aspect, the CAR comprises a chimeric fusion protein comprising an extracellular antigen binding domain, a transmembrane domain and an intracellular signaling domain comprising a functional signaling domain derived from a stimulatory molecule. In one aspect, the CAR comprises a chimeric fusion protein comprising an extracellular antigen binding domain, a transmembrane domain and an intracellular signaling domain comprising a functional signaling domain derived from a costimulatory molecule and a functional signaling domain derived from a stimulatory molecule. In one aspect, the CAR comprises a chimeric fusion protein comprising an extracellular antigen binding domain, a transmembrane domain and an intracellular signaling domain comprising two functional signaling domains derived from one or more costimulatory molecule(s) and a functional signaling domain derived from a stimulatory molecule. In one aspect the CAR comprises an optional leader sequence at the amino-terminus (N-ter) of the CAR fusion protein. In one aspect, the CAR further comprises a leader sequence at the N-terminus of the extracellular antigen binding domain, wherein the leader sequence is optionally cleaved from the antigen binding domain (e.g., an scFv) during cellular processing and localization of the CAR to the cellular membrane.

[0076] Cancer: As used herein, the term “cancer” refers to a disease characterized by the rapid and uncontrolled growth of aberrant cells. Cancer cells can spread locally or through the bloodstream and lymphatic system to other parts of the body. Examples of various cancers are described herein and include but are not limited to, breast cancer, prostate cancer, ovarian cancer, cervical cancer, skin cancer, pancreatic cancer, colorectal cancer, renal cancer, liver cancer, brain cancer, lymphoma, leukemia, lung cancer and the like.

[0077] Disease or disorder: As used herein, the terms “disease” and “disorder” are used interchangeably. The term “disease” is a state of health of an animal wherein the animal cannot maintain homeostasis, and wherein if the disease is not ameliorated then the animal’s health continues to deteriorate. In contrast, a “disorder” in an animal is a state of health in which the animal is able to maintain homeostasis, but in which the animal’s state of health is less favorable than it would be in the absence of the disorder. Left untreated, a disorder does not necessarily cause a further decrease in the animal’s state of health.

[0078] Identical: As used herein, the term “identical” in the context of polynucleotide and nucleic acid sequences, refers to a first sequence (e.g., an amino acid sequence or a nucleic acid sequence) that contains a sufficient or minimum number

of amino acid residues or nucleotide residues that are i) identical to, or ii) conservative substitutions of aligned amino acid or nucleotide residues in a second amino acid sequence or in a second nucleic acid sequence such that the first and second amino acid sequences or nucleic acid sequences can have a common structural domain and/or common functional activity. For example, amino acid sequences contain a common structural domain having at least about 70%, 75%, 80%, 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98% or 99% identity to a reference amino acid sequence, e.g., a sequence provided herein. In another example, nucleic acid sequences have at least about 70%, 75%, 80%, 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98% or 99% identity to a reference nucleic acid sequence, e.g., a sequence provided herein.

[0079] Pharmaceutical composition: As used herein, a “pharmaceutical composition” refers to a composition formulated in pharmaceutically-acceptable or physiologically-acceptable solutions for administration to a cell or an animal, either alone, or in combination with one or more other modalities of therapy. It will also be understood that, if desired, the compositions may be administered in combination with other agents as well, such as, e.g., cytokines, growth factors, hormones, small molecules, chemotherapeutics, pro-drugs, drugs, antibodies, or other various pharmaceutically-active agents. There is virtually no limit to other components that may also be included in the compositions, provided that the additional agents do not adversely affect the ability of the composition to deliver the intended therapy. In preferred embodiments, a pharmaceutical composition comprises a pharmaceutically acceptable carrier, diluent or excipient and one or more cells modified to express a CAR as contemplated herein.

[0080] Pharmaceutically acceptable carrier: As used herein, the term “pharmaceutically acceptable carrier” includes any and all solvents, dispersion media, coatings, surfactants, antioxidants, preservatives (e.g., antibacterial agents, antifungal agents), isotonic agents, absorption delaying agents, salts, preservatives, drugs, drug stabilizers, gels, binders, excipients, disintegration agents, lubricants, sweetening agents, flavoring agents, dyes, such like materials and combinations thereof, as would be known to one of ordinary skill in the art (see, for example, Remington’s Pharmaceutical Sciences, 18th Ed. Mack Printing Company, 1990, pp. 1289-1329, incorporated herein by reference). Except insofar as any conventional carrier is incompatible with the active ingredient, its use in the pharmaceutical compositions is contemplated.

[0081] The terms “specific binding affinity” or “specifically binds” or “specifically bound” or “specific binding” or “specifically targets” as used herein, describe binding of an anti-BCMA antibody or antigen binding domain thereof (or a CAR comprising the same) to BCMA (e.g., human BCMA) at greater binding affinity than background binding. A BCMA binding domain (or a CAR comprising the BCMA binding domain) “specifically binds” to a BCMA if it binds to or associates with BCMA with a dissociation constant (K_d) of about 1×10^{-7} M. In some embodiments, the antigen binding molecule specifically binds an antigen with “high affinity” when the K_d is about 1×10^{-9} M to about 5×10^{-9} M. In some embodiments, the antigen binding molecule specifically binds an antigen with “very high affinity” when the K_d is 1×10^{-10} M to about 5×10^{-10} M. In one embodiment, the antigen binding molecule has a K_d of 10^{-9} M. In one

embodiment, the off-rate is less than about 1×10^{-5} . In other embodiments, the antigen binding molecule binds human BCMA with a K_d of between about 1×10^{-7} M and about 1×10^{-13} M. In yet another embodiment, the antigen binding molecule binds human BCMA with a K_d of about 1×10^{-10} M to about 5×10^{-10} M. Affinities of the BCMA binding domains and CAR proteins according to the present invention can be readily determined using conventional techniques, e.g., by competitive ELISA (enzyme-linked immunosorbent assay), or by binding association, or displacement assays using labeled ligands.

[0082] Subject: As used herein, the term “subject” is intended to include living organisms in which an immune response can be elicited (e.g., mammals). Examples of subjects include humans, dogs, cats, mice, rats, and transgenic species thereof.

[0083] Therapeutically effective amount: As used herein, the term “therapeutically effective amount” includes an amount that is effective to “treat” a subject (e.g., a patient). When a therapeutic amount is indicated, the precise amount of the compositions to be administered can be determined by a physician with consideration of individual differences in age, weight, tumor size, extent of infection or metastasis, and condition of the patient (subject).

[0084] Treat: As used herein, the terms “treatment,” “treat,” and “treating,” refer to a clinical intervention aimed to reverse, alleviate, delay the onset of, or inhibit the progress, and/or prevent or delay the recurrence of a disease or disorder, or one or more symptoms thereof, as described herein. Treatment, e.g., in the form of BCMA CAR expressing NK cells as described herein, may be administered to a subject after one or more symptoms have developed and/or after a disease has been diagnosed. Treatment may be administered in the absence of symptoms, e.g., to prevent or delay onset of a symptom or inhibit onset or progression of a disease. For example, treatment may be administered to a susceptible individual prior to the onset of symptoms (e.g., in light of genetic or other susceptibility factors). Treatment may also be continued after symptoms have resolved, for example to prevent or delay their recurrence.

[0085] Various aspects of the compositions and methods herein are described in further detail below. Additional definitions are set out throughout the specification.

Chimeric Antigen Receptor (CAR)

[0086] In one aspect, the present invention relates to BCMA (B-cell maturation antigen) targeting CAR polypeptides and polynucleotides encoding the same. The BCMA targeting CAR comprises an extracellular antigen binding region that specifically binds to BCMA, a hinge domain, a transmembrane domain, a DAP10 costimulatory domain, and at least one intracellular activation/signaling domain. The BCMA targeting CAR may further comprise one or more additional polypeptides such as a cytokine (e.g., IL-15). Each component within the CAR is linked by one or more linker sequences.

1. BCMA Binding Region

[0087] In accordance with the present invention, the antigen binding region of the present CAR comprises at least one BCMA binding domain (i.e., BCMA binder). The BCMA binding domain can be any agent that binds to BCMA or a portion of BCMA. The BCMA binding domain

may be an antibody that specifically binds to BCMA, or antigen binding fragment thereof. The antibody or antigen-binding fragment that specifically binds to BCMA may be a monoclonal antibody, a monospecific antibody, a humanized antibody, a human antibody, a single chain antibody, a domain-specific antibody, a single domain antibody, a domain-deleted antibody, an scFv fusion protein, a single-chain antibody, a chimeric antibody, a synthetic antibody, a recombinant antibody, a hybrid antibody, a mutated antibody, a CDR-grafted antibody, an antibody fragment such as a Fab, a F(ab) fragment, an Fab' fragment, an F(ab)2 fragment, a Fv fragment, a single-chain Fv (scFv) fragment, a Fd fragment; a dAb fragment, a diabody, a nanobody, a bivalent nanobody, a shark variable IgNAR domain, a VHH antibody, a camelid antibody, or a minibody.

[0088] A suitable BCMA binder according to the present invention may be a scFv that specifically binds to BCMA. A “Single-chain Fv” or “scFv” comprises the VH and VL domains of antibody, wherein these domains are present in a single polypeptide chain and in either orientation (e.g., VL-VH or VH-VL). Typically, scFv can be in a form of VH-linker-VL or VL-linker-VH.

[0089] The linker to link the VH and VL chain may comprise an amino acid sequence of (GGGGS)n (SEQ ID NO: 65) (n is an integer of at least 1, 2, 3, 4, 5, 6, 7, 8, 9, or 10). Exemplary linker sequences may include but are not limited to, GGGGSGGGGSGGGGG (SEQ ID NO: 15), GGGGSGGGGSGGGGG (SEQ ID NO: 16), GGGGSGGGGSGGGGGSGGGG (SEQ ID NO: 17), and GGGGSGGGGSGGGGGSGGGG (SEQ ID NO: 18). In some embodiments, the linker comprises an amino acid sequence at least about 70%, at least about 75%, at least about 85%, at least about 85%, at least about 90%, at least about 91%, at least about 92%, at least about 93%, at least about 94%, at least about 95%, at least 96%, at least about 97%, at least about 98%, at least about 99%, or 100% identical to one of SEQ ID NOS: 15-18.

[0090] In one exemplary embodiment, the linker of the anti-BCMA scFv comprises an amino acid sequence of GGGGSGGGGSGGGG (SEQ ID NO: 15).

[0091] In some embodiments, the linker is encoded by a nucleic acid sequence comprising SEQ ID NO: 19, SEQ ID NO: 9 or SEQ ID NO: 10.

(SEQ ID NO: 9)
GGGGGCAGGGCTGGAGGAGGGGGAGCAGGGGGAGCGGCTCT

(SEQ ID NO: 10)
GGCGGAGGGGATCTGGAGGAGGAAGTGAGCCGTGGCAGC

(SEQ ID NO: 19)
GGTGGTGGTGGTCTGGTGGTGGTTCTGGCGGGCGGCTCCGGTG
GTGGTGGATCC

[0092] In some embodiments, the BCMA binder comprises three heavy chain complementarity determining regions (HCDRs), i.e., HCDR1, HCDR2 and HCDR3 in the heavy chain variable region (VH), and/or three light chain complementarity determining regions (LCDRs), i.e., LCDR1, LCDR2 and LCDR3, in the light chain variable region (VL). In some embodiments, the BCMA binder comprises a VH and/or a VL.

[0093] In some embodiments, the BCMA binding domain of the present CAR comprises the HCDR1 having the amino acid sequence of SYAIH (SEQ ID NO: 2), the HCDR2

having the amino acid sequence of VTWHDGSNKYYAESVMG (SEQ ID NO: 3), and the HCDR3 having the amino acid sequence of AKFGEQYFQH (SEQ ID NO: 4).

[0094] In some embodiments, the BCMA binding domain of the present CAR comprises the LCDR1 having the amino acid sequence of RASQGINNYLA (SEQ ID NO: 6), the LCDR2 having the amino acid sequence of AASTLQS (SEQ ID NO: 7), and the LCDR3 having the amino acid sequence of QQLKSYPFT (SEQ ID NO: 8).

[0095] In some embodiments, the BCMA binding region comprises a heavy chain variable region (VH) that comprises three complementarity determining regions: HCDR1 comprising SYAIH (SEQ ID NO: 2), HCDR2 comprising VTWHDGSNKYYAESVMG (SEQ ID NO: 3), and HCDR3 comprising AKFGEQYFQH (SEQ ID NO: 4), and a light chain variable region (VL) that comprises three complementarity determining regions: LCDR1 comprising RASQGINNYLA (SEQ ID NO: 6), LCDR2 comprising AASTLQS (SEQ ID NO: 7), and LCDR3 comprising QQLKSYPFT (SEQ ID NO: 8).

[0096] In some embodiments, the BCMA binding domain comprises a VH chain having the amino acid sequence presented by SEQ ID NO: 1.

(SEQ ID NO: 1)
QITLRESGGDVVQPGRSLRLSCAASGFTFSSYAIHWVRQAPGKGLEWVA
VTWHDGSNKYYAESVMGRFTISRDNSKNTLYLHMNSLRAEDTGVYYCAR
AKFGEQYFQHWGQGTLTVSS.

[0097] It is envisioned that any amino acid substitution at any position other than the CDR sequences can be changed to another amino acid, for example a conservative amino acid substitution (as defined herein). In some embodiments, the VH comprises a sequence that is 70% identical to SEQ ID NO: 1. In some embodiments, the VH comprises a sequence that is 75% identical to SEQ ID NO: 1. In some embodiments, the VH comprises a sequence that is 80% identical to SEQ ID NO: 1. In some embodiments, the VH comprises a sequence that is 85% identical to SEQ ID NO: 1. In some embodiments, the VH comprises a sequence that is 90% identical to SEQ ID NO: 1. In some embodiments, the VH comprises a sequence that is 95% identical to SEQ ID NO: 1. In some embodiments, the VH comprises a sequence that is 96% identical to SEQ ID NO: 1. In some embodiments, the VH comprises a sequence that is 97% identical to SEQ ID NO: 1. In some embodiments, the VH comprises a sequence that is 98% identical to SEQ ID NO: 1. In some embodiments, the VH comprises a sequence that is 99% identical to SEQ ID NO: 1.

[0098] In some embodiments, the BCMA binding domain comprises a VL chain having the amino acid sequence of SEQ ID NO: 5.

(SEQ ID NO: 5)
DIVMTQSPSFLSASVGDRVVTITCRASQGINNYLAWYQQKPGIAPKLLIY
AASTLQSGVPSRFGGSGSGTEFTLTISLQPEDFATYYCQQLKSYPFTF
GPGTKVEIK.

[0099] It is envisioned that any amino acid substitution at any position other than the CDR sequences can be changed to another amino acid, for example a conservative amino

acid substitution (as defined herein). In some embodiments, the VL comprises a sequence that is 70% identical to SEQ ID NO: 5. In some embodiments, the VL comprises a sequence that is 75% identical to SEQ ID NO: 5. In some embodiments, the VL comprises a sequence that is 80% identical to SEQ ID NO: 5. In some embodiments, the VL comprises a sequence that is 85% identical to SEQ ID NO: 5. In some embodiments, the VL comprises a sequence that is 90% identical to SEQ ID NO: 5. In some embodiments, the VL comprises a sequence that is 95% identical to SEQ ID NO: 5. In some embodiments, the VL comprises a sequence that is 96% identical to SEQ ID NO: 5. In some embodiments, the VL comprises a sequence that is 97% identical to SEQ ID NO: 5. In some embodiments, the VL comprises a sequence that is 98% identical to SEQ ID NO: 5. In some embodiments, the VL comprises a sequence that is 99% identical to SEQ ID NO: 5.

[0100] In some embodiments, the BCMA binding domain of the present chimeric antigen receptor comprises a VH chain of SEQ ID NO: 1 and a VL chain of SEQ ID NO: 5.

[0101] In some embodiments, the BCMA binding domain of the present chimeric antigen receptor comprises a scFv including a VH chain of SEQ ID NO: 1 and a VL chain of SEQ ID NO: 5 wherein the VH and VL chains are linked by any one of the linker sequences described herein (e.g., SEQ ID Nos: 15-18).

[0102] In some embodiments, the BCMA binding domain of the present chimeric antigen receptor comprises a scFv comprising a VH chain of SEQ ID NO: 1 and a VL chain of SEQ ID NO: 5.

[0103] As a non-limiting example, the BCMA binding domain of the present chimeric antigen receptor comprises the amino acid sequence presented by SEQ ID NO: 20.

(SEQ ID NO: 20)
 Q1TLRESGGDVVQPGRSLRLSCAASGFTFSSYAIHWVRQAPGKGLEWVA
 VTWHDGSNKYYAESVMGRFTISRDNSKNTLYLHMNSLRAEDTGVYYCAR
 AKPGEPEQYFQHWGQGTLVTVSSGGGGGGGGSDIVMTQSPSFLS
 ASVGDRVTITCRASQGINNYLAQQKPGIAPKLLIYAASLTQSGVPSR
 FGGSGSGTEFTLTISSLOPEDPATYYCQQLKSYPFTFGPGTKVEIK.

[0104] In some embodiments, the BCMA binding domain comprises a scFv having an amino acid sequence that is at least 70%, at least 75%, at least 80%, at least 85%, at least 90%, at least 91%, at least 92%, at least 93%, at least 94%, at least 95%, at least 96%, at least 97%, at least 98%, or at least 99% identical to SEQ ID NO: 20.

[0105] In some embodiments, the BCMA binding scFv is encoded by a nucleic acid sequence of SEQ ID NO: 35, or SEQ ID NO: 51.

[0106] In some embodiments, molecules that specifically bind to an antigen bind with a dissociation constant (K_d) of about 1×10^{-7} M. In some embodiments, the antigen binding molecule specifically binds an antigen with “high affinity” when the K_d is about 1×10^{-9} M to about 5×10^{-9} M. In some embodiments, the antigen binding molecule specifically binds an antigen with “very high affinity” when the K_d is 1×10^{-10} M to about 5×10^{-10} M. In one embodiment, the antigen binding molecule has a K_d of 10^{-9} M. In one embodiment, the off-rate is less than about 1×10^{-5} . In other embodiments, the antigen binding molecule binds human BCMA with a K_d of between about 1×10^{-7} M and about

1×10^{-13} M. In yet another embodiment, the antigen binding molecule binds human BCMA with a K_d of about 1×10^{-10} M to about 5×10^{-10} M.

[0107] In another specific embodiment, molecules that specifically bind to BCMA do not cross react with other proteins under similar binding conditions. In another specific embodiment, molecules that specifically bind to BCMA do not cross react with other non-BCMA proteins. In a specific embodiment, provided herein is an antibody or fragment thereof that binds to BCMA with higher affinity than to another unrelated antigen. In certain embodiments, provided herein is an antibody or fragment thereof that binds to BCMA (e.g., human BCMA) with a 20%, 25%, 30%, 35%, 40%, 45%, 50%, 55%, 60%, 65%, 70%, 75%, 80%, 85%, 90%, 95% or higher affinity than to another, unrelated antigen as measured by, e.g., a radioimmunoassay, surface plasmon resonance, or kinetic exclusion assay. In a specific embodiment, the extent of binding of an anti-BCMA antibody or antigen-binding fragment thereof described herein to an unrelated, non-BCMA protein is less than 10%, 15%, or 20% of the binding of the antibody to BCMA protein as measured by, e.g., a radioimmunoassay.

[0108] In a specific embodiment, provided herein is a chimeric antigen receptor that binds to human BCMA with higher affinity than to another species of BCMA. In certain embodiments, provided herein is an antibody or fragment thereof that binds to human BCMA with a 5%, 10%, 15%, 20%, 25%, 30%, 35%, 40%, 45%, 50%, 55%, 60%, 65%, 70%, 75%, 80%, 85%, 90%, 95% or higher affinity than to another species of BCMA as measured by, e.g., a radioimmunoassay, surface plasmon resonance, or kinetic exclusion assay. In a specific embodiment, a chimeric antigen receptor comprising a BCMA binder, which binds to human BCMA, will bind to another species of BCMA protein with less than 10%, 15%, or 20% of the binding of the antibody or fragment thereof to the human BCMA protein as measured by, e.g., a radioimmunoassay, surface plasmon resonance, or kinetic exclusion assay.

