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FIGURE 1



(57) Abstract: Chimeric antigen receptors containing ROR1 antigen binding domains are disclosed. Nucleic acids, recombinant expression vectors, host cells, antigen binding fragments, and pharmaceutical compositions, relating to the chimeric antigen receptors are also disclosed. Methods of treating or preventing cancer in a subject, and methods of making chimeric antigen receptor T cells are also disclosed.



COMPOSITIONS AND METHODS FOR TREATING CANCER WITH ANTI-ROR1 IMMUNOTHERAPY

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of priority under 35 U.S.C. Section 119(e) to U.S. Provisional Patent Application No. 62/581,284 filed on November 3, 2017, the entire contents of which are incorporated herein by reference.

SEQUENCE LISTING

The instant application contains a Sequence Listing which has been submitted electronically in ASCII format and is hereby incorporated by reference in its entirety. The ASCII copy, created on October 25, 2018, is named SequenceListing.txt and is 90.0 kilobytes in size.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

This invention was created in the performance of a Cooperative Research and Development Agreement with the National Institutes of Health, an Agency of the Department of Health and Human Services. The Government of the United States has certain rights in this invention.

FIELD OF THE DISCLOSURE

This application relates to the field of cancer, particularly to ROR1 antigen binding domains and chimeric antigen receptors (CARs) containing such ROR1 antigen binding domains and methods of use thereof.

BACKGROUND

Cancer is one of the most deadly threats to human health. In the U.S. alone, cancer affects nearly 1.3 million new patients each year, and is the second leading cause of death after cardiovascular disease, accounting for approximately 1 in 4 deaths. Solid tumors are responsible

for most of those deaths. Although there have been significant advances in the medical treatment of certain cancers, the overall 5-year survival rate for all cancers has improved only by about 10% in the past 20 years. Cancers, or malignant tumors, metastasize and grow rapidly in an uncontrolled manner, making treatment extremely difficult.

There are numerous unmet therapeutic needs in the treatment of solid and liquid tumors. ROR1, receptor tyrosine kinase-like orphan receptor 1, is an embryonic protein that is highly expressed in many cancer types, including CLL, carcinoma of the breast, glioblastoma, lung adenocarcinoma and sarcomas (Ewing sarcoma, osteosarcoma, rhabdomyosarcoma, and fibrosarcoma), and is generally absent in normal tissues (Suping Zhang, et al., 2012, The Onco-Embryonic Antigen ROR1 Is Expressed by a Variety of Human Cancers. *Am J Pathol*, 181: 1903–1910, Ashwini Balakrishnan, et al., 2017, Analysis of ROR1 Protein Expression in Human Cancer and Normal Tissues., *Clin Cancer Res* 23:3061-3071, Borcharding, Nicholas et al., 2017, ROR1, an Embryonic Protein with an Emerging Role in Cancer Biology. *Protein & Cell* 5.7 (2014): 496–502). ROR1 has three splice variants, including a 104 kDa (up to 120 kDa depending on glycosylation) transmembrane glycoprotein comprised of 937 amino acids (1-29 signal peptide), and 2 smaller variants of intracellular and secreted forms (GeneBank NP_005003, Masiakowski, P., and Carroll, R.D., 1992, A Novel Family of Cell Surface Receptors with Tyrosine Kinase-like Domain, *J Biol Chem* 36: 26181-26190.). The presence of ROR1 on the surface of transformed cells indicates that targeting ROR1 will enable novel cancer treatments to be developed for a range of liquid cancer such as chronic lymphocytic leukemia (CLL) and other solid tumors (Borcharding, N., Kusner, D. et al., 2014, ROR1, an embryonic protein with an emerging role in cancer biology. *Protein & Cell*, 5:496–502).

Though generally absent in adult tissues, at least one report found ROR1 expression in parathyroid; pancreatic islets; and regions of the esophagus, stomach, and duodenum (Ashwini Balakrishnan, et al., 2017, Analysis of ROR1 Protein Expression in Human Cancer and Normal Tissues., *Clin Cancer Res* 23:3061-3071), warranting caution in clinical application of ROR1-targeted anti-cancer therapies. ROR1 receptor contains a cytosolic protein kinase domain, which, according to some reports, participates in Wnt and EGFR signaling (Borcharding, N., Kusner, D. et al., 2014, ROR1, an embryonic protein with an emerging role in cancer biology. *Protein & Cell*, 5:496–502). In tumors, ROR1 can induce epithelial to mesenchymal transition (EMT), and promote tumor proliferation, aggressiveness, and metastases formation, and mediate resistance to apoptosis (Yamaguchi, Tomoya, et al., 2012, "NKX2-1/TTF1/TTF-1-Induced ROR1 is required to sustain EGFR survival signaling in lung adenocarcinoma." *Cancer cell* 21.3: 348-361; Borcharding, N., Kusner, D. et al., 2014, ROR1, an embryonic protein with an emerging role in

cancer biology. *Protein & Cell*, 5:496–502). Its role in contributing to tumor phenotype indicates that it may serve an important function in tumor initiation or progression and therefore is a driver protein.

Earlier approaches in cancer treatment include surgery, radiation therapy, chemotherapy, and, for blood tumors – bone marrow transplant. However, the present first line treatments warrant further improvement. Such improvements are sought by the novel immunotherapeutic strategies. Ongoing pre-clinical investigations and clinical trials investigate targeting ROR 1 antigen have been developed using multiple modalities. T lymphocytes expressing ROR1-specific CARs have been tested both in murine and non-human primate systems (Huang X, Park H, Greene J, Pao J, Mulvey E, Zhou SX, et al., 2015, IGF1R- and ROR1-Specific CAR T Cells as a Potential Therapy for High Risk Sarcomas. *PLoS ONE* 10(7): e0133152; Hudecek M, Schmitt TM, Baskar S, Lupo-Stanghellini MT, Nishida T, Yamamoto TN, Bleakley M, Turtle CJ, Chang WC, Greisman HA, Wood B, Maloney DG, Jensen MC, Rader C, Riddell SR, 2010, The B-cell tumor-associated antigen ROR1 can be targeted with T cells modified to express a ROR1-specific chimeric antigen receptor. *Blood* 116:4532-41.). The lack of toxicity in non-human primates lends confidence that human studies can be approached (Berger, C., et al., 2015, Safety of targeting ROR1 in primates with chimeric antigen receptor-modified T cells. *Cancer Immunol Res* 3: 2016-216.). Both unmodified, and immunotoxin-linked antibodies to ROR1 have also been proposed for therapeutic use (Yang, Jiahui, et al., 2011, "Therapeutic potential and challenges of targeting receptor tyrosine kinase ROR1 with monoclonal antibodies in B-cell malignancies." *PloS One* 6.6: e21018; Baskar, Sivasubramanian, et al., 2012, "Targeting malignant B cells with an immunotoxin against ROR1." *MAbs*, 4:3, 349-361.). The present standard of care for B-lineage leukemias may consists of remission induction treatment by high dose of chemotherapy or radiation, followed by consolidation, and may feature stem cell transplantation and additional courses of chemotherapy as needed (*see the world wide web at cancer.gov*). High toxicity associated with these treatments, as well as the risk of complications, such as relapse, secondary malignancy, or GVHD, motivate the search for better therapeutic alternatives. Current open clinical trials include ROR1-targeted T cells for hematologic malignancy (Genetically Modified T-Cell Therapy in Treating Patients with Advanced ROR1+ Malignancies, NCT02706392, Sponsor: Fred Hutchinson Cancer Research Center, [ClinicalTrials.gov](https://clinicaltrials.gov) accessed 9/20/2017.), and ROR1-specific antibody for breast cancer given in the context of chemotherapy (Study of Circumtuzumab and Paclitaxel for Metastatic or Locally Advanced, Unresectable Breast Cancer, NCT02776917, Sponsor: Barbara Parker, MD, University of California, San Diego, [ClinicalTrials.gov](https://clinicaltrials.gov) accessed 9/20/2017).

Chimeric Antigen Receptors (CARs) are hybrid molecules comprising three essential units: (1) an extracellular antigen-binding motif, (2) linking/transmembrane motifs, and (3) intracellular T-cell signaling motifs (Long AH, Haso WM, Orentas RJ. Lessons learned from a highly-active CD22-specific chimeric antigen receptor, *OncoImmunology*. 2013; 2 (4):e23621). The antigen-binding motif of a CAR is commonly fashioned after a single chain Fragment variable (ScFv), the minimal binding domain of an immunoglobulin (Ig) molecule. Alternate antigen-binding motifs, such as receptor ligands (i.e., IL-13 has been engineered to bind tumor expressed IL-13 receptor), intact immune receptors, library-derived peptides, and innate immune system effector molecules (such as NKG2D) also have been engineered. Alternate cell targets for CAR expression (such as NK or gamma-delta T cells) are also under development (Brown CE et al *Clin Cancer Res*. 2012;18(8):2199–209; Lehner M et al. *PLoS One*. 2012; 7 (2):e31210). There remains significant work to be done with regard to defining the most active T-cell population to transduce with CAR vectors, determining the optimal culture and expansion techniques, and defining the molecular details of the CAR protein structure itself.

The linking motifs of a CAR can be a relatively stable structural domain, such as the constant domain of IgG, or designed to be an extended flexible linker. Structural motifs, such as those derived from IgG constant domains, can be used to extend the ScFv binding domain away from the T-cell plasma membrane surface. This may be important for some tumor targets where the binding domain is particularly close to the tumor cell surface membrane (such as for the disialoganglioside GD2; Orentas et al., unpublished observations). To date, the signaling motifs used in CARs always include the CD3- ζ chain because this core motif is the key signal for T cell activation. The first reported second-generation CARs featured CD28 signaling domains and the CD28 transmembrane sequence. This motif was used in third-generation CARs containing CD137 (4-1BB) signaling motifs as well (Zhao Y et al *J Immunol*. 2009; 183 (9): 5563–74). With the advent of new technology, the activation of T cells with beads linked to anti-CD3 and anti-CD28 antibody, and the presence of the canonical “signal 2” from CD28 was no longer required to be encoded by the CAR itself. Using bead activation, third-generation vectors were found to be not superior to second-generation vectors in *in vitro* assays, and they provided no clear benefit over second-generation vectors in mouse models of leukemia (Haso W, Lee DW, Shah NN, Stetler-Stevenson M, Yuan CM, Pastan IH, Dimitrov DS, Morgan RA, FitzGerald DJ, Barrett DM, Wayne AS, Mackall CL, Orentas RJ. Anti-CD22-chimeric antigen receptors targeting B cell precursor acute lymphoblastic leukemia, *Blood*. 2013; 121 (7):1165–74; Kochenderfer JN et al. *Blood*. 2012; 119 (12):2709–20). This is borne out by the clinical success of CD19-specific CARs that are in a second generation CD28/CD3- ζ (Lee DW et al. American Society of

Hematology Annual Meeting. New Orleans, LA; December 7-10, 2013) and CD137/CD3- ζ signaling formats (Porter DL et al. N Engl J Med. 2011; 365 (8): 725–33). In addition to CD137, other tumor necrosis factor receptor superfamily members such as OX40 also are able to provide important persistence signals in CAR-transduced T cells (Yvon E et al. Clin Cancer Res. 2009;15(18):5852–60). Equally important are the culture conditions under which the CAR T-cell populations were cultured, for example the inclusion of the cytokines IL-2, IL-7, and/or IL-15 (Kaiser AD et al. Cancer Gene Ther. 2015; 22(2):72-78).

Current challenges in the more widespread and effective adaptation of CAR therapy for cancer relate to a paucity of compelling targets. Creating binders to cell surface antigens is now readily achievable, but discovering a cell surface antigen that is specific for tumor while sparing normal tissues remains a formidable challenge. One potential way to imbue greater target cell specificity to CAR-expressing T cells is to use combinatorial CAR approaches. In one system, the CD3- ζ and CD28 signal units are split between two different CAR constructs expressed in the same cell; in another, two CARs are expressed in the same T cell, but one has a lower affinity and thus requires the alternate CAR to be engaged first for full activity of the second (Lanitis E et al. Cancer Immunol Res. 2013;1(1):43–53; Kloss CC et al. Nat Biotechnol. 2013;31(1):71–5). A second challenge for the generation of a single ScFv-based CAR as an immunotherapeutic agent is tumor cell heterogeneity. At least one group has developed a CAR strategy for glioblastoma whereby the effector cell population targets multiple antigens (HER2, IL-13Ra, EphA2) at the same time in the hope of avoiding the outgrowth of target antigen-negative populations. (Hegde M et al. Mol Ther. 2013;21(11):2087–101).

T-cell-based immunotherapy has become a new frontier in synthetic biology; multiple promoters and gene products are envisioned to steer these highly potent cells to the tumor microenvironment, where T cells can both evade negative regulatory signals and mediate effective tumor killing. The elimination of unwanted T cells through the drug-induced dimerization of inducible caspase 9 constructs with chemical-based dimerizers, such as AP1903, demonstrates one way in which a powerful switch that can control T-cell populations can be initiated pharmacologically (Di Stasi A et al. N Engl J Med. 2011;365(18):1673–83). The creation of effector T-cell populations that are immune to the negative regulatory effects of transforming growth factor- β by the expression of a decoy receptor further demonstrates the degree to which effector T cells can be engineered for optimal antitumor activity (Foster AE et al. J Immunother. 2008;31(5):500–5). Thus, while it appears that CARs can trigger T-cell activation in a manner similar to an endogenous T-cell receptor, a major impediment to the clinical application of this technology to date has been limited *in vivo* expansion of CAR⁺ T cells, rapid disappearance of the

cells after infusion, and disappointing clinical activity. This may be due in part to the murine origin of some of the CAR sequences employed.

The requirement of patients who have received either antibody or CAR-T therapy to subsequently undergo HSCT in order to maintain durable responses remains an area of active debate. Although high responses are reported for CD19 CAR-T trials, at least 20% of patients fail in the near-term (Davis KL, Mackall CL, 2016, *Blood Advances* 1:265-268). The best results at 12 months post-CAR19 treatment reported show a RFS of 55% and OS of 79% in patients who were able to receive the T cell product at the University of Pennsylvania (Maude SL, Teachey DT, Rheingold SR, Shaw PA, Aplenc R, Barrett DM, Barker CS, Callahan C, Frey NV, Farzana N, Lacey SF, Zheng A, Levine B, Melenhorst JJ, Motley L, Porter DL, June CH, Grupp SA, 2016, *J Clin Oncol* 34, no.15_suppl (May 2016) 3011-3011). Given the expected long term responses of 50% or less, there remains significant clinical need for new B cell malignancy targets such as ROR1.

The present invention addresses these needs by providing CAR compositions and therapeutic methods that can be used to treat cancers and other diseases and/or conditions. In particular, the present invention as disclosed and described herein provides CARs that may be used for the treatment of diseases, disorders or conditions associated with dysregulated expression of ROR1 and which CARs contain ROR1 antigen binding domains that exhibit a high surface expression on transduced T cells, exhibit a high degree of cytotoxicity of ROR1-expressing cells, and in which the transduced T cells demonstrate *in vivo* expansion and persistence.

SUMMARY

Novel anti-ROR1 antibodies or antigen binding domains thereof and chimeric antigen receptors (CARs) that contain such ROR1 antigen binding domains are provided herein, as well as host cells (e.g., T cells) expressing the receptors, and nucleic acid molecules encoding the receptors. The CARs exhibit a high surface expression on transduced T cells, with a high degree of cytotoxicity, and with transduced T cell expansion and persistence *in vivo*. Methods of using the disclosed CARs, host cells, and nucleic acid molecules are also provided, for example, to treat a cancer in a subject.

Thus, in one aspect, an isolated polynucleotide encoding a human anti-ROR1 antibody or a fragment thereof is provided comprising a nucleic acid sequence selected from the group consisting of SEQ ID NOs: 1 and 7.

In one embodiment, an isolated polynucleotide encoding a fully human anti-ROR1 antibody or a fragment thereof is provided, wherein the antibody or a fragment thereof comprises a fragment selected from the group consisting of an Fab fragment, an F(ab')₂ fragment, an Fv fragment, and a single chain Fv (ScFv).

In one embodiment, an isolated polynucleotide encoding a fully human anti-ROR1 antibody or a fragment thereof is provided, wherein the antibody or a fragment thereof comprises an amino acid sequence selected from the group consisting of SEQ ID NOs: 2 and 8.

In one aspect, an isolated nucleic acid molecule encoding a chimeric antigen receptor (CAR) is provided comprising, from N-terminus to C-terminus, at least one ROR1 antigen binding domain encoded by a nucleotide sequence comprising a nucleic acid sequence selected from the group consisting of SEQ ID NOs: 1 and 7, at least one transmembrane domain, and at least one intracellular signaling domain.

In one embodiment, an isolated nucleic acid molecule encoding the CAR is provided wherein the encoded extracellular ROR1 antigen binding domain comprises at least one single chain variable fragment of an antibody that binds to ROR1.

In another embodiment, an isolated nucleic acid molecule encoding the CAR is provided wherein the encoded extracellular ROR1 antigen binding domain comprises at least one heavy chain variable region of an antibody that binds to ROR1.

In yet another embodiment, an isolated nucleic acid molecule encoding the CAR is provided wherein the encoded CAR extracellular ROR1 antigen binding domain further comprises at least one lipocalin-based antigen binding antigen (anticalins) that binds to ROR1.

In one embodiment, an isolated nucleic acid molecule is provided wherein the encoded extracellular ROR1 antigen binding domain is connected to the transmembrane domain by a linker domain.

In another embodiment, an isolated nucleic acid molecule encoding the CAR is provided wherein the encoded ROR1 extracellular antigen binding domain is preceded by a sequence encoding a leader or signal peptide.

In yet another embodiment, an isolated nucleic acid molecule encoding the CAR is provided comprising at least one ROR1 antigen binding domain encoded by a nucleotide sequence comprising a nucleic acid sequence selected from the group consisting of SEQ ID NOs: 1 and 7, and wherein the CAR additionally encodes an extracellular antigen binding domain targets an antigen that includes, but is not limited to, CD19, CD20, CD22, mesothelin, CD33, CD38, CD123 (IL3RA), CD138, BCMA (CD269), GPC2, GPC3, FGFR4, c-Met, PSMA, Glycolipid F77, EGFRvIII, GD-2, TSLPR, NY-ESO-1 TCR, MAGE A3 TCR, or any combination thereof.

In certain embodiments, an isolated nucleic acid molecule encoding the CAR is provided wherein the additionally encoded extracellular antigen binding domain comprises an anti-CD19 ScFv antigen binding domain, an anti-CD20 ScFv antigen binding domain, an anti-CD22 ScFv antigen binding domain, an anti-mesothelin ScFv antigen binding domain, an anti-CD33 ScFv antigen binding domain, an anti-CD38 ScFv antigen binding domain, an anti-CD123 (IL3RA) ScFv antigen binding domain, an anti-CD138 ScFv antigen binding domain, an anti-BCMA (CD269) ScFv antigen binding domain, an anti-GPC2 ScFv antigen binding domain, an anti-GPC3 ScFv antigen binding domain, an anti-FGFR4 ScFv antigen binding domain, an anti-TSLPR ScFv antigen binding domain, an anti-c-Met ScFv antigen binding domain, an anti-PMSA ScFv antigen binding domain, an anti-glycolipid F77 ScFv antigen binding domain, an anti-EGFRvIII ScFv antigen binding domain, an anti-GD-2 ScFv antigen binding domain, an anti-NY-ESO-1 TCR ScFv antigen binding domain, an anti-MAGE A3 TCR ScFv antigen binding domain, or an amino acid sequence with 85%, 90%, 95%, 96%, 97%, 98% or 99% identity thereof, or any combination thereof.

In one aspect, the CARs provided herein further comprise a linker or spacer domain.

In one embodiment, an isolated nucleic acid molecule encoding the CAR is provided wherein the extracellular ROR1 antigen binding domain, the intracellular signaling domain, or both are connected to the transmembrane domain by a linker (L), hinge (H), or spacer domain.

In one embodiment, an isolated nucleic acid molecule encoding the CAR is provided wherein the encoded linker domain is derived from the extracellular domain of CD8 or CD28, and is linked to a transmembrane domain.

In another embodiment, an isolated nucleic acid molecule encoding the CAR is provided wherein the encoded CAR further comprises a transmembrane domain that comprises a transmembrane domain of a protein selected from the group consisting of the alpha, beta or zeta chain of the T-cell receptor, CD28, CD3 epsilon, CD45, CD4, CD5, CD8, CD9, CD16, CD22, CD33, CD37, CD64, CD80, CD83, CD86, CD134, CD137 and CD154, or a combination thereof.

In yet another embodiment, an isolated nucleic acid molecule encoding the CAR is provided wherein the encoded intracellular signaling domain further comprises a CD3 zeta intracellular domain.

In one embodiment, an isolated nucleic acid molecule encoding the CAR is provided wherein the encoded intracellular signaling domain is arranged on the N-terminal side relative to the CD3 zeta intracellular domain.

In another embodiment, an isolated nucleic acid molecule encoding the CAR is provided wherein the encoded at least one intracellular signaling domain comprises a costimulatory domain, a primary signaling domain, or a combination thereof.

In further embodiments, an isolated nucleic acid molecule encoding the CAR is provided wherein the encoded at least one costimulatory domain comprises a functional signaling domain of OX40, CD70, CD27, CD28, CD5, ICAM-1, LFA-1 (CD11a/CD18), ICOS (CD278), DAP10, DAP12, and 4-1BB (CD137), or a combination thereof.

In one embodiment, an isolated nucleic acid molecule encoding the CAR is provided that further contains a leader sequence or signal peptide wherein the leader or signal peptide (LP) nucleotide sequence comprises the nucleotide sequence of SEQ ID NO: 19.

In yet another embodiment, an isolated nucleic acid molecule encoding the CAR is provided wherein the encoded leader sequence comprises the amino acid sequence of SEQ ID NO: 20.

In one aspect, a chimeric antigen receptor (CAR) is provided herein comprising, from N-terminus to C-terminus, at least one ROR1 antigen binding domain, at least one transmembrane domain, and at least one intracellular signaling domain.

In one embodiment, a CAR is provided wherein the extracellular ROR1 antigen binding domain comprises at least one single chain variable fragment of an antibody that binds to the antigen, or at least one heavy chain variable region of an antibody that binds to the antigen, or a combination thereof.

In another embodiment, a CAR is provided wherein the at least one transmembrane domain comprises a transmembrane domain of a protein selected from the group consisting of the alpha, beta or zeta chain of the T-cell receptor, CD28, CD3 epsilon, CD45, CD4, CD5, CD8, CD9, CD16, CD22, CD33, CD37, CD64, CD80, CD86, CD134, CD137, CD154, TNFRSF19, or a combination thereof.

In some embodiments, the CAR is provided wherein CAR additionally encodes an extracellular antigen binding domain comprising CD19, CD20, CD22, mesothelin, CD33, CD38, CD123 (IL3RA), CD138, BCMA (CD269), GPC2, GPC3, FGFR4, TSLPR, c-Met, PSMA, Glycolipid F77, EGFRvIII, GD-2, TSLPR, NY-ESO-1 TCR, MAGE A3 TCR, or an amino acid sequence with 85%, 90%, 95%, 96%, 97%, 98% or 99% identity thereof, or any combination thereof.

In one embodiment, the CAR is provided wherein the extracellular antigen binding domain comprises an anti-CD19 ScFv antigen binding domain, an anti-CD20 ScFv antigen binding domain, an anti-CD22 ScFv antigen binding domain, an anti-mesothelin ScFv antigen binding

domain, an anti-CD33 ScFv antigen binding domain, an anti-CD38 ScFv antigen binding domain, an anti-CD123 (IL3RA) ScFv antigen binding domain, an anti-CD138 ScFv antigen binding domain, an anti-BCMA (CD269) ScFv antigen binding domain, an anti-GPC2 ScFv antigen binding domain, an anti-GPC3 ScFv antigen binding domain, an anti-FGFR4 ScFv antigen binding domain, anti-TSLPR ScFv antigen binding domain, an anti-c-Met ScFv antigen binding domain, an anti-PMSA ScFv antigen binding domain, an anti-glycolipid F77 ScFv antigen binding domain, an anti-EGFRvIII ScFv antigen binding domain, an anti-GD-2 ScFv antigen binding domain, an anti-NY-ESO-1 TCR ScFv antigen binding domain, an anti-MAGE A3 TCR ScFv antigen binding domain, or an amino acid sequence with 85%, 90%, 95%, 96%, 97%, 98% or 99% identity thereof, or any combination thereof.

In another embodiment, a CAR is provided wherein the at least one intracellular signaling domain comprises a costimulatory domain and a primary signaling domain.

In yet another embodiment, a CAR is provided wherein the at least one intracellular signaling domain comprises a costimulatory domain comprising a functional signaling domain of a protein selected from the group consisting of OX40, CD70, CD27, CD28, CD5, ICAM-1, LFA-1 (CD11a/CD18), ICOS (CD278), DAP10, DAP12, and 4-1BB (CD137), or a combination thereof.

In one embodiment, the nucleic acid sequence encoding a CAR comprises the nucleic acid sequence of SEQ ID NO: 3 (LTG 1941 LP-ScFv4-CD8H/CD8TM-41BB-CD3zeta CAR nucleic acid sequence (FIGURE 2A)). In one embodiment, the nucleic acid sequence encodes a CAR comprising the amino acid sequence of SEQ ID NO: 4 (LTG 1941 LP-ScFv4-CD8H/CD8TM-41BB-CD3zeta CAR amino acid sequence (FIGURE 2A)).

In another embodiment, the nucleic acid sequence encoding a CAR comprises the nucleic acid sequence of SEQ ID NO: 5 (LTG 2528 LP-ScFv4-IgG4H/CD8TM-41BB-CD3zeta CAR nucleic acid sequence (FIGURE 2B)). In one embodiment, the nucleic acid sequence encodes a CAR comprising the amino acid sequence of SEQ ID NO: 6 (LTG 2528 LP-ScFv4-IgG4H/CD8TM-41BB-CD3 zeta CAR amino acid sequence (FIGURE 2B)).

In another embodiment, the nucleic acid sequence encoding a CAR comprises the nucleic acid sequence of SEQ ID NO: 9 (LTG1942 LP-ScFv9-CD8H/CD8TM-41BB-CD3zeta CAR nucleotide sequence (FIGURE 2C)). In one embodiment, the nucleic acid sequence encodes a CAR comprising the amino acid sequence of SEQ ID NO: 10 (LTG1942 LP-ScFv9-CD8H/CD8TM-41BB-CD3zeta CAR amino acid sequence (FIGURE 2C)).

In another embodiment, the nucleic acid sequence encoding a CAR comprises the nucleic acid sequence of SEQ ID NO: 11 (LTG2529 LP-ScFv9-IgG4H/CD8TM-41BB-CD3zeta CAR

nucleic acid sequence (FIGURE 2D)). In one embodiment, the nucleic acid sequence encodes a CAR comprising the amino acid sequence of SEQ ID NO: 12 (LTG2529 LP-ScFv9-IgG4H/CD8 TM-41BB-CD3zeta CAR amino acid sequence (FIGURE 2D)).

In one aspect, the CARs disclosed herein are modified to express or contain a detectable marker for use in diagnosis, monitoring, and/or predicting the treatment outcome such as progression free survival of cancer patients or for monitoring the progress of such treatment.

In one embodiment, the nucleic acid molecule encoding the disclosed CARs can be contained in a vector, such as a viral vector. The vector is a DNA vector, an RNA vector, a plasmid vector, a cosmid vector, a herpes virus vector, a measles virus vector, a lentivirus vector, adenoviral vector, or a retrovirus vector, or a combination thereof.

In certain embodiments, the vector further comprises a promoter wherein the promoter is an inducible promoter, a tissue specific promoter, a constitutive promoter, a suicide promoter or any combination thereof.

In yet another embodiment, the vector expressing the CAR can be further modified to include one or more operative elements to control the expression of CAR T cells, or to eliminate CAR-T cells by virtue of a suicide switch. The suicide switch can include, for example, an apoptosis inducing signaling cascade or a drug that induces cell death. In a preferred embodiment, the vector expressing the CAR can be further modified to express an enzyme such thymidine kinase (TK) or cytosine deaminase (CD).

In another aspect, host cells including the nucleic acid molecule encoding the CAR are also provided. In some embodiments, the host cell is a T cell, such as a primary T cell obtained from a subject. In one embodiment, the host cell is a CD8⁺ T cell.

In yet another aspect, a pharmaceutical composition is provided comprising an anti-tumor effective amount of a population of human T cells, wherein the T cells comprise a nucleic acid sequence that encodes a chimeric antigen receptor (CAR), wherein the CAR comprises at least one extracellular antigen binding domain comprising a human ROR1 antigen binding domain comprising the amino acid sequence of SEQ ID NO. 2, or 8, at least one linker domain, at least one transmembrane domain, and at least one intracellular signaling domain, wherein the T cells are T cells of a human having a cancer. The cancer includes, *inter alia*, a hematological cancer such as leukemia (e.g., chronic lymphocytic leukemia (CLL), acute lymphocytic leukemia (ALL), or chronic myelogenous leukemia (CML), lymphoma (e.g., mantle cell lymphoma, non-Hodgkin's lymphoma or Hodgkin's lymphoma) or multiple myeloma, or a combination thereof.

In one embodiment, a pharmaceutical composition is provided wherein the at least one transmembrane domain of the CAR contains a transmembrane domain of a protein selected from

the group consisting of the alpha, beta or zeta chain of the T-cell receptor, CD28, CD3 epsilon, CD45, CD4, CD5, CD8, CD9, CD16, CD22, Mesothelin, CD33, CD37, CD64, CD80, CD83, CD86, CD134, CD137, CD154, TNFRSF19, or a combination thereof.

In another embodiment, a pharmaceutical composition is provided wherein the human cancer includes an adult carcinoma comprising oral and pharynx cancer (tongue, mouth, pharynx, head and neck), digestive system cancers (esophagus, stomach, small intestine, colon, rectum, anus, liver, intrahepatic bile duct, gallbladder, pancreas), respiratory system cancers (larynx, lung and bronchus), bone and joint cancers, soft tissue cancers, skin cancers (melanoma, basal and squamous cell carcinoma), pediatric tumors (neuroblastoma, rhabdomyosarcoma, osteosarcoma, Ewing's sarcoma), tumors of the central nervous system (brain, astrocytoma, glioblastoma, glioma), and cancers of the breast, the genital system (uterine cervix, uterine corpus, ovary, vulva, vagina, prostate, testis, penis, endometrium), the urinary system (urinary bladder, kidney and renal pelvis, ureter), the eye and orbit, the endocrine system (thyroid), and the brain and other nervous system, or any combination thereof.

In yet another embodiment, a pharmaceutical composition is provided comprising an anti-tumor effective amount of a population of human T cells of a human having a cancer wherein the cancer is a refractory cancer non-responsive to one or more chemotherapeutic agents. The cancer includes hematopoietic cancer, myelodysplastic syndrome pancreatic cancer, head and neck cancer, cutaneous tumors, minimal residual disease (MRD) in acute lymphoblastic leukemia (ALL), acute myeloid leukemia (AML), adult B cell malignancies including, CLL (Chronic lymphocytic leukemia), CML (chronic myelogenous leukemia), non-Hodgkin's lymphoma (NHL), pediatric B cell malignancies (including B lineage ALL (acute lymphocytic leukemia)), multiple myeloma lung cancer, breast cancer, ovarian cancer, prostate cancer, colon cancer, melanoma or other hematological cancer and solid tumors, or any combination thereof.

In another aspect, methods of making CAR-containing T cells (hereinafter "CAR-T cells") are provided. The methods include transducing a T cell with a vector or nucleic acid molecule encoding a disclosed CAR that specifically binds ROR1, thereby making the CAR-T cell.

In yet another aspect, a method of generating a population of RNA-engineered cells is provided that comprises introducing an *in vitro* transcribed RNA or synthetic RNA of a nucleic acid molecule encoding a disclosed CAR into a cell of a subject, thereby generating a CAR-expressing cell.

In yet another aspect, a method for diagnosing a disease, disorder or condition associated with the expression of ROR1 on a cell, is provided comprising a) contacting the cell with a human anti-ROR1 antibody or fragment thereof, wherein the antibody or a fragment thereof comprises an

amino acid sequence selected from the group consisting of SEQ ID NOs: 2, or 8; and b) detecting the presence of ROR1 wherein the presence of ROR1 diagnoses for the disease, disorder or condition associated with the expression of ROR1.

In one embodiment, the disease, disorder or condition associated with the expression of ROR1 is cancer including hematopoietic cancer, myelodysplastic syndrome pancreatic cancer, head and neck cancer, cutaneous tumors, minimal residual disease (MRD) in acute lymphoblastic leukemia (ALL), acute myeloid leukemia (AML), adult B cell malignancies including, CLL (Chronic lymphocytic leukemia), CML (chronic myelogenous leukemia), non-Hodgkin's lymphoma (NHL), pediatric B cell malignancies (including B lineage ALL (acute lymphocytic leukemia)), multiple myeloma lung cancer, breast cancer, ovarian cancer, prostate cancer, colon cancer, melanoma or other hematological cancer and solid tumors, or any combination thereof.

In another embodiment, a method of diagnosing, prognosing, or determining risk of a ROR1-related disease in a mammal, is provided comprising detecting the expression of ROR1 in a sample derived from the mammal comprising: a) contacting the sample with a human anti-ROR1 antibody or fragment thereof, wherein the antibody or a fragment thereof comprises an amino acid sequence selected from the group consisting of SEQ ID NOs: 2, or 8; and b) detecting the presence of ROR1 wherein the presence of ROR1 diagnoses for a ROR1-related disease in the mammal.

In another embodiment, a method of inhibiting ROR1-dependent T cell inhibition, is provided comprising contacting a cell with a human anti-ROR1 antibody or fragment thereof, wherein the antibody or a fragment thereof comprises an amino acid sequence selected from the group consisting of SEQ ID NOs: 2, or 8. In one embodiment, the cell is selected from the group consisting of a ROR1-expressing tumor cell, a tumor-associated macrophage, and any combination thereof.

In another embodiment, a method of blocking T-cell inhibition mediated by a ROR1-expressing cell and altering the tumor microenvironment to inhibit tumor growth in a mammal, is provided comprising administering to the mammal an effective amount of a composition comprising an isolated anti-ROR1 antibody or fragment thereof, wherein the antibody or a fragment thereof comprises an amino acid sequence selected from the group consisting of SEQ ID NOs: 2, and 8. In one embodiment, the cell is selected from the group consisting of a ROR1-expressing tumor cell, a tumor-associated macrophage, and any combination thereof.

In another embodiment, a method of inhibiting, suppressing or preventing immunosuppression of an anti-tumor or anti-cancer immune response in a mammal, is provided comprising administering to the mammal an effective amount of a composition comprising an

isolated anti-ROR1 antibody or fragment thereof, wherein the antibody or a fragment thereof comprises an amino acid sequence selected from the group consisting of SEQ ID NOs: 2, and 8. In one embodiment, the antibody or fragment thereof inhibits the interaction between a first cell with a T cell, wherein the first cell is selected from the group consisting of a ROR1-expressing tumor cell, a tumor-associated macrophage, and any combination thereof.

In another aspect, a method is provided for inducing an anti-tumor immunity in a mammal comprising administering to the mammal a therapeutically effective amount of a T cell transduced with vector or nucleic acid molecule encoding a disclosed CAR.

In another embodiment, a method of treating or preventing cancer in a mammal is provided comprising administering to the mammal one or more of the disclosed CARs, in an amount effective to treat or prevent cancer in the mammal. The method includes administering to the subject a therapeutically effective amount of host cells expressing a disclosed CAR that specifically binds ROR1 and/or one or more of the aforementioned antigens, under conditions sufficient to form an immune complex of the antigen binding domain on the CAR and the extracellular domain of ROR1 and/or one or more of the aforementioned antigens in the subject.

In yet another embodiment, a method is provided for treating a mammal having a disease, disorder or condition associated with an elevated expression of a tumor antigen, the method comprising administering to the subject a pharmaceutical composition comprising an anti-tumor effective amount of a population of T cells, wherein the T cells comprise a nucleic acid sequence that encodes a chimeric antigen receptor (CAR), wherein the CAR includes at least one extracellular ROR1 antigen binding domain comprising the amino acid sequence of SEQ ID NOs. 2, and 8, or any combination thereof, at least one linker or spacer domain, at least one transmembrane domain, at least one intracellular signaling domain, and wherein the T cells are T cells of the subject having cancer.

In yet another embodiment, a method is provided for treating cancer in a subject in need thereof comprising administering to the subject a pharmaceutical composition comprising an anti-tumor effective amount of a population of T cells, wherein the T cells comprise a nucleic acid sequence that encodes a chimeric antigen receptor (CAR), wherein the CAR comprises at least one ROR1 antigen binding domain comprising the amino acid sequence of SEQ ID NOs. 2, or 8, or any combination thereof, at least one linker or spacer domain, at least one transmembrane domain, at least one intracellular signaling domain, wherein the T cells are T cells of the subject having cancer. In some embodiments of the aforementioned methods, the at least one transmembrane domain comprises a transmembrane the alpha, beta or zeta chain of the T-cell receptor, CD28, CD3 epsilon, CD45, CD4, CD5, CD8, CD9, CD16, CD19, CD22, Mesothelin,

CD33, CD37, CD64, CD80, CD83, CD86, CD134, CD137, CD154, TNFRSF16, TNFRSF19, or a combination thereof.

In yet another embodiment, a method is provided for generating a persisting population of genetically engineered T cells in a human diagnosed with cancer. In one embodiment, the method comprises administering to a human a T cell genetically engineered to express a CAR wherein the CAR comprises at least one ROR1 antigen binding domain comprising the amino acid sequence of SEQ ID NOs. 2, or 8, or any combination thereof, at least one transmembrane domain, and at least one intracellular signaling domain wherein the persisting population of genetically engineered T cells, or the population of progeny of the T cells, persists in the human for at least one month, two months, three months, four months, five months, six months, seven months, eight months, nine months, ten months, eleven months, twelve months, two years, or three years after administration.

In one embodiment, the progeny T cells in the human comprise a memory T cell. In another embodiment, the T cell is an autologous T cell.

In all of the aspects and embodiments of methods described herein, any of the aforementioned cancers, diseases, disorders or conditions associated with an elevated expression of a tumor antigen that may be treated or prevented or ameliorated using one or more of the CARs disclosed herein,

In yet another aspect, a kit is provided for making a chimeric antigen receptor T-cell as described *supra* or for preventing, treating, or ameliorating any of the cancers, diseases, disorders or conditions associated with an elevated expression of a tumor antigen in a subject as described *supra*, comprising a container comprising any one of the nucleic acid molecules, vectors, host cells, or compositions disclosed *supra* or any combination thereof, and instructions for using the kit.

It will be understood that the CARs, host cells, nucleic acids, and methods are useful beyond the specific aspects and embodiments that are described in detail herein. The foregoing features and advantages of the disclosure will become more apparent from the following detailed description, which proceeds with reference to the accompanying figures.

BRIEF DESCRIPTION OF THE FIGURES

FIGURE 1 depicts a schematic of the general domain structure of CARs with novel extracellular ROR1 antigen binding domain sequences. A chimeric antigen receptor is composed

of an extracellular ROR1-binding ScFv domain, a spacer or hinge domain (derived from IgG4 or CD8), a transmembrane domain, an intracellular signaling CD137 costimulatory domain, and a CD3zeta signaling domain.