2. Hinge Region

[0109] In certain aspects, the BCMA targeting CAR polypeptide of the present invention can include a hinge domain positioned between the extracellular antigen binding domain and the transmembrane domain. A hinge domain may be included in CAR polypeptides to provide adequate distance between the antigen binding domain and the cell surface or to alleviate possible steric hindrance that could adversely affect antigen binding or effector function of CAR-gene modified immune cells. For example, the hinge domain can position the antigen binding domain away from the effector cell surface to enable proper cell/cell contact, antigen binding and activation.

[0110] The hinge domain is of a particular length, such as 10-50, 10-40, 10-30, 10-20, 10-15, 20-50, 20-40, 20-30, 15-50, 15-45, 15-30, 15-20, 12-20, 12-15, or 15-20 amino acids in length.

[0111] In some embodiments, the hinge domain is derived from human CD28 hinge domain. As a non-limiting example, the hinge domain of the BCMA targeting CAR polypeptide comprises a CD28 hinge domain having the amino acid sequence of SEQ ID NO: 21: RAAIAEVMYPPPYLDNEKSNGTIHVKGKHLCPSPLFPGPSPKDPK. In certain specific aspects, the hinge domain comprises an amino acid sequence that is at least about 70%, at least about

75%, at least about 80%, at least about 85%, at least about 90%, at least about 91%, at least about 92%, at least about 93%, at least about 94%, at least about 95%, at least about 96%, at least about 97%, at least about 98%, or at least about 99% identical to SEQ ID NO: 21. In some embodiments, the CD28 hinge domain may be encoded by a nucleic acid sequence of SEQ ID NO: 37, or SEQ ID NO: 54.

[0112] In some embodiments, the hinge domain is derived from human CD28 hinge domain. As a non-limiting example, the hinge domain of the BCMA targeting CAR polypeptide comprises a CD28 hinge domain having the amino acid sequence of SEQ ID NO: 61: IEVMYPPPYLD-NEKSNGTIIHVKGKHLCPSPLFPGPSKP. In certain specific aspects, the hinge domain comprises an amino acid sequence that is at least about 70%, at least about 75%, at least about 80%, at least about 85%, at least about 90%, at least about 91%, at least about 92%, at least about 93%, at least about 94%, at least about 95%, at least about 96%, at least about 97%, at least 98%, or at least about 99% identical to SEQ ID NO: 61. In some embodiments, the CD28 hinge domain may be encoded by a nucleic acid sequence of SEQ ID NO: 62, or SEQ ID NO: 63.

[0113] Alternatively, and optionally, one or more hinge or spacer domains derived from other protein may be used. As used herein, the term “spacer domain” refers to the region that moves the antigen binding domain away from the effector cell surface to enable proper cell/cell contact, antigen binding and activation (Patel et al., *Gene Therapy*, 1999; 6: 412-419). The spacer domain may be derived either from a natural, synthetic, semi-synthetic, or recombinant source. For example, the hinge and spacer domains can be derived from a human IgG hinge domain, a CD8a hinge domain, or an Fc domain from a human immunoglobulin (e.g., IgG1, IgG2, IgG3, IgG4, IgA1, IgA2, IgM, IgD or IgE) that binds to an Fc receptor.

[0114] In some embodiments, the BCMA targeting CARs contemplated herein may comprise a modified hinge domain and/or spacer domain. The modified hinge domain and/or spacer domain may comprise up to 30% amino acid changes (e.g., up to 25%, 20%, 15%, 10%, or 5% amino acid substitutions or deletions), or a portion of a naturally occurring hinge region that is at least 10 amino acids (e.g., at least 12, 13, 14 or 15 amino acids) in length with up to 30% amino acid changes (e.g., up to 25%, 20%, 15%, 10%, or 5% amino acid substitutions or deletions), or a portion of a naturally occurring hinge region that comprises the core hinge region (which may be 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, or 15, or at least 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, or 15 amino acids in length).

3. Transmembrane Domain

[0115] In various embodiments, the extracellular antigen binding domain and the intracellular signaling domain of the BCMA targeting CAR of the present invention may be fused by a transmembrane domain. The transmembrane domain can also anchor the CAR to the plasma membrane of the immune effector cell. The transmembrane domain may be derived from any membrane-bound or transmembrane protein. The transmembrane domain may be derived from a natural, synthetic, semi-synthetic, or recombinant source. In some aspects, the amino acid sequence of the transmembrane domain may be modified or substituted so as to

minimize, e.g., interactions with the binding domains of the native binding partner present in the same CAR-expressing cell.

[0116] In some embodiments, the transmembrane domain of the BCMA targeting CAR of the present invention is derived from the transmembrane domain of human CD28. For example, the CD28 transmembrane domain of the BCMA targeting CAR polypeptide may comprise the amino acid sequence of SEQ ID NO: 22: FWVLVVVGGLVACYSLLVTVAIFIWV. In some aspects, for example, the transmembrane domain comprises a sequence at least 70%, at least about 75%, at least about 80%, at least about 85%, at least about 90%, at least about 91%, at least about 92%, at least about 93%, at least about 94%, at least about 95%, at least about 96%, at least about 97%, at least about 98%, or at least about 99% identical to SEQ ID NO: 22. In some embodiments, the CD28 transmembrane domain may be encoded by a nucleic acid sequence of SEQ ID NO: 38, or SEQ ID NO: 56.

[0117] Alternatively, the transmembrane domain of the CAR may include the transmembrane region(s) of the alpha, beta or zeta chain of the T-cell receptor, CD3 epsilon, CD45, CD4, CD5, CD8, CD9, CD16, CD22, CD33, CD37, CD64, CD80, CD86, CD134, CD137, CD154.

4. Cytoplasmic Domains

[0118] The cytoplasmic region of a CAR polypeptide includes an intracellular activation signaling domain. The intracellular signaling domain of the chimeric antigen receptor is responsible for activation of at least one of the normal effector functions of the immune cell engineered to express a chimeric antigen receptor. The term “effector function” in general refers to a specialized function of a differentiated cell. Effector function of an immune cell (e.g., NK cell or T cell) can be the cytolytic activity, cytotoxic activity or helper activity including the secretion of cytokines, to kill tumor cells. In this context, the term “intracellular signaling domain” refers to the portion of a protein that transduces the effector function signal and directs the cell to perform a specialized function. In some embodiments, the intracellular signaling domain is derived from the intracellular signaling domain of a native activating protein. Examples of such native activating proteins such as native receptors including the zeta chain of the T-cell receptor or any of its homologs (e.g., eta, delta, gamma, or epsilon), M B1 chain, B29, Fc RIII, Fc RI, signaling molecules such as CD3 ζ , CD28, CD27, 4-IBB, DAP10, OX 40, and other similar molecules. While usually the entire intracellular signaling domain will be employed, in many cases it will not be necessary to use the entire intracellular polypeptide. To the extent that a truncated portion of the intracellular signaling domain may find use, such truncated portion may be used in place of the intact chain as long as it still transduces the effector function signal. The term “intracellular signaling domain” is thus meant to include a truncated portion of the intracellular signaling domain sufficient to transduce the effector function signal, upon CAR binding to a target.

[0119] In one preferred embodiment, the human CD3 ζ intracellular signaling domain is used as the intracellular signaling domain for a BCMA targeting CAR polypeptide of the present invention. An example of the CD3 ζ intracellular signaling domain comprises the amino acid sequence of SEQ ID NO: 23.

(SEQ ID NO: 23)
 RVKFSRSADAPAYQQGQNQLYNELNLRREYDVLKRRGRDPEMGKP
 RRKNPQEGLYNELQKDKMAEAYSEIGMKGERRGKGDGLYQGLSTATK
 DTYDALHMQALPPR.

[0120] In certain specific aspects, the intracellular signaling domain comprises an amino acid sequence that is at least about 70%, at least about 75%, at least about 80%, at least about 85%, at least about 90%, at least about 91%, at least about 92%, at least about 93%, at least about 94%, at least about 95%, at least about 96%, at least about 97%, at least 98%, or at least about 99% identical to SEQ ID NO: 23. In some embodiments, the CD3(intracellular signaling domain may be encoded by a nucleic acid sequence of SEQ ID NO: 40, or SEQ ID NO: 58.

[0121] In some embodiments, the BCMA targeting CAR polypeptide may comprise one or more co-stimulatory signaling domains. An intracellular costimulatory signaling domain refers to the intracellular portion of a costimulatory molecule. The term “costimulatory molecule” refers to the cognate binding partner on an immune cell that specifically binds with a costimulatory ligand, thereby mediating a costimulatory response by the immune cell, such as, but not limited to, proliferation.

[0122] In some embodiments, the present BCMA targeting CAR polypeptide comprises a costimulatory domain derived from DAP10 (Hematopoietic cell signal transducer precursor (DNAX-activation protein 10)). An example of the DAP10 derived costimulatory domain comprises the amino acid sequence of LCARPRRSPAQEDGKVYINMPGRG (SEQ ID NO: 24). In certain aspects, the DAP10 costimulatory domain comprises an amino acid sequence that is at least about 70%, at least about 75%, at least about 80%, at least about 85%, at least about 90%, at least about 91%, at least about 92%, at least about 93%, at least about 94%, at least about 95%, at least about 96%, at least about 97%, at least 98%, or at least about 99% identical to SEQ ID NO: 24. In some embodiments, the DAP10 costimulatory domain may be encoded by a nucleic acid sequence of SEQ ID NO: 39, or SEQ ID NO: 57.

[0123] The costimulatory domain derived from CD28 may be utilized in the present BCMA targeting CAR polypeptide. An example of CD28 co-stimulatory domain comprises the amino acid sequence of SEQ ID NO: 64.

(SEQ ID NO: 64)
 RSKRSRLLHSYDMNMTPRPGPTRKHYQPYAPPDFAAQRS.

[0124] In addition to the DAP10 derived costimulatory domain and the CD3 ζ intracellular signaling domain, a BCMA targeting CAR polypeptide as described herein may comprise one or more costimulatory domains, and/or one or more intracellular activation signaling domains. The costimulatory domains and intracellular activation signaling domains may be derived from, e.g., an MHC class I molecule, TN F receptor proteins, Immunoglobulin-like proteins, cytokine receptors, integrins, signaling lymphocytic activation molecules (SLA M proteins), activating NK cell receptors, BTLA, Toll ligand receptor, OX-40, 4-1BB/CD137, CD2, CD7, CD27, CD28, CD30, CD40, programmed death-1 (PD-1), inducible T cell costimulator (ICOS), CDS gamma, CD3 delta, CD3 epsilon, CD247,

CD276 (B7-H3), LIGHT (tumor necrosis factor superfamily member 14; TNFSF1.4), NKG2C, 2B4, Ig alpha (CD79a), DAP12, Fc gamma receptor, MHC class I molecule, TN F receptor proteins, Immunoglobulin-like proteins, cytokine receptors, integrins, signaling lymphocytic activation molecules (SLA M proteins), activating NK cell receptors, BTLA, a Toll ligand receptor, ICAM-1, B7-H3, CDS, ICAM-1, GITR, BAFFR, LIGHT, HVEM (LIGHTR), KIRDS2, SLAM F7, NKp80 (KLRF1), NKp44, NKp30, NKp46, CD 19, CD4, CDSalpha, CDSbeta, 11.2 beta, IL2R gamma, IL7R alpha, ITGA4, VLA1, CD49a, ITGA4, IA4, CD49D, ITGA6, VLA-6, CD49f, ITGAD, ITGAE, CD103, ITGAL, LFA-1, ITGAM, ITGAX, ITGB1, CD29, ITGB2, ICOS, CD18, LFA-1, ITGB7, NKG2D, TNFR2, TRANCE RANKL, DNAM1(CD226), SLAMF4(CD244, 2B4), CD84, CD96(Tactile), CEA CAM 1, CRTAM, Ly9 (CD229), CD160 (BY 55), PSGLI, CD100 (SEMA4D), CD69, SLAM F6 (NTB-A, Ly108), BLAME (SLAM F8), SELPLG (CD 162), LTBR, LAT, GADS, SLP-76, PAG/Cbp, CD 19a, a ligand that specifically binds with CD83, or any combination thereof.

5. Other Components

[0125] In some embodiments, one or more other polypeptides and/or proteins may be incorporated into the BCMA targeting CAR constructs as described herein. The additional proteins and polypeptides may be utilized for any function, e.g., the activity of the CAR polypeptide and/or any cells expressing the CAR.

[0126] In some embodiments, the BCMA targeting CAR polypeptide as described herein may further comprise one or more cytokines. The CAR and the other protein(s) may be separated by a cleavable 2A sequence, for example.

[0127] In one exemplary embodiment, the cytokine IL-15 is incorporated into the BCMA targeting CAR construct. IL-15 is a proinflammatory cytokine, important for the differentiation and proliferation of T-cells, NK-cells, and the development of dendritic cells. An example of IL15 comprises the amino acid sequence of SEQ ID NO: 26.

(SEQ ID NO: 26)
 GIHVILGCFSAGLPKTEANWVNVISDLKKIEDLIQSMHIDATLYTESD
 VHPSCVKVTAMKCFLLQLVISLESGDASIHDTVENLIIILANNSSLSSGN
 VTESGCKCEEELEEKNIKEFLQSFVHIVQMFINTS

[0128] In some embodiments, the IL15 protein incorporated into the BCMA targeting CAR construct comprises an amino acid sequence that is at least about 70%, at least about 75%, at least about 80%, at least about 85%, at least about 90%, at least about 91%, at least about 92%, at least about 93%, at least about 94%, at least about 95%, at least about 96%, at least about 97%, at least 98%, or at least about 99% identical to SEQ ID NO: 26.

[0129] In one embodiment, the IL-15 peptide encoded by the nucleic acid sequence of SEQ ID NO: 52, or SEQ ID NO:53.

[0130] In some aspects, the CAR polypeptide and other proteins e.g., IL-15) in the same construct are intended to be produced into two different polypeptides, a cleavable 2A sequence may be utilized (e.g., T2A, F2A, and E2A). The 2A self-cleaving peptides (i.e., 2A peptides), are a class of 18-22 AA-long peptides, which can induce ribosomal skip-

ping during translation of a protein in a cell. These peptides share a core sequence motif of D×ExNPGP and are found in a wide range of viral families. They help generating polyproteins by causing the ribosome to fail at making a peptide bond. The members of 2A peptides are named after the virus in which they have been first described. For example, F2A, the first described 2A peptide, is derived from foot-and-mouth disease virus. The name "2A" itself comes from the gene numbering scheme of this virus.

[0131] In some embodiments, the cleavable peptide is E2A. As a non-limiting example, the E2A comprises the sequence of GPQCTNYALLKLAGDVESNPGP (SEQ ID NO: 27). In some embodiments, the cleavable peptide is positioned between the CAR polypeptide and IL-15.

[0132] The BCMA targeting CAR as described herein may further comprise a signal peptide. The signal peptide may comprise 3-30, 3-20, 3-15, 5-30, 5-20, 5-15, 10-30, 10-20, or 10-15 amino acid residues. An example of the signal peptide comprises the sequence of MEFGLSWLFLVAILKGVQC (SEQ ID NO: 28). An example of the signal peptide comprises the sequence of MRISKPHLRSISIQCYL-CLLLNSHFLTEA (SEQ ID NO: 59).

[0133] In one exemplary embodiment, the BCMA targeting CAR comprises a signal peptide, a BCMA binding domain, a hinge and a transmembrane domain, a DAP10 costimulatory domain and at least one intracellular signaling domain.

[0134] In another exemplary embodiment, the construct to express the BCMA targeting CAR comprises a signal peptide, an extracellular BCMA binding domain, a hinge and a transmembrane domain, a DAP10 costimulatory domain and at least one intracellular signaling domain and a cytokine.

[0135] In one exemplary embodiment, a suicide gene product such as caspase 9 (e.g., inducible caspase 9) is utilized in conjunction with the CAR.

[0136] Example caspase 9 amino acid sequence:

(SEQ ID NO: 14)
MLEGVQETISPQGDGRTPKRGQTCVVHYTGMLEDGKKVDSSRDRNKP
KFMLGKQEVRGWEEGVAQMSVGQRALKTISPDYAYGATGHPGIIPPPA
TLVFDVELLKLESGGSGVDGFVGVALESLRGNADLAYILSMEPCGHC
LIINNVNFCRESGLRTRTGSNDCEKLRRRFSSLHFMVEVKGDLTAKKM
VIALLELAQQDHGALDCVVVILSHGCQASHLQFPGAVYGTDGCPVSVE
KIVNIFNGTSCPSSLGGKPKLFFIQACCGEQKDHGFEVASTSPEDESPGS
NPEPDATPFQEQCLRFDQLDAISSLPTPSDIFVSYSTFPGFVSWRDPKS
GWSYVETLDDIFPEQWAHSEDLQSLLLRVANAVSVKGKIQKMPGCFNFLR
KKLFFKTSAS

[0137] Any polypeptide encompassed by the present disclosure may comprise SEQ ID NO:14 or an amino acid sequence that is at least 70%, 75%, 80%, 85%, 90%, 95%, 96%, 97%, 98%, 99%, or 100% identical to SEQ ID NO:14.

6. Linkers

[0138] The BCMA targeting CAR contemplated herein may comprise linker residues between the various domains. In some embodiments, the BCMA targeting CARs contemplated herein, may comprise one, two, three, four, or five or more linkers. In particular embodiments, the length of a

linker is about 1 to about 30 amino acids, about 1 to about 25 amino acids, about 5 to about 30 amino acids, about 5 to about 25 amino acids, about 5 to about 20 amino acids, or about 10 to about 20 amino acids, or any intervening length of amino acids. In some embodiments, the linker is 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30 or more amino acids in length. The ordinarily skilled artisan will recognize that design of a CAR in particular embodiments can include linkers that are all or partially flexible, such that the linker can include a flexible linker as well as one or more portions that confer less flexible structure to provide for a desired CAR structure.

[0139] In one exemplary embodiment, the BCMA targeting CAR polypeptide of the present invention comprises the amino acid sequence of SEQ ID NO: 29.

(SEQ ID NO: 29)
QITLRESGGDVVQPGRSLRLSCAASGFTESSYAIHWVRQAPGKGLEWVA
VTWHDGSNKYYAESVMGRFTISRDNSKNTLYLHMNSLRAEDTGVYYCAR
AKPGEQYFQHWGQGTLTVSSGGGGGGGGSDIVMTQSPLS
ASVGDRVTITCRASQGINNYLAWYQQKPGIAPKLIIYAASTLQSGVPSR
FGGSGSGTEFTLTISLOPEDFATYYCQQLKSYPFTFGPGTKVEIKRAA
AIEVMYPPYLDNEKSNGTIHVKGKHLCPSPLFPGPSKPKDPKFWVL
VVGGVLACYSLLVTVAIFIWFVLCARPRRSPAQEDGKVYINMPGRGRVK
FSRSADAPAYQQGQNQLYNELNLGRREYDVLVDKRRGDPEMGGKPRRK
NPQEGLYNELQKDCKMAEAYSEIGMKGERRGKGDGLYQGLSTATKDTY
DALHMQALPPR

[0140] In some embodiments, the BCMA targeting CAR polypeptide may comprise an amino acid sequence that is at least about 70%, at least about 75%, at least about 80%, at least about 85%, at least about 90%, at least about 91%, at least about 92%, at least about 93%, at least about 94%, at least about 95%, at least about 96%, at least about 97%, at least about 98%, or at least about 99% identical to SEQ ID NO: 29.

[0141] In one aspect of the present invention, a BCMA targeting CAR polypeptide includes, from N-terminal to C-terminal end:

[0142] Signal Sequence 1-BCMA binder-linker-CD28 (hinge)-linker-CD28(TM)-DAP10(costim)-CD3z-E2A-Signal sequence 2-sIL15.

[0143] In one exemplary embodiment, the BCMA targeting CAR polypeptide of the present invention comprises the amino acid sequence of SEQ ID NO: 13.