FIGURES 2A-F depict nucleic acid and amino acid sequences of several chimeric antigen receptors (CARs) containing novel human extracellular ROR1 antigen binding domain sequences. The general scheme for the CARs includes, from the N terminus to the C terminus, a Signal Peptide (SP or LP, leader peptide), an human anti-ROR1 binder single chain fragment variable (ScFv), an extracellular linker (or hinge, H), a transmembrane domain (TM), a 4-1BB (CD137) signaling domain, and a CD3zeta signaling domain.

FIGURE 2A depicts a lentiviral vector expressing the CAR LTG1941 (LP-ScFv4-CD8H/CD8TM-41BB-CD3zeta) nucleic acid sequence (SEQ ID NO: 3) and the encoded amino acid sequence (SEQ ID NO: 4).

FIGURE 2B depicts a lentiviral vector expressing the CAR LTG2528 (LP-ScFv4-IgG4H/CD8TM-41BB-CD3zeta) nucleic acid sequence (SEQ ID NO: 5) and the encoded amino acid sequence (SEQ ID NO: 6).

FIGURE 2C depicts a lentiviral vector expressing the CAR LTG1942 (LP-ScFv9-CD8H/CD8TM-41BB-CD3zeta) nucleotide sequence (SEQ ID NO: 9) and the encoded amino acid sequence (SEQ ID NO: 10).

FIGURE 2D depicts a lentiviral vector expressing the CAR LTG2529 (LP-ScFv9-IgG4H/CD8TM-41BB-CD3 zeta) nucleic acid sequence (SEQ ID NO 11) and the encoded amino acid sequence (SEQ ID NO: 12).

FIGURE 2E depicts a lentiviral vector expressing the CAR LTG 1943 (LP-ControlScFv-CD8H/CD8TM-41BB-CD3zeta) nucleic acid sequence (SEQ ID NO: 15) and the encoded amino acid sequence (SEQ ID NO: 16).

FIGURE 2F depicts a lentiviral vector expressing the CAR LTG2527: (LP-ControlScFv-IgG4H/CD8TM-41BB-CD3zeta) nucleic acid sequence (SEQ ID NO: 17) and the encoded amino acid sequence (SEQ ID NO: 18).

FIGURE 3 depicts anti-ROR1 CAR surface expression in primary human T cells. CAR T cells redirected to ROR1 tumor antigen via the use of ScFv domains were generated by lentiviral transduction with CAR expression constructs. CART detection was performed by flow cytometry. T cells were washed twice in cold PBS-EDTA buffer and stained with ROR1-Fc peptide followed by fluorescently labeled anti-human-Fc polyclonal F(ab)'2 fragment. Cells were gated based on forward scatter and side scatter, singlet discrimination, and 7AAD negativity so that only viable cells were analyzed. Data were acquired on MACSQuant 10 flow cytometer in the APC channel.

Samples analyzed are listed along the left axis: UTD, un-transduced negative control cells, GFP-LV control transduction, LTG1941 (ScFv4), LTG1942 (ScFv9), and LTG1943 (control-ScFv). The vertical dotted line denotes the gate for CAR expression and percent CAR expression in each population is listed, CAR%MFI.

FIGURE 4 depicts anti-ROR1 CAR T cells incorporating ScFv binders (LTG1941, LTG1942, and LTG1943) mediating cytotoxicity of ROR1-positive tumors *in vitro*. CAR T cells expressing anti-ROR1 constructs were incubated with ROR1-positive cell lines (Jeko-Luc and A431-Luc), or ROR1-negative line (Reh-luc), each line is stably transduced with firefly luciferase, at effector to target ratio (E:T) listed on the x-axis, overnight. CAR T cytotoxic activity was assessed by luciferase activity measurement as described in the Materials and Methods. UTD – untransduced T cell negative control, 1538-LTG1538 FMC63 murine anti-CD19 CAR positive control.

FIGURE 5 depicts ROR1-specific CAR T cell production of high levels of cytokines when co-cultured with the ROR1-positive leukemia line (Jeko, gray, or A432, light gray), or T cells were incubated with non-expressor (Reh) or incubated alone (gray, last column in series). The assay was carried out overnight at E:T ratio of 10:1, then supernatants were analyzed for cytokine concentrations by ELISA. N=2 technical replicates +/- SD. Negative controls: UT-un-transduced T cells, LTG1941, LTG1942, LTG1943, anti-ROR1-transduced T cells. LTG1398, GFP-LV transduced control T cells, as listed on the x-axis.

DETAILED DESCRIPTION

Definitions

As used herein, the singular forms “a,” “an,” and “the,” refer to both the singular as well as plural, unless the context clearly indicates otherwise. For example, the term “an antigen” includes single or plural antigens and can be considered equivalent to the phrase “at least one antigen.” As used herein, the term “comprises” means “includes.” Thus, “comprising an antigen” means “including an antigen” without excluding other elements. The phrase “and/or” means “and” or “or.” It is further to be understood that any and all base sizes or amino acid sizes, and all molecular weight or molecular mass values, given for nucleic acids or polypeptides are approximate, and are provided for descriptive purposes, unless otherwise indicated. Although many methods and materials similar or equivalent to those described herein can be used, particular suitable methods and materials are described below. In case of conflict, the present specification, including explanations of terms, will control. In addition, the materials, methods, and examples

are illustrative only and not intended to be limiting. To facilitate review of the various embodiments, the following explanations of terms are provided:

The term "about" 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 in some instances $\pm 10\%$, or in some instances $\pm 5\%$, or in some instances $\pm 1\%$, or in some instances $\pm 0.1\%$ from the specified value, as such variations are appropriate to perform the disclosed methods.

Unless otherwise noted, the technical terms herein are used according to conventional usage. Definitions of common terms in molecular biology can be found in Benjamin Lewin, *Genes VII*, published by Oxford University Press, 1999; Kendrew *et al.* (eds.), *The Encyclopedia of Molecular Biology*, published by Blackwell Science Ltd., 1994; and Robert A. Meyers (ed.), *Molecular Biology and Biotechnology: a Comprehensive Desk Reference*, published by VCH Publishers, Inc., 1995; and other similar references.

The present disclosure provides for ROR1 antibodies or fragments thereof as well as chimeric antigen receptors (CARs) having such ROR1 antigen binding domains. The enhancement of the functional activity of the CAR directly relates to the enhancement of functional activity of the CAR-expressing T cell. As a result of one or more of these modifications, the CARs exhibit both a high degree of cytokine-induced cytotoxicity and cell surface expression on transduced T cells, along with an increased level of *in vivo* T cell expansion and persistence of the transduced CAR-expressing T cell.

The unique ability to combine functional moieties derived from different protein domains has been a key innovative feature of Chimeric Antigen Receptors (CARs). The choice of each of these protein domains is a key design feature, as is the way in which they are specifically combined. Each design domain is an essential component that can be used across different CAR platforms to engineer the function of lymphocytes. For example, the choice of the extracellular binding domain can make an otherwise ineffective CAR be effective.

The invariable framework components of the immunoglobulin-derived protein sequences used to create the extracellular antigen binding domain of a CAR can either be entirely neutral, or they can self-associate and drive the T cell to a state of metabolic exhaustion, thus making the therapeutic T cell expressing that CAR far less effective. This occurs independently of the antigen binding function of this CAR domain. Furthermore, the choice of the intracellular signaling domain(s) also can govern the activity and the durability of the therapeutic lymphocyte population used for immunotherapy. While the ability to bind target antigen and the ability to transmit an activation signal to the T cell through these extracellular and intracellular domains, respectively, are important CAR design aspects, what has also become apparent is that the choice

of the source of the extracellular antigen binding fragments can have a significant effect on the efficacy of the CAR and thereby have a defining role for the function and clinical utility of the CAR.

Surprisingly and unexpectedly it has now been discovered that use of an entirely human antigen binding domain in a CAR, rather than using mouse-derived antigen binding fragments which are prone to induce anti-mouse immune response and CAR T elimination in a host (*c.f.*, the UPenn-sponsored clinical trial using mouse derived SS1 ScFv sequence, NCT02159716), may also determine the functional activity of a CAR-expressing T cell.

In light of this discovery, a series of ROR1 binders from a human scFv expression library have been developed. These fully-human ROR1 CARs are less likely to induce an allergic or rejection response by the patient as they are no longer of murine origin (see Maus MV, Haas AR, Beatty GL, Albelda SM, Levine BL, Liu X, Zhao Y, Kalos M, June CH, 2013, *Cancer Immunology Research*, 1:26-31). Thus, when these “fully human” CARs are expressed in T cells and then infused into patients, they are likely to be more therapeutically effective. These human sequence-derived CAR binders may be used for the treatment of human cancer, leukemias, and lymphomas that express the ROR1 antigen, including; but not limited to, B-CLL, ovarian cancer, triple negative breast cancer, lung adenocarcinoma, and glioblastoma (Balakrishnan, A., et al., 2016, *Clin Cancer Res*, 23:3061-3071; and Baskar, S., et al., 2008, *Clin Cancer Res* 14:396-404; and Jung, E.H., et al., *Cell Biochem Funct*, 34:149-157).

The CARs disclosed herein are expressed at a high level in a cell. A cell expressing the CAR has a high *in vivo* proliferation rate, produces large amounts of cytokines, and has a high cytotoxic activity against a cell having, on its surface, a ROR1 antigen to which a CAR binds. The use of a human extracellular ROR1 antigen-binding domain results in generation of a CAR that functions better *in vivo*, while avoiding the induction of anti-CAR immunity in the host immune response and the killing of the CAR T cell population. The CARs expressing the entirely human extracellular ROR1 ScFv antigen-binding domain exhibit superior activities/properties including i) prevention of poor CAR T persistence and function as seen with mouse-derived binding sequences; ii) lack of regional (*i.e.* intrapleural) delivery of the CAR to be efficacious; and iii) ability to generate CAR T cell designs based both on binders with high and low affinity to ROR1. This latter property allows investigators to better tune efficacy vs toxicity, and/or tissue specificity of the CAR T product, since lower-affinity binders may have higher specificity to tumors vs normal tissues due to higher expression of ROR1 on tumors than normal tissue, which may prevent on-target off tumor toxicity and bystander cell killing.

What follows is a detailed description of the inventive CARs including a description of their extracellular ROR1 antigen binding domain, the transmembrane domain and the intracellular domain, along with additional description of the CARs, antibodies and antigen binding fragments thereof, conjugates, nucleotides, expression, vectors, and host cells, methods of treatment, compositions, and kits employing the disclosed CARs.

A. Chimeric Antigen Receptors (CARs)

The CARs disclosed herein comprise at least one ROR1 antigen binding domain capable of binding to ROR1, at least one transmembrane domain, and at least one intracellular domain.

A chimeric antigen receptor (CAR) is an artificially constructed hybrid protein or polypeptide containing the antigen binding domains of an antibody (e.g., single chain variable fragment (ScFv)) linked to T-cell signaling domains via the transmembrane domain. Characteristics of CARs include their ability to redirect T-cell specificity and reactivity toward a selected target in a non-MHC-restricted manner, and exploiting the antigen-binding properties of monoclonal antibodies. The non-MHC-restricted antigen recognition gives T cells expressing CARs the ability to recognize antigen independent of antigen processing, thus bypassing a major mechanism of tumor escape. Moreover, when expressed in T-cells, CARs advantageously do not dimerize with endogenous T cell receptor (TCR) alpha and beta chains.

As disclosed herein, the intracellular T cell signaling domains of the CARs can include, for example, a T cell receptor signaling domain, a T cell costimulatory signaling domain, or both. The T cell receptor signaling domain refers to a portion of the CAR comprising the intracellular domain of a T cell receptor, such as, for example, and not by way of limitation, the intracellular portion of the CD3 zeta protein. The costimulatory signaling domain refers to a portion of the CAR comprising the intracellular domain of a costimulatory molecule, which is a cell surface molecule other than an antigen receptor or their ligands that are required for an efficient response of lymphocytes to antigen.

1. Extracellular Domain

In one embodiment, the CAR comprises a target-specific binding element otherwise referred to as an antigen binding domain or moiety. The choice of domain depends upon the type and number of ligands that define the surface of a target cell. For example, the antigen binding domain may be chosen to recognize a ligand that acts as a cell surface marker on target cells

associated with a particular disease state. Thus examples of cell surface markers that may act as ligands for the antigen binding domain in the CAR include those associated with viral, bacterial and parasitic infections, autoimmune disease and cancer cells.

In one embodiment, the CAR can be engineered to target a tumor antigen of interest by way of engineering a desired antigen binding domain that specifically binds to an antigen on a tumor cell. Tumor antigens are proteins that are produced by tumor cells that elicit an immune response, particularly T-cell mediated immune responses. The selection of the antigen binding domain will depend on the particular type of cancer to be treated. Tumor antigens include, for example, a glioma-associated antigen, carcinoembryonic antigen (CEA), .beta.-human chorionic gonadotropin, alphafetoprotein (AFP), lectin-reactive AFP, thyroglobulin, RAGE-1, MN-CA IX, human telomerase reverse transcriptase, RU1, RU2 (AS), intestinal carboxyl esterase, mut hsp70-2, M-CSF, prostase, prostate-specific antigen (PSA), PAP, NY-ESO-1, LAGE-1a, p53, prostein, PSMA, Her2/neu, survivin and telomerase, prostate-carcinoma tumor antigen-1 (PCTA-1), MAGE, ELF2M, neutrophil elastase, ephrinB2, CD20, CD22, ROR1, insulin growth factor (IGF)-I, IGF-II, IGF-I receptor and CD19. The tumor antigens disclosed herein are merely included by way of example. The list is not intended to be exclusive and further examples will be readily apparent to those of skill in the art.

In one embodiment, the tumor antigen comprises one or more antigenic cancer epitopes associated with a malignant tumor. Malignant tumors express a number of proteins that can serve as target antigens for an immune attack. These molecules include, but are not limited to, tissue-specific antigens such as MART-1, tyrosinase and GP 100 in melanoma and prostatic acid phosphatase (PAP) and prostate-specific antigen (PSA) in prostate cancer. Other target molecules belong to the group of transformation-related molecules such as the oncogene HER-2/Neu/ErbB-2. Yet another group of target antigens are onco-fetal antigens such as carcinoembryonic antigen (CEA). In B-cell lymphoma the tumor-specific idiotype immunoglobulin constitutes a truly tumor-specific immunoglobulin antigen that is unique to the individual tumor. B-cell differentiation antigens such as CD19, CD20, CD22, BCMA, ROR1, and CD37 are other candidates for target antigens in B-cell lymphoma. Some of these antigens (CEA, HER-2, CD19, CD20, idiotype) have been used as targets for passive immunotherapy with monoclonal antibodies with limited success.

In one preferred embodiment, the tumor antigen is ROR1 and the tumors associated with expression of ROR1 comprise lung mesothelioma, ovarian, and pancreatic cancers that express high levels of the extracellular protein ROR1, or any combination thereof.

The type of tumor antigen may also be a tumor-specific antigen (TSA) or a tumor-associated antigen (TAA). A TSA is unique to tumor cells and does not occur on other cells in the body. A TAA is not unique to a tumor cell and instead is also expressed on a normal cell under conditions that fail to induce a state of immunologic tolerance to the antigen. The expression of the antigen on the tumor may occur under conditions that enable the immune system to respond to the antigen. TAAs may be antigens that are expressed on normal cells during fetal development when the immune system is immature and unable to respond or they may be antigens that are normally present at extremely low levels on normal cells but which are expressed at much higher levels on tumor cells.

Non-limiting examples of TSAs or TAAs include the following: Differentiation antigens such as MART-1/MelanA (MART-I), gp100 (Pmel 17), tyrosinase, TRP-1, TRP-2 and tumor-specific multi-lineage antigens such as MAGE-1, MAGE-3, BAGE, GAGE-1, GAGE-2, p15; overexpressed embryonic antigens such as CEA; overexpressed oncogenes and mutated tumor-suppressor genes such as p53, Ras, HER-2/neu; unique tumor antigens resulting from chromosomal translocations; such as BCR-ABL, E2A-PRL, H4-RET, IGH-IGK, MYL-RAR; and viral antigens, such as the Epstein Barr virus antigens EBVA and the human papillomavirus (HPV) antigens E6 and E7. Other large, protein-based antigens include TSP-180, MAGE-4, MAGE-5, MAGE-6, RAGE, NY-ESO, p185erbB2, p180erbB-3, c-met, nm-23H1, PSA, TAG-72, CA 19-9, CA 72-4, CAM 17.1, NuMa, K-ras, beta-Catenin, CDK4, Mum-1, p 15, p 16, 43-9F, 5T4, 791Tgp72, alpha-fetoprotein, beta-HCG, BCA225, BTAA, CA 125, CA 15-3\CA 27.29\BCAA, CA 195, CA 242, CA-50, CAM43, CD68\P1, CO-029, FGF-5, G250, Ga733\EpCAM, HTgp-175, M344, MA-50, MG7-Ag, MOV18, NB/70K, NY-CO-1, RCAS1, SDCCAG16, TA-90\Mac-2 binding protein\cyclophilin C-associated protein, TAAL6, TAG72, TLP, and TPS.

In one embodiment, the antigen binding domain portion of the CAR targets an antigen that includes but is not limited to CD19, CD20, CD22, ROR1, CD33, CD38, CD123, CD138, BCMA, c-Met, PSMA, Glycolipid F77, EGFRvIII, GD-2, FGFR4, TSLPR, NY-ESO-1 TCR, MAGE A3 TCR, and the like.

In a preferred embodiment, the antigen binding domain portion of the CAR targets the extracellular ROR1 antigen.

In one preferred embodiment, the isolated nucleic acid molecule encoding the extracellular ROR1 binding domain scFv4 comprises a nucleotide sequence of SEQ ID NO: 1, or a sequence with 85%, 90%, 95%, 96%, 97%, 98% or 99% identity thereof. In one embodiment, an isolated nucleic acid molecule is provided wherein the encoded extracellular ROR1 antigen binding

domain scFv4 comprises an amino acid sequence of SEQ ID NO: 2, or an amino acid sequence with 85%, 90%, 95%, 96%, 97%, 98% or 99% identity to an amino acid sequence of SEQ ID NO: 2.

In one preferred embodiment, the isolated nucleic acid molecule encoding the extracellular ROR1 antigen binding domain ScV9 comprises a nucleotide sequence of SEQ ID NO: 7, or a sequence with 85%, 90%, 95%, 96%, 97%, 98% or 99% identity thereof. In one embodiment, an isolated nucleic acid molecule is provided wherein the encoded extracellular ROR1 antigen binding domain ScFv9 comprises an amino acid sequence of SEQ ID NO: 8, or an amino acid sequence with 85%, 90%, 95%, 96%, 97%, 98% or 99% identity to an amino acid sequence of SEQ ID NO: 8.

In one preferred embodiment, the isolated nucleic acid molecule encoding the extracellular ROR1 control ScFv antigen binding domain comprises a nucleotide sequence of SEQ ID NO: 13, or a sequence with 85%, 90%, 95%, 96%, 97%, 98% or 99% identity thereof. In one embodiment, an isolated nucleic acid molecule is provided wherein the encoded extracellular ROR1 control ScFv antigen binding domain comprises an amino acid sequence of SEQ ID NO: 14, or an amino acid sequence with 85%, 90%, 95%, 96%, 97%, 98% or 99% identity to an amino acid sequence of SEQ ID NO: 14.

In the various embodiments of the ROR1-specific CARs disclosed herein, the general scheme is set forth in FIGURE 1 and includes, from the N-terminus to the C-terminus, a signal or leader peptide, anti-ROR1 ScFv, extracellular linker or hinge (H) domain, transmembrane (TM) domain, 4-1BB, CD3 zeta, wherein the bolded text represents the cloning sites for linking domains.

In one embodiment, the nucleic acid sequence encoding a CAR comprises the nucleic acid sequence of SEQ ID NO: 3, and encodes the CAR comprising the amino acid sequence as set forth in SEQ ID NO: 4 [LTG1941 LP-ScFv4-CD8H/CD8TM-41BB-CD3zeta amino acid sequence (as depicted in Figure 2A)].

In one embodiment, the nucleic acid sequence encoding a CAR comprises the nucleic acid sequence of SEQ ID NO: 3, or a sequence with 85%, 90%, 95%, 96%, 97%, 98% or 99% identity thereof, and encodes the CAR comprising the amino acid sequence as set forth in SEQ ID NO: 4 or a sequence with 85%, 90%, 95%, 96%, 97%, 98% or 99% identity thereof LTG1941 LP-ScFv4-CD8H/CD8TM-41BB-CD3zeta amino acid sequence (as depicted in Figure 2A)].

In another embodiment, the nucleic acid sequence encoding a CAR comprises the nucleic acid sequence of SEQ ID NO: 5, and encodes the CAR comprising the amino acid sequence as

set forth in SEQ ID NO: 6 [LTG2528 LP-ScFv4-IgG4H/CD8TM-41BB-CD3zeta amino acid sequence (as depicted in Figure 2B)].

In another embodiment, the nucleic acid sequence encoding a CAR comprises the nucleic acid sequence of SEQ ID NO: 5 or a sequence with 85%, 90%, 95%, 96%, 97%, 98% or 99% identity thereof, and encodes the CAR comprising the amino acid sequence as set forth in SEQ ID NO: 6 or a sequence with 85%, 90%, 95%, 96%, 97%, 98% or 99% identity thereof [LTG2528 LP-ScFv4-CD8H/CD8TM-41BB-CD3zeta amino acid sequence (as depicted in Figure 2B)].

In another embodiment, the nucleic acid sequence encoding a CAR comprises the nucleic acid sequence of SEQ ID NO: 9, and encodes the CAR comprising the amino acid sequence as set forth in SEQ ID NO: 10 LTG1942 LP-ScFv9-CD8H/CD8TM-41BB-CD3zeta CAR amino acid sequence (as depicted in Figure 2C)].

In another embodiment, the nucleic acid sequence encoding a CAR comprises the nucleic acid sequence of SEQ ID NO: 9 or a sequence with 85%, 90%, 95%, 96%, 97%, 98% or 99% identity thereof, and encodes the CAR comprising the amino acid sequence as set forth in SEQ ID NO: 10 or a sequence with 85%, 90%, 95%, 96%, 97%, 98% or 99% identity thereof [LTG1942 LP-ScFv9-CD8H/CD8TM-41BB-CD3zeta CAR amino acid sequence (as depicted in Figure 2C)].

In yet another embodiment, the nucleic acid sequence encoding a CAR comprises the nucleic acid sequence of SEQ ID NO: 11, and encodes the CAR comprising the amino acid sequence as set forth in SEQ ID NO: 12 [LTG2529 LP-ScFv9-IgG4H/CD8TM-41BB-CD3zeta amino acid sequence (as depicted in Figure 2D)].

In yet another embodiment, the nucleic acid sequence encoding a CAR comprises the nucleic acid sequence of SEQ ID NO: 11 or a sequence with 85%, 90%, 95%, 96%, 97%, 98% or 99% identity thereof, and encodes the CAR comprising the amino acid sequence as set forth in SEQ ID NO: 12 or a sequence with 85%, 90%, 95%, 96%, 97%, 98% or 99% identity thereof [LTG2529 LP-ScFv9-IgG4H/CD8TM-41BB-CD3zeta amino acid sequence (as depicted in Figure 2D)].

In yet another embodiment, the nucleic acid sequence encoding a CAR comprises the nucleic acid sequence of SEQ ID NO: 15, and encodes the CAR comprising the amino acid sequence as set forth in SEQ ID NO: 16 [LTG1943 LP-controlScFv-CD8H/CD8TM-41BB-CD3zeta amino acid sequence (as depicted in Figure 2E)].

In yet another embodiment, the nucleic acid sequence encoding a CAR comprises the nucleic acid sequence of SEQ ID NO: 15 or a sequence with 85%, 90%, 95%, 96%, 97%, 98% or 99% identity thereof, and encodes the CAR comprising the amino acid sequence as set forth in SEQ ID NO: 16 or a sequence with 85%, 90%, 95%, 96%, 97%, 98% or 99% identity thereof

[LTG1943 LP-controlScFv-CD8H/CD8TM-41BB-CD3zeta amino acid sequence (as depicted in Figure 2E)].

In yet another embodiment, the nucleic acid sequence encoding a CAR comprises the nucleic acid sequence of SEQ ID NO: 17, and encodes the CAR comprising the amino acid sequence as set forth in SEQ ID NO: 18 [(LTG2527 LP-controlScFv-IgG4H/CD8TM-41BB-CD3zeta amino acid sequence (as depicted in Figure 2F)].

In yet another embodiment, the nucleic acid sequence encoding a CAR comprises the nucleic acid sequence of SEQ ID NO: 17 or a sequence with 85%, 90%, 95%, 96%, 97%, 98% or 99% identity thereof, and encodes the CAR comprising the amino acid sequence as set forth in SEQ ID NO: 18 or a sequence with 85%, 90%, 95%, 96%, 97%, 98% or 99% identity thereof [LTG2527 LP-controlScFv-IgG4H/CD8TM-41BB-CD3zeta amino acid sequence (as depicted in Figure 2F)].

The surface expression of anti-ROR1 CARs incorporating single chain fragment variable (ScFv) sequences reactive with ROR1 antigen, is shown in Example 2 *infra* and summarized in Table 2. The expression level for each ScFv-containing CAR was determined by flow cytometric analysis of LV-transduced T cells from healthy donors using a recombinant ROR1-Fc peptide, followed by anti-human Fc F(ab')₂ fragment conjugated to AF647, and detected in the APC channel, (*c.f.*, Figure 3). The ScFv-based anti-ROR1 CAR constructs LTG1941, LTG1942-LTG1943 were highly expressed in human primary T cells (as indicated by the gated population) as compared to non-transduced T cell controls (non-gated cell population). Representative results from one donor are shown.

As shown in Example 2 and Figure 4, high cytolytic activity of the ROR1 CARs was demonstrated when lentiviral vectors (LV) expressing the following CARs were created and tested for anti-leukemia activity. Each experimental CAR contains the 4-1BB/CD3-zeta chain signaling motif and the specific anti-ROR1 binding motif/domain noted therein. Leukemia target lines with ROR1 surface expression were used: Jeko and A431; and ROR1 negative Reh. ScFv-based anti-ROR1 CAR constructs LTG1941, LTG1942, and LTG1943 were able to efficiently lyse A431, whereas they had no specific lytic activity against Reh, (*c.f.*, Figure 4). The ability to lyse Jeko by anti-ROR1 CARs LTG1941 and LTG1942 differed, indicating differential biological activity. These results demonstrate the efficiency and specificity of the generated CAR constructs.

The capacity of anti-ROR1 CAR T cells for cytokine secretion was then evaluated. Tumor cells were co-incubated with CAR T cells or control T cells at effector to target ratio of 10:1 overnight, and culture supernatants were analyzed by ELISA for IFN gamma, TNF alpha and IL-2

(c.f., Figure 5). Of note, CAR T-expressing cells LTG1942 and LTG1943 generated high levels of IFN gamma, and LTG1941 generated moderate amounts of IFN-gamma only in response to Jeko, but not the A431 leukemia cell line. A similar result was seen for IL-2 and TNF-alpha expression. Negative controls (untransduced T cells, UN, or T cells transduced with the control LTG1398 LV) yielded no appreciable cytokine induction. Importantly, the results seen in cytolytic and cytokine function highlight that LTG1942 performs similarly to the control ScFv-bearing CAR, LTG1943, whereas LTG1941 has much lower cytokine production and ability to lyse the Jeko leukemia cell line. Nevertheless, the ability to lyse A431 by LTG1941 indicates that we have a differentiated product that may be preferred if LTG1942 proves to be active or too toxic in clinical studies of CAR-T.

Without being intended to limit to any particular mechanism of action, it is believed that possible reasons for the enhanced therapeutic function associated with the exemplary CARs of the invention include, for example, and not by way of limitation, a) improved lateral movement within the plasma membrane allowing for more efficient signal transduction, b) superior location within plasma membrane microdomains, such as lipid rafts, and greater ability to interact with transmembrane signaling cascades associated with T cell activation, c) superior location within the plasma membrane by preferential movement away from dampening or down-modulatory interactions, such as less proximity to or interaction with phosphatases such as CD45, and d) superior assembly into T cell receptor signaling complexes (i.e. the immune synapse), or any combination thereof.

While the disclosure has been illustrated with an exemplary extracellular ROR1 ScFv antigen binding domains, other nucleotide and/or amino acid variants within the ROR1 variable ScFv antigen binding domains may be used to derive heavy-chain only binding domains, or subsets thereof, and thus comprise the ROR1 antigen binding domains for use in the CARs described herein.

Depending on the desired antigen to be targeted, the CAR can be additionally engineered to include the appropriate antigen binding domain that is specific to the desired antigen target. For example, if ROR1 is the desired antigen that is to be targeted, an antibody for ROR1 can be used as the antigen binding domain incorporation into the CAR.

In one exemplary embodiment, the antigen binding domain portion of the CAR additionally targets CD33. Preferably, the antigen binding domain in the CAR is anti-CD33 ScFv, wherein the nucleic acid sequence of the anti-CD33 ScFv comprises the sequence set forth in SEQ ID NO: 34. In one embodiment, the anti-CD33 ScFv comprises the nucleic acid sequence that

encodes the amino acid sequence of SEQ ID NO: 35. In another embodiment, the anti-CD33 ScFv portion of the CAR comprises the amino acid sequence set forth in SEQ ID NO: 35.

In one exemplary embodiment, the antigen binding domain portion of the CAR additionally targets mesothelin. Preferably, the antigen binding domain in the CAR is anti-mesothelin ScFv, wherein the nucleic acid sequence of the anti-mesothelin ScFv comprises the sequence set forth in SEQ ID NO: 36. In one embodiment, the anti-mesothelin ScFv comprises the nucleic acid sequence that encodes the amino acid sequence of SEQ ID NO: 37. In another embodiment, the anti-mesothelin ScFv portion of the CAR comprises the amino acid sequence set forth in SEQ ID NO: 37.

In one exemplary embodiment, the antigen binding domain portion of the CAR additionally targets CD19. Preferably, the antigen binding domain in the CAR is anti-CD19 ScFv, wherein the nucleic acid sequence of the anti-mesothelin ScFv comprises the sequence set forth in SEQ ID NO: 32. In one embodiment, the anti-mesothelin ScFv comprises the nucleic acid sequence that encodes the amino acid sequence of SEQ ID NO: 33. In another embodiment, the anti-CD19 ScFv portion of the CAR comprises the amino acid sequence set forth in SEQ ID NO: 33.

In one aspect of the present invention, there is provided a CAR capable of binding to a non-TSA or non-TAA including, for example and not by way of limitation, an antigen derived from Retroviridae (e.g. human immunodeficiency viruses such as HIV-1 and HIV-LP), Picornaviridae (e.g. poliovirus, hepatitis A virus, enterovirus, human coxsackievirus, rhinovirus, and echovirus), rubella virus, coronavirus, vesicular stomatitis virus, rabies virus, ebola virus, parainfluenza virus, mumps virus, measles virus, respiratory syncytial virus, influenza virus, hepatitis B virus, parvovirus, Adenoviridae, Herpesviridae [e.g. type 1 and type 2 herpes simplex virus (HSV), varicella-zoster virus, cytomegalovirus (CMV), and herpes virus], Poxviridae (e.g. smallpox virus, vaccinia virus, and pox virus), or hepatitis C virus, or any combination thereof.

In another aspect of the present invention, there is provided a CAR capable of binding to an antigen derived from a bacterial strain of Staphylococci, Streptococcus, Escherichia coli, Pseudomonas, or Salmonella. Particularly, there is provided a CAR capable of binding to an antigen derived from an infectious bacterium, for example, Helicobacter pylori, Legionella pneumophila, a bacterial strain of Mycobacteria sps. (e.g. M. tuberculosis, M. avium, M. intracellulare, M. kansaii, or M. goodii), Staphylococcus aureus, Neisseria gonorrhoeae, Neisseria meningitidis, Listeria monocytogenes, Streptococcus pyogenes, Group A Streptococcus, Group B Streptococcus (Streptococcus agalactiae), Streptococcus pneumoniae, or Clostridium tetani, or a combination thereof.

2. Transmembrane Domain

With respect to the transmembrane domain, the CAR comprises one or more transmembrane domains fused to the extracellular ROR1 antigen binding domain of the CAR.

The transmembrane domain may be derived either from a natural or from a synthetic source. Where the source is natural, the domain may be derived from any membrane-bound or transmembrane protein.

Transmembrane regions of particular use in the CARs described herein may be derived from (*i.e.* comprise at least the transmembrane region(s) of) the alpha, beta or zeta chain of the T-cell receptor, CD28, CD3 epsilon, CD45, CD4, CD5, CD8, CD9, CD16, CD22, mesothelin, CD33, CD37, CD64, CD80, CD83, CD86, CD134, CD137, CD154, TNFRSF16, or TNFRSF19. Alternatively the transmembrane domain may be synthetic, in which case it will comprise predominantly hydrophobic residues such as leucine and valine. Preferably a triplet of phenylalanine, tryptophan and valine will be found at each end of a synthetic transmembrane domain. Optionally, a short oligo- or polypeptide linker, preferably between 2 and 10 amino acids in length may form the linkage between the transmembrane domain and the cytoplasmic signaling domain of the CAR. A glycine-serine doublet provides a particularly suitable linker.

In one embodiment, the transmembrane domain that naturally is associated with one of the domains in the CAR is used in addition to the transmembrane domains described *supra*.

In some instances, the transmembrane domain can be selected or by amino acid substitution to avoid binding of such domains to the transmembrane domains of the same or different surface membrane proteins to minimize interactions with other members of the receptor complex.

In one embodiment, the transmembrane domain in the CAR of the invention is the CD8 transmembrane domain. In one embodiment, the CD8 transmembrane domain comprises the nucleic acid sequence of SEQ ID NO: 21. In one embodiment, the CD8 transmembrane domain comprises the nucleic acid sequence that encodes the amino acid sequence of SEQ ID NO: 22. In another embodiment, the CD8 transmembrane domain comprises the amino acid sequence of SEQ ID NO: 22.

In one embodiment, the encoded transmembrane domain comprises an amino acid sequence having at least one, two or three modifications (e.g., substitutions) but not more than 20, 10 or 5 modifications (e.g., substitutions) of an amino acid sequence of SEQ ID NO: 22, or a sequence with 95-99% identity to an amino acid sequence of SEQ ID NO: 22.

In some instances, the transmembrane domain of the CAR comprises the CD8.alpha.hinge domain. In one embodiment, the CD8 hinge domain comprises the nucleic acid sequence of SEQ ID NO: 23. In one embodiment, the CD8 hinge domain comprises the nucleic acid sequence that encodes the amino acid sequence of SEQ ID NO: 24. In another embodiment, the CD8 hinge domain comprises the amino acid sequence of SEQ ID NO: 24, or a sequence with 95-99% identity thereof.

In one embodiment, an isolated nucleic acid molecule is provided wherein the encoded linker domain is derived from the extracellular domain of CD8, and is linked to the transmembrane CD8 domain, the transmembrane CD28 domain, or a combination thereof.

3. Spacer (Hinge, H) Domain

In the CAR, a spacer domain can be arranged between the extracellular domain and the transmembrane domain, or between the intracellular domain and the transmembrane domain. The spacer domain means any oligopeptide or polypeptide that serves to link the transmembrane domain with the extracellular domain and/or the transmembrane domain with the intracellular domain. The spacer domain comprises up to 300 amino acids, preferably 10 to 100 amino acids, and most preferably 25 to 50 amino acids.

In several embodiments, the linker can include a spacer element, which, when present, increases the size of the linker such that the distance between the effector molecule or the detectable marker and the antibody or antigen binding fragment is increased. Exemplary spacers are known to the person of ordinary skill, and include those listed in U.S. Pat. Nos. 7,964,566, 7,498,298, 6,884,869, 6,323,315, 6,239,104, 6,034,065, 5,780,588, 5,665,860, 5,663,149, 5,635,483, 5,599,902, 5,554,725, 5,530,097, 5,521,284, 5,504,191, 5,410,024, 5,138,036, 5,076,973, 4,986,988, 4,978,744, 4,879,278, 4,816,444, and 4,486,414, as well as U.S. Pat. Pub. Nos. 20110212088 and 20110070248, each of which is incorporated by reference herein in its entirety.

The spacer domain preferably has a sequence that promotes binding of a CAR with an antigen and enhances signaling into a cell. Examples of an amino acid that is expected to promote the binding include cysteine, a charged amino acid, and serine and threonine in a potential glycosylation site, and these amino acids can be used as an amino acid constituting the spacer domain.

As the spacer domain, the entire or a part of amino acid numbers 137-206 (SEQ ID NO: 25) which is a hinge region of CD8.alpha. (NCBI RefSeq: NP.sub.--001759.3), amino acid

numbers 135 to 195 of CD8.beta. (GenBank: AAA35664.1), amino acid numbers 315 to 396 of CD4 (NCBI RefSeq: NP.sub.--000607.1), or amino acid numbers 137 to 152 of CD28 (NCBI RefSeq: NP.sub.--006130.1) can be used. Also, as the spacer domain, a part of a constant region of an antibody H chain or L chain can be used. Further, the spacer domain may be an artificially synthesized sequence.

A spacer domain can also be comprised of elements of Immunoglobulin (Ig) constant domains, such as those derived for IgG4, including sequences that link immunoglobulin domains that comprise an immunoglobulin protein. The spacer or hinge domain exists at the C-terminus of the scFv ROR1-binding domain and extends to the CAR transmembrane domain. In one embodiment, the IgG4 hinge (H) domain comprises the nucleic acid sequence of SEQ ID NO: 38. In one embodiment, the CD8 hinge domain comprises the nucleic acid sequence that encodes the amino acid sequence of SEQ ID NO: 39. In another embodiment, the CD8 hinge domain comprises the amino acid sequence of SEQ ID NO: 39, or a sequence with 95-99% identity thereof.

In some instances, the IgG4 constant regions serve as a hinge (H) and are linked to the transmembrane domain of CD8. In one embodiment, the IgG4H domain is linked to the CD8 transmembrane domain and together comprises the nucleic acid sequence of SEQ ID NO: 40. In one embodiment, the IgG4H domain linked to the CD8 transmembrane domain comprises the nucleic acid sequence that encodes the amino acid sequence of SEQ ID NO: 41. In another embodiment, the IgG4H linked to the CD8 transmembrane domain comprises the amino acid sequence of SEQ ID NO: 41, or a sequence with 95-99% identity thereof.

Further, in the CAR, a signal peptide sequence can be linked to the N-terminus. The signal peptide sequence exists at the N-terminus of many secretory proteins and membrane proteins, and has a length of 15 to 30 amino acids. Since many of the protein molecules mentioned above as the intracellular domain have signal peptide sequences, the signal peptides can be used as a signal peptide for the CAR. In one embodiment, the signal peptide comprises the amino acid sequence shown in SEQ ID NO: 20.