(SEQ ID NO: 13)
MEFGLSWLFLVAILKGVCQITLRESGGDVVQPGRSLRLSCAASGFTES
SYAIHWVRQAPGKGLEWVAVTWHDGSNKYYAESVMGRFTISRDNSKNTL
YLMNSLRAEDTGVYYCARAKPGEQYFQHWGQGTLTVSSGGGGGG
GSGGGSDIVMTQSPLSASVGDRVTITCRASQGINNYLAWYQQKPGI
APKLIYAASTLQSGVPSRFGSGSGTEFTLTISLQPEDFATYYCQQL
KSYPFTFGPGTKVEIKRAAAIEVMYPPYLDNEKSNGTIHVKGKHLCP

- continued

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SPLFPGPSKPKDPKFVLLVVGGVLACYSLVTVAFIIFWVLCARPRRS
PAQEDGKVYINMPGRGRVKFSRSADAPAYQQQNOLYNELNLGRREYD
VLDKRRGRDPEMGGKPRRKNPQEGLYNELQDKMAEAYSEIGMKGERRR
GKGHDGLYQGLSTATKDTYDALHMQLPPRGPQCTNYALLLAGDVESN
PGPMRISKPHLRSISIQCYLCLLLNSHFLTEAGIHVFILGCFSAGLPKT
EANWVNVISDLKKIEDLIQSMHIDATLYTESDVHPSCCKVTAMKCFLLEL
QVISLESGDASIHDTVENLIIANNSSLSSNGNVTESGCKECEELEEKNI
KEFLQSFVHVQMFINTS
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[0144] The BCMA targeting CAR polypeptide may comprise an amino acid sequence that is at least about 70%, at least about 75%, at least about 80%, at least about 85%, at least about 90%, at least about 91%, at least about 92%, at least about 93%, at least about 94%, at least about 95%, at least about 96%, at least about 97%, at least about 98%, or at least about 99% identical to SEQ ID NO: 13.

Polynucleotides Encoding BCMA Targeting CARs

[0145] In another aspect, the present invention provides nucleic acid molecules encoding one or more CAR polypeptides as described herein. As used herein, the terms “nucleic acid molecule” and “polynucleotide” are used interchangeably. In some embodiments, the nucleic acid molecule is provided as a messenger RNA (mRNA) molecule. In other embodiments, the nucleic acid molecule is provided as a DNA construct. In some aspects, the DNA construct is a non-viral vector such as a plasmid, a cosmid or an artificial chromosome. In other aspects, the DNA construct is a viral based vector such as AAV, lentivirus and retrovirus.

[0146] Accordingly, the present invention provides a polynucleotide encoding a BCMA targeting CAR polypeptide, wherein the CAR comprises an anti-BCMA binding domain (e.g., a human anti-BCMA binding domain), a hinge domain, a transmembrane domain, a DAP10 costimulatory domain and an intracellular signaling domain comprising a primary signaling domain of CD3 ζ . In some embodiments, the polynucleotide further comprises a nucleic acid sequence encoding one or more polypeptides that are incorporated into the CAR construct. For example, the polynucleotide further comprises a nucleic acid sequence encoding a cytokine such as IL-15. In some embodiments, the polynucleotide further comprises nucleic acid sequences for a single peptide and/or a linker sequence (e.g., E2A).

[0147] In some embodiments, the BCMA binding domain is an anti-BCMA binding domain described herein. In some examples, the BCMA binding domain is encoded by a nucleic acid sequence of any one of SEQ ID NOs: 30, 35-36 and 47-51. In some embodiments, the nucleic acid sequence encoding the BCMA binding domain of the CAR comprises a nucleic acid sequence that is at least about 70%, at least about 75%, at least about 80%, at least about 85%, at least about 90%, at least about 91%, at least about 92%, at least about 93%, at least about 94%, at least about 95%, at least about 96%, at least about 97%, at least about 98%, or at least about 99% identical to one of the sequences of SEQ ID NOs: 30, 35-36 and 47-51.

[0148] In some embodiments, the polynucleotide encoding the BCMA targeting CAR comprises the nucleic acid sequence of SEQ ID NO: 30 and the nucleic acid sequence of SEQ ID NO: 32.

[0149] In some embodiments, the polynucleotide encoding the BCMA targeting CAR comprises the nucleic acid sequence of SEQ ID NO: 30 and the nucleic acid sequence of SEQ ID NO: 49.

[0150] In some embodiments, the polynucleotide encoding the BCMA targeting CAR comprises the nucleic acid sequence of SEQ ID NO: 30 and the nucleic acid sequence of SEQ ID NO: 50.

[0151] In some embodiments, the polynucleotide encoding the BCMA targeting CAR comprises the nucleic acid sequence of SEQ ID NO: 32 and the nucleic acid sequence of SEQ ID NO: 47.

[0152] In some embodiments, the polynucleotide encoding the BCMA targeting CAR comprises the nucleic acid sequence of SEQ ID NO: 32 and the nucleic acid sequence of SEQ ID NO: 48.

[0153] In some embodiments, the polynucleotide encoding the BCMA targeting CAR comprises the nucleic acid sequence of SEQ ID NO: 47 and the nucleic acid sequence of SEQ ID NO: 49.

[0154] In some embodiments, the polynucleotide encoding the BCMA targeting CAR comprises the nucleic acid sequence of SEQ ID NO: 48 and the nucleic acid sequence of SEQ ID NO: 50.

[0155] An exemplary nucleic acid sequence encoding the BCMA binding domain comprises SEQ ID NO: 35, or a sequence that is about 70%, 75%, 80%, 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, or 99% identical to SEQ ID NO: 35.

[0156] An exemplary nucleic acid sequence encoding the BCMA binding domain comprises SEQ ID NO: 36, or a sequence that is about 70%, 75%, 80%, 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, or 99% identical to SEQ ID NO: 36.

[0157] The nucleic acid sequence encoding the BCMA binding domain may be codon optimized. In one embodiment, the codon-optimized nucleic acid sequence encoding the BCMA binding domain comprises SEQ ID NO: 51. In some embodiments, the codon-optimized nucleic acid sequence encoding the BCMA binding domain comprises a nucleic acid sequence about 75% identical to SEQ ID NO: 51. In some embodiments, the codon-optimized nucleic acid sequence encoding the BCMA binding domain comprises a nucleic acid sequence about 80% identical to SEQ ID NO: 51. In some embodiments, the codon-optimized nucleic acid sequence encoding the BCMA binding domain comprises a nucleic acid sequence about 85% identical to SEQ ID NO: 51. In some embodiments, the codon-optimized nucleic acid sequence encoding the BCMA binding domain comprises a nucleic acid sequence about 90% identical to SEQ ID NO: 51. In some embodiments, the codon-optimized nucleic acid sequence encoding the BCMA binding domain comprises a nucleic acid sequence about 91% identical to SEQ ID NO: 51. In some embodiments, the codon-optimized nucleic acid sequence encoding the BCMA binding domain comprises a nucleic acid sequence about 92% identical to SEQ ID NO: 51. In some embodiments, the codon-optimized nucleic acid sequence encoding the BCMA binding domain comprises a nucleic acid sequence about 93% identical to SEQ ID NO: 51. In some embodiments, the codon-optimized nucleic acid sequence encoding the BCMA binding domain comprises a nucleic acid sequence about 94% identical to SEQ ID NO: 51. In some embodiments, the codon-optimized nucleic acid sequence encoding the BCMA binding domain comprises a nucleic acid sequence about 95% identical to SEQ ID NO: 51. In some embodiments, the codon-optimized nucleic acid sequence encoding the BCMA binding domain comprises a nucleic acid sequence about 96% identical to SEQ ID NO: 51. In some embodiments, the codon-optimized nucleic acid sequence encoding the BCMA binding domain comprises a nucleic acid sequence about 97% identical to SEQ ID NO: 51. In some embodiments, the codon-optimized nucleic acid sequence encoding the BCMA binding domain comprises a nucleic acid sequence about 98% identical to SEQ ID NO: 51. In some embodiments, the codon-optimized nucleic acid sequence encoding the BCMA binding domain comprises a nucleic acid sequence about 99% identical to SEQ ID NO: 51.

sequence encoding the BCMA binding domain comprises a nucleic acid sequence about 94% identical to SEQ ID NO: 51. In some embodiments, the codon-optimized nucleic acid sequence encoding the BCMA binding domain comprises a nucleic acid sequence about 95% identical to SEQ ID NO: 51. In some embodiments, the codon-optimized nucleic acid sequence encoding the BCMA binding domain comprises a nucleic acid sequence about 96% identical to SEQ ID NO: 51. In some embodiments, the codon-optimized nucleic acid sequence encoding the BCMA binding domain comprises a nucleic acid sequence about 97% identical to SEQ ID NO: 51. In some embodiments, the codon-optimized nucleic acid sequence encoding the BCMA binding domain comprises a nucleic acid sequence about 98% identical to SEQ ID NO: 51. In some embodiments, the codon-optimized nucleic acid sequence encoding the BCMA binding domain comprises a nucleic acid sequence about 99% identical to SEQ ID NO: 51.

[0158] In another embodiment, the codon optimized nucleic acid sequence encoding the BCMA binding domain comprises SEQ ID NO: 35. In some embodiments, the codon-optimized nucleic acid sequence encoding the BCMA binding domain comprises a nucleic acid sequence about 75% identical to SEQ ID NO: 35. In some embodiments, the codon-optimized nucleic acid sequence encoding the BCMA binding domain comprises a nucleic acid sequence about 80% identical to SEQ ID NO: 35. In some embodiments, the codon-optimized nucleic acid sequence encoding the BCMA binding domain comprises a nucleic acid sequence about 85% identical to SEQ ID NO: 35. In

some embodiments, the codon-optimized nucleic acid sequence encoding the BCMA binding domain comprises a nucleic acid sequence about 90% identical to SEQ ID NO: 35. In some embodiments, the codon-optimized nucleic acid sequence encoding the BCMA binding domain comprises a nucleic acid sequence about 91% identical to SEQ ID NO: 35. In some embodiments, the codon-optimized nucleic acid sequence encoding the BCMA binding domain comprises a nucleic acid sequence about 92% identical to SEQ ID NO: 35. In some embodiments, the codon-optimized nucleic acid sequence encoding the BCMA binding domain comprises a nucleic acid sequence about 93% identical to SEQ ID NO: 35. In some embodiments, the codon-optimized nucleic acid sequence encoding the BCMA binding domain comprises a nucleic acid sequence about 94% identical to SEQ ID NO: 35. In some embodiments, the codon-optimized nucleic acid sequence encoding the BCMA binding domain comprises a nucleic acid sequence about 95% identical to SEQ ID NO: 35. In some embodiments, the codon-optimized nucleic acid sequence encoding the BCMA binding domain comprises a nucleic acid sequence about 96% identical to SEQ ID NO: 35. In some embodiments, the codon-optimized nucleic acid sequence encoding the BCMA binding domain comprises a nucleic acid sequence about 97% identical to SEQ ID NO: 35. In some embodiments, the codon-optimized nucleic acid sequence encoding the BCMA binding domain comprises a nucleic acid sequence about 98% identical to SEQ ID NO: 35. In some embodiments, the codon-optimized nucleic acid sequence encoding the BCMA binding domain comprises a nucleic acid sequence about 99% identical to SEQ ID NO: 35.

TABLE 1

Sequences of BCMA binding domains		
Ab#	Type	Sequence (5'-3')
VH	Amino acid	QITLRESGGDVVQPGRSRLSCAASGFTFSSYAIHWVRQAPGKGLEWVAVT WHDGSNKYYAESVMGRFTISRDNSKNTLYLHMNSLRAEDTGYYYCARAKF GEPQYFQHWGQGTLVTVSS (SEQ ID NO: 1)
	Nucleotide	cagatcacatttaaggggagagccggaggcgatgtggtcagccccggctgtttaagactgagctgtgccggccacgggctt caccttcagcagctacgcacactgggtgagacaagctcccgtaaagggttagagtgggtggctgtgacttggcag acggctccaacaagaatctatccgcgagacgcgtatgggtcgatccatctctcgtaaacacagcaagaacactttat ttacatcatgaactctttaaggggcaggacaccgggtgtactactgcgcagagccaaatccggcgagccccagactt ccagcactggggccaaaggactgtgacccgtgtccagg (SEQ ID NO: 30)
	Nucleotide	cagataactctgcgcgagtcaggaggacgtggcaaccgggagatctctcaggcttcatgtgccggcagtggctt cacat tagcttatgcataatcatgggtcaggcaggctctggcaagggttgcataatggtagcggttacctggcatg atggatcaacaataactacgcgcgactgttgcattatgggtcgatccatctcgagacaattcaaaaaacacactctac ctgcataatgcacttaggcaggacactgtgttactactgcgcagagccaaatccggcgagccacagatatt ccagcactggggacaaggaaacctctgttaacatgtatctatgcgcacccgttgcgcacatgtatctatgcgcac cagatcacccctggggagctggaggcgacgtggcagccgttgcaggactgagctgcgcgcctctgg attcaccttcagcagctacgcacactgggtcaggcaggctctggcaagggtactggactgtggccgttacctgg cagacggcagcaacaagaatactacgcgcgaggcgtatgggcagggttccatctcgaggacacagaacac cctgtacttcgcacatgcacttgcaggggcaggacacaggcgtgtactactgcgcacccgttgcgcac cagttttccagcactggggcaggaaacctctgtgacccgttgc (SEQ ID NO: 48)
	Nucleotide	DIVMTQSPLSASVGDRTVITCRASQGINNYLAWYQQKPGIAPKLILYAAST LQSGVPSRFGSGSGTEFTLTISSLQPEDFATYYCQQLKSYPFTFGPGTKVEIK (SEQ ID NO: 5)
VL	Amino acid	gacatcgtatgaccaggccctagcttttaagccgcaggcgatggcgcacaggactgaccatcacttgcgtgccagcc aggatatcaacaactattatgcgttgcaccaggcagaagcccgatcgcgcgcacac tgcagacggcgtgcctagcaggatgggtggcaggcgcttgcgcacaggacttgcgtatcgcgcgcac gaggacttcgcacactactgcgcaggcgttgcgcacaggacttgcgcac g (SEQ ID NO: 32)
	Nucleotide	gatattgttatgacccaaattccatcttttgcggcgttgcgtggcgcacagggttacaatcacatgcgc agccaaaggaaatcaacaattatctcgcatgttgcacaaaaccaggatcgcgc gcataaccctgcggaggatgggttttagatgggtggcaggcgctccggact cctcccttcaccccaagatccgcacatattactgcgcaggcgttgc aactaaaggatcaaa (SEQ ID NO: 49)
	Nucleotide	

TABLE 1-continued

[0159] In some embodiments, the polynucleotide encoding a BCMA targeting CAR polypeptides comprises a nucleic acid sequence that encodes a DAP10 costimulatory domain having the sequence of SEQ ID NO: 24. In some embodiments, the nucleic acid sequence encoding the DAP10 costimulatory domain is codon optimized. As a non-limiting example, the codon-optimized DAP10 costimulatory domain encoding sequence comprises the sequence of SEQ ID NO: 57. In some embodiments, the nucleic acid sequence encoding the DAP10 costimulatory domain comprises the sequence of SEQ ID NO: 39.

[0160] In some embodiments, the polynucleotide encoding a BCMA targeting CAR polypeptide comprises a nucleic acid sequence that encodes a CD28 hinge domain having the sequence of SEQ ID NO: 21. In other embodiments, the

nucleic acid sequence encoding the CD 28 hinge domain is codon optimized. As a non-limiting example, the codon-optimized CD28 hinge domain encoding sequence comprises the sequence of SEQ ID NO: 37, or SEQ ID NO: 54. In other embodiments, the polynucleotide encoding a BCMA targeting CAR polypeptide comprises a nucleic acid sequence encoding a CD28 hinge domain having the sequence of SEQ ID NO: 61; the nucleic acid sequence encoding the CD28 hinge domain is codon optimized. As a non-limiting example, the codon-optimized CD28 hinge domain coding sequence comprises the sequence of SEQ ID NO:62, or SEQ ID NO: 63.

[0161] An exemplary nucleic acid sequence for each of other components of the present BCMA targeting CAR is included in Table 2.

TABLE 2

Exemplary nucleic acid sequences of components of a BCMA targeting CAR	
Component	Sequence (5'-3')
1 st Signal peptide	atggattcggtgtctggcttttctggtcgcatttcggccatgt (SEQ ID NO: 33)
CD28 hinge	atggagttcggtgttcggctgtggctctggccatcttgcggccatgt (SEQ ID NO: 34)
	atcgaaggatgtatcttcccttccatggacaataggaaaccattatcatgtgaaaggaaac accttttgtcaatcccatttcccqacccatctaaqccc (SEQ ID NO: 31)

TABLE 2-continued

[0162] An exemplary polynucleotide that encodes a BCMA targeting CAR comprising a DAP10 derived costimulatory domain comprises the nucleic acid sequence presented by SEQ ID NO: 44. In some embodiments, the polynucleotide encoding the BCMA targeting CAR polypeptide may comprise a nucleic acid sequence at least 75% identical to SEQ ID NO: 44. In some embodiments, the polynucleotide encoding the BCMA targeting CAR polypeptide may comprise a nucleic acid sequence at least 80%

identical to SEQ ID NO: 44. In some embodiments, the polynucleotide encoding the BCMA targeting CAR poly-peptide may comprise a nucleic acid sequence at least 85% identical to SEQ ID NO: 44. In some embodiments, the polynucleotide encoding the BCMA targeting CAR poly-peptide may comprise a nucleic acid sequence at least 90% identical to SEQ ID NO: 44. In some embodiments, the polynucleotide encoding the BCMA targeting CAR poly-peptide may comprise a nucleic acid sequence at least 91%

polynucleotide encoding the BCMA targeting CAR polypeptide may comprise a nucleic acid sequence at least 92% identical to SEQ ID NO: 55. In some embodiments, the polynucleotide encoding the BCMA targeting CAR polypeptide may comprise a nucleic acid sequence at least 93% identical to SEQ ID NO: 55. In some embodiments, the polynucleotide encoding the BCMA targeting CAR polypeptide may comprise a nucleic acid sequence at least 94% identical to SEQ ID NO: 55. In some embodiments, the polynucleotide encoding the BCMA targeting CAR polypeptide may comprise a nucleic acid sequence at least 95% identical to SEQ ID NO: 55. In some embodiments, the

polynucleotide encoding the BCMA targeting CAR polypeptide may comprise a nucleic acid sequence at least 96% identical to SEQ ID NO: 55. In some embodiments, the polynucleotide encoding the BCMA targeting CAR polypeptide may comprise a nucleic acid sequence at least 97% identical to SEQ ID NO: 55. In some embodiments, the polynucleotide encoding the BCMA targeting CAR polypeptide may comprise a nucleic acid sequence at least 98% identical to SEQ ID NO: 55. In some embodiments, the polynucleotide encoding the BCMA targeting CAR polypeptide may comprise a nucleic acid sequence at least 99% identical to SEQ ID NO: 55.