4. Intracellular Domain

The cytoplasmic domain or otherwise the intracellular signaling domain of the CAR is responsible for activation of at least one of the normal effector functions of the immune cell in which the CAR has been placed in. The term "effector function" refers to a specialized function of a cell. Effector function of a T cell, for example, may be cytolytic activity or helper activity

including the secretion of cytokines. Thus the term "intracellular signaling domain" refers to the portion of a protein which transduces the effector function signal and directs the cell to perform a specialized function. While usually the entire intracellular signaling domain can be employed, in many cases it is not necessary to use the entire chain. To the extent that a truncated portion of the intracellular signaling domain is used, such truncated portion may be used in place of the intact chain as long as it transduces the effector function signal. The term intracellular signaling domain is thus meant to include any truncated portion of the intracellular signaling domain sufficient to transduce the effector function signal.

Preferred examples of intracellular signaling domains for use in the CAR include the cytoplasmic sequences of the T cell receptor (TCR) and co-receptors that act in concert to initiate signal transduction following antigen receptor engagement, as well as any derivative or variant of these sequences and any synthetic sequence that has the same functional capability.

It is known that signals generated through the TCR alone are insufficient for full activation of the T cell and that a secondary or co-stimulatory signal is also required. Thus, T cell activation can be said to be mediated by two distinct classes of cytoplasmic signaling sequence: those that initiate antigen-dependent primary activation through the TCR (primary cytoplasmic signaling sequences) and those that act in an antigen-independent manner to provide a secondary or co-stimulatory signal (secondary cytoplasmic signaling sequences).

Primary cytoplasmic signaling sequences regulate primary activation of the TCR complex either in a stimulatory way, or in an inhibitory way. Primary cytoplasmic signaling sequences that act in a stimulatory manner may contain signaling motifs which are known as immunoreceptor tyrosine-based activation motifs or ITAMs.

Examples of ITAM containing primary cytoplasmic signaling sequences that are of particular use in the CARS disclosed herein include those derived from TCR zeta (CD3 Zeta), FcR gamma, FcR beta, CD3 gamma, CD3 delta, CD3 epsilon, CD5, CD22, CD79a, CD79b, and CD66d. Specific, non-limiting examples, of the ITAM include peptides having sequences of amino acid numbers 51 to 164 of CD3.zeta. (NCBI RefSeq: NP.sub.--932170.1), amino acid numbers 45 to 86 of Fc.epsilon.RI.gamma. (NCBI RefSeq: NP.sub.--004097.1), amino acid numbers 201 to 244 of Fc.epsilon.RI.beta. (NCBI RefSeq: NP.sub.--000130.1), amino acid numbers 139 to 182 of CD3.gamma. (NCBI RefSeq: NP.sub.--000064.1), amino acid numbers 128 to 171 of CD3 .delta. (NCBI RefSeq: NP.sub.--000723.1), amino acid numbers 153 to 207 of CD3.epsilon. (NCBI RefSeq: NP.sub.--000724.1), amino acid numbers 402 to 495 of CD5 (NCBI RefSeq: NP.sub.--055022.2), amino acid numbers 707 to 847 of 0022 (NCBI RefSeq: NP.sub.--001762.2), amino acid numbers 166 to 226 of CD79a (NCBI RefSeq: NP.sub.--

001774.1), amino acid numbers 182 to 229 of CD79b (NCBI RefSeq: NP.sub.--000617.1), and amino acid numbers 177 to 252 of CD66d (NCBI RefSeq: NP.sub.--001806.2), and their variants having the same function as these peptides have. The amino acid number based on amino acid sequence information of NCBI RefSeq ID or GenBank described herein is numbered based on the full length of the precursor (comprising a signal peptide sequence etc.) of each protein. In one embodiment, the cytoplasmic signaling molecule in the CAR comprises a cytoplasmic signaling sequence derived from CD3 zeta.

In a preferred embodiment, the intracellular domain of the CAR can be designed to comprise the CD3-zeta signaling domain by itself or combined with any other desired cytoplasmic domain(s) useful in the context of the CAR. For example, the intracellular domain of the CAR can comprise a CD3 zeta chain portion and a costimulatory signaling region. The costimulatory signaling region refers to a portion of the CAR comprising the intracellular domain of a costimulatory molecule. A costimulatory molecule is a cell surface molecule other than an antigen receptor or their ligands that is required for an efficient response of lymphocytes to an antigen. Examples of such costimulatory molecules include CD27, CD28, 4-1BB (CD137), OX40, CD30, CD40, PD-1, ICOS, lymphocyte function-associated antigen-1 (LFA-1), CD2, CD7, LIGHT, NKG2C, B7-H3, and a ligand that specifically binds with CD83, and the like. Specific, non-limiting examples, of such costimulatory molecules include peptides having sequences of amino acid numbers 236 to 351 of CD2 (NCBI RefSeq: NP.sub.--001758.2), amino acid numbers 421 to 458 of CD4 (NCBI RefSeq: NP.sub.--000607.1), amino acid numbers 402 to 495 of CD5 (NCBI RefSeq: NP.sub.--055022.2), amino acid numbers 207 to 235 of CD8.alpha. (NCBI RefSeq: NP.sub.--001759.3), amino acid numbers 196 to 210 of CD83 (GenBank: AAA35664.1), amino acid numbers 181 to 220 of CD28 (NCBI RefSeq: NP.sub.--006130.1), amino acid numbers 214 to 255 of CD137 (4-1BB, NCBI RefSeq: NP.sub.--001552.2), amino acid numbers 241 to 277 of CD134 (OX40, NCBI RefSeq: NP.sub.--003318.1), and amino acid numbers 166 to 199 of ICOS (NCBI RefSeq: NP.sub.--036224.1), and their variants having the same function as these peptides have. Thus, while the disclosure herein is exemplified primarily with 4-1BB as the co-stimulatory signaling element, other costimulatory elements are within the scope of the disclosure.

The cytoplasmic signaling sequences within the cytoplasmic signaling portion of the CAR may be linked to each other in a random or specified order. Optionally, a short oligo- or polypeptide linker, preferably between 2 and 10 amino acids in length may form the linkage. A glycine-serine doublet provides a particularly suitable linker.

In one embodiment, the intracellular domain is designed to comprise the signaling domain of CD3-zeta and the signaling domain of CD28. In another embodiment, the intracellular domain is designed to comprise the signaling domain of CD3-zeta and the signaling domain of 4-1BB. In yet another embodiment, the intracellular domain is designed to comprise the signaling domain of CD3-zeta and the signaling domain of CD28 and 4-1BB.

In one embodiment, the intracellular domain in the CAR is designed to comprise the signaling domain of 4-1BB and the signaling domain of CD3-zeta, wherein the signaling domain of 4-1BB comprises the nucleic acid sequence set forth in SEQ ID NO: 26 and the signaling domain of CD3-zeta comprises the nucleic acid sequence set forth in SEQ ID NO: 28 and in the variant nucleic acid sequence set forth in SEQ ID NO: 30. In one embodiment, the intracellular domain in the CAR is designed to comprise the signaling domain of 4-1BB and the signaling domain of CD3-zeta, wherein the signaling domain of 4-1BB comprises the nucleic acid sequence set forth in SEQ ID NO: 26 and the signaling domain of CD3-zeta comprises the nucleic acid sequence set forth in SEQ ID NO: 28 and in the variant nucleic acid sequence set forth in SEQ ID NO: 30.

In one embodiment, the intracellular domain in the CAR is designed to comprise the signaling domain of 4-1BB and the signaling domain of CD3-zeta, wherein the signaling domain of 4-1BB comprises the nucleic acid sequence that encodes the amino acid sequence of SEQ ID NO: 27 and the signaling domain of CD3-zeta comprises the nucleic acid sequence that encodes the amino acid sequence of SEQ ID NO: 29 and in the variant nucleic acid that encodes the amino acid sequence of SEQ ID NO: 31.

In one embodiment, the intracellular domain in the CAR is designed to comprise the signaling domain of 4-1BB and the signaling domain of CD3-zeta, wherein the signaling domain of 4-1BB comprises the amino acid sequence set forth in SEQ ID NO: 27 and the signaling domain of CD3-zeta comprises the amino acid sequence set forth in SEQ ID NO: 29 and the variant amino acid sequence set forth in SEQ ID NO: 31.

5. Additional Description of CARs

Also expressly included within the scope of the invention are functional portions of the CARs disclosed herein. The term "functional portion" when used in reference to a CAR refers to any part or fragment of one or more of the CARs disclosed herein, which part or fragment retains the biological activity of the CAR of which it is a part (the parent CAR). Functional portions encompass, for example, those parts of a CAR that retain the ability to recognize target cells, or

detect, treat, or prevent a disease, to a similar extent, the same extent, or to a higher extent, as the parent CAR. In reference to the parent CAR, the functional portion can comprise, for instance, about 10%, 25%, 30%, 50%, 68%, 80%, 90%, 95%, or more, of the parent CAR.

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

Included in the scope of the disclosure are functional variants of the CARs disclosed herein. The term "functional variant" as used herein refers to a CAR, polypeptide, or protein having substantial or significant sequence identity or similarity to a parent CAR, which functional variant retains the biological activity of the CAR of which it is a variant. Functional variants encompass, for example, those variants of the CAR described herein (the parent CAR) that retain the ability to recognize target cells to a similar extent, the same extent, or to a higher extent, as the parent CAR. In reference to the parent CAR, the functional variant can, for instance, be at least about 30%, 50%, 75%, 80%, 90%, 98% or more identical in amino acid sequence to the parent CAR.

A functional variant can, for example, comprise the amino acid sequence of the parent CAR with at least one conservative amino acid substitution. Alternatively, or additionally, the functional variants can comprise the amino acid sequence of the parent CAR with at least one non-conservative amino acid substitution. In this case, it is preferable for the non-conservative amino acid substitution to not interfere with or inhibit the biological activity of the functional variant. The non-conservative amino acid substitution may enhance the biological activity of the functional variant, such that the biological activity of the functional variant is increased as compared to the parent CAR.

Amino acid substitutions of the CARs are preferably conservative amino acid substitutions. Conservative amino acid substitutions are known in the art, and include amino acid substitutions in which one amino acid having certain physical and/or chemical properties is exchanged for another amino acid that has the same or similar chemical or physical properties. For instance, the conservative amino acid substitution can be an acidic/negatively charged polar amino acid substituted for another acidic/negatively charged polar amino acid (e.g., Asp or Glu), an amino acid with a nonpolar side chain substituted for another amino acid with a nonpolar side chain (e.g., Ala, Gly, Val, Ile, Leu, Met, Phe, Pro, Trp, Cys, Val, etc.), a basic/positively charged

polar amino acid substituted for another basic/positively charged polar amino acid (e.g. Lys, His, Arg, etc.), an uncharged amino acid with a polar side chain substituted for another uncharged amino acid with a polar side chain (e.g., Asn, Gln, Ser, Thr, Tyr, etc.), an amino acid with a beta-branched side-chain substituted for another amino acid with a beta-branched side-chain (e.g., Ile, Thr, and Val), an amino acid with an aromatic side-chain substituted for another amino acid with an aromatic side chain (e.g., His, Phe, Trp, and Tyr), etc.

The CAR can consist essentially of the specified amino acid sequence or sequences described herein, such that other components, e.g., other amino acids, do not materially change the biological activity of the functional variant.

The CARs (including functional portions and functional variants) can be of any length, i.e., can comprise any number of amino acids, provided that the CARs (or functional portions or functional variants thereof) retain their biological activity, e.g., the ability to specifically bind to antigen, detect diseased cells in a mammal, or treat or prevent disease in a mammal, etc. For example, the CAR can be about 50 to about 5000 amino acids long, such as 50, 70, 75, 100, 125, 150, 175, 200, 300, 400, 500, 600, 700, 800, 900, 1000 or more amino acids in length.

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

The CARs (including functional portions and functional variants) can be glycosylated, amidated, carboxylated, phosphorylated, esterified, N-acylated, cyclized via, e.g., a disulfide bridge, or converted into an acid addition salt and/or optionally dimerized or polymerized, or conjugated.

The CARs (including functional portions and functional variants thereof) can be obtained by methods known in the art. The CARs may be made by any suitable method of making polypeptides or proteins. Suitable methods of *de novo* synthesizing polypeptides and proteins are

described in references, such as Chan et al., *Fmoc Solid Phase Peptide Synthesis*, Oxford University Press, Oxford, United Kingdom, 2000; *Peptide and Protein Drug Analysis*, ed. Reid, R., Marcel Dekker, Inc., 2000; *Epitope Mapping*, ed. Westwood et al., Oxford University Press, Oxford, United Kingdom, 2001; and U.S. Patent 5,449,752. Also, polypeptides and proteins can be recombinantly produced using the nucleic acids described herein using standard recombinant methods. See, for instance, Sambrook et al., *Molecular Cloning: A Laboratory Manual*, 3rd ed., Cold Spring Harbor Press, Cold Spring Harbor, NY 2001; and Ausubel et al., *Current Protocols in Molecular Biology*, Greene Publishing Associates and John Wiley & Sons, NY, 1994. Further, some of the CARs (including functional portions and functional variants thereof) can be isolated and/or purified from a source, such as a plant, a bacterium, an insect, a mammal, e.g., a rat, a human, etc. Methods of isolation and purification are well-known in the art. Alternatively, the CARs described herein (including functional portions and functional variants thereof) can be commercially synthesized by companies. In this respect, the CARs can be synthetic, recombinant, isolated, and/or purified.

B. Antibodies and Antigen Binding Fragments

One embodiment further provides a CAR, a T cell expressing a CAR, an antibody, or antigen binding domain or portion thereof, which specifically binds to one or more of the antigens disclosed herein. As used herein, a “T cell expressing a CAR,” or a “CAR T cell” means a T cell expressing a CAR, and has antigen specificity determined by, for example, the antibody-derived targeting domain of the CAR.

As used herein, and “antigen binding domain” can include an antibody and antigen binding fragments thereof. The term “antibody” is used herein in the broadest sense and encompasses various antibody structures, including but not limited to monoclonal antibodies, polyclonal antibodies, multi-specific antibodies (e.g., bispecific antibodies), and antigen binding fragments thereof, so long as they exhibit the desired antigen-binding activity. Non-limiting examples of antibodies include, for example, intact immunoglobulins and variants and fragments thereof known in the art that retain binding affinity for the antigen.

A “monoclonal antibody” is an antibody obtained from a population of substantially homogeneous antibodies, i.e., the individual antibodies comprising the population are identical except for possible naturally occurring mutations that may be present in minor amounts. Monoclonal antibodies are highly specific, being directed against a single antigenic epitope. The modifier “monoclonal” indicates the character of the antibody as being obtained from a

substantially homogeneous population of antibodies, and is not to be construed as requiring production of the antibody by any particular method. In some examples, a monoclonal antibody is an antibody produced by a single clone of B lymphocytes or by a cell into which nucleic acid encoding the light and heavy variable regions of the antibody of a single antibody (or an antigen binding fragment thereof) have been transfected, or a progeny thereof. In some examples monoclonal antibodies are isolated from a subject. Monoclonal antibodies can have conservative amino acid substitutions which have substantially no effect on antigen binding or other immunoglobulin functions. Exemplary methods of production of monoclonal antibodies are known, for example, see Harlow & Lane, *Antibodies, A Laboratory Manual*, 2nd ed. Cold Spring Harbor Publications, New York (2013).

Typically, an immunoglobulin has heavy (H) chains and light (L) chains interconnected by disulfide bonds. Immunoglobulin genes include the kappa, lambda, alpha, gamma, delta, epsilon and mu constant region genes, as well as the myriad immunoglobulin variable domain genes. There are two types of light chain, lambda (λ) and kappa (κ). There are five main heavy chain classes (or isotypes) which determine the functional activity of an antibody molecule: IgM, IgD, IgG, IgA and IgE.

Each heavy and light chain contains a constant region (or constant domain) and a variable region (or variable domain; see, e.g., Kindt et al. *Kuby Immunology*, 6th ed., W.H. Freeman and Co., page 91 (2007).) In several embodiments, the heavy and the light chain variable regions combine to specifically bind the antigen. In additional embodiments, only the heavy chain variable region is required. For example, naturally occurring camelid antibodies consisting of a heavy chain only are functional and stable in the absence of light chain (see, e.g., Hamers-Casterman et al., *Nature*, 363:446-448, 1993; Sheriff et al., *Nat. Struct. Biol.*, 3:733-736, 1996). References to “VH” or “VH” refer to the variable region of an antibody heavy chain, including that of an antigen binding fragment, such as Fv, ScFv, dsFv or Fab. References to “VL” or “VL” refer to the variable domain of an antibody light chain, including that of an Fv, ScFv, dsFv or Fab.

Light and heavy chain variable regions contain a “framework” region interrupted by three hypervariable regions, also called “complementarity-determining regions” or “CDRs” (see, e.g., Kabat et al., *Sequences of Proteins of Immunological Interest*, U.S. Department of Health and Human Services, 1991). The sequences of the framework regions of different light or heavy chains are relatively conserved within a species. The framework region of an antibody, that is the combined framework regions of the constituent light and heavy chains, serves to position and align the CDRs in three-dimensional space.

The CDRs are primarily responsible for binding to an epitope of an antigen. The amino acid sequence boundaries of a given CDR can be readily determined using any of a number of well-known schemes, including those described by Kabat *et al.* ("Sequences of Proteins of Immunological Interest," 5th Ed. Public Health Service, National Institutes of Health, Bethesda, MD, 1991; "Kabat" numbering scheme), Al-Lazikani *et al.*, (JMB 273,927-948, 1997; "Chothia" numbering scheme), and Lefranc *et al.* ("IMGT unique numbering for immunoglobulin and T cell receptor variable domains and Ig superfamily V-like domains," Dev. Comp. Immunol., 27:55-77, 2003; "IMGT" numbering scheme). The CDRs of each chain are typically referred to as CDR1, CDR2, and CDR3 (from the N-terminus to C-terminus), and are also typically identified by the chain in which the particular CDR is located. Thus, a VH CDR3 is the CDR3 from the variable domain of the heavy chain of the antibody in which it is found, whereas a VL CDR1 is the CDR1 from the variable domain of the light chain of the antibody in which it is found. Light chain CDRs are sometimes referred to as LCDR1, LCDR2, and LCDR3. Heavy chain CDRs are sometimes referred to as LCDR1, LCDR2, and LCDR3.

An "antigen binding fragment" is a portion of a full length antibody that retains the ability to specifically recognize the cognate antigen, as well as various combinations of such portions. Non-limiting examples of antigen binding fragments include Fv, Fab, Fab', Fab'-SH, F(ab')₂; diabodies; linear antibodies; single-chain antibody molecules (e.g. ScFv); and multi-specific antibodies formed from antibody fragments. Antibody fragments include antigen binding fragments either produced by the modification of whole antibodies or those synthesized *de novo* using recombinant DNA methodologies (see, e.g., Kontermann and Dubel (Ed), Antibody Engineering, Vols. 1-2, 2nd Ed., Springer Press, 2010).

A single-chain antibody (ScFv) is a genetically engineered molecule containing the VH and VL domains of one or more antibody(ies) linked by a suitable polypeptide linker as a genetically fused single chain molecule (see, for example, Bird *et al.*, Science, 242:423-426, 1988; Huston *et al.*, Proc. Natl. Acad. Sci., 85:5879-5883, 1988; Ahmad *et al.*, Clin. Dev. Immunol., 2012, doi:10.1155/2012/980250; Marbry, IDrugs, 13:543-549, 2010). The intramolecular orientation of the VH-domain and the VL-domain in a ScFv, is typically not decisive for ScFvs. Thus, ScFvs with both possible arrangements (VH-domain-linker domain-VL-domain; VL-domain-linker domain-VH-domain) may be used.