TABLE 3

TABLE 3-continued

Exemplary nucleic acid sequences encoding the BCMA targeting DAP10 CAR polypeptide

tggccaacaacagcctgagcagcaacgggaacgtgaccgagtcggctgcagaaggagtgcgaggagctggaggagaagaacatca
aggagttcctgcagtcctcgtcagatgttcatcaacaccagct (SEQ ID NO: 25)

atggaattcggctgtctgggtttttcgcaattttaaggcgctccatgtcagataactctgcgcgagtcaggaggagacgtgg
tgcaaccggcgacatcttcagggcttcatgtgcgcgcagtgccatcacatttagtgcataatcattgggtcaggcaggctctggc
aagggttggatgggtacgggtatctggcatgtggatcaacaatactacgcgcgagtcgttatgggtcattcacaatttcgcag
acaatttcaaaaaacacatctacatgcataatgcacttgcggagggactgtgttattactgcgcgcagacaaatttcgcg
agccccacgtatcccgcactggggacaaggaaacctctgtacacgtatctgtggggcgaggggtctggaggagggggggcg
ggaggcgctctgtatattgttgcaccaatcaccatcttgcagcgctatgtgcggcagacagggttacaatcacaatgcgcg
caaggatcaacaatcttcgcatgttgcaccaatcacaacaaaacccaggatgcgcggcggactgtatcttgcgcacatattact
gagttccttcgcatgttgcgcggcggactgtatcttgcgcacatccatgcgcacatcaaccctgcgcgg
ccacgc
cttaccttagacaatgagaagagacaatggaaaccattatccatgtgaaaggaaacaccttgcgcgcgcgcgcgcgcgc
gc
gtgc
agcaggaggcgacgc
atgtttggacaaaagacgtgtgcgcggaccctcgatgtggggaaagccgagaaggaacccctcggcgcgcgcgcgc
ctgcagaaagataagatggcgaggcctacagtgc
accagggtctcgc
tgctcttcgttgcatttgc
gc
aagaccgcggcacaactgggtgaaacgtgcgcgcgcgcgcgcgcgcgcgcgcgcgcgcgcgc
gtacacccgc
cggc
agcggc
acaccagctga (SEQ ID NO: 55)

[0167] In some embodiments, the polynucleotide comprises at least one modified nucleotide. In other embodiments, the polynucleotide comprises unmodified nucleotides only.

[0168] The polynucleotide encoding the CAR polypeptide of the present invention can be obtained using recombinant methods known in the art, for example by screening libraries from cells expressing the CAR construct, by deriving the CAR construct from a vector known to include the same, or by isolating directly from cells and tissues containing the same, using standard techniques. Alternatively, the polynucleotide can be produced synthetically in vitro.

[0169] In alternative embodiments, the polynucleotide sequence encoding various components of a BCMA targeting CAR can be disposed on the different nucleic acid molecules, e.g., different plasmids or vectors, e.g., viral vector, e.g., lentiviral vector. For example, the (i) sequence encoding an antigen binding domain can be present on a first nucleic acid, e.g., a first vector, and the (ii) sequence encoding an intracellular signaling domain can be present on the second nucleic acid, e.g., the second vector.

[0170] In some embodiments, the polynucleotide encoding the present CAR is a mRNA molecule. The mRNA may further comprise a poly (A) sequence, e.g., a sequence encompassing 50-5000, 100-5000, 50-2000, 100-2000, 50-1000, or 100-1000 adenines.

Cells

[0171] In one aspect, the invention provides a cell genetically engineered to express a BCMA targeting CAR polypeptide described herein. The cell may be a stem cell or an immune effector cell, or mixture thereof. An “immune effector cell,” is any cell of the immune system that has one or more effector functions (e.g., cytotoxic cell killing activity, secretion of cytokines, induction of AD CC and/or CDC). Specific immune cells include but are not limited to,

natural killer (NK) cell, T cell, gamma delta T cell, alpha beta T cell, invariant NKT (iNKT) cell, B cell, macrophage, mesenchymal stromal cell, dendritic cell, or a mixture thereof. In one embodiment, the immune effector cell is T cell. In another embodiment, the immune effector cell is NK cell.

[0172] As used herein, the term “genetically engineered” or “genetically modified” refers to the addition of extra genetic material in the form of DNA or RNA, such as DNA or RNA encoding a BCMA targeting CAR polypeptide of the present invention, into the total genetic material in a cell. The terms, “genetically modified cells,” “modified cells,” and “cells that are genetically engineered or modified to express,” are used interchangeably.

[0173] In some embodiments, the immune effector cell (e.g., T cell or NK cell) is transformed with the polynucleotide encoding the CAR construct and the CAR is expressed on the cell surface. The CART cell or CAR-NK cell exhibits an antitumor property.

[0174] Methods for making the immune effector cells that express a CAR contemplated herein are provided. In one embodiment, the method comprises transfecting or transducing immune effector cells isolated from an individual such that the immune effector cells express one or more CARs contemplated herein. In certain embodiments, the immune effector cells are isolated from an individual and genetically modified without further manipulation in vitro. Such cells can then be directly readministered into the individual. In further embodiments, the immune effector cells are first activated and stimulated to proliferate in vitro prior to being genetically modified to express a CAR. In this regard, the immune effector cells may be cultured before and/or after being genetically modified (i.e., transduced or transfected to express a BCMA targeting CAR contemplated herein).

[0175] For example, the immune effector cell (e.g., T cell or NK cell) is transduced with a viral vector encoding a BCMA targeting CAR polypeptide of the present invention. The viral vector is a retroviral vector, such as a lentiviral

vector and an AAV vector. In other examples, the immune effector cell (e.g., T cell or NK cell) is transfected with a nucleic acid molecule, e.g., mRNA, cDNA, DNA, encoding a BCMA targeting CAR polypeptide of the present invention.

Sources of Cells

[0176] In accordance with the present invention, the immune effector cells (e.g., T cells and NK cells) are obtained from a subject for expansion and genetic modification to express the CAR polypeptide of the present invention.

[0177] Immune effector cells can be autologous/autogeneic ("self") or non-autologous ("non-self", e.g., allogeneic, syngeneic or xenogeneic). "Autologous", as used herein, refers to cells from the same subject. "Allogeneic", as used herein, refers to cells of the same species that differ genetically to the cell in comparison. "Syngeneic", as used herein, refers to cells of a different subject that are genetically identical to the cell in comparison. "Xenogeneic", as used herein, refers to cells of a different species to the cell in comparison. In preferred embodiments, the cells are autologous.

[0178] In some embodiments, immune effector cells engineered to expressing a BCMA targeting CAR contemplated herein are T cells (also called T lymphocytes). T cells can be immature T cells, mature T cells, resting T cells, or activated T cells, T helper (Th) cells (e.g., T helper 1 (Th1) or T helper 2 (Th2) cells), or any other subset of T cells. Other illustrative populations of T cells suitable for use in particular embodiments include naive T cells (TN), T memory stem cells (TSCM), central memory T cells (TCM), effector memory T cells (TEM), and effector T cells (TEFF). T cells can be obtained from a number of sources, including peripheral blood mononuclear cells, bone marrow, lymph node tissue, cord blood, thymus tissue, tissue from a site of infection, ascites, pleural effusion, and spleen tissue. In some embodiments, T cells can be obtained from a unit of blood collected from a subject using any number of techniques known to the skilled artisan. For example, T cells are isolated from peripheral blood lymphocytes by lysing the red blood cells and depleting the monocytes.

[0179] In some embodiments, immune effector cells include NK cells. NK cells may be derived from cord blood, peripheral blood, induced pluripotent stem cells, hematopoietic stem cells, bone marrow. The NK cell may be derived from a cord blood mononuclear cell. The NK cell may be a CD56+ NK cell.

[0180] In some embodiments, any immune effector cell (e.g., T cell or NK cell) lines available in the art, may be used. For example, NK cells may be derived from the NK-92 cell line.

[0181] In some embodiments, cells transduced with a polynucleotide encoding the BCMA targeting CAR as described herein are expanded. In some embodiments, the cells are expanded in culture for a period of several hours (e.g., about 2, 3, 4, 5, 6, 7, 8, 9, 10, 15, 18, 21 hours) to about 14 days (e.g., 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13 or 14 days).

[0182] In some embodiments, the cells are expanded in an appropriate media that includes one or more interleukin that result in at least a 100 fold, at least a 150 fold, at least a 200-fold (e.g., 200-fold, 250-fold, 300-fold, 350-fold)

increase in cells over a 14 day expansion period, e.g., as measured by a method such as flow cytometry.

[0183] In some embodiments, a population of modified immune effector cells for the treatment of cancer comprises a BCMA targeting CAR contemplated herein. For example, a population of modified immune effector cells are a population of T cells and/or a population of NK cells.

Pharmaceutical Compositions and Formulations

[0184] In accordance with the present invention, compositions comprising BCMA targeting CARs, nucleic acid molecules encoding the same, cells expressing BCMA targeting CARs are provided. The compositions contemplated herein may comprise one or more BCMA targeting CAR polypeptides, polynucleotides, vectors comprising same, or genetically modified immune effector cells, etc., as contemplated herein. Compositions include, but are not limited to pharmaceutical compositions. The preparation of a pharmaceutical composition that comprises the compositions will be known to those of skill in the art in light of the present disclosure. In preferred embodiments, a composition comprises one or more cells modified to express one or more BCMA targeting CAR polypeptides as described herein. In some embodiments, pharmaceutical compositions comprising an effective amount of cells, compositions comprising immune effector cells (e.g., NK cells) as described herein are provided. In some embodiments, a pharmaceutical composition comprises a pharmaceutically acceptable carrier, diluent or excipient and cells expressing a BCMA targeting CAR polypeptide as contemplated herein.

[0185] The pharmaceutically acceptable carrier, diluent or excipient includes without limitation any adjuvant, carrier, excipient, glidant, sweetening agent, diluent, preservative, dye/colorant, flavor enhancer, surfactant, wetting agent, dispersing agent, suspending agent, stabilizer, isotonic agent, solvent, surfactant, or emulsifier which has been approved by the United States Food and Drug Administration as being acceptable for use in humans or domestic animals. Exemplary pharmaceutically acceptable carriers include, but are not limited to, to sugars, such as lactose, glucose and sucrose; starches, such as corn starch and potato starch; cellulose, and its derivatives, such as sodium carboxymethyl cellulose, ethyl cellulose and cellulose acetate; tragacanth; malt; gelatin; talc; cocoa butter, waxes, animal and vegetable fats, paraffins, silicones, bentonites, silicic acid, zinc oxide; oils, such as peanut oil, cottonseed oil, safflower oil, sesame oil, olive oil, corn oil and soybean oil; glycols, such as propylene glycol; polyols, such as glycerin, sorbitol, mannitol and polyethylene glycol; esters, such as ethyl oleate and ethyl laurate; agar; buffering agents, such as magnesium hydroxide and aluminum hydroxide; alginic acid; pyrogen-free water; isotonic saline; Ringer's solution; ethyl alcohol; phosphate buffer solutions; and any other compatible substances employed in pharmaceutical formulations.

[0186] In particular embodiments, pharmaceutical compositions comprise an effective amount of CAR-expressing immune effector cells contemplated herein. As used herein, the term "an effective amount" refers to an amount effective of a genetically modified therapeutic cell, e.g., NK cell, to achieve a beneficial or desired prophylactic or therapeutic result, including clinical results (e.g., anti-cancer).

[0187] Pharmaceutical compositions comprising an immune effector cell population modified to express a BCMA targeting CAR of the present invention (e.g., NK

cells) may comprise buffers such as neutral buffered saline, phosphate buffered saline and the like; carbohydrates such as glucose, mannose, sucrose or dextrans, mannitol; proteins; polypeptides or amino acids such as glycine; antioxidants; chelating agents such as EDTA or glutathione; adjuvants (e.g., aluminum hydroxide); and preservatives. Compositions are preferably formulated for parenteral administration, e.g., intravascular (intravenous or intraarterial), intraperitoneal or intramuscular administration.

[0188] The compositions may be liquid compositions. The liquid pharmaceutical compositions, whether they be solutions, suspensions or other like form, may include one or more of the following: sterile diluents such as water for injection, saline solution, preferably physiological saline, Ringer's solution, isotonic sodium chloride, fixed oils such as synthetic mono or diglycerides which may serve as the solvent or suspending medium, polyethylene glycols, glycerin, propylene glycol or other solvents; antibacterial agents such as benzyl alcohol or methyl paraben; antioxidants such as ascorbic acid or sodium bisulfite; chelating agents such as ethylenediaminetetraacetic acid; buffers such as acetates, citrates or phosphates and agents for the adjustment of tonicity such as sodium chloride or dextrose. The parenteral preparation can be enclosed in ampoules, disposable syringes or multiple dose vials made of glass or plastic. A n injectable pharmaceutical composition is preferably sterile.

[0189] In some embodiments, the immune effector cells (e.g., NK cells) discussed herein, and compositions contemplated herein are formulated in a pharmaceutically acceptable cell culture medium. Such compositions are suitable for administration to human subjects. In particular embodiments, the pharmaceutically acceptable cell culture medium is a serum free medium. Serum-free medium has several advantages over serum containing medium, including a simplified and better-defined composition, a reduced degree of contaminants, elimination of a potential source of infectious agents, and lower cost. In various embodiments, the serum-free medium is animal-free, and may optionally be protein-free. Optionally, the medium may contain biopharmaceutically acceptable recombinant proteins. "Animal-free" medium refers to medium wherein the components are derived from non-animal sources. Recombinant proteins replace native animal proteins in animal-free medium and the nutrients are obtained from synthetic, plant or microbial sources. "Protein-free" medium, in contrast, is defined as substantially free of protein.

[0190] In other embodiments, compositions comprising immune effector cells as described herein are formulated in a solution comprising a cryopreservation medium. For example, cryopreservation media with cryopreservation agents may be used to maintain a high cell viability outcome post-thaw. For example, compositions comprising immune effector cells as described herein may be cryopreserved in a medium discussed in the PCT application publication WO2022173866A1(the contents of which are incorporated herein by reference in their entirety). In some embodiments, the cryopreservation medium comprises a non-pyrogenic and isotonic crystalloid solution, a disaccharide, a cryoprotectant and an albumin. In some embodiments, the non-pyrogenic and isotonic crystalloid solution is present at a concentration of 25% v/v to 50% v/v. In some embodiments, the non-pyrogenic and isotonic crystalloid solution is present at a concentration of about 25%, 30%, 35%, 40%, 45%,

or 50%. In some embodiments, the non-pyrogenic and isotonic crystalloid solution is present at a concentration of 30% v/v to 40% v/v.

[0191] In some embodiments, the non-pyrogenic and isotonic crystalloid solution is present at a concentration of 37.1% v/v, 37.3% v/v, 37.5% v/v, 37.7% v/v, or 37.9% v/v.

[0192] In some embodiments, the non-pyrogenic and isotonic crystalloid solution is present at a concentration of 37.7% v/v.

[0193] In some embodiments, the non-pyrogenic and isotonic crystalloid solution is present at a concentration of 38.0% v/v, 38.2% v/v, 38.4% v/v, 38.6% v/v, 38.8% v/v, or 39.0% v/v.

[0194] In some embodiments, the non-pyrogenic and isotonic crystalloid solution is present at a concentration of 38.6% v/v.

[0195] In some embodiments, the disaccharide is selected from the group consisting of sucrose, lactose, maltose, trehalose, cellobiose, and chitobiose. Accordingly, in some embodiments, the disaccharide is sucrose. In some embodiments, the disaccharide is lactose. In some embodiments, the disaccharide is maltose. In some embodiments, the disaccharide is trehalose. In some embodiments, the disaccharide is cellobiose. In some embodiments, the disaccharide is chitobiose.

[0196] In some embodiments, a cryopreservation medium provided herein comprises one or more of sodium chloride, potassium chloride, magnesium chloride hexahydrate, sodium acetate trihydrate, sodium gluconate, adenosine, dextran-40, lactobionic acid, HEPES, sodium hydroxide, L-glutathione, potassium chloride, potassium bicarbonate; potassium phosphate, dextrose, sucrose, mannitol, calcium chloride dihydrate, magnesium chloride, sodium hydroxide, potassium hydroxide, DMSO, human serum albumin and trehalose.

[0197] In some embodiments, a cryopreservation medium provided herein comprises about 2.35% w/v human serum albumin (HSA). In some embodiments, the cryopreservation medium comprises between about 2.0% w/v and 5.0% w/v human serum albumin (HSA). In some embodiments, the cryopreservation medium comprises between about 2.0% w/v and 3.0% w/v human serum albumin (HSA). In some embodiments, a cryopreservation medium provided herein comprises about 1% v/v to 10% v/v human serum albumin (HSA). In some embodiments, a cryopreservation medium provided herein comprises about 5% v/v to 10% v/v human serum albumin (HSA). In some embodiments, the cryopreservation medium comprises 9.4% v/v human serum albumin.

[0198] In some embodiments, the cryopreservation medium comprises between about 10 mM-100 mM trehalose. In some embodiments, the cryopreservation medium comprises between about 10 mM-50 mM trehalose. In some embodiments, the cryopreservation medium comprises between about 20 mM-40 mM trehalose. In some embodiments, the cryopreservation medium comprises about 30 mM trehalose.

[0199] In some embodiments, a cryopreservation medium is provided comprising: human serum albumin (HSA), sodium chloride, sodium gluconate, sodium acetate trihydrate, potassium chloride, magnesium chloride, dimethyl sulfoxide (DMSO), and a trehalose.

[0200] In some embodiments, a cryopreservation medium is provided, the medium comprising: a non-pyrogenic and

isotonic crystalloid solution, a cryoprotectant, an albumin, and a disaccharide. In some embodiments, a cryopreservation medium is provided, the medium comprising: PLASM A-LYTE A, a cryoprotectant, human serum albumin (HSA), and trehalose. In some embodiments, the cryoprotectant is DMSO. In some embodiments, a cryopreservation medium is provided, the medium comprising 37.7% PLA SM A-LYTE A, 50% DMSO, 2.35% w/v HSA and 30 mM trehalose.

[0201] In some embodiments, the effector cells modified to express a BCMA targeting CAR polypeptide described herein are formulated in a balanced crystalloid solution such as Plasma-Lyte. In some embodiments, the effector cells are formulated in Plasma-Lyte A. In some embodiments, the concentration of Plasma-Lyte A is 20-60%. In some embodiments, the concentration of Plasma-Lyte A is 40%. In some embodiments, the effector cells are further formulated in a stabilizing agent such as serum albumin. In exemplary embodiments, the serum albumin is human serum albumin (HSA) at a concentration of 5% to 20%. In some embodiments, the concentration of HSA is 10%. In some embodiments, the effector cells are further formulated in a stabilizing agent such as trehalose. In exemplary embodiments, the concentration of trehalose is 5 mM to 50 mM. In some embodiments, the concentration of trehalose is 30 mM. In some embodiments, the effector cells are formulated in a cryofreezing medium. In some embodiments, the cryofreezing medium is CS10. In some embodiments, the concentration of CS10 is 40% to 60%. In some embodiments, the concentration of CS10 is 50%.

[0202] As a non-limiting example, the cryofreezing medium is composed of 50% CS10, 40% (v/v) Plasma-LyteA, 10% HSA and 30 mM Trehalose dihydrate.

[0203] In some embodiments, compositions comprise an effective amount of immune effector cells modified to express a BCMA targeting CAR polypeptide described herein, alone or in combination with one or more therapeutic agents. Thus, the CAR-expressing immune effector cell compositions may be administered alone or in combination with other known cancer treatments, such as radiation therapy, chemotherapy, transplantation, immunotherapy, hormone therapy, photodynamic therapy, etc.

Packages and Kits

[0204] Any of the compositions described herein may be comprised in a package and/or a kit for clinical use. In a non-limiting example, cells, reagents to produce cells, vectors, and reagents to produce vectors and/or components thereof may be comprised in a kit. In certain embodiments, NK cells may be comprised in a kit, and they may or may not yet express a BCMA targeting CAR comprising a DAP10 costimulatory domain, an optional cytokine, or an optional suicide gene. Such a kit may or may not have one or more reagents for manipulation of cells. Such reagents include small molecules, proteins, nucleic acids, antibodies, buffers, primers, nucleotides, salts, and/or a combination thereof, for example. Nucleotides that encode one or more CARs, suicide gene products, and/or cytokines may be included in the kit. Proteins, such as cytokines or antibodies, including monoclonal antibodies, may be included in the kit. Nucleotides that encode components of engineered CAR receptors may be included in the kit, including reagents to generate same

Methods of Use

[0205] In another aspect of the present invention, methods, among other things, of use of BCMA targeting CARs, cells and compositions comprising the same are provided.

[0206] The BCMA targeting CARs, and genetically modified immune effector cells expressing a BCMA targeting CAR contemplated herein provide improved methods of adoptive immunotherapy for use in the prevention, treatment, and amelioration of B cell related conditions. The BCMA targeting CARs, and genetically modified immune effector cells expressing a BCMA targeting CAR described herein, provide improved methods of immunotherapy for use in increasing the cytotoxicity in cancer cells in a subject or for use in decreasing the number of cancer cells in a subject.

[0207] In some embodiments, a type of cellular therapy where T cells or NK cells are genetically modified to express the present CAR polypeptide that targets BCMA expressing cancer cells, and the T cells and/or the NK cells are infused to a recipient in need thereof is provided. The infused cell is able to kill disease causing cells, e.g., tumor cells, in the recipient. T cells and NK cells that express the present BCMA targeting CAR can undergo robust *in vivo* cell expansion and can persist for an extended amount of time.

[0208] In some embodiments, methods of treating a cancer such as a BCMA associated cancer in a subject in need are provided; the methods involve in administering to the subject in need a therapeutically effective amount of compositions as described in the present disclosure. The therapeutically effective amount of the composition comprising a genetically modified therapeutic cell may vary according to factors such as the disease state, age, sex, and weight of the individual, and the ability of the stem and progenitor cells to elicit a desired response in the individual. A therapeutically effective amount is also one in which any toxic or detrimental effects of the virus or transduced therapeutic cells are outweighed by the therapeutically beneficial effects.

[0209] In accordance with the present invention, it can generally be stated that a pharmaceutical composition comprising the immune effector cells (e.g., NK cells) contemplated herein may be administered at a dosage of 10^4 to 10^{10} cells/kg body weight, or 10^6 to 10^8 cells/kg body weight, preferably 10^5 to 10^6 cells/kg body weight, including all integer values within those ranges. For example, in some embodiments, the pharmaceutical composition comprising the NK cells may be administered at a dosage of 1×10^8 cells. In some embodiments, the pharmaceutical composition comprising the NK cells may be administered at a dosage of 2×10^8 cells. In some embodiments, the pharmaceutical composition comprising the NK cells may be administered at a dosage of 3×10^8 cells. In some embodiments, the pharmaceutical composition comprising the NK cells may be administered at a dosage of 4×10^8 cells. In some embodiments, the pharmaceutical composition comprising the NK cells may be administered at a dosage of 5×10^8 cells. In some embodiments, the pharmaceutical composition comprising the NK cells may be administered at a dosage of 6×10^8 cells. In some embodiments, the pharmaceutical composition comprising the NK cells may be administered at a dosage of 7×10^8 cells. In some embodiments, the pharmaceutical composition comprising the NK cells may be administered at a dosage of 8×10^8 cells. In some embodiments, the pharmaceutical composition comprising the NK cells may be administered at a dosage of 9×10^8 cells. In

some embodiments, the pharmaceutical composition comprising the NK cells may be administered at a dosage of 1.0×10^9 cells. In some embodiments, the pharmaceutical composition comprising the NK cells may be administered at a dosage of 1.1×10^9 cells. In some embodiments, the pharmaceutical composition comprising the NK cells may be administered at a dosage of 1.2×10^9 cells. In some embodiments, the pharmaceutical composition comprising the NK cells may be administered at a dosage of 1.3×10^9 cells. In some embodiments, the pharmaceutical composition comprising the NK cells may be administered at a dosage of 1.4×10^9 cells. In some embodiments, the pharmaceutical composition comprising the NK cells may be administered at a dosage of 1.5×10^9 cells. In some embodiments, the pharmaceutical composition comprising the NK cells may be administered at a dosage of 1.6×10^9 cells. In some embodiments, the pharmaceutical composition comprising the NK cells may be administered at a dosage of 1.7×10^9 cells. In some embodiments, the pharmaceutical composition comprising the NK cells may be administered at a dosage of 1.8×10^9 cells. In some embodiments, the pharmaceutical composition comprising the NK cells may be administered at a dosage of 1.9×10^9 cells. In some embodiments, the pharmaceutical composition comprising the NK cells may be administered at a dosage of 2.0×10^9 cells. The number of cells will depend upon the ultimate use for which the composition is intended as will the type of cells included therein. For uses provided herein, the cells are generally in a volume of a liter or less, 950 mL or less, 900 mL or less, 850 mL or less, 800 mL or less, 750 mL or less, 700 mL or less, 650 mL or less, 600 mL or less, 500 mL or less, even 250 mL or 100 mL or less. Hence the density of the desired cells is typically greater than 10^6 cells/ml and generally is greater than 10^7 cells/ml, generally 10^8 cells/ml, generally 10^9 or greater. The clinically relevant number of immune cells can be apportioned into multiple infusions that cumulatively equal or exceed 10^5 , 10^6 , 10^7 , 10^8 , 10^9 , 10^{10} , 10^{11} , or 10^{12} cells. In some aspects, particularly since all the infused cells will be redirected to a particular target antigen, lower numbers of cells, in the range of 10^6 - 10^9 /kilogram (e.g., about 6×10^7 - 6×10^{10} per patient) may be administered. Compositions may be administered multiple times at dosages within these ranges.

[0210] In some embodiments, the immune effector cells, e.g., T cells that express a BCMA targeting CAR of the present invention, are administered to a subject in need at a dose of at least 0.1×10^5 cells, at least 0.5×10^5 cells, at least 1×10^5 cells, at least 5×10^5 cells, at least 1×10^6 cells, at least 0.5×10^7 cells, at least 1×10^7 cells, at least 0.5×10^8 cells, at least 1×10^8 cells, at least 0.5×10^9 cells, at least 1×10^9 cells, at least 2×10^9 cells, at least 3×10^9 cells, at least 4×10^9 cells, at least 5×10^9 cells, or at least 1×10^{10} cells.

[0211] In some embodiments, the immune effector cells, e.g., NK cells that express a BCMA targeting CAR of the present invention, are administered to a subject in need at a dose of at least 0.1×10^5 cells, at least 0.5×10^5 cells, at least 1×10^5 cells, at least 5×10^5 cells, at least 1×10^6 cells, at least 0.5×10^7 cells, at least 1×10^7 cells, at least 0.5×10^8 cells, at least 1×10^8 cells, at least 0.5×10^9 cells, at least 1×10^9 cells, at least 2×10^9 cells, at least 3×10^9 cells, at least 4×10^9 cells, at least 5×10^9 cells, or at least 1×10^{10} cells.

[0212] As non-limiting examples, the NK cells engineered to express a BCMA targeting CAR of the present invention are administered at a dose of about 1×10^6 to 1×10^{10} , or about

5×10^6 to about 5×10^9 , or about 1×10^7 to 3×10^9 , or about 2×10^7 to 5×10^8 , or about 4×10^7 to 1.0×10^9 , or about 1×10^8 to 1.5×10^9 viable cells. In some embodiments, the NK cells engineered to express a BCMA targeting CAR described herein are administered at a dose of 1×10^8 viable cells, or at a dose of 5×10^8 viable cells, or at a dose of 1.5×10^9 viable cells.

[0213] In some embodiments, the amount of immune effector cells (e.g., T cells and NK cells) that express a BCMA targeting CAR of the present invention, are administered to a subject is at least 0.1×10^4 cells/kg of body weight, at least 0.5×10^4 cells/kg of body weight, at least 1×10^4 cells/kg of body weight, at least 5×10^4 cells/kg of body weight, at least 0.5×10^5 cells/kg of body weight, at least 1×10^5 cells/kg of body weight, at least 0.5×10^6 cells/kg of body weight, at least 1×10^6 cells/kg of body weight, at least 1.5×10^6 cells/kg of body weight, at least 2.0×10^6 cells/kg of body weight, at least 3.0×10^6 cells/kg of body weight, at least 4.0×10^6 cells/kg of body weight, at least 5.0×10^6 cells/kg of body weight, at least 6.0×10^6 cells/kg of body weight, at least 7.0×10^6 cells/kg of body weight, 8.0×10^6 cells/kg of body weight, at least 9.0×10^6 cells/kg of body weight, at least 6.0×10^6 cells/kg of body weight, at least 7.0×10^6 cells/kg of body weight, 8.0×10^6 cells/kg of body weight or 9.0×10^6 cells/kg of body weight, at least 0.5×10^7 cells/kg of body weight, at least 1×10^7 cells/kg of body weight, at least 0.5×10^8 cells/kg of body weight, at least 1×10^8 cells/kg of body weight, at least 2×10^8 cells/kg of body weight, at least 3×10^8 cells/kg of body weight, at least 4×10^8 cells/kg of body weight, at least 5×10^8 cells/kg of body weight, at least 1×10^9 cells/kg, or at least 1×10^{10} cells/kg of body weight. In some embodiments, the amount of immune effector cells (e.g., T cells and NK cells) that express a BCMA targeting CAR of the present invention, are administered to a subject is at least 1.5×10^6 cells/kg of body weight. In some embodiments, the amount of immune effector cells (e.g., T cells and NK cells) that express a BCMA targeting CAR of the present invention, are administered to a subject is at least 8.0×10^6 cells/kg of body weight. In some embodiments, the amount of immune effector cells (e.g., T cells and NK cells) that express a BCMA targeting CAR of the present invention, are administered to a subject is at least 2.5×10^7 cells/kg of body weight. In particular embodiments, about 1×10^6 NK cells/kg of body weight to about 1×10^8 NK cells/kg of body weight, about 2×10^6 NK cells/kg of body weight to about 0.9×10^8 NK cells/kg of body weight, about 3×10^6 NK cells/kg of body weight to about 0.8×10^8 NK cells/kg of body weight, about 4×10^6 NK cells/kg of body weight to about 0.7×10^8 NK cells/kg of body weight, about 5×10^6 NK cells/kg of body weight to about 0.6×10^8 NK cells/kg of body weight, or about 5×10^6 NK cells/kg of body weight to about 0.5×10^8 NK cells/kg of body weight are administered to a subject.

[0214] It is recognizable that multiple administrations of the compositions contemplated herein may be required to affect the desired therapy. For example, a composition may be administered 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, or more times over a span of 1 week, 2 weeks, 3 weeks, 1 month, 2 months, 3 months, 4 months, 5 months, 6 months, 1 year, 2 years, 5 years, 10 years, or during the life time of a subject in need.

[0215] The administration of the present compositions may be carried out in any convenient manner, including by aerosol inhalation, injection, ingestion, transfusion, implantation, or transplantation. In a preferred embodiment, compositions are administered parenterally. The phrases "par-

enteral administration" and "administered parenterally" as used herein refers to modes of administration other than enteral and topical administration, usually by injection, and includes, without limitation, intravascular, intravenous, intramuscular, intraarterial, intrathecal, intracapsular, intraorbital, intratumoral, intracardiac, intradermal, intraperitoneal, transtracheal, subcutaneous, subcuticular, intraarticular, subcapsular, subarachnoid, intraspinal and intrasternal injection and infusion. In one embodiment, the compositions contemplated herein are administered to a subject by direct injection into a tumor, lymph node, or site of infection. As administration of the present compositions, intravenous is preferable.

[0216] Accordingly, the subject being administered to an effective amount of a composition increases a cellular immune response to a B cell related condition in the subject. The immune response may include cellular immune responses mediated by cytotoxic T cells capable of killing infected cells, regulatory T cells, and helper T cell responses. Humoral immune responses, mediated primarily by helper T cells capable of activating B cells thus leading to antibody production, may also be induced.

Therapeutic Applications

[0217] In some embodiments, BCMA targeting CAR polypeptides, cells comprising BCMA-CARs and compositions of the present invention may be used to treat a disease associated with expression of BCMA. The disease associated with expression of BCMA includes, but is not limited to, a disease associated with a cell which expresses BCMA (e.g., wild-type or mutant BCMA) or condition associated with a cell which expresses BCMA (e.g., wild-type or mutant BCMA) including, e.g., proliferative diseases such as a cancer or malignancy or a precancerous condition such as a myelodysplasia, a myelodysplastic syndrome or a preleukemia; or a noncancer related indication associated with a cell which expresses BCMA (e.g., wild-type or mutant BCMA). For example, a disease associated with expression of BCMA may include a condition associated with a cell which does not presently express BCMA, e.g., because BCMA expression has been downregulated, e.g., due to treatment with a molecule targeting BCMA, e.g., a BCMA inhibitor described herein, but which at one time expressed BCMA. In one aspect, a cancer associated with expression of BCMA (e.g., wild-type or mutant BCMA) is a hematological cancer. In one aspect, the hematological cancer is a leukemia or a lymphoma. In one aspect, a cancer associated with expression of BCMA (e.g., wild-type or mutant BCMA) is a malignancy of differentiated plasma B cells. In one aspect, a cancer associated with expression of BCMA (e.g., wild-type or mutant BCMA) includes cancers and malignancies including, but not limited to, e.g., one or more acute leukemias including but not limited to, e.g., B-cell acute Lymphoid Leukemia ("BALL"), T-cell acute Lymphoid Leukemia ("TALL"), acute lymphoid leukemia (ALL); one or more chronic leukemias including but not limited to, e.g., chronic myelogenous leukemia (CML), Chronic Lymphoid Leukemia (CLL). Additional cancers or hematologic conditions associated with expression of BMCA (e.g., wild-type or mutant BCMA) comprise, but are not limited to, e.g., B cell prolymphocytic leukemia, blastic plasmacytoid dendritic cell neoplasm, Burkitt's lymphoma, diffuse large B cell lymphoma, Follicular lymphoma, Flairly cell leukemia, small cell- or a large cell-follicular lym-

phoma, malignant lymphoproliferative conditions, MALT lymphoma, mantle cell lymphoma, Marginal zone lymphoma, multiple myeloma, myelodysplasia and myelodysplastic syndrome, non-Hodgkin's lymphoma, plasmablastic lymphoma, plasmacytoid dendritic cell neoplasm, Waldenstrom macroglobulinemia, and "preleukemia" which are a diverse collection of hematological conditions united by ineffective production (or dysplasia) of myeloid blood cells, and the like.

[0218] In some embodiments, the cancer is multiple myeloma, Hodgkin's lymphoma, non-Hodgkin's lymphoma, or glioblastoma. In embodiments, a disease associated with expression of BCMA includes a plasma cell proliferative disorder, e.g., asymptomatic myeloma (smoldering multiple myeloma or indolent myeloma), monoclonal gammopathy of undetermined significance (MGUS), Waldenstrom's macroglobulinemia, plasmacytomas (e.g., plasma cell dyscrasias, solitary myeloma, solitary plasmacytoma, extramedullary plasmacytoma, and multiple plasmacytoma), systemic amyloid light chain amyloidosis, and POEM S syndrome (also known as Crow-Fukase syndrome, Takatsuki disease, and PEP syndrome). Further diseases associated with expression of BCMA (e.g., wild-type or mutant BCMA) expression include, but not limited to, e.g., atypical and/or non-classical cancers, malignancies, precancerous conditions or proliferative diseases associated with expression of BCMA (e.g., wild-type or mutant BCMA), e.g., a cancer described herein, e.g., a prostate cancer (e.g., castrate-resistant or therapy-resistant prostate cancer, or metastatic prostate cancer), pancreatic cancer, or lung cancer.

[0219] In some embodiments, NK cells comprising the BCMA targeting CAR(s) and compositions of the present invention may be administered to a subject having multiple myeloma, who is anti-BCMA-naïve. In some embodiments, the NK cells comprising the BCMA targeting CAR(s) and compositions of the present invention may be administered to a subject having multiple myeloma who is previously received anti-BCMA therapy. In some embodiments, the NK cells comprising the BCMA targeting CAR(s) and compositions of the present invention may be administered to a subject having at least one prior multiple myeloma line of therapy. In some embodiments, the NK cells comprising the BCMA targeting CAR(s) and compositions of the present invention may be administered to a subject having at least 2 prior multiple myeloma lines of therapy. In some embodiments, the NK cells comprising the BCMA targeting CAR(s) and compositions of the present invention may be administered to a subject having at least 3 prior multiple myeloma lines of therapy. For example, the subject having multiple myeloma may be refractory to an immunomodulatory agent. For example, the subject having multiple myeloma may be refractory to a proteasome inhibitor. For example, the subject having multiple myeloma may be refractory to an anti-CD38 antibody. In some embodiments, the previous anti-BCMA therapy is therapy in which BCMA targeting chimeric antigen receptor (CAR)T cells, BCMA targeting antibody-drug-conjugates and/or BCMA targeting antibodies are administered to an individual. In one embodiment, the previous anti-BCMA therapy is BCMA targeting chimeric antigen receptor (CAR) T therapy.

[0220] Non-cancer related conditions that are associated with BCMA (e.g., wild-type or mutant BCMA) include viral infections; e.g., HIV, fungal infections, e.g., C. neoformans,

autoimmune disease; e.g. rheumatoid arthritis, system lupus erythematosus (SL E or lupus), pemphigus vulgaris, and Sjogren's syndrome; inflammatory bowel disease, ulcerative colitis; transplant-related allospecific immunity disorders related to mucosal immunity; and unwanted immune responses towards biologics (e.g., Factor V III) where humoral immunity is important. In embodiments, a non-cancer related indication associated with expression of BCMA includes but is not limited to, e.g., autoimmune disease, (e.g., lupus), inflammatory disorders (allergy and asthma) and transplantation.

[0221] Preferred cancers treated by the methods described herein include B cell malignancy, e.g., multiple myeloma, Hodgkin's lymphoma or non-Hodgkin's lymphoma. In some embodiments, the BCMA targeting CAR polypeptides, cells comprising BCMA-CARs and compositions of the present invention may be used to treat multiple myeloma. In some embodiments, the BCMA targeting CAR polypeptides, cells comprising BCMA-CARs and compositions of the present invention may be used to treat relapsed multiple myeloma. In some embodiments, the BCMA targeting CAR polypeptides, cells comprising BCMA-CARs and compositions of the present invention may be used to treat refractory multiple myeloma.

Combination Therapies

[0222] The BCMA targeting CAR and the immune effector cells expressing the same may be used in combination with other known agents and therapies. The BCMA targeting CAR therapy and the at least one additional therapeutic agent can be administered simultaneously, in the same or in separate compositions, or sequentially. For sequential administration, the CAR-expressing cells described herein can be administered first, and the additional agent can be administered second, or the order of administration can be reversed. The administrations may be in intervals ranging from concurrently to minutes to days to weeks to months.

[0223] In some embodiments, the additional therapy is the administration of side-effect limiting agents (e.g., agents intended to lessen the occurrence and/or severity of side effects of treatment, such as anti-nausea agents, etc.).

[0224] In some embodiments, the additional therapy may be another specific anti-cancer therapy such as radiation therapy, surgery (e.g., lumpectomy and a mastectomy), chemotherapy, gene therapy, DNA therapy, viral therapy, RNA therapy, immunotherapy, bone marrow transplantation, nanotherapy, monoclonal antibody therapy, hormone therapy, oncolytic viruses, or a combination of the foregoing.

[0225] A wide variety of chemotherapeutic agents may be used in combination with the present composition. A "chemotherapeutic agent" is used to connote a compound or composition that is administered in the treatment of cancer.

[0226] Additional immunotherapies may be used in combination or in conjunction with composition and methods described herein. Exemplary immunotherapeutic agents may include antibodies, antibody-drug conjugates, cancer vaccines, immune effector cells and immune checkpoint inhibitors.

[0227] The present compositions and methods may be used in combination with surgery. Approximately 60% of persons with cancer will undergo surgery of some type, which includes preventative, diagnostic or staging, curative,

and palliative surgery. After and/or before surgery, a patient in need may be treated immune effector cells.

[0228] In some embodiments, other agents may be used in combination with certain aspects of the present embodiments to improve the therapeutic efficacy of treatment. Exemplary therapeutic agents that can be combined with the present composition may include small molecule enzymatic inhibitors, anti-metastatic agents, cytokines, growth factors, steroids, NSAIDs, DMARDs, anti-inflammatories, chemotherapeutics, radiotherapeutics, therapeutic antibodies, or other active and ancillary agents.