In a dsFv, the heavy and light chain variable chains have been mutated to introduce a disulfide bond to stabilize the association of the chains. Diabodies also are included, which are bivalent, bispecific antibodies in which VH and VL domains are expressed on a single polypeptide chain, but using a linker that is too short to allow for pairing between the two

domains on the same chain, thereby forcing the domains to pair with complementary domains of another chain and creating two antigen binding sites (see, for example, Holliger et al., *Proc. Natl. Acad. Sci.*, 90:6444-6448, 1993; Poljak et al., *Structure*, 2:1121-1123, 1994).

Antibodies also include genetically engineered forms such as chimeric antibodies (such as humanized murine antibodies) and heteroconjugate antibodies (such as bispecific antibodies). See also, *Pierce Catalog and Handbook*, 1994-1995 (Pierce Chemical Co., Rockford, IL); Kuby, J., *Immunology*, 3rd Ed., W.H. Freeman & Co., New York, 1997.

Non-naturally occurring antibodies can be constructed using solid phase peptide synthesis, can be produced recombinantly, or can be obtained, for example, by screening combinatorial libraries consisting of variable heavy chains and variable light chains as described by Huse et al., *Science* 246:1275-1281 (1989), which is incorporated herein by reference. These and other methods of making, for example, chimeric, humanized, CDR-grafted, single chain, and bifunctional antibodies, are well known to those skilled in the art (Winter and Harris, *Immunol. Today* 14:243-246 (1993); Ward et al., *Nature* 341:544-546 (1989); Harlow and Lane, *supra*, 1988; Hilyard et al., *Protein Engineering: A practical approach* (IRL Press 1992); Borrabeck, *Antibody Engineering*, 2d ed. (Oxford University Press 1995); each of which is incorporated herein by reference).

An “antibody that binds to the same epitope” as a reference antibody refers to an antibody that blocks binding of the reference antibody to its antigen in a competition assay by 50% or more, and conversely, the reference antibody blocks binding of the antibody to its antigen in a competition assay by 50% or more. Antibody competition assays are known, and an exemplary competition assay is provided herein.

A “humanized” antibody or antigen binding fragment includes a human framework region and one or more CDRs from a non-human (such as a mouse, rat, or synthetic) antibody or antigen binding fragment. The non-human antibody or antigen binding fragment providing the CDRs is termed a “donor,” and the human antibody or antigen binding fragment providing the framework is termed an “acceptor.” In one embodiment, all the CDRs are from the donor immunoglobulin in a humanized immunoglobulin. Constant regions need not be present, but if they are, they can be substantially identical to human immunoglobulin constant regions, such as at least about 85-90%, such as about 95% or more identical. Hence, all parts of a humanized antibody or antigen binding fragment, except possibly the CDRs, are substantially identical to corresponding parts of natural human antibody sequences.

A “chimeric antibody” is an antibody which includes sequences derived from two different antibodies, which typically are of different species. In some examples, a chimeric antibody

includes one or more CDRs and/or framework regions from one human antibody and CDRs and/or framework regions from another human antibody.

A “fully human antibody” or “human antibody” is an antibody which includes sequences from (or derived from) the human genome, and does not include sequence from another species. In some embodiments, a human antibody includes CDRs, framework regions, and (if present) an Fc region from (or derived from) the human genome. Human antibodies can be identified and isolated using technologies for creating antibodies based on sequences derived from the human genome, for example by phage display or using transgenic animals (see, e.g., Barbas et al. Phage display: A Laboratory Manual. 1st Ed. New York: Cold Spring Harbor Laboratory Press, 2004. Print.; Lonberg, Nat. Biotech., 23: 1117-1125, 2005; Lonenberg, Curr. Opin. Immunol., 20:450-459, 2008).

An antibody may have one or more binding sites. If there is more than one binding site, the binding sites may be identical to one another or may be different. For instance, a naturally-occurring immunoglobulin has two identical binding sites, a single-chain antibody or Fab fragment has one binding site, while a bispecific or bifunctional antibody has two different binding sites.

Methods of testing antibodies for the ability to bind to any functional portion of the CAR are known in the art and include any antibody-antigen binding assay, such as, for example, radioimmunoassay (RIA), ELISA, Western blot, immunoprecipitation, and competitive inhibition assays (see, e.g., Janeway et al., *infra*, U.S. Patent Application Publication No. 2002/0197266 A1, and U.S. Patent No. 7,338,929).

Also, a CAR, a T cell expressing a CAR, an antibody, or antigen binding portion thereof, can be modified to comprise a detectable label, such as, for instance, a radioisotope, a fluorophore (e.g., fluorescein isothiocyanate (FITC), phycoerythrin (PE)), an enzyme (e.g., alkaline phosphatase, horseradish peroxidase), and element particles (e.g., gold particles).

C. Conjugates

A CAR, a T cell expressing a CAR, or monoclonal antibodies, or antigen binding fragments thereof, specific for one or more of the antigens disclosed herein, can be conjugated to an agent, such as an effector molecule or detectable marker, using any number of means known to those of skill in the art. Both covalent and noncovalent attachment means may be used. Conjugates include, but are not limited to, molecules in which there is a covalent linkage of an effector molecule or a detectable marker to an antibody or antigen binding fragment that

specifically binds one or more of the antigens disclosed herein. One of skill in the art will appreciate that various effector molecules and detectable markers can be used, including (but not limited to) chemotherapeutic agents, anti-angiogenic agents, toxins, radioactive agents such as ^{125}I , ^{32}P , ^{14}C , ^3H and ^{35}S and other labels, target moieties and ligands, etc.

The choice of a particular effector molecule or detectable marker depends on the particular target molecule or cell, and the desired biological effect. Thus, for example, the effector molecule can be a cytotoxin that is used to bring about the death of a particular target cell (such as a tumor cell).

The procedure for attaching an effector molecule or detectable marker to an antibody or antigen binding fragment varies according to the chemical structure of the effector. Polypeptides typically contain a variety of functional groups; such as carboxylic acid (COOH), free amine ($-\text{NH}_2$) or sulfhydryl ($-\text{SH}$) groups, which are available for reaction with a suitable functional group on an antibody to result in the binding of the effector molecule or detectable marker. Alternatively, the antibody or antigen binding fragment is derivatized to expose or attach additional reactive functional groups. The derivatization may involve attachment of any of a number of known linker molecules such as those available from Pierce Chemical Company, Rockford, IL. The linker can be any molecule used to join the antibody or antigen binding fragment to the effector molecule or detectable marker. The linker is capable of forming covalent bonds to both the antibody or antigen binding fragment and to the effector molecule or detectable marker. Suitable linkers are well known to those of skill in the art and include, but are not limited to, straight or branched-chain carbon linkers, heterocyclic carbon linkers, or peptide linkers. Where the antibody or antigen binding fragment and the effector molecule or detectable marker are polypeptides, the linkers may be joined to the constituent amino acids through their side groups (such as through a disulfide linkage to cysteine) or to the alpha carbon amino and carboxyl groups of the terminal amino acids.

In several embodiments, the linker can include a spacer element, which, when present, increases the size of the linker such that the distance between the effector molecule or the detectable marker and the antibody or antigen binding fragment is increased. Exemplary spacers are known to the person of ordinary skill, and include those listed in U.S. Pat. Nos. 7,964,566, 7,498,298, 6,884,869, 6,323,315, 6,239,104, 6,034,065, 5,780,588, 5,665,860, 5,663,149, 5,635,483, 5,599,902, 5,554,725, 5,530,097, 5,521,284, 5,504,191, 5,410,024, 5,138,036, 5,076,973, 4,986,988, 4,978,744, 4,879,278, 4,816,444, and 4,486,414, as well as U.S. Pat. Pub. Nos. 20110212088 and 20110070248, each of which is incorporated by reference herein in its entirety.

In some embodiments, the linker is cleavable under intracellular conditions, such that cleavage of the linker releases the effector molecule or detectable marker from the antibody or antigen binding fragment in the intracellular environment. In yet other embodiments, the linker is not cleavable and the effector molecule or detectable marker is released, for example, by antibody degradation. In some embodiments, the linker is cleavable by a cleaving agent that is present in the intracellular environment (for example, within a lysosome or endosome or caveolea). The linker can be, for example, a peptide linker that is cleaved by an intracellular peptidase or protease enzyme, including, but not limited to, a lysosomal or endosomal protease. In some embodiments, the peptide linker is at least two amino acids long or at least three amino acids long. However, the linker can be 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14 or 15 amino acids long, such as 1-2, 1-3, 2-5, 3-10, 3-15, 1-5, 1-10, 1-15 amino acids long. Proteases can include cathepsins B and D and plasmin, all of which are known to hydrolyze dipeptide drug derivatives resulting in the release of active drug inside target cells (see, for example, Dubowchik and Walker, 1999, *Pharm. Therapeutics* 83:67-123). For example, a peptide linker that is cleavable by the thiol-dependent protease cathepsin-B, can be used (for example, a Phenylalanine -Leucine or a Glycine- Phenylalanine -Leucine-Glycine linker). Other examples of such linkers are described, for example, in U.S. Pat. No. 6,214,345, incorporated herein by reference. In a specific embodiment, the peptide linker cleavable by an intracellular protease is a Valine-Citruline linker or a Phenylalanine-Lysine linker (see, for example, U.S. Pat. No. 6,214,345, which describes the synthesis of doxorubicin with the Valine-Citruline linker).

In other embodiments, the cleavable linker is pH-sensitive, i.e., sensitive to hydrolysis at certain pH values. Typically, the pH-sensitive linker is hydrolyzable under acidic conditions. For example, an acid-labile linker that is hydrolyzable in the lysosome (for example, a hydrazone, semicarbazone, thiosemicarbazone, cis-aconitic amide, orthoester, acetal, ketal, or the like) can be used. (See, for example, U.S. Pat. Nos. 5,122,368; 5,824,805; 5,622,929; Dubowchik and Walker, 1999, *Pharm. Therapeutics* 83:67-123; Neville et al., 1989, *Biol. Chem.* 264:14653-14661.) Such linkers are relatively stable under neutral pH conditions, such as those in the blood, but are unstable at below pH 5.5 or 5.0, the approximate pH of the lysosome. In certain embodiments, the hydrolyzable linker is a thioether linker (such as, for example, a thioether attached to the therapeutic agent via an acylhydrazone bond (see, for example, U.S. Pat. No. 5,622,929).

In other embodiments, the linker is cleavable under reducing conditions (for example, a disulfide linker). A variety of disulfide linkers are known in the art, including, for example, those that can be formed using SATA (N-succinimidyl-S-acetylthioacetate), SPDP (N-succinimidyl-3-(2-pyridyldithio)propionate), SPDB (N-succinimidyl-3-(2-pyridyldithio)butyrate) and SMPT (N-

succinimidyl-oxycarbonyl-alpha-methyl-alpha-(2-pyridyl-dithio)toluene)-, SPDB and SMPT. (See, for example, Thorpe et al., 1987, *Cancer Res.* 47:5924-5931; Wawrzynczak et al., In *Immunoconjugates: Antibody Conjugates in Radioimagery and Therapy of Cancer* (C. W. Vogel ed., Oxford U. Press, 1987); Phillips et al., *Cancer Res.* 68:92809290, 2008). See also U.S. Pat. No. 4,880,935.)

In yet other specific embodiments, the linker is a malonate linker (Johnson et al., 1995, *Anticancer Res.* 15:1387-93), a maleimidobenzoyl linker (Lau et al., 1995, *Bioorg-Med-Chem.* 3(10):1299-1304), or a 3'-N-amide analog (Lau et al., 1995, *Bioorg-Med-Chem.* 3(10):1305-12).

In yet other embodiments, the linker is not cleavable and the effector molecule or detectable marker is released by antibody degradation. (See U.S. Publication No. 2005/0238649 incorporated by reference herein in its entirety).

In several embodiments, the linker is resistant to cleavage in an extracellular environment. For example, no more than about 20%, no more than about 15%, no more than about 10%, no more than about 5%, no more than about 3%, or no more than about 1% of the linkers, in a sample of conjugate, are cleaved when the conjugate is present in an extracellular environment (for example, in plasma). Whether or not a linker is resistant to cleavage in an extracellular environment can be determined, for example, by incubating the conjugate containing the linker of interest with plasma for a predetermined time period (for example, 2, 4, 8, 16, or 24 hours) and then quantitating the amount of free effector molecule or detectable marker present in the plasma. A variety of exemplary linkers that can be used in conjugates are described in WO 2004-010957, U.S. Publication No. 2006/0074008, U.S. Publication No. 20050238649, and U.S. Publication No. 2006/0024317, each of which is incorporated by reference herein in its entirety.

In several embodiments, conjugates of a CAR, a T cell expressing a CAR, an antibody, or antigen binding portion thereof, and one or more small molecule toxins, such as a calicheamicin, maytansinoids, dolastatins, auristatins, a trichothecene, and CC1065, and the derivatives of these toxins that have toxin activity, are provided.

Maytansine compounds suitable for use as maytansinoid toxin moieties are well known in the art, and can be isolated from natural sources according to known methods, produced using genetic engineering techniques (see Yu et al (2002) *PNAS* 99:7968-7973), or maytansinol and maytansinol analogues prepared synthetically according to known methods. Maytansinoids are mitototic inhibitors which act by inhibiting tubulin polymerization. Maytansine was first isolated from the east African shrub *Maytenus serrata* (U.S. Pat. No. 3,896,111). Subsequently, it was discovered that certain microbes also produce maytansinoids, such as maytansinol and C-3 maytansinol esters (U.S. Pat. No. 4,151,042). Synthetic maytansinol and derivatives and

analogues thereof are disclosed, for example, in U.S. Pat. Nos. 4,137,230; 4,248,870; 4,256,746; 4,260,608; 4,265,814; 4,294,757; 4,307,016; 4,308,268; 4,308,269; 4,309,428; 4,313,946; 4,315,929; 4,317,821; 4,322,348; 4,331,598; 4,361,650; 4,364,866; 4,424,219; 4,450,254; 4,362,663; and 4,371,533, each of which is incorporated herein by reference. Conjugates containing maytansinoids, methods of making same, and their therapeutic use are disclosed, for example, in U.S. Pat. Nos. 5,208,020; 5,416,064; 6,441,163 and European Patent EP 0 425 235 B1, the disclosures of which are hereby expressly incorporated by reference.

Additional toxins can be employed with a CAR, a T cell expressing a CAR, an antibody, or antigen binding portion thereof. Exemplary toxins include *Pseudomonas* exotoxin (PE), ricin, abrin, diphtheria toxin and subunits thereof, ribotoxin, ribonuclease, saporin, and calicheamicin, as well as botulinum toxins A through F. These toxins are well known in the art and many are readily available from commercial sources (for example, Sigma Chemical Company, St. Louis, MO). Contemplated toxins also include variants of the toxins (see, for example, see, U.S. Patent Nos. 5,079,163 and 4,689,401).

Saporin is a toxin derived from *Saponaria officinalis* that disrupts protein synthesis by inactivating the 60S portion of the ribosomal complex (Stirpe et al., *Bio/Technology*, 10:405-412, 1992). However, the toxin has no mechanism for specific entry into cells, and therefore requires conjugation to an antibody or antigen binding fragment that recognizes a cell-surface protein that is internalized in order to be efficiently taken up by cells.

Diphtheria toxin is isolated from *Corynebacterium diphtheriae*. Typically, diphtheria toxin for use in immunotoxins is mutated to reduce or to eliminate non-specific toxicity. A mutant known as CRM107, which has full enzymatic activity but markedly reduced non-specific toxicity, has been known since the 1970's (Laird and Groman, *J. Virol.* 19:220, 1976), and has been used in human clinical trials. See, U.S. Patent No. 5,792,458 and U.S. Patent No. 5,208,021.

Ricin is the lectin RCA60 from *Ricinus communis* (Castor bean). For examples of ricin, see, U.S. Patent No. 5,079,163 and U.S. Patent No. 4,689,401. *Ricinus communis* agglutinin (RCA) occurs in two forms designated RCA₆₀ and RCA₁₂₀ according to their molecular weights of approximately 65 and 120 kD, respectively (Nicholson & Blaustein, *J. Biochim. Biophys. Acta* 266:543, 1972). The A chain is responsible for inactivating protein synthesis and killing cells. The B chain binds ricin to cell-surface galactose residues and facilitates transport of the A chain into the cytosol (Olsnes et al., *Nature* 249:627-631, 1974 and U.S. Patent No. 3,060,165).

Ribonucleases have also been conjugated to targeting molecules for use as immunotoxins (see Suzuki et al., *Nat. Biotech.* 17:265-70, 1999). Exemplary ribotoxins such as α -sarcin and restrictocin are discussed in, for example Rathore et al., *Gene* 190:31-5, 1997; and Goyal and

Batra, Biochem. 345 Pt 2:247-54, 2000. Calicheamicins were first isolated from *Micromonospora echinospora* and are members of the enediyne antitumor antibiotic family that cause double strand breaks in DNA that lead to apoptosis (see, for example Lee et al., J. Antibiot. 42:1070-87, 1989). The drug is the toxic moiety of an immunotoxin in clinical trials (see, for example, Gillespie et al., Ann. Oncol. 11:735-41, 2000).

Abrin includes toxic lectins from *Abrus precatorius*. The toxic principles, abrin a, b, c, and d, have a molecular weight of from about 63 and 67 kD and are composed of two disulfide-linked polypeptide chains A and B. The A chain inhibits protein synthesis; the B chain (abrin-b) binds to D-galactose residues (see, Funatsu et al., Agr. Biol. Chem. 52:1095, 1988; and Olsnes, Methods Enzymol. 50:330-335, 1978).

A CAR, a T cell expressing a CAR, monoclonal antibodies, antigen binding fragments thereof, specific for one or more of the antigens disclosed herein, can also be conjugated with a detectable marker; for example, a detectable marker capable of detection by ELISA, spectrophotometry, flow cytometry, microscopy or diagnostic imaging techniques (such as computed tomography (CT), computed axial tomography (CAT) scans, magnetic resonance imaging (MRI), nuclear magnetic resonance imaging (NMRI), magnetic resonance tomography (MTR), ultrasound, fiberoptic examination, and laparoscopic examination). Specific, non-limiting examples of detectable markers include fluorophores, chemiluminescent agents, enzymatic linkages, radioactive isotopes and heavy metals or compounds (for example super paramagnetic iron oxide nanocrystals for detection by MRI). For example, useful detectable markers include fluorescent compounds, including fluorescein, fluorescein isothiocyanate, rhodamine, 5-dimethylamine-1-naphthalenesulfonyl chloride, phycoerythrin, lanthanide phosphors and the like. Bioluminescent markers are also of use, such as luciferase, Green fluorescent protein (GFP), Yellow fluorescent protein (YFP). A CAR, a T cell expressing a CAR, an antibody, or antigen binding portion thereof, can also be conjugated with enzymes that are useful for detection, such as horseradish peroxidase, β -galactosidase, luciferase, alkaline phosphatase, glucose oxidase and the like. When a CAR, a T cell expressing a CAR, an antibody, or antigen binding portion thereof, is conjugated with a detectable enzyme, it can be detected by adding additional reagents that the enzyme uses to produce a reaction product that can be discerned. For example, when the agent horseradish peroxidase is present the addition of hydrogen peroxide and diaminobenzidine leads to a colored reaction product, which is visually detectable. A CAR, a T cell expressing a CAR, an antibody, or antigen binding portion thereof, may also be conjugated with biotin, and detected through indirect measurement of avidin or streptavidin binding. It should be noted that the avidin itself can be conjugated with an enzyme or a fluorescent label.

A CAR, a T cell expressing a CAR, an antibody, or antigen binding portion thereof, may be conjugated with a paramagnetic agent, such as gadolinium. Paramagnetic agents such as superparamagnetic iron oxide are also of use as labels. Antibodies can also be conjugated with lanthanides (such as europium and dysprosium), and manganese. An antibody or antigen binding fragment may also be labeled with a predetermined polypeptide epitopes recognized by a secondary reporter (such as leucine zipper pair sequences, binding sites for secondary antibodies, metal binding domains, epitope tags).