[0229] In some embodiments, known agents and therapies may be administered prior to administration of the BCMA targeting CAR and the immune effector cells (e.g., NK cells) expressing the same. In some exemplary embodiments, lymphodepleting chemotherapy is administered prior to the BCMA targeting CAR therapy. Fludarabine is an exemplary lymphodepleting chemotherapy. Exemplary lymphodepleting agents are disclosed in WO2010046917A2, WO2003099007A1, among others, which are incorporated by reference in their entirety. Fludarabine phosphate typically is administered as a single dose of 25 mg/m²-per day for 5, 4, 3, or 2 consecutive days. Dosages up to 30 mg/m²-per day for 5, 4, 3, and/or 2 consecutive days also may be used. Fludarabine phosphate may be administered as a single dose of 25 mg/m²-per day for 5 consecutive days before administration of the BCMA targeting CAR and the immune effector cells (e.g., NK cells) expressing the same. Fludarabine phosphate may be administered as a single dose of 25 mg/m²-per day for 4 consecutive days before administration of the BCMA targeting CAR and the immune effector cells (e.g., NK cells) expressing the same. Fludarabine phosphate may be administered as a single dose of 25 mg/m²-per day for 3 consecutive days before administration of the BCMA targeting CAR and the immune effector cells (e.g., NK cells) expressing the same.

[0230] In some embodiments, the subject is treated with cyclophosphamide prior to receiving the BCMA targeting CAR therapy. The subject may receive a single dose of cyclophosphamide at 300 mg/m² BSA per day 5 days, 4 days, or 3 days before on receiving the BCMA targeting CAR therapy. For example, the subject may receive a single dose of cyclophosphamide at 300 mg/m² BSA per day 5 days, 4 days, or 3 days before on receiving NK cells expressing an anti-BCMA CAR described herein.

EXAMPLES

[0231] The following examples are included to demonstrate certain embodiments of the invention. It should be appreciated by those of skill in the art that the techniques disclosed in the examples which follow represent techniques discovered by the inventor to function well in the practice of the invention, and thus can be considered to constitute certain modes for its practice. However, those of skill in the art should, in light of the present disclosure, appreciate that many changes can be made in the specific embodiments which are disclosed and still obtain a like or similar result without departing from the spirit and scope of the invention.

Example 1: Construct of Chimeric Antigen Receptor

[0232] This example shows the BMCA CAR construct used for reducing tumor burden. As illustrated in FIG. 1, the construct comprising nucleotide encoding BCMA DAP10

CAR comprising an anti-BCMA specific binder, a CD28 hinge, a CD28 transmembrane domain, a DAP10 costimulatory domain, and IL-15 cytokine (e.g., soluble IL-15), etc. was used in the Example 1 to 9. The amino acid sequences

that expressed from the construct and the nucleic acid sequences encoding the amino acid sequences are described in the Table 4. These sequences were used in the Example 2 to 9.

TABLE 4

Sequences of BCMA targeting CAR constructs

TABLE 4 -continued

Sequences of BCMA targeting CAR constructs

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cacttctgaccggaggccggatccacgtgtcatcctggctgcttcagcgccggactgc
ccaagaccggccaaactgggtgaacgtgatc
agcgacctgaagaagatcgaggacactgatccagagcatgcacatcgacgc
cccccgtacaccggagcgacgtgcaccccgatc
ccgcccattgaagtgcctctgtggaaactgc
cggcgtacgcctggaaagcgccgacgc
cagcatccacgacaccgtggagaac
ctgtatcatct
ggccaaacaacacgacgtggcagc
aaccggcaacgtgac
cgagcggcggctgcaa
aagagtgcgaggaaactgg
aaagagaacatcaa
aagagttctg
cagagcttcgtgcacatcgtgcagatgtt
catcaacaccaggctga (SEQ ID NO: 46)

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Example 2: In Vivo Efficacy of BCMA CAR Constructs Against MM1S Tumor

[0233] This Example shows the efficacy of BCMA-DAP10-CAR comprised in SEQ ID NO: 29 and BCMA-CD28-CAR comprised in SEQ ID NO: 45, expressed in CB-NK cells, against MM1S tumor.

[0234] 10-12 week old female NSG mice were whole-body irradiated at 150 cGy 24 hours prior to tumor inoculation. MM. 1S-fluc-MDA cells were prepared in PBS suspension at a concentration of 2.5×10^6 cells/ml, for intravenous inoculation of cells at 0.5×10^6 /animal. Bioluminescent images were taken 1 day prior to dosing, 6 days after tumor inoculation, and animals were randomized based on total flux into groups of 4 animals per arm. Animals were dosed 7 days after tumor inoculation. The CAR expressing NK (i.e., CAR NK) cells in the relevant concentrations were resuspended in PBS and transferred to the vivarium on ice in small batches to ensure timely infusion into the animals while maintaining the CAR expressing NK cell viability. Bioluminescent images were carried out weekly on a Xenogen IVIS to monitor tumor progression. Body weights were taken three times a week, alongside clinical observations to monitor for any signs of toxicity. Microsampling (via submandibular collection of blood) was carried out once a week for cellular kinetics analysis to quantify CAR NK expansion *in vivo*, either by ddPCR or flow cytometric analysis. At humane or study endpoint, necropsy of animals from studies of interest was carried out to obtain various tissues for tox/pathology assessment.

[0235] For single dose of 10M the CAR expressing NK cells, both BCMA-DAP10-CAR and BCMA-CD28-CAR performed equivalently. For 2 doses of 10M the CAR expressing NK cells, BCMA-DAP10-CAR outperformed BCMA-CD28-CAR with 3 mice surviving to Day 49 compared to only one for BCMA-CD28-CAR (FIG. 2A). All CAR transduced NK cells showed a benefit when compared to tumor alone (FIG. 2B).

CAR-NK Cell Manufacturing

[0236] For CAR-NK production, cord blood (C B) units for research were obtained from the M D Anderson Cancer Center Cord Blood Bank. CB mononuclear cells were isolated from frozen CB units by Ficoll density gradient centrifugation. Ex vivo expansion of cord-blood derived NK cells (CB-NK cells) used uAPC stimulation on Day 0 in addition to feeding IL-2 every 2 days. On Day 6, cells were transduced with RD114 virus using spinoculation. Cells were stimulated with a second round of uAPC addition on Day 8 or 9 and fed IL-2 every 2 days until they were used for *in vivo* or *in vitro* studies on Day 15 or cryopreserved on Day 21 for later use.

Example 3: In Vitro Efficacy of BCMA CAR Constructs Against Multiple Tumor Lines

[0237] This Example shows the efficacy of BCMA-DAP10-CAR comprised in SEQ ID NO: 29 and BCMA-CD28-CAR comprised in SEQ ID NO: 45, expressed in CB-NK cells, against different tumor cells.

[0238] MM1S-Luc, RPMI-8226-Luc, JJN3-Luc and JJN3-Luc BCMA KO cells were washed with PBS once, cells were incubated with cell tracer deep red dye (Invitrogen #C34565) at 1: 10,000 dilution in PBS at 37° C. for 20 minutes with the cell density at 2.5 million/ml. At the end of incubation, 20 ml cell culture medium were added to the cells and cells were spun down at 500 g for 5 minutes, supernatant was removed and cells were washed one more time using corresponding cell culture medium. Cells were then resuspended in culture medium at 0.25 million/ml, and 30 ul cells were added to each well of the v-bottom 384 well assay plates (Greiner, catalog: 781280). Cells were incubated at 37° C. cell culture incubator with 5% CO₂ for 1-2 hours. Fresh effector cells were harvested at day 15 and cells were washed once in the cytokine free NK cell medium (CellGenix GM P SCGM with 10% HI-FBS and 2 mM Glutamine), 10 ul effector cells were then added to the assay plates at different E to T ratios. Target cells and effector wells were co-cultured for 20 hours, cells were then spun down and supernatant was collected for cytokine release assay. Cells were incubated with 10 ul caspase3/7 reagent (Inteliclyt, catalog: 91035) diluted at 1:500 in corresponding target cell medium for 1 hour in cell culture incubator at 37° C. and then submitted for FACS analysis using either Sartorius iQue3 or Sartorius iQue screener Plus. The percentage of target cells with positive caspase 3/7 staining was used to report the cytotoxicity of effector cells.

[0239] In vitro killing activity was superior overall in the BCMA-DAP10-CAR construct for multiple tumor cell lines (as shown in FIG. 3).

Example 4: Ability of BCMA CAR NK Cells to Kill Tumor Cells In Vitro with Multiple Rounds of Restimulation

[0240] This Example shows the efficacy of BCMA-DAP10-CAR comprised in SEQ ID NO: 29 and BCMA-CD28-CAR comprised in SEQ ID NO: 45, expressed in CB-NK cells.

[0241] Effector cells were harvested and resuspended in SCGM (CellGenix, catalogue no.:20802-0500) supplemented with 10% Heat Inactivated FBS (Sigma, catalogue no.:F4135-500 mL), 1% L-Glutamine (Gibco, catalogue no.:25030-081), 1% Penn Strep (Gibco, catalogue no.: 15140-122) and 100 IU/mL Human IL-2 (Miltenyi, catalogue no.:130-097-748). Effector cells were seeded in triplicate into a 48 well flat bottom non-tissue culture treated plate (Corning, catalogue no.:3548) at a density of 2e5

cells/well (MM1S model, FIG. 4A-4B) or 5e4 cells/well (RPMI-8226 model, FIG. 5A-5B). Target cells previously transduced with NucLight Red Lentivirus (Sartorius, catalogue no.:4476) and selected with 1 µg/mL puromycin (Sigma, catalogue no.:P8833-10M G) were harvested and resuspended in the complete media described above and seeded at a density of 5e4 cells/well. Plates were placed in an IncuCyte S3 (Sartorius Inc.) and quadruplicate readings per well were measured in both the bright field and red channel using the 10x objective every 30 minutes. Target cells were prepared as described above and reseeded at a density of 5e4 cells/well every 48-72 hours (MM1S model, FIG. 4A, 4B) or every 48 hours (RPMI-8226, FIG. 5A, 5B) for a total of 9 tumor stimulations/rechallenges. Target cell cytosis is represented as mean red object count per image (FIG. 4A-4B) and total average area under the curve of the red object count (FIG. 5A-5B).

[0242] BCMA-DAP10-CAR showed superior efficacy over the BCMA-CD28-CAR against repeated stimulation with MM1S and also showed outstanding control of RPMI-8226 tumor cells upon repeated stimulation.

Example 5: In Vivo Efficacy of BCMA CAR Constructs Against RPM 1-8226 Tumor

[0243] This Example shows the in vivo efficacy of BCMA-DAP10-CAR comprised in SEQ ID NO: 29 and BCMA-CD28-CAR comprised in SEQ ID NO:45, in CB-NK cells, against RPMI-8226 tumor.

[0244] 10-12 week old female NSG mice were whole-body irradiated at 150 cGy 24 hours prior to tumor inoculation. RPMI-8226-luc cells were prepared in PBS suspension at a concentration of 2.5×10^6 cells/ml, for intravenous inoculation of cells at 0.5×10^6 /animal. Bioluminescent images were taken 1 day prior to dosing, 6 days after tumor inoculation, and animals were randomized based on total flux into groups of 4 animals per arm. Animals were dosed 7 days after tumor inoculation. The CAR expressing NK cells in the relevant concentrations were resuspended in PBS and transferred to the vivarium on ice in small batches to ensure timely infusion into the animals while maintaining the CAR expressing NK cell viability. Bioluminescent images were carried out weekly on a Xenogen IVIS to monitor tumor progression. Body weights were taken three times a week, alongside clinical observations to monitor for any signs of toxicity. Microsampling (via submandibular collection of blood) was carried out once a week for cellular kinetics analysis to quantify CAR NK expansion in vivo, either by ddPCR or flow cytometric analysis. At humane or study endpoint, necropsy of animals from studies of interest was carried out to obtain various tissues for tox/pathology assessment.

[0245] BCMA-DAP10-CAR showed superior efficacy with twice as many mice surviving on Day 63 and one mouse surviving on Day 75, compared to all mice in controls succumbing to tumor growth by Day 63 (FIG. 6).

Example 6: In Vivo Expansion of BCMA CAR NK Cells in RPMI-8226 Tumor Model

[0246] This Example shows the expansion efficacy of CB-NK cells that are engineered to express BCMA-DAP10-CAR comprised in SEQ ID NO: 29 or BCMA-CD28-CAR comprised in SEQ ID NO: 45 in response to tumor in RPMI-8226 tumor model.

[0247] 10-12 week old female NSG mice were whole-body irradiated at 150 cGy 24 hours prior to tumor inoculation. RPMI-8226-luc cells were prepared in PBS suspension at a concentration of 2.5×10^6 cells/ml, for intravenous inoculation of cells at 0.5×10^6 /animal. Bioluminescent images were taken 1 day prior to dosing, 6 days after tumor inoculation, and animals were randomized based on total flux into groups of 4 animals per arm. Animals were dosed 7 days after tumor inoculation. CAR NK cells in the relevant concentrations were resuspended in PBS and transferred to the vivarium on ice in small batches to ensure timely infusion into the animals while maintaining the CAR expressing NK cell viability. Bioluminescent images were carried out weekly on a Xenogen IVIS to monitor tumor progression. Body weights were taken three times a week, alongside clinical observations to monitor for any signs of toxicity. Microsampling (via submandibular collection of blood) was carried out once a week for cellular kinetics analysis to quantify CAR NK expansion in vivo, either by ddPCR or flow cytometric analysis. At humane or study endpoint, necropsy of animals from studies of interest was carried out to obtain various tissues for tox/pathology assessment.

[0248] As shown in FIG. 7, NK cells expressing the BCMA-DAP10-CAR construct and NK cells expressing the BCMA-CD28-CAR construct both expand in vivo in response to RPM 1-8226 tumor. Furthermore, NK cells expressing the BCMA-DAP10-CAR construct expand at a higher efficacy as compared to the expansion of NK cells expressing the BCMA-CD28-CAR construct (FIG. 7).

Example 7: In Vivo Efficacy of BCMA CAR in RPM 1-8226 Tumor Model at Multiple Doses

[0249] This Example shows the efficacy of BCMA-DAP10-CAR comprised in SEQ ID NO: 29 and expressed in CB-NK cells against RPMI-8226 tumor; the CAR expressing NK cells were administered at multiple doses.

[0250] 10-12 week old female NSG mice were whole-body irradiated at 150 cGy 24 hours prior to tumor inoculation. RPM 1-8226-luc cells were prepared in PBS suspension at a concentration of 2.5×10^6 cells/ml, for intravenous inoculation of cells at 0.5×10^6 /animal. Bioluminescent images were taken 1 day prior to dosing, 6 days after tumor inoculation, and animals were randomized based on total flux into groups of 4 animals per arm. Animals were dosed 7 days after tumor inoculation. The CAR expressing NK cells in the relevant concentrations were resuspended in PBS and transferred to the vivarium on ice in small batches to ensure timely infusion into the animals while maintaining the CAR expressing NK cell viability. Bioluminescent images were carried out weekly on a Xenogen IVIS to monitor tumor progression. Body weights were taken three times a week, alongside clinical observations to monitor for any signs of toxicity. Microsampling (via submandibular collection of blood) was carried out once a week for cellular kinetics analysis to quantify CAR NK expansion in vivo, either by ddPCR or flow cytometric analysis. At humane or study endpoint, necropsy of animals from studies of interest was carried out to obtain various tissues for tox/pathology assessment.

[0251] BCMA-DAP10-CAR showed highest efficacy in vivo at a dose of 3M CAR-NK cells per mouse (FIGS. 8A and 8B).

Example 8: In Vitro Efficacy of BCMA DAP10 CAR Against Tumor Lines Expressing Different Levels of Stress Ligands

[0252] This Example shows the efficacy of BCMA-DAP10-CAR comprised in SEQ ID NO: 29 and BCMA-CD28-CAR comprised in SEQ ID NO: 45, expressed in CB-NK cells.

[0253] JJN3(BCMA KO), JJN3(BCMA KO)+MICA/MICB, JJN3(BCMA WT), and JJN3 (BCMA WT)+MICA/MICB target cells were prepared and seeded in a 96 well plate in a 100 μ L volume to obtain 20,000 target cells/well. The CAR expressing NK cells and control NK cells (Untransduced; UTD) were prepared and resuspended in assay medium at a concentration of 1.8×10^6 cells/mL. The effector cell suspensions were then diluted and 100 μ L of the diluent was added to the plate containing target cells to achieve the effector-to-target (E:T) ratios indicated in the plots as shown in FIGS. 9-11C. The cells were incubated in a 37 °C/5% CO₂ incubator for 20-24 hours.

[0254] Following the incubation, the cells were transferred to another round bottom 96-well plate for cell staining. The cells, after pelleted by centrifugation, were stained with fixable viability dye eFluor-780 (1:1000 dilution in PBS) for 15 minutes on ice in the dark. After washed and re-pelleted, the cells were resuspended in 50 μ L of human Fc block (diluted 1:10 in staining buffer) and incubated at room temperature for 10 minutes in the dark. The cells were then stained with 50 μ L of a fluorescently conjugated mouse anti-human CD138 antibody for 30 minutes on ice in the dark. The stained cells were washed, resuspended and recorded on an Attune flow cytometer.

[0255] Data were exported and analyzed using FlowJo v10.6.2. Live CD138+target cells excluding the viability dye were quantified. The average live target cell count was determined for all control wells (target cells alone; no treatment). The cytotoxicity was calculated using the following equation:

$$\text{Cytotoxicity} = 100 - \frac{(\text{target cell count in test well}/\text{average target cell count in control wells}) * 100}{100}$$

Cell Titer Glo-based cytotoxicity assay

[0256] M C38 parent, M C38-ULBP2 High, and primary bronchial epithelial target cells were prepared at a concentration of 2×10^5 cells/mL in assay medium (SCGM supplemented with 10% FBS). Target cells were seeded in a 100 μ L volume to obtain 20,000 target cells per well in a flat 96-well plate, and allowed to adhere for 12-14 hours prior to effector cell addition. The CAR expressing NK cells and control NK cells (Untransduced; UTD) were prepared and resuspended in assay medium at a concentration of 1.8×10^6 cells/mL. The effector cell suspensions were then diluted and 100 μ L of the diluent was added to the plate containing target cells to achieve the effector-to-target (E:T) ratios indicated in the plots in FIGS. 9-11C. The cells were incubated in a 37 °C/5% CO₂ incubator for 20-24 hours.

[0257] Following the incubation, the cell supernatant was aspirated. Each well, after washed with 200 μ L assay media, was supplemented with 100 μ L of assay media and 100 μ L of cell titer glo solution. Cells were incubated for ~7 minutes at room temperature with gentle shaking. Luminescence was measured on a Tecan spark instrument.

[0258] The average luminescence (relative luminescence unit, RLU) was determined for all control wells (target cells alone; no treatment). In addition, RLU was determined for each effector cell alone in the absence of target cell stimulation. Cytotoxicity was calculated using the following equation:

$$\text{Cytotoxicity} = 100 -$$

$$(RLU(\text{test well}) - RLU(\text{effector cell alone})/\text{average RLU control}) * 100$$

Example 9: BCMA CAR Surface Expression Improvement Following Codon Optimization

[0259] This Example shows the surface expression of BCMA-DAP10-CAR using construct comprising SEQ ID NO: 25 and SEQ ID NO: 55 in Table 5 on NK cells of 4 different CBU donors. In this example, construct comprising sequence represented by SEQ ID NO: 25 enhanced the surface expression of the BCMA CAR in all 4 CBU donors.

[0260] Serial dilution of virus was performed using 2-fold dilution for a total of 8 points. A 24-well plate was pre-coated with 40 μ g/mL retronectin overnight then blocked with complete media for 10 minutes at 37 °C. prior to use. 1 mL of virus dilution was added to the plate then centrifuged at 2000×g at 32 °C. for 90 minutes. After centrifugation, plate was aspirated and 1×10^6 NK in 1 mL of media was added along with 1 mL of appropriate virus dilution. The plate was then centrifuged at 400×g for 5 mins at 32 °C. and placed inside the incubator at 37 °C. for 48 hrs.

[0261] Following the incubation, the cells were transferred to a v-bottom 96-well plate for cell staining. The cells, after pelleted by centrifugation and washed with flow buffer, were stained in 1:10 Fc block with fluorescently conjugated mouse anti-human CD3, mouse anti-human CD56, mouse anti-human NKG2D, and recombinantly produced human BCMA for 30 minutes on ice in the dark. The stained cells were washed, resuspended in Sytox Viability Dye and recorded on an MACSquant flow cytometer. Data were exported and analyzed using FlowJo v10.6.2. Live CD3-CD56+BCMA⁺ target cells excluding the viability dye were quantified.

[0262] The surface expression of the BCMA CAR using construct comprising SEQ ID NO: 55 or SEQ ID NO: 25 in 4 CBU donors is shown in FIG. 12A-12B. The surface expression of the BCMA CAR using construct comprising SEQ ID NO: 25 yielded higher transduction efficiency against the BCMA-DAP10 CAR construct comprising SEQ ID NO: 55 across all four Cord blood NK donors.

TABLE 5

Sequences of BCMA targeting CAR constructs

Amino acid sequence comprising BCMA-DAP10 CAR
 MEFGLSWLFLVAILKGVQCOITLREGSGDVVPQRGSRLRSLCAASGFTFSSYYAIHWVRQAPGK
 LEHGVAVTWHDSGNKYYAESVMGRFTISRDNSKNTLYLHMNSLRALDTGVYYCARAKFG
 EPOYFQHGWGGFTLVTSGGGGGGGGGGGGGGSDIVMTQSPSFLSASVGDRVTITCRASQGI
 NNLYLAWYQQKPGIAPKLIIYAATLQSQGPVSRFGGSGSGTEFTLTISSLQPEDFATYYCQLK
 SYPFTFGPGTKVEIKRAAAEIIVMWPYPYLDNEKNSGTIIVHVKGHKLCPSFLPFGPSKPKDPKF
 WLVVLVVVGGVLACYSLLTVFAIFIWFVLCPRRRSAPAQEDGQVHINMPGRGRVKFSRSADAP
 AYQQCQGQNLNYENLNLRGREYDVLDKRGRDPEMGCKPQRKNPQBEGLYNELNQDKMAEA
 YSEIGGMKGERRRGKGDGLYQGLSTATKDTYDALHMQALPPRGPCQTNYALLKLAGDVES
 NPGCPMRKSKPLHRSISIQCYCLLNLNSHFTLEAGIHVFILGCFSAAGLKPTEANWNVNISSLKKIE
 DLIQSMHIDATLYTESDVHPSCKVTAWCFLLEQVVISLESGDASIHDTVENLILJANNLSSSN
 GNVTECSCKECBELEEKNIKFELQFOSFVHVIMQFINTS (SEQ ID NO: 13)

Example 10: In Vivo Efficacy of Codon-Optimized BCMA CAR NK at Low Doses

[0263] 10-12 week old female NSG mice were whole-body irradiated at 150 cGy 24 hours prior to tumor inoculation. MM. 1S-fluc-MDA cells were prepared in PBS suspension at a concentration of 2.5×10^6 cells/ml, for intravenous inoculation of cells at 0.5×10^6 /animal. Bioluminescent images were taken 1 day prior to dosing, 6 days after

tumor inoculation, and animals were randomized based on total flux into groups of 5 animals per arm. Animals were dosed 7 days after tumor inoculation. The CAR (coded by nucleic acid sequence represented by SEQ ID NO: 25) expressing NK (i.e., CAR NK) cells in the relevant concentrations were resuspended in PBS and transferred to the vivarium on ice in small batches to ensure timely infusion into the animals while maintaining the CAR expressing NK cell viability. Bioluminescent images were carried out

weekly on a Xenogen IVIS to monitor tumor progression. Body weights were taken three times a week, alongside clinical observations to monitor for any signs of toxicity. Microsampling (via submandibular collection of blood) was carried out once a week for cellular kinetics analysis to quantify CAR NK expansion in vivo, either by ddPCR or flow cytometric analysis. At humane or study endpoint, necropsy of animals from studies of interest was carried out to obtain various tissues for tox/pathology assessment.

[0264] As shown in FIG. 13, CAR⁺NK cells were capable of suppressing tumor growth in 2 of the 3 groups tested.

EQUIVALENTS

[0265] The disclosures of each and every patent, patent application, and publication cited herein are hereby incorporated herein by reference in their entirety. While this invention has been disclosed with reference to specific aspects, it is apparent that other aspects and variations of this invention may be devised by others skilled in the art without departing from the true spirit and scope of the invention. The appended claims are intended to be construed to include all such aspects and equivalent variations.

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AESVMGRFTI SRDNNSKNTLY LHMNSLRAED TGVYYCARAK FGEPEQYFQHW GQGTLTVSS 120

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mol_type = protein
organism = synthetic construct
SEQUENCE: 2
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RGFGSGSGTE FTLTISSLQP EDFATYYCQQ LKSYPFTFGP GTKVEIK 107

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mol_type = protein
organism = synthetic construct
SEQUENCE: 6
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organism = synthetic construct
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SEQ ID NO: 8      moltype = AA  length = 9

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	organism = synthetic construct
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	organism = synthetic construct
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ggccccc	66
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	organism = synthetic construct
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ggaccc	66
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	mol_type = protein
	organism = synthetic construct
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GKGLEWVAVT WHDGSNKYYA ESVMGRFTIS RDMSKNLTLYH MNNSLRAEDT GVYYCARAKF	120
GEPQYFQHWG QTGLTVSSG GGGGGGGSG GGGSDIVMTQ SPSFLSASVG DRVTITCRAS	180
QGINNYLAWY QOKPGIAPKL LIYAASTLQS GPSPRGSSG SGTEFTLTIS SLQPEDFATY	240
YCQQLKSYPF TFGPGTKVEI KRAAAIEVMY PPPYLDNEKS NGTIHVKGK HLCPSPLFPG	300
PSKPKDPKFW VLVVVGGVLA CYSLLVTVAF IIPFWVLCARP RRSPAQEDGE VYINMPGRGR	360
VKFSSRSADAP AYQQQNQLY NELNLGRREE YDVLDRKRRR DPEMGGKPRR KNPQEGLYNE	420
LQDKDMAEAY SEIGMKGERP RGKGDGLYQ GLSTATKDTY DALHMQLPP RGPQCTNIAL	480
LKLAGDVESN PGPMRISKPH LRSISIQCYL CLLLNSHFLT EAGIHFILG CFSAGLPKTE	540
ANWVNVISDL KKIIEDLIQSM HIDATLYTES DVHPSCKVTA MKCFLLELQV ISLESGDASI	600
HDTVENLIL ANNSLSSNGN VTESGCKECE ELEEKNIKEF LQSFVHIVQM FINTS	655
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	organism = synthetic construct
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GWEEGVAQMS VGQRALKLIS PDYAYGATGH PGIIPPHATL VFDVELLKLE SGGGSGVDGF	120
GDVGALESLR GNADLAYILS MEGPCGHCLII NNVNFCRESG LRTRTGNSID CEKLRRRFSS	180
LHFMVEVKGD LTAKKMVLAL LELAQODHGA LDCCVVVILS HGCQASHLQF PGAVYGT DGC	240
PVSVEKIVNI FNGBTCPH GPKLFFIQA CGGEQKDHGF EVASTSPDE SPGSNPEPDA	300
TPFQEGLRTF DQLDAISL TPSPDFVSYT TFPFGFVSWRD PKSGSWYVET LDDIFEQWAH	360
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organism = synthetic construct
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organism = synthetic construct
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SFVHIVQMFI NTS                                         133

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LIIYAASTLQ SGVPSRFGGS GSGTEFTLTI SSLQPEDFAT YYCQQLKSYP FTFGPGTKVE 240
IKRAAAIEVM YPPPYLDNEK SNGTIIHVKG KHLCPSPPLFP GPSKPDKPKF WVLVVVGGVL 300
ACYSLLVTVA PIIFWVLCAR PRRSPAQEDG KVYINMPGRG RVKFERSADA PAYQQQNQL 360
YNELNLRRE EYDVLDKRRG RDPEMGGKPR RKNPQEGLYN ELQDKMAEA YSEIGMKGER 420
RRGKGHDGLY QGLSTATKDT YDALHMQALP PR 452

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mol_type = other DNA
organism = synthetic construct

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ccccgttaaa gtttagagtg ggtggctgtg acttggcacg acggctccaa caagtactat 180
ggcgagagcg tgatgggtcg tttcaccatc tctcgtgaca acagcaagaa cactttatat 240
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mol_type = other DNA
organism = synthetic construct

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atcgaagttt tggatccctcc tccttaccta gacaatgaga agagcaatgg aaccattatc 60
catgtgaag ggaaacacactt ttgtcaagt cccctatttc ccggacccctc taagccc 117

SEQ ID NO: 32          moltype = DNA length = 321
FEATURE               Location/Qualifiers
source                1..321
mol_type = other DNA
organism = synthetic construct

SEQUENCE: 32
gacatcgtga tgaccaggag ccctagcttt ttaagcgcga gcgtggcga cagagtgacc 60
atcaacttgtc gtgccgcga aggtatcaac aactatttag ctggtacca gcagaaggccc 120
ggtatcgccc ccaagctgtct gatctacgcgc gccagcacac tgcagagcgg cgtgcctagc 180
agatttgggt gcagcggctc tggcacagag ttcactttaa ccatcagctc tttacagccc 240
gaggacttcg ccacactacta ctgcgcacag ctgaagagct accccttac cttcggccccc 300
ggcaccacagg tggagatcaa g 321

SEQ ID NO: 33          moltype = DNA length = 57
FEATURE               Location/Qualifiers
source                1..57
mol_type = other DNA
organism = synthetic construct

SEQUENCE: 33
atggaatttcg ggctgtcctg gcttttctt gtcgcaattc ttaaggcgt ccaatgt 57

SEQ ID NO: 34          moltype = DNA length = 57
FEATURE               Location/Qualifiers
source                1..57
mol_type = other DNA
organism = synthetic construct

SEQUENCE: 34
atggagttcg ggctgagctg gctgttcctg gtggccatcc tgaaggcgt gcagtgc 57

SEQ ID NO: 35          moltype = DNA length = 725
FEATURE               Location/Qualifiers
source                1..725
mol_type = other DNA
organism = synthetic construct

SEQUENCE: 35
agataactctt ggcgcgactca ggaggagacg tggtgcaacc gggcagatct ctcaaggctt 60
catgtgcgc cagtggcttc acatttagct cttatgcattt acattgggtc aggccaggctc 120
ctggcaaggg ctggaaatgg gtagcggta cctggcatga tggatctaac aaatactacg 180
ccagactgtgt tatgggtcga ttccacaattt ctgcagacaa ttcaaaaaac acactctacc 240
tgcataatgaa ctcactttaga gcagaggaca ctggtgtcta ttactgcgcc agagcaaat 300
tcggcgagcc acagtatttc cagcactggg gacaaggaaac cctcgttaaca gtagcttagt 360
ggggcggagg gtctggagga ggggggagcg ggggaggcgg ctctgtatatt gttatgaccc 420
aatcaccatc ttttctgagc gctagtgtcg ggcacagggt tacaatcaca tgccgagcaa 480

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SEQ ID NO: 42      moltype = DNA length = 66
FEATURE
source          Location/Qualifiers
1..66
mol_type = other DNA
organism = synthetic construct
SEQUENCE: 42
ggaccgcagt gtactaatta tgctcttgc aaattggctg gagatgttga gagcaatccc 60
gggccc                                66

SEQ ID NO: 43      moltype = DNA length = 66
FEATURE
source          Location/Qualifiers
1..66
mol_type = other DNA
organism = synthetic construct
SEQUENCE: 43
ggccctcagt gcaccaacta cgccctgctc aagctggctg gcgacgtcga gagcaacccc 60
ggaccc                                66

SEQ ID NO: 44      moltype = DNA length = 1356
FEATURE
source          Location/Qualifiers
1..1356
mol_type = other DNA
organism = synthetic construct
SEQUENCE: 44
caagataactc tgcgcgagtc aggaggagac gtggtgcaac cgggcagatc ttcaggcgtt 60
tcatgtgcgc coagtggctt cacatttgcgatc ttttatgcata tacattgggt caggcaggct 120
ccttggcaagg gtttggaaat ggttagcggtt acctggcatg atggatctaa caaatactac 180
gcgcgatcttc ttatgggtcg attacaatt ttcgagaca attcaaaaaa cacactctac 240
ctgcataatgc actcaatttc agcagaggac actgggtctt attactgcgc cagagaaaa 300
tttggcgagtc cacatgtt ccacactgg ggacaaggaa ccctcgtaac agtatactgt 360
ggggggcgag ggtctggagg aggggggggg gggggggggc gctctgatat tgttatgacc 420
caatcaccat cttttctgag cgctgtgtc gggcacaggg ttacaatcac atgcggagca 480
agccaaggaa tcaacaattt tctcgatgg tatcaacaaa aaccaggat cgcggggaaa 540
cttcttattt acgcacgatc aaccttgcac agcggaggtt cttcttagatt tggtggcagc 600
ggotccggga ctgaaatttcc tcttactatc tccctcccttc aacccgaaga tttcgccaca 660
tattactgcg acgcgtttaa gtcatcccccc ttcaactttt gcccaggaaac taaagtggaa 720
atcaaacggg cggccgcaat tgaagttatg tttttttttt cttttttttt caatgagaag 780
agaatgtggaa ccatttttca tttttttttt aaacacccctt gtccaaatccc cttttttttt 840
ggaccccttca agcccaaaaatc tttttttttt tttttttttt tttttttttt tttttttttt 900
gtttgttataa gttttttttt aacatgtggcc tttttttttt tttttttttt tttttttttt 960
ccacacccca agcccccggc agaagatggc aaagtctaca tcaacatgcc aggcggggc 1020
cgccgttgcgtt tttttttttt tttttttttt tttttttttt tttttttttt tttttttttt 1080
tataacggc tttttttttt tttttttttt tttttttttt tttttttttt tttttttttt 1140
cgccggacccctt agatggggggg aaagccgaga aggaagaaccc tttttttttt tttttttttt 1200
gaactgcaga aagataagat ggcggggggc tacagtggaa tttttttttt tttttttttt 1260
cgccggggggc aaggggcggc tttttttttt tttttttttt tttttttttt tttttttttt 1320
tacggacggcc tttttttttt tttttttttt tttttttttt tttttttttt tttttttttt 1386

SEQ ID NO: 45      moltype = AA length = 672
FEATURE
source          Location/Qualifiers
1..672
mol_type = protein
organism = synthetic construct
SEQUENCE: 45
MEFGLSWLFL VAILKGVQCQ ITLRESGGDV VQPGRSLRLS CAASGFTFSS YAIHWVRQAP 60
GKGLEWVAVT WHDGSNKYYA ESVMGRFTIS RDNSKNLTYL HMNSLRAEDT GVYYCARAKF 120
GEPOQYFQHWG QGTLVTVSSG GGGGGGGSG GGGSDIVMTQ SPSFLSASVG DRVTITCRAS 180
QQINNYLAWY QOKPGIAPKL LIYAASTLQS GPSPRFGGSG SGTEFTLTIS SLQPEDFATY 240
YCQQLKSYPPF TFGPGTKVEI KRAAAIEVMY NGTIIHVKGK HLCPSPLFPG 300
PSKPKDPKFV VLVVVGGVLA CYSLLVTVAF IIIFWVRSKRS RLLHSDYMMN TP RRPGPTRK 360
HYQPYAPPRD FAAYRSRVKF SRSADAPAYQ QQQNQLYNEL NLGRREEYDV LDKRGRDPE 420
MGKKPDRKNP QEGGLYNELOK DKMAEAYSEI GMKGERRRGK GH DGLYCGLS TATKDTYDAL 480
HMQLALPPRGQ QCTNYALLKL AGDVESNPGP MRISKPHLRS ISIQCYLCLL LNSHPLTEAG 540
IHVFILGCFS AGLPKTEANW VNVVISDLKKI EDLIQSMHID ATLYTESDVH PSCKVTAMKC 600
FILLELOVISL ESGDASIHDT VENLILANN SLSSNGNVTE SGCKECEELE EKNIKEFLQS 660
FVHIVQMFN TS                                672

SEQ ID NO: 46      moltype = DNA length = 2019
FEATURE
source          Location/Qualifiers
1..2019
mol_type = other DNA
organism = synthetic construct
SEQUENCE: 46
atggaaattcg ggctgtcctg gcttttcttgc gtcgcaattc ttaaggccgtt ccaatgtcag 60
ataactctgc gcgagtcagg aggagacgtg gtgcaaccgg cagatcttca caggcttca 120

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tgtgccgcca	gtggcttcac	attnagctct	tatgcataac	attgggtcag	gcaggctcct	180
ggcaaggcgt	ttgaatgggt	agcggttacc	tggcatgat	gatccaaacaa	atactacgccc	240
gagtctgtta	ttgggtcgatt	cacaatttct	cgagacaatt	caaaaaaacac	actctactgt	300
catatgaact	cacttagagc	agaggacact	ggtgtctatt	actgcgcacag	agcaaaattc	360
ggcgagccac	agtatttcca	gcactggga	caaggaaccc	tcgttaacagt	atctagtggtt	420
ggcggagggt	ctggaggagg	ggggagcggg	ggaggcggct	ctgtatattgt	tatgacccaa	480
tcaccatctt	ttctgagcgc	tagtgcggc	gacagggttta	caatcacatg	ccgagcaagc	540
caaggaatca	acaatttatct	cgcgtgtat	caacaaaacac	caggatctgc	cccgaaactt	600
cttattttacg	cagcatcaac	cctgc当地	ggagtcttctt	ctagattttgg	tggcagcggc	660
tcggggactg	aattttactt	taacttcc	tccttcaac	ccgaagattt	cgccacatat	720
tactgc当地	agcttaatgc	atacccttcc	atctttggcc	caggactaa	agttgaatc	780
aaacggggccg	ccgc当地	agttatgtat	ccttc当地	acctagacaa	tgagaagagc	840
aatggaaacca	ttatccatgt	gaaaggggaa	caccttgc	caagttccct	attttccgga	900
ccttctaa	ccaaagatcc	caaattttgg	gtgctgggtt	ttgggtgggg	agttctggct	960
tgetatagct	tgtcttagtac	agttggctt	atttttttctt	gggtgaggag	taagaggagc	1020
aggctcttcg	acagtgacta	catgaaatcg	actcccccc	gccccgggg	caccccaag	1080
cattaccagc	ctatgc当地	accacgc当地	tgc当地	atcgctca	cgtgaagttc	1140
agcaggagcgc	cagacgcccc	cgc当地	caggccgca	accagctcta	taacgagctc	1200
aatcttagc	gaagagagga	gtacgttgc	ttggacaaa	gacgtggccg	ggaccctgag	1260
atggggggaa	agccgagaag	gaagaaccc	caggaaaggc	tgtacaatga	actgc当地	1320
gataagatgg	cgaggccct	cagtggat	gggatgaaag	gctggccg	gaggggcaag	1380
gggc当地	gcttacc	gggttca	acagccacca	aggacaccta	cgacgccc	1440
cacatgc	ccctgc当地	tcgeggac	cgtgtacta	attatgtct	cttgc当地	1500
gtctggatgt	ttgagagca	tcggcc	atgc当地	gcaagccca	cctgc当地	1560
atcagcatcc	agtgtctac	gtgtctgc	ctgaa	acttctgc	cgaggccg	1620
atccacgtgt	tcatgc当地	ctgttca	gccc当地	ccaagacca	ggccaa	1680
gtgaacgtga	tcagc当地	gaagaatgc	gaggac	ttccagacat	gcacatcg	1740
gccacccctgt	acaccgagag	ccacgtc	ccca	agggtggcc	catgaatgc	1800
tttctgttgg	aactgc当地	gtc当地	gaaagccg	acgccc	ccacgacacc	1860
gtggagaa	ttgtatcc	ggccaa	acgc当地	gcaacgc	cgtgacc	1920
agcggctgca	aagatgc	ggaatgg	gagaagaa	tcaaa	aggttctgc	1980
ttctgtcaca	tcgtgc当地	accatgc	tttcatca	accatgc	tttcatca	2019