A CAR, a T cell expressing a CAR, an antibody, or antigen binding portion thereof, can also be conjugated with a radiolabeled amino acid. The radiolabel may be used for both diagnostic and therapeutic purposes. For instance, the radiolabel may be used to detect one or more of the antigens disclosed herein and antigen expressing cells by x-ray, emission spectra, or other diagnostic techniques. Further, the radiolabel may be used therapeutically as a toxin for treatment of tumors in a subject, for example for treatment of a neuroblastoma. Examples of labels for polypeptides include, but are not limited to, the following radioisotopes or radionucleotides: ^3H , ^{14}C , ^{15}N , ^{35}S , ^{90}Y , ^{99}Tc , ^{111}In , ^{125}I , ^{131}I .

Means of detecting such detectable markers are well known to those of skill in the art. Thus, for example, radiolabels may be detected using photographic film or scintillation counters, fluorescent markers may be detected using a photodetector to detect emitted illumination. Enzymatic labels are typically detected by providing the enzyme with a substrate and detecting the reaction product produced by the action of the enzyme on the substrate, and colorimetric labels are detected by simply visualizing the colored label.

D. Nucleotides, Expression, Vectors, and Host Cells

Further provided by an embodiment of the invention is a nucleic acid comprising a nucleotide sequence encoding any of the CARs, an antibody, or antigen binding portion thereof, described herein (including functional portions and functional variants thereof). The nucleic acids of the invention may comprise a nucleotide sequence encoding any of the leader sequences, antigen binding domains, transmembrane domains, and/or intracellular T cell signaling domains described herein.

In some embodiments, the nucleotide sequence may be codon-modified. Without being bound to a particular theory, it is believed that codon optimization of the nucleotide sequence increases the translation efficiency of the mRNA transcripts. Codon optimization of the nucleotide sequence may involve substituting a native codon for another codon that encodes the

same amino acid, but can be translated by tRNA that is more readily available within a cell, thus increasing translation efficiency. Optimization of the nucleotide sequence may also reduce secondary mRNA structures that would interfere with translation, thus increasing translation efficiency.

In an embodiment of the invention, the nucleic acid may comprise a codon-modified nucleotide sequence that encodes the antigen binding domain of the inventive CAR. In another embodiment of the invention, the nucleic acid may comprise a codon-modified nucleotide sequence that encodes any of the CARs described herein (including functional portions and functional variants thereof).

"Nucleic acid" as used herein includes "polynucleotide," "oligonucleotide," and "nucleic acid molecule," and generally means a polymer of DNA or RNA, which can be single-stranded or double-stranded, synthesized or obtained (e.g., isolated and/or purified) from natural sources, which can contain natural, non-natural or altered nucleotides, and which can contain a natural, non-natural or altered internucleotide linkage, such as a phosphoramidate linkage or a phosphorothioate linkage, instead of the phosphodiester found between the nucleotides of an unmodified oligonucleotide. In some embodiments, the nucleic acid does not comprise any insertions, deletions, inversions, and/or substitutions. However, it may be suitable in some instances, as discussed herein, for the nucleic acid to comprise one or more insertions, deletions, inversions, and/or substitutions.

A recombinant nucleic acid may be one that has a sequence that is not naturally occurring or has a sequence that is made by an artificial combination of two otherwise separated segments of sequence. This artificial combination is often accomplished by chemical synthesis or, more commonly, by the artificial manipulation of isolated segments of nucleic acids, e.g., by genetic engineering techniques, such as those described in Sambrook et al., *supra*. The nucleic acids can be constructed based on chemical synthesis and/or enzymatic ligation reactions using procedures known in the art. See, for example, Sambrook *et al.*, *supra*, and Ausubel *et al.*, *supra*. For example, a nucleic acid can be chemically synthesized using naturally occurring nucleotides or variously modified nucleotides designed to increase the biological stability of the molecules or to increase the physical stability of the duplex formed upon hybridization (e.g., phosphorothioate derivatives and acridine substituted nucleotides). Examples of modified nucleotides that can be used to generate the nucleic acids include, but are not limited to, 5-fluorouracil, 5-bromouracil, 5-chlorouracil, 5-iodouracil, hypoxanthine, xanthine, 4-acetylcytosine, 5-(carboxyhydroxymethyl) uracil, 5-carboxymethylaminomethyl-2-thiouridine, 5-carboxymethylaminomethyluracil, dihydrouracil, beta-D-galactosylqueosine, inosine, N6-isopentenyladenine, 1-methylguanine, 1 -

methylinosine, 2,2-dimethylguanine, 2-methyladenine, 2-methylguanine, 3-methylcytosine, 5-methylcytosine, N6-substituted adenine, 7-methylguanine, 5-methylaminomethyluracil, 5-methoxyaminomethyl-2-thiouracil, beta-D-mannosylqueosine, 5'-methoxycarboxymethyluracil, 5-methoxyuracil, 2-methylthio-N6-isopentenyladenine, uracil-5-oxyacetic acid (v), wybutoxosine, pseudouracil, queosine, 2-thiocytosine, 5-methyl-2-thiouracil, 2-thiouracil, 4-thiouracil, 5-methyluracil, uracil-5-oxyacetic acid methylester, 3- (3-amino-3-N-2-carboxypropyl) uracil, and 2,6-diaminopurine. Alternatively, one or more of the nucleic acids of the invention can be purchased from companies, such as Integrated DNA Technologies (Coralville, IA, USA).

The nucleic acid can comprise any isolated or purified nucleotide sequence which encodes any of the CARs or functional portions or functional variants thereof. Alternatively, the nucleotide sequence can comprise a nucleotide sequence which is degenerate to any of the sequences or a combination of degenerate sequences.

An embodiment also provides an isolated or purified nucleic acid comprising a nucleotide sequence which is complementary to the nucleotide sequence of any of the nucleic acids described herein or a nucleotide sequence which hybridizes under stringent conditions to the nucleotide sequence of any of the nucleic acids described herein.

The nucleotide sequence which hybridizes under stringent conditions may hybridize under high stringency conditions. By "high stringency conditions" is meant that the nucleotide sequence specifically hybridizes to a target sequence (the nucleotide sequence of any of the nucleic acids described herein) in an amount that is detectably stronger than non-specific hybridization. High stringency conditions include conditions which would distinguish a polynucleotide with an exact complementary sequence, or one containing only a few scattered mismatches from a random sequence that happened to have a few small regions (e.g., 3-10 bases) that matched the nucleotide sequence. Such small regions of complementarity are more easily melted than a full-length complement of 14-17 or more bases, and high stringency hybridization makes them easily distinguishable. Relatively high stringency conditions would include, for example, low salt and/or high temperature conditions, such as provided by about 0.02-0.1 M NaCl or the equivalent, at temperatures of about 50-70 °C. Such high stringency conditions tolerate little, if any, mismatch between the nucleotide sequence and the template or target strand, and are particularly suitable for detecting expression of any of the inventive CARs. It is generally appreciated that conditions can be rendered more stringent by the addition of increasing amounts of formamide.

Also provided is a nucleic acid comprising a nucleotide sequence that is at least about 70% or more, e.g., about 80%, about 90%, about 91 %, about 92%, about 93%, about 94%, about 95%,

about 96%, about 97%, about 98%, or about 99% identical to any of the nucleic acids described herein.

In an embodiment, the nucleic acids can be incorporated into a recombinant expression vector. In this regard, an embodiment provides recombinant expression vectors comprising any of the nucleic acids. For purposes herein, the term "recombinant expression vector" means a genetically-modified oligonucleotide or polynucleotide construct that permits the expression of an mRNA, protein, polypeptide, or peptide by a host cell, when the construct comprises a nucleotide sequence encoding the mRNA, protein, polypeptide, or peptide, and the vector is contacted with the cell under conditions sufficient to have the mRNA, protein, polypeptide, or peptide expressed within the cell. The vectors are not naturally-occurring as a whole.

However, parts of the vectors can be naturally-occurring. The recombinant expression vectors can comprise any type of nucleotides, including, but not limited to DNA and RNA, which can be single-stranded or double-stranded, synthesized or obtained in part from natural sources, and which can contain natural, non-natural or altered nucleotides. The recombinant expression vectors can comprise naturally-occurring or non-naturally-occurring internucleotide linkages, or both types of linkages. Preferably, the non-naturally occurring or altered nucleotides or internucleotide linkages do not hinder the transcription or replication of the vector.

In an embodiment, the recombinant expression vector can be any suitable recombinant expression vector, and can be used to transform or transfect any suitable host cell. Suitable vectors include those designed for propagation and expansion or for expression or both, such as plasmids and viruses. The vector can be selected from the group consisting of the pUC series (Fermentas Life Sciences, Glen Burnie, MD), the pBluescript series (Stratagene, LaJolla, CA), the pET series (Novagen, Madison, WI), the pGEX series (Pharmacia Biotech, Uppsala, Sweden), and the pEX series (Clontech, Palo Alto, CA).

Bacteriophage vectors, such as λ gt10, λ gt11, λ ZapII (Stratagene), EMBL4, and λ NMI 149, also can be used. Examples of plant expression vectors include pBIOL, pBI101.2, pBHO1.3, pBI121 and pBIN19 (Clontech). Examples of animal expression vectors include pEUK-Cl, pMAM, and pMAMneo (Clontech). The recombinant expression vector may be a viral vector, e.g., a retroviral vector or a lentiviral vector. A lentiviral vector is a vector derived from at least a portion of a lentivirus genome, including especially a self-inactivating lentiviral vector as provided in Milone et al., Mol. Ther. 17(8): 1453-1464 (2009). Other examples of lentivirus vectors that may be used in the clinic, include, for example, and not by way of limitation, the LENTIVECTOR.RTM. gene delivery technology from Oxford BioMedica plc, the

LENTIMAX.TM. vector system from Lentigen and the like. Nonclinical types of lentiviral vectors are also available and would be known to one skilled in the art.

A number of transfection techniques are generally known in the art (see, e.g., Graham et al., *Virology*, 52: 456-467 (1973); Sambrook et al., *supra*; Davis et al., *Basic Methods in Molecular Biology*, Elsevier (1986); and Chu et al, *Gene*, 13: 97 (1981).

Transfection methods include calcium phosphate co-precipitation (see, e.g., Graham et al., *supra*), direct micro injection into cultured cells (see, e.g., Capecchi, *Cell*, 22: 479-488 (1980)), electroporation (see, e.g., Shigekawa et al., *BioTechniques*, 6: 742-751 (1988)), liposome mediated gene transfer (see, e.g., Mannino et al., *BioTechniques*, 6: 682-690 (1988)), lipid mediated transduction (see, e.g., Feigner et al., *Proc. Natl. Acad. Sci. USA*, 84: 7413-7417 (1987)), and nucleic acid delivery using high velocity microprojectiles (see, e.g., Klein et al, *Nature*, 327: 70-73 (1987)).

In an embodiment, the recombinant expression vectors can be prepared using standard recombinant DNA techniques described in, for example, Sambrook et al., *supra*, and Ausubel et al., *supra*. Constructs of expression vectors, which are circular or linear, can be prepared to contain a replication system functional in a prokaryotic or eukaryotic host cell. Replication systems can be derived, e.g., from ColEI, 2 μ plasmid, λ , SV40, bovine papilloma virus, and the like.

The recombinant expression vector may comprise regulatory sequences, such as transcription and translation initiation and termination codons, which are specific to the type of host cell (e.g., bacterium, fungus, plant, or animal) into which the vector is to be introduced, as appropriate, and taking into consideration whether the vector is DNA- or RNA-based. The recombinant expression vector may comprise restriction sites to facilitate cloning.

The recombinant expression vector can include one or more marker genes, which allow for selection of transformed or transfected host cells. Marker genes include biocide resistance, e.g., resistance to antibiotics, heavy metals, etc., complementation in an auxotrophic host to provide prototrophy, and the like. Suitable marker genes for the inventive expression vectors include, for instance, neomycin/G418 resistance genes, hygromycin resistance genes, histidinol resistance genes, tetracycline resistance genes, and ampicillin resistance genes.

The recombinant expression vector can comprise a native or nonnative promoter operably linked to the nucleotide sequence encoding the CAR (including functional portions and functional variants thereof), or to the nucleotide sequence which is complementary to or which hybridizes to the nucleotide sequence encoding the CAR. The selection of promoters, e.g., strong, weak, inducible, tissue-specific and developmental-specific, is within the ordinary skill of the artisan.

Similarly, the combining of a nucleotide sequence with a promoter is also within the skill of the artisan. The promoter can be a non-viral promoter or a viral promoter, e.g., a cytomegalovirus (CMV) promoter, an SV40 promoter, an RSV promoter, or a promoter found in the long-terminal repeat of the murine stem cell virus.

The recombinant expression vectors can be designed for either transient expression, for stable expression, or for both. Also, the recombinant expression vectors can be made for constitutive expression or for inducible expression.

Further, the recombinant expression vectors can be made to include a suicide gene. As used herein, the term "suicide gene" refers to a gene that causes the cell expressing the suicide gene to die. The suicide gene can be a gene that confers sensitivity to an agent, e.g., a drug, upon the cell in which the gene is expressed, and causes the cell to die when the cell is contacted with or exposed to the agent. Suicide genes are known in the art (see, for example, *Suicide Gene Therapy: Methods and Reviews*, Springer, Caroline J. (Cancer Research UK Centre for Cancer Therapeutics at the Institute of Cancer Research, Sutton, Surrey, UK), Humana Press, 2004) and include, for example, the Herpes Simplex Virus (HSV) thymidine kinase (TK) gene, cytosine deaminase, purine nucleoside phosphorylase, and nitroreductase.

An embodiment further provides a host cell comprising any of the recombinant expression vectors described herein. As used herein, the term "host cell" refers to any type of cell that can contain the inventive recombinant expression vector. The host cell can be a eukaryotic cell, e.g., plant, animal, fungi, or algae, or can be a prokaryotic cell, e.g., bacteria or protozoa. The host cell can be a cultured cell or a primary cell, i.e., isolated directly from an organism, e.g., a human. The host cell can be an adherent cell or a suspended cell, i.e., a cell that grows in suspension. Suitable host cells are known in the art and include, for instance, DH5a *E. coli* cells, Chinese hamster ovarian cells, monkey VERO cells, COS cells, HEK293 cells, and the like. For purposes of amplifying or replicating the recombinant expression vector, the host cell may be a prokaryotic cell, e.g., a DH5a cell. For purposes of producing a recombinant CAR, the host cell may be a mammalian cell. The host cell may be a human cell. While the host cell can be of any cell type, can originate from any type of tissue, and can be of any developmental stage, the host cell may be a peripheral blood lymphocyte (PBL) or a peripheral blood mononuclear cell (PBMC). The host cell may be a T cell.

For purposes herein, the T cell can be any T cell, such as a cultured T cell, e.g., a primary T cell, or a T cell from a cultured T cell line, e.g., Jurkat, SupT1, etc., or a T cell obtained from a mammal. If obtained from a mammal, the T cell can be obtained from numerous sources, including but not limited to blood, bone marrow, lymph node, the thymus, or other tissues or

fluids. T cells can also be enriched for or purified. The T cell may be a human T cell. The T cell may be a T cell isolated from a human. The T cell can be any type of T cell and can be of any developmental stage, including but not limited to, CD4+/CD8+ double positive T cells, CD4+ helper T cells, e.g., Th1 and Th2 cells, CD8+ T cells (e.g., cytotoxic T cells), tumor infiltrating cells, memory T cells, memory stem cells, i.e. Tscm, naive T cells, and the like. The T cell may be a CD8+ T cell or a CD4+ T cell.

In an embodiment, the CARs as described herein can be used in suitable non-T cells. Such cells are those with an immune-effector function, such as, for example, NK cells, and T-like cells generated from pluripotent stem cells.

Also provided by an embodiment is a population of cells comprising at least one host cell described herein. The population of cells can be a heterogeneous population comprising the host cell comprising any of the recombinant expression vectors described, in addition to at least one other cell, e.g., a host cell (e.g., a T cell), which does not comprise any of the recombinant expression vectors, or a cell other than a T cell, e.g., a B cell, a macrophage, a neutrophil, an erythrocyte, a hepatocyte, an endothelial cell, an epithelial cell, a muscle cell, a brain cell, etc. Alternatively, the population of cells can be a substantially homogeneous population, in which the population comprises mainly host cells (e.g., consisting essentially of) comprising the recombinant expression vector. The population also can be a clonal population of cells, in which all cells of the population are clones of a single host cell comprising a recombinant expression vector, such that all cells of the population comprise the recombinant expression vector. In one embodiment of the invention, the population of cells is a clonal population comprising host cells comprising a recombinant expression vector as described herein.

CARs (including functional portions and variants thereof), nucleic acids, recombinant expression vectors, host cells (including populations thereof), and antibodies (including antigen binding portions thereof), can be isolated and/or purified. For example, a purified (or isolated) host cell preparation is one in which the host cell is more pure than cells in their natural environment within the body. Such host cells may be produced, for example, by standard purification techniques. In some embodiments, a preparation of a host cell is purified such that the host cell represents at least about 50%, for example at least about 70%, of the total cell content of the preparation. For example, the purity can be at least about 50%, can be greater than about 60%, about 70% or about 80%, or can be about 100%.

E. Methods of Treatment

It is contemplated that the CARs disclosed herein can be used in methods of treating or preventing a disease in a mammal. In this regard, an embodiment provides a method of treating or preventing cancer in a mammal, comprising administering to the mammal the CARs, the nucleic acids, the recombinant expression vectors, the host cells, the population of cells, the antibodies and/or the antigen binding portions thereof, and/or the pharmaceutical compositions in an amount effective to treat or prevent cancer in the mammal.

An embodiment further comprises lymphodepleting the mammal prior to administering the CARs disclosed herein. Examples of lymphodepletion include, but may not be limited to, nonmyeloablative lymphodepleting chemotherapy, myeloablative lymphodepleting chemotherapy, total body irradiation, etc.

For purposes of the methods, wherein host cells or populations of cells are administered, the cells can be cells that are allogeneic or autologous to the mammal. Preferably, the cells are autologous to the mammal. As used herein, allogeneic means any material derived from a different animal of the same species as the individual to whom the material is introduced. Two or more individuals are said to be allogeneic to one another when the genes at one or more loci are not identical. In some aspects, allogeneic material from individuals of the same species may be sufficiently unlike genetically to interact antigenically. As used herein, "autologous" means any material derived from the same individual to whom it is later to be re-introduced into the individual.

The mammal referred to herein can be any mammal. As used herein, the term "mammal" refers to any mammal, including, but not limited to, mammals of the order Rodentia, such as mice and hamsters, and mammals of the order Logomorpha, such as rabbits. The mammals may be from the order Carnivora, including Felines (cats) and Canines (dogs). The mammals may be from the order Artiodactyla, including Bovines (cows) and Swines (pigs) or of the order Perssodactyla, including Equines (horses). The mammals may be of the order Primates, Ceboids, or Simoids (monkeys) or of the order Anthropoids (humans and apes). Preferably, the mammal is a human.