SEQ ID NO: 47	moltype = DNA length = 360					
FEATURE	Location/Qualifiers					
source	1..360					
	mol_type = other DNA					
	organism = synthetic construct					
SEQUENCE: 47						
cagataactc	tgc当地	aggaggagac	gtggtgca	cgggcagatc	tctcaggctt	60
tcatgtgoc	ccatgtgctt	cacatttgc	tcttatca	tacattgggt	caggcaggct	120
cctggcaagg	gtttggatg	ggttagcgtt	acctggcat	atggatctaa	caaataactac	180
gccc当地	ttatgggtcg	atttca	tctcgagaca	attcaaaa	cacactctac	240
ctgc当地	actacttag	agcaggag	actgggtgtt	attactgc	cagagcaaaa	300
ttcggc当地	cacatgtt	ccacgtt	ggacaaggaa	ccctcgta	actatcttagt	360

SEQ ID NO: 48	moltype = DNA length = 360					
FEATURE	Location/Qualifiers					
source	1..360					
	mol_type = other DNA					
	organism = synthetic construct					
SEQUENCE: 48						
caagatcaccc	tgaggggatc	tggaggc	gtggc	cagg	cctgagact	60
agctgc当地	cctctgatt	cacattc	agctacgc	tccact	gggt	120
cctggcaagg	gactggatg	ggtggcgtt	acctggc	acggc	caag	180
gccc当地	ttatggcag	gttcc	agcagg	aca	acgcaaaa	240
ctgc当地	actctctg	ggccgagg	acagg	ctgt	cagg	300
ttcggt当地	ccca	ccag	actgg	ccct	gtgac	360

SEQ ID NO: 49	moltype = DNA length = 321					
FEATURE	Location/Qualifiers					
source	1..321					
	mol_type = other DNA					
	organism = synthetic construct					
SEQUENCE: 49						
gtatattgtt	tgaccaatc	accatcttt	ctgagc	gtgtc	ggcga	60
atcacatgc	gagcaagca	aggaatca	aattatct	catgtt	atca	120
ggtatcgcc	cgaaaacttct	tat	tcgca	gtca	aaaggcgg	180
agatttgg	gcagcggctc	cgggact	aa	tat	ttct	240
gaagat	ccacatatta	ctggc	aggcag	ctt	aaat	300
ggaactaa	at	ggc	actt	cc	tttgg	321

SEQ ID NO: 50	moltype = DNA length = 321
FEATURE	Location/Qualifiers
source	1..321
	mol_type = other DNA

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SEQUENCE: 50
organism = synthetic construct
gacatcgtga tgaccaggag ccctagttc ctgtctgcca gcgtgggaga cagggtgacc 60
atcacctgca gagccagcca gggcatcaat aactacctgg cctggtacca gcagaaggccc 120
ggcattgccc ccaagctct gatctaegcc gccagcaccc tgcaaagccg cgtgcctct 180
aggttcgccg gatctggaaag cggcaccgag ttacccctga ccattagcag cctgcagccc 240
gaggacttcg ccacactacta ctggcagcag ctgaagagct accccttcac cttcgccct 300
ggcacaagg tggagatcaa g 321

SEQ ID NO: 51      moltype = DNA length = 726
FEATURE           Location/Qualifiers
source            1..726
                  mol_type = other DNA
                  organism = synthetic construct

SEQUENCE: 51
caqatcaccc tgaggggagtc tggaggcgac qtgggtcagc ctggaggagg cctgagactg 60
agctgcgcg cctctggatt cacttcago agtacgcaca tccactgggt caggcaggct 120
cctggcaagg gactggagt ggtggccgtt acctggcagc acggcagccaa caagtactac 180
ggcgagagc ttatggcag gttcaccatc agcaggggaca acagaagaaa caccctgtac 240
ctgcacatga actctcttag ggcgaggac acaggcgtgt actactgcgc cagggccaag 300
ttcggtgagc cccagttactt ccagoactgg ggccaggggaa cctctggac cgtgtctct 360
ggcggagggg gatctggagg aggagaagt ggaggcggtt gcagcgcacat cgtgtatgacc 420
cagagcccta gtttctgtc tgccagcgtt ggagacagggg tgaccatcac ctgcagagcc 480
agccaggggca tcaataacta cttggccctgg taccaggaga agccccggat tgcccccaag 540
ctctgtatct acggcccgac caccctgca aegggcgtgc cctcttaggtt cggggatct 600
gaaagcggca ccgagttcac cttgaccatt agcagcgtgc agcccgaggaa ctteggccacc 660
tactactgca agcagctgaa gagctacccc ttacacccctg gcccctggac caaggtggag 720
atcaag 726

SEQ ID NO: 52      moltype = DNA length = 486
FEATURE           Location/Qualifiers
source            1..486
                  mol_type = other DNA
                  organism = synthetic construct

SEQUENCE: 52
atgcgcattt gcaagcccca cctgcggagc atcagcatcc agtgcgtaccc gtgcctgtc 60
ctgaacacggc acttcctgac cgaggccggc atccacgtgt tcacccctggg ctgcttcagc 120
ggcggactgc ccaagaccga gggcaactgg gtgaacgtga tcagcgcact gaagaagatc 180
gaggacctga tccagcgtat gcacatcgac gcccacccgtt acaccggag cgacgtgcac 240
cccacgtca aggtgaccgc catgaagtgc ttctctgtgg aactgcgtt gatcgcctg 300
gaaagcggcg acggccgcatt ccacgcaccc gtggagaacc tgatcatctt ggcacaaac 360
agcctgagca gcaacggcaa cgtgaccggag aegggcgtgc aagagtgcga ggaactggaa 420
gagaagaaca tcaaaagagtt tctgcagago ttctgtgcaca tcgtgcagat gttcatcaac 480
accagc 486

SEQ ID NO: 53      moltype = DNA length = 486
FEATURE           Location/Qualifiers
source            1..486
                  mol_type = other DNA
                  organism = synthetic construct

SEQUENCE: 53
atgaggatca gcaagcctca cctgaggagc attagcatcc agtgcgtaccc gtgcctgtc 60
ctgaactccc acttcctgac cgaggccggc atccacgttc tcacccctggg ctgcttcagc 120
gtctggctgc ccaaaaaccga gggcaactgg gtgaacgtga tcagcgcact caagaagatc 180
gaggacctga tccagcgtat gcacatcgac gcccacccgtt ataccggag cgacgtgcac 240
cccacgtca aggtgaccgc catgaagtgc ttctctgtgg aactgcgtt catcgcctg 300
gagagcggcg atggccgcatt ccacgcaccc gtggagaacc tgatcatctt ggcacaaac 360
agecctgagca gcaacggaa cgtgaccggag tccggctgcata aggagtgcga ggagctggag 420
gagaagaaca tcaaggagtt cctgcagttt tcgtgcaca tcgtgcagat gttcatcaac 480
accagc 486

SEQ ID NO: 54      moltype = DNA length = 141
FEATURE           Location/Qualifiers
source            1..141
                  mol_type = other DNA
                  organism = synthetic construct

SEQUENCE: 54
aggggccgccc ccattgaggt gatgtacccc cccccctacc tggacaacga gaagagcaac 60
ggcaccatca tccacgtgaa gggcaagcac ctctgcccata gccccctgtt ccctggaccc 120
agcaagccca aggaccccaa g 141

SEQ ID NO: 55      moltype = DNA length = 1968
FEATURE           Location/Qualifiers
source            1..1968
                  mol_type = other DNA
                  organism = synthetic construct

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SEQUENCE: 55

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atggaatttcg ggctgtcctg gctttctt gtgcatttca ttaaggcggt ccaatgtcag 60
ataactctgc gcgagtccgg aggagacgtg gtgcacccgg gcagatctt caggcttca 120
tgtgcccoca gtggcttac attagctt tatgcaatac attgggtcag gcaggcttct 180
ggcaaggcggt tggaaatgggt agcggttacc tggcatgtg gatctaaca atactacgcc 240
gagtctgtta tgggtcgatt cacaatttctt cgagacaat caaaaaacac actcttacccg 300
catatgaact cacttagagc agaggacact ggtgtctatt actgcgcagc agcaaaaattc 360
ggcgagccac agatattcca gcaactggga caaggAACCC tcgtaaacagt atctatggg 420
ggcgagggtt ctggaggagg gggggcggtt ggaggcggtt ctgtatattgt tatgacc 480
tcaccatctt ttctgacgc tagtgcgcg gacagggttta caatcacatg ccgagcaacg 540
caaggaaatca acaattatcc cgcgttacc aacaaaaaaac caggatcgc cccgaaactt 600
cttattttacg cagcatcaac cctgcacaaagg ggagtccctt ctagattttgg tggcagccgc 660
tccgggacty aatttactt tactattttcc tcccttcaac ccgaagattt cgccacatata 720
taactgcggc agcttaatgc ataccccttc acctttggcc caggaactaa agtttgaatc 780
aaacggggcc cgcgaatgtt agttatgtat ctccttccat acctagacaa tgagaagagc 840
aatggaaacca ttatccatgt gaaaaggaaa cacccttgc tcagtcctt atttcccgaa 900
ccttctaaacg ccaaaagatcc caaattttgg gtgtcggtgg tgggtgggtt agtcttggct 960
tgctatagct tgcttagtaa cttttttttt attttttttt ggggtgtttt cgcacccca 1020
cgccgcgcgc cgcgcacaa agatgtttttt gtcttacatca acatgcgcagg caggggccgc 1080
gtgaaggatca gcaaggacgc agacgcggcc gcttaccaggc agggccggaa ccagtcctat 1140
aacgagctca atcttaggacg aagagaggag tacgtatgtt tggacaaaag acgtggccgg 1200
gaccctgaga tggggggaaa gcccggaaagg aagaacccctc aggaaggctt gtacaatgaa 1260
ctgcagaaag ataaatggc ggaggcttac agtgatgggg ggtggaaagg cggcgcgg 1320
agggggcaagg ggcacgtgg ctttttccagg ggttccatgtt cagccaccaa ggacacctac 1380
gacgccttc acatgcggc cttttttttt cggggacgcg agtgtactaa ttatgtctc 1440
ttgaaatggg ctggagatgt tgagacaaat cccggggccca tgcgcattttt caagccccac 1500
ctgcggagca tcagcatccca gtgttacccctt tgcgttgc tgaacacgcga ctttttgcacc 1560
gaggccggca tccacgtttt cttttttttt tgcttccatgtt cggggacttcc caagaccgg 1620
gccaacttgg tgaacgtgtat cagegacccgtt aagaagatcg agggactgtat ccagatcgat 1680
cacatcgacg ccacccctgtt caccggagac gacgtgcacc ccagctgcac ggttaccgc 1740
atgaagtgct ttctgttgcgactgcggatgtt atcagcgttgcgaaatggggccca cggccgcac 1800
caccgacatccggagaaatccatgtt caccggatgtt gatcatcttgcaccaacaa gcttccatgtt ccacggcaac 1860
gtgacccgaga gcccgttgcacca agatgtgcgag gaaactggaa agaagaaatcat cttttttttt 1920
ctgcagatgtt tcgtgcacatgtt cttttttttt cttttttttt cttttttttt 1968

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SEQ ID NO: 56 moltype = DNA length = 81
 FEATURE Location/Qualifiers
 source 1..81
 mol_type = other DNA
 organism = synthetic construct

SEQUENCE: 56 ttctgggtgc tgggtcggtt gggggcggtt ctggcctgtt acagcctgtt ggtgacatgtt 60
 gcctttatca tcttctgggtt c 81

SEQ ID NO: 57 moltype = DNA length = 72
 FEATURE Location/Qualifiers
 source 1..72
 mol_type = other DNA
 organism = synthetic construct

SEQUENCE: 57 ctgtgcgcaca gaccttaggag aagcccccgc caggaagacg gaaaggcttta catcaacatgtt 60
 cccggaaagg gaa 72

SEQ ID NO: 58 moltype = DNA length = 336
 FEATURE Location/Qualifiers
 source 1..336
 mol_type = other DNA
 organism = synthetic construct

SEQUENCE: 58 agggtaatgtt tcagccggtc tgctgtatgtt cccggcttacc agcaaggccca aaaccaggctt 60
 tacaacgacg tgaaccttggg caggagagaa ggttccatgtt cggggacttcc caagaccgg 120
 agggaccccg agatgggggg caagccacaa aggaagaacc cccaggagggtt cttttttttt 180
 gagctgcaga aggacaatgtt gggccggcc tacagcgtttt gggcgagaga 240
 agaaaggccca agggccacgtt cggattgttcc cggggcttgcacca gacccgttcc 300
 tacgacgcgcgc tgcataatgtt agtcttgcctt cttttttttt 336

SEQ ID NO: 59 moltype = AA length = 29
 FEATURE Location/Qualifiers
 source 1..29
 mol_type = protein
 organism = synthetic construct

SEQUENCE: 59 MRISKPHLRS ISIQCYLCALL LNSHFLTEA 29

SEQ ID NO: 60 moltype = DNA length = 1356
 FEATURE Location/Qualifiers

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source          1..1356
               mol_type = other DNA
               organism = synthetic construct

SEQUENCE: 60
cagatcaccc tgagggagtc tggaggcgac gtgggtgcage ctggaaaggag cctgagactg 60
agotgcgcg cctctggatt caccctcagc agtacgcaca tccactgggt caggcaggct 120
cctggcaagg gactggagt ggtggccgtt acctggcactc acggcagcaa caagtactac 180
gcggagagcg ttatggcag gttcaccatc agcaggagaca acagcaagaa caccctgtac 240
ctgcacatga actctctgag ggccgaggac acaggcgtgt actactgcgc cagggccaag 300
ttcggtgacg ccacgtactt ccacgtactgg ggcaggggaa cctgggtgac cgtgtcttct 360
ggccgggggg gatctggagg aggaggaaat ggaggcgttg gcaggcgcacat cgtgtatgacc 420
cagagcccta gttctctgtc tgccagcgttg ggagacagggg tgaccatcac ctgcagagcc 480
agccaggcga tcaataacta cctggctgg taccagcaga agcccgcat tgccccaaag 540
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SEQ ID NO: 61      moltype = AA  length = 39
FEATURE
source          1..39
               mol_type = protein
               organism = synthetic construct

SEQUENCE: 61
IEVMYPPPYL DNEKSNGTII HVKGKHLCP S PLFPGPSKP 39

SEQ ID NO: 62      moltype = DNA  length = 117
FEATURE
source          1..117
               mol_type = other DNA
               organism = synthetic construct

SEQUENCE: 62
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catgttggaaat ggaaacacctt ttgttccaaat cccctatttc ccggaccccttc taagccc 117

SEQ ID NO: 63      moltype = DNA  length = 117
FEATURE
source          1..117
               mol_type = other DNA
               organism = synthetic construct

SEQUENCE: 63
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cacgttggaaat gcaaggccatc ctggccatgg cccctgttcc ctggacccgg caagccc 117

SEQ ID NO: 64      moltype = AA  length = 41
FEATURE
source          1..41
               mol_type = protein
               organism = synthetic construct

SEQUENCE: 64
RSKRSRLLHS DYMNMTPRRP GPTRKHYPQY APPRDFAAYR S 41

SEQ ID NO: 65      moltype = AA  length = 5
FEATURE
source          1..5
               mol_type = protein
               organism = synthetic construct
REPEAT
               note = GGGGS can be repeated n times where n is an integer
               of at least 1, 2, 3, 4, 5, 6, 7, 8, 9, or 10.

SEQUENCE: 65
GGGGS

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1. A method for treating a cancer in a subject in need thereof, comprising administering to the subject a therapeutically effective amount of cells expressing a chimeric antigen receptor (CAR) comprising an anti-B-cell maturation antigen antibody or antigen binding fragment thereof, a hinge domain, a transmembrane domain, a DAP10 costimulatory domain, and at least one intracellular signaling domain.
2. The method of claim 2, wherein the cancer is a relapsed or refractory multiple myeloma.
3. The method of claim 2, wherein the therapeutically effective amount of cells is formulated in a cryopreservation medium comprising a non-pyrogenic and isotonic crystalloid solution, dimethyl sulfoxide (DMSO), a disaccharide and human serum albumin (HSA).
4. The method of claim 3, wherein the cryopreservation medium comprises 37.7% v/v PLASMA-LYTE, 50% v/v dimethyl sulfoxide (DMSO), 30 mM trehalose and 2.35% w/v human serum albumin (HSA).
5. The method of claim 1, wherein the therapeutically effective amount is about 100 million cells, 500 million cells or 1500 million cells.
6. The method of claim 1, wherein the administration is intravenous.
7. The method of claim 1, wherein the anti-BCMA antibody or antigen binding fragment thereof comprises (a) a heavy chain variable region comprising complementarity determining regions (CDRs) of SEQ ID NOS: 2, 3 and 4; and (b) a light chain variable region comprising CDRs of SEQ ID NOS: 6, 7 and 8.
8. The method of claim 1, wherein the anti-BCMA antibody or antigen binding fragment thereof comprises, a heavy chain variable region (VH) comprising an amino acid sequence having at least about 85% identity to SEQ ID NO: 1; and a light chain variable region (VL) comprising an amino acid sequence having at least about 85% identity to SEQ ID NO: 5.
9. The method of claim 1, wherein the anti-BCMA antibody or antigen binding fragment thereof is a single chain variable fragment (scFv) comprising an amino acid sequence having at least about 85% identity to SEQ ID NO: 20.
10. The method of claim 1, wherein the DAP10 co-stimulatory domain comprises an amino acid sequence having at least 85% identity to SEQ ID NO: 24.
11. The method of claim 1, wherein the hinge is a CD28 hinge having at least 85% identity to the amino acid sequence of SEQ ID NO: 21.
12. The method of claim 1, wherein the transmembrane domain is a CD28 transmembrane domain having at least 85% identity to the amino acid sequence of SEQ ID NO: 22.
13. The method of claim 1, wherein the intracellular signaling domain is a CD3ζ signaling domain having at least 85% identity to the amino acid sequence of SEQ ID NO: 23.
14. The method of claim 1, wherein the CAR further comprises an IL-15, or variant thereof.
15. The method of claim 14, wherein the IL-15 comprises at least 85% identity to the amino acid sequence of SEQ ID NO: 26.
16. The method of claim 1, wherein the CAR comprises an amino acid sequence having at least 85% identity to SEQ ID NO: 13.
17. The method of claim 16, wherein the CAR has 100% identity to any one of SEQ ID NO: 13.
18. The method of claim 1, wherein the CAR comprises an amino acid sequence having at least 85% identity to SEQ ID NO: 29.
19. The method of claim 18, wherein the CAR has 100% identity to any one of SEQ ID NO: 29.
20. A method for treating a cancer in a subject in need thereof, comprising administering to the subject a therapeutically effective amount of polynucleotide encoding a chimeric antigen receptor (CAR) comprising an anti-B-cell maturation antigen antibody or antigen binding fragment thereof, a hinge domain, a transmembrane domain, a DAP10 costimulatory domain, and at least one intracellular signaling domain.
21. The method of claim 20, wherein the polynucleotide comprises a nucleic acid sequence having at least 95% identity to SEQ ID NO: 25.
22. The method of claim 21, wherein the polynucleotide comprises the nucleic acid sequence of SEQ ID NO: 25.
23. The method of claim 20, wherein the polynucleotide comprises a nucleic acid sequence having at least 95% identity to SEQ ID NO: 60.
24. The method of claim 23, wherein the polynucleotide comprises the nucleic acid sequence of SEQ ID NO: 60.
25. The method of claim 20, wherein the polynucleotide encoding a BCMA chimeric antigen receptor (CAR) comprises a codon optimized sequence having at least 95% identity to any one of SEQ ID NO: 35 or SEQ ID NO: 51.
26. The polynucleotide of claim 25, wherein the codon-optimized sequence has 100% identity to any one of SEQ ID NO: 35 or SEQ ID NO: 51.
27. The method of claim 1, wherein the cell comprises a polynucleotide encoding a BCMA specific chimeric antigen receptor, wherein the polynucleotide comprises a codon optimized sequence of SEQ ID NO: 35 or SEQ ID NO: 51.
28. The method of claim 27, wherein the cell is an immune cell.
29. The method of claim 28, wherein the cell is a natural killer (NK) cell, T cell, gamma delta T cell, alpha beta T cell, invariant NKT (iNKT) cell, B cell, macrophage, mesenchymal stromal cell, dendritic cell, or a mixture thereof.
30. The cell of claim 29, wherein the cell is a T cell or a NK cell.

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