With respect to the methods, the cancer can be any cancer, including any of acute lymphocytic cancer, acute myeloid leukemia, alveolar rhabdomyosarcoma, bladder cancer (e.g., bladder carcinoma), bone cancer, brain cancer (e.g., medulloblastoma), breast cancer, cancer of the anus, anal canal, or anorectum, cancer of the eye, cancer of the intrahepatic bile duct, cancer of the joints, cancer of the neck, gallbladder, or pleura, cancer of the nose, nasal cavity, or middle ear, cancer of the oral cavity, cancer of the vulva, chronic lymphocytic leukemia, chronic myeloid cancer, colon cancer, esophageal cancer, cervical cancer, fibrosarcoma, gastrointestinal carcinoid

tumor, head and neck cancer (e.g., head and neck squamous cell carcinoma), Hodgkin lymphoma, hypopharynx cancer, kidney cancer, larynx cancer, leukemia, liquid tumors, liver cancer, lung cancer (e.g., non-small cell lung carcinoma and lung adenocarcinoma), lymphoma, mesothelioma, mastocytoma, melanoma, multiple myeloma, nasopharynx cancer, non-Hodgkin lymphoma, B-chronic lymphocytic leukemia, hairy cell leukemia, acute lymphocytic leukemia (ALL), and Burkitt's lymphoma, ovarian cancer, pancreatic cancer, peritoneum, omentum, and mesentery cancer, pharynx cancer, prostate cancer, rectal cancer, renal cancer, skin cancer, small intestine cancer, soft tissue cancer, solid tumors, synovial sarcoma, gastric cancer, testicular cancer, thyroid cancer, and ureter cancer.

The terms "treat," and "prevent" as well as words stemming therefrom, as used herein, do not necessarily imply 100% or complete treatment or prevention. Rather, there are varying degrees of treatment or prevention of which one of ordinary skill in the art recognizes as having a potential benefit or therapeutic effect. In this respect, the methods can provide any amount or any level of treatment or prevention of cancer in a mammal.

Furthermore, the treatment or prevention provided by the method can include treatment or prevention of one or more conditions or symptoms of the disease, e.g., cancer, being treated or prevented. Also, for purposes herein, "prevention" can encompass delaying the onset of the disease, or a symptom or condition thereof.

Another embodiment provides a method of detecting the presence of cancer in a mammal, comprising: (a) contacting a sample comprising one or more cells from the mammal with the CARs, the nucleic acids, the recombinant expression vectors, the host cells, the population of cells, the antibodies, and/or the antigen binding portions thereof, or the pharmaceutical compositions, thereby forming a complex, (b) and detecting the complex, wherein detection of the complex is indicative of the presence of cancer in the mammal.

The sample may be obtained by any suitable method, e.g., biopsy or necropsy. A biopsy is the removal of tissue and/or cells from an individual. Such removal may be to collect tissue and/or cells from the individual in order to perform experimentation on the removed tissue and/or cells. This experimentation may include experiments to determine if the individual has and/or is suffering from a certain condition or disease-state. The condition or disease may be, e.g., cancer.

With respect to an embodiment of the method of detecting the presence of a proliferative disorder, e.g., cancer, in a mammal, the sample comprising cells of the mammal can be a sample comprising whole cells, lysates thereof, or a fraction of the whole cell lysates, e.g., a nuclear or cytoplasmic fraction, a whole protein fraction, or a nucleic acid fraction. If the sample comprises

whole cells, the cells can be any cells of the mammal, e.g., the cells of any organ or tissue, including blood cells or endothelial cells.

The contacting can take place *in vitro* or *in vivo* with respect to the mammal. Preferably, the contacting is *in vitro*.

Also, detection of the complex can occur through any number of ways known in the art. For instance, the CARs disclosed herein, polypeptides, proteins, nucleic acids, recombinant expression vectors, host cells, populations of cells, or antibodies, or antigen binding portions thereof, described herein, can be labeled with a detectable label such as, for instance, a radioisotope, a fluorophore (e.g., fluorescein isothiocyanate (FITC), phycoerythrin (PE)), an enzyme (e.g., alkaline phosphatase, horseradish peroxidase), and element particles (e.g., gold particles) as disclosed *supra*.

Methods of testing a CAR for the ability to recognize target cells and for antigen specificity are known in the art. For instance, Clay et al., J. Immunol, 163: 507-513 (1999), teaches methods of measuring the release of cytokines (e.g., interferon- γ , granulocyte/monocyte colony stimulating factor (GM-CSF), tumor necrosis factor α (TNF- α) or interleukin 2 (IL-2)). In addition, CAR function can be evaluated by measurement of cellular cytotoxicity, as described in Zhao et al, J. Immunol , 174: 4415-4423 (2005).

Another embodiment provides for the use of the CARs, nucleic acids, recombinant expression vectors, host cells, populations of cells, antibodies, or antigen binding portions thereof, and/or pharmaceutical compositions of the invention, for the treatment or prevention of a proliferative disorder, e.g., cancer, in a mammal. The cancer may be any of the cancers described herein.

Any method of administration can be used for the disclosed therapeutic agents, including local and systemic administration. For example topical, oral, intravascular such as intravenous, intramuscular, intraperitoneal, intranasal, intradermal, intrathecal and subcutaneous administration can be used. The particular mode of administration and the dosage regimen will be selected by the attending clinician, taking into account the particulars of the case (for example the subject, the disease, the disease state involved, and whether the treatment is prophylactic). In cases in which more than one agent or composition is being administered, one or more routes of administration may be used; for example, a chemotherapeutic agent may be administered orally and an antibody or antigen binding fragment or conjugate or composition may be administered intravenously. Methods of administration include injection for which the CAR, CAR T Cell, conjugates, antibodies, antigen binding fragments, or compositions are provided in a nontoxic pharmaceutically acceptable carrier such as water, saline, Ringer's solution, dextrose solution, 5%

human serum albumin, fixed oils, ethyl oleate, or liposomes. In some embodiments, local administration of the disclosed compounds can be used, for instance by applying the antibody or antigen binding fragment to a region of tissue from which a tumor has been removed, or a region suspected of being prone to tumor development. In some embodiments, sustained intra-tumoral (or near-tumoral) release of the pharmaceutical preparation that includes a therapeutically effective amount of the antibody or antigen binding fragment may be beneficial. In other examples, the conjugate is applied as an eye drop topically to the cornea, or intravitreally into the eye.

The disclosed therapeutic agents can be formulated in unit dosage form suitable for individual administration of precise dosages. In addition, the disclosed therapeutic agents may be administered in a single dose or in a multiple dose schedule. A multiple dose schedule is one in which a primary course of treatment may be with more than one separate dose, for instance 1-10 doses, followed by other doses given at subsequent time intervals as needed to maintain or reinforce the action of the compositions. Treatment can involve daily or multi-daily doses of compound(s) over a period of a few days to months, or even years. Thus, the dosage regime will also, at least in part, be determined based on the particular needs of the subject to be treated and will be dependent upon the judgment of the administering practitioner.

Typical dosages of the antibodies or conjugates can range from about 0.01 to about 30 mg/kg, such as from about 0.1 to about 10 mg/kg.

In particular examples, the subject is administered a therapeutic composition that includes one or more of the conjugates, antibodies, compositions, CARs, CAR T cells or additional agents, on a multiple daily dosing schedule, such as at least two consecutive days, 10 consecutive days, and so forth, for example for a period of weeks, months, or years. In one example, the subject is administered the conjugates, antibodies, compositions or additional agents for a period of at least 30 days, such as at least 2 months, at least 4 months, at least 6 months, at least 12 months, at least 24 months, or at least 36 months.

In some embodiments, the disclosed methods include providing surgery, radiation therapy, and/or chemotherapeutics to the subject in combination with a disclosed antibody, antigen binding fragment, conjugate, CAR or T cell expressing a CAR (for example, sequentially, substantially simultaneously, or simultaneously). Methods and therapeutic dosages of such agents and treatments are known to those skilled in the art, and can be determined by a skilled clinician. Preparation and dosing schedules for the additional agent may be used according to manufacturer's instructions or as determined empirically by the skilled practitioner. Preparation

and dosing schedules for such chemotherapy are also described in Chemotherapy Service, (1992) Ed., M. C. Perry, Williams & Wilkins, Baltimore, Md.

In some embodiments, the combination therapy can include administration of a therapeutically effective amount of an additional cancer inhibitor to a subject. Non-limiting examples of additional therapeutic agents that can be used with the combination therapy include microtubule binding agents, DNA intercalators or cross-linkers, DNA synthesis inhibitors, DNA and RNA transcription inhibitors, antibodies, enzymes, enzyme inhibitors, gene regulators, and angiogenesis inhibitors. These agents (which are administered at a therapeutically effective amount) and treatments can be used alone or in combination. For example, any suitable anti-cancer or anti-angiogenic agent can be administered in combination with the CARS, CAR- T cells, antibodies, antigen binding fragment, or conjugates disclosed herein. Methods and therapeutic dosages of such agents are known to those skilled in the art, and can be determined by a skilled clinician.

Additional chemotherapeutic agents include, but are not limited to alkylating agents, such as nitrogen mustards (for example, chlorambucil, chlormethine, cyclophosphamide, ifosfamide, and melphalan), nitrosoureas (for example, carmustine, fotemustine, lomustine, and streptozocin), platinum compounds (for example, carboplatin, cisplatin, oxaliplatin, and BBR3464), busulfan, dacarbazine, mechlorethamine, procarbazine, temozolomide, thiotepa, and uramustine; antimetabolites, such as folic acid (for example, methotrexate, pemetrexed, and raltitrexed), purine (for example, cladribine, clofarabine, fludarabine, mercaptopurine, and tioguanine), pyrimidine (for example, capecitabine), cytarabine, fluorouracil, and gemcitabine; plant alkaloids, such as podophyllum (for example, etoposide, and teniposide), taxane (for example, docetaxel and paclitaxel), vinca (for example, vinblastine, vincristine, vindesine, and vinorelbine); cytotoxic/antitumor antibiotics, such as anthracycline family members (for example, daunorubicin, doxorubicin, epirubicin, idarubicin, mitoxantrone, and valrubicin), bleomycin, rifampicin, hydroxyurea, and mitomycin; topoisomerase inhibitors, such as topotecan and irinotecan; monoclonal antibodies, such as alemtuzumab, bevacizumab, cetuximab, gemtuzumab, rituximab, panitumumab, pertuzumab, and trastuzumab; photosensitizers, such as aminolevulinic acid, methyl aminolevulinate, porfimer sodium, and verteporfin; and other agents, such as alitretinoin, altretamine, amsacrine, anagrelide, arsenic trioxide, asparaginase, axitinib, bexarotene, bevacizumab, bortezomib, celecoxib, denileukin diftitox, erlotinib, estramustine, gefitinib, hydroxycarbamide, imatinib, lapatinib, pazopanib, pentostatin, masoprocol, mitotane, pegaspargase, tamoxifen, sorafenib, sunitinib, vemurafenib, vandetanib, and tretinoin. Selection

and therapeutic dosages of such agents are known to those skilled in the art, and can be determined by a skilled clinician.

The combination therapy may provide synergy and prove synergistic, that is, the effect achieved when the active ingredients used together is greater than the sum of the effects that results from using the compounds separately. A synergistic effect may be attained when the active ingredients are: (1) co-formulated and administered or delivered simultaneously in a combined, unit dosage formulation; (2) delivered by alternation or in parallel as separate formulations; or (3) by some other regimen. When delivered in alternation, a synergistic effect may be attained when the compounds are administered or delivered sequentially, for example by different injections in separate syringes. In general, during alternation, an effective dosage of each active ingredient is administered sequentially, i.e. serially, whereas in combination therapy, effective dosages of two or more active ingredients are administered together.

In one embodiment, an effective amount of an antibody or antigen binding fragment that specifically binds to one or more of the antigens disclosed herein or a conjugate thereof is administered to a subject having a tumor following anti-cancer treatment. After a sufficient amount of time has elapsed to allow for the administered antibody or antigen binding fragment or conjugate to form an immune complex with the antigen expressed on the respective cancer cell, the immune complex is detected. The presence (or absence) of the immune complex indicates the effectiveness of the treatment. For example, an increase in the immune complex compared to a control taken prior to the treatment indicates that the treatment is not effective, whereas a decrease in the immune complex compared to a control taken prior to the treatment indicates that the treatment is effective.

F. Biopharmaceutical Compositions

Biopharmaceutical or biologics compositions (hereinafter, “compositions”) are provided herein for use in gene therapy, immunotherapy and/or cell therapy that include one or more of the disclosed CARs, or T cells expressing a CAR, antibodies, antigen binding fragments, conjugates, CARs, or T cells expressing a CAR that specifically bind to one or more antigens disclosed herein, in a carrier (such as a pharmaceutically acceptable carrier). The compositions can be prepared in unit dosage forms for administration to a subject. The amount and timing of administration are at the discretion of the treating clinician to achieve the desired outcome. The compositions can be formulated for systemic (such as intravenous) or local (such as intra-tumor) administration. In one example, a disclosed CARs, or T cells expressing a CAR, antibody,

antigen binding fragment, conjugate, is formulated for parenteral administration, such as intravenous administration. Compositions including a CAR, or T cell expressing a CAR, a conjugate, antibody or antigen binding fragment as disclosed herein are of use, for example, for the treatment and detection of a tumor, for example, and not by way of limitation, a neuroblastoma. In some examples, the compositions are useful for the treatment or detection of a carcinoma. The compositions including a CAR, or T cell expressing a CAR, a conjugate, antibody or antigen binding fragment as disclosed herein are also of use, for example, for the detection of pathological angiogenesis.

The compositions for administration can include a solution of the CAR, or T cell expressing a CAR, conjugate, antibody or antigen binding fragment dissolved in a pharmaceutically acceptable carrier, such as an aqueous carrier. A variety of aqueous carriers can be used, for example, buffered saline and the like. These solutions are sterile and generally free of undesirable matter. These compositions may be sterilized by conventional, well known sterilization techniques. The compositions may contain pharmaceutically acceptable auxiliary substances as required to approximate physiological conditions such as pH adjusting and buffering agents, toxicity adjusting agents, adjuvant agents, and the like, for example, sodium acetate, sodium chloride, potassium chloride, calcium chloride, sodium lactate and the like. The concentration of a CAR, or T cell expressing a CAR, antibody or antigen binding fragment or conjugate in these formulations can vary widely, and will be selected primarily based on fluid volumes, viscosities, body weight and the like in accordance with the particular mode of administration selected and the subject's needs. Actual methods of preparing such dosage forms for use in in gene therapy, immunotherapy and/or cell therapy are known, or will be apparent, to those skilled in the art.

A typical composition for intravenous administration includes about 0.01 to about 30 mg/kg of antibody or antigen binding fragment or conjugate per subject per day (or the corresponding dose of a CAR, or T cell expressing a CAR, conjugate including the antibody or antigen binding fragment). Actual methods for preparing administrable compositions will be known or apparent to those skilled in the art and are described in more detail in such publications as *Remington's Pharmaceutical Science, 19th ed.*, Mack Publishing Company, Easton, PA (1995).

A CAR, or T cell expressing a CAR, antibodies, antigen binding fragments, or conjugates may be provided in lyophilized form and rehydrated with sterile water before administration, although they are also provided in sterile solutions of known concentration. The CARs, or T cells expressing a CAR, antibody or antigen binding fragment or conjugate solution is then added to an infusion bag containing 0.9% sodium chloride, USP, and in some cases administered at a dosage

of from 0.5 to 15 mg/kg of body weight. Considerable experience is available in the art in the administration of antibody or antigen binding fragment and conjugate drugs; for example, antibody drugs have been marketed in the U.S. since the approval of RITUXAN® in 1997. A CAR, or T cell expressing a CAR, antibodies, antigen binding fragments and conjugates thereof can be administered by slow infusion, rather than in an intravenous push or bolus. In one example, a higher loading dose is administered, with subsequent, maintenance doses being administered at a lower level. For example, an initial loading dose of 4 mg/kg antibody or antigen binding fragment (or the corresponding dose of a conjugate including the antibody or antigen binding fragment) may be infused over a period of some 90 minutes, followed by weekly maintenance doses for 4-8 weeks of 2 mg/kg infused over a 30 minute period if the previous dose was well tolerated.

Controlled release parenteral formulations can be made as implants, oily injections, or as particulate systems. For a broad overview of protein delivery systems see, Banga, A.J., *Therapeutic Peptides and Proteins: Formulation, Processing, and Delivery Systems*, Technomic Publishing Company, Inc., Lancaster, PA, (1995). Particulate systems include microspheres, microparticles, microcapsules, nanocapsules, nanospheres, and nanoparticles. Microcapsules contain the therapeutic protein, such as a cytotoxin or a drug, as a central core. In microspheres, the therapeutic is dispersed throughout the particle. Particles, microspheres, and microcapsules smaller than about 1 μm are generally referred to as nanoparticles, nanospheres, and nanocapsules, respectively. Capillaries have a diameter of approximately 5 μm so that only nanoparticles are administered intravenously. Microparticles are typically around 100 μm in diameter and are administered subcutaneously or intramuscularly. See, for example, Kreuter, J., *Colloidal Drug Delivery Systems*, J. Kreuter, ed., Marcel Dekker, Inc., New York, NY, pp. 219-342 (1994); and Tice & Tabibi, *Treatise on Controlled Drug Delivery*, A. Kydonieus, ed., Marcel Dekker, Inc. New York, NY, pp. 315-339, (1992).

Polymers can be used for ion-controlled release of the CARs, or T cells expressing a CAR, antibody or antigen binding fragment or conjugate compositions disclosed herein. Various degradable and nondegradable polymeric matrices for use in controlled drug delivery are known in the art (Langer, *Accounts Chem. Res.* 26:537-542, 1993). For example, the block copolymer, polaxamer 407, exists as a viscous yet mobile liquid at low temperatures but forms a semisolid gel at body temperature. It has been shown to be an effective vehicle for formulation and sustained delivery of recombinant interleukin-2 and urease (Johnston *et al.*, *Pharm. Res.* 9:425-434, 1992; and Pec *et al.*, *J. Parent. Sci. Tech.* 44(2):58-65, 1990). Alternatively, hydroxyapatite has been used as a microcarrier for controlled release of proteins (Ijntema *et al.*, *Int. J. Pharm.* 112:215-224,

1994). In yet another aspect, liposomes are used for controlled release as well as drug targeting of the lipid-capsulated drug (Betageri *et al.*, *Liposome Drug Delivery Systems*, Technomic Publishing Co., Inc., Lancaster, PA (1993)). Numerous additional systems for controlled delivery of therapeutic proteins are known (see U.S. Patent No. 5,055,303; U.S. Patent No. 5,188,837; U.S. Patent No. 4,235,871; U.S. Patent No. 4,501,728; U.S. Patent No. 4,837,028; U.S. Patent No. 4,957,735; U.S. Patent No. 5,019,369; U.S. Patent No. 5,055,303; U.S. Patent No. 5,514,670; U.S. Patent No. 5,413,797; U.S. Patent No. 5,268,164; U.S. Patent No. 5,004,697; U.S. Patent No. 4,902,505; U.S. Patent No. 5,506,206; U.S. Patent No. 5,271,961; U.S. Patent No. 5,254,342 and U.S. Patent No. 5,534,496).

G. Kits

In one aspect, kits employing the CARs disclosed herein are also provided. For example, kits for treating a tumor in a subject, or making a CAR T cell that expresses one or more of the CARs disclosed herein. The kits will typically include a disclosed antibody, antigen binding fragment, conjugate, nucleic acid molecule, CAR or T cell expressing a CAR as disclosed herein. More than one of the disclosed antibodies, antigen binding fragments, conjugates, nucleic acid molecules, CARs or T cells expressing a CAR can be included in the kit.

The kit can include a container and a label or package insert on or associated with the container. Suitable containers include, for example, bottles, vials, syringes, etc. The containers may be formed from a variety of materials such as glass or plastic. The container typically holds a composition including one or more of the disclosed antibodies, antigen binding fragments, conjugates, nucleic acid molecules, CARs or T cells expressing a CAR. In several embodiments the container may have a sterile access port (for example the container may be an intravenous solution bag or a vial having a stopper pierceable by a hypodermic injection needle). A label or package insert indicates that the composition is used for treating the particular condition.

The label or package insert typically will further include instructions for use of a disclosed antibodies, antigen binding fragments, conjugates, nucleic acid molecules, CARs or T cells expressing a CAR, for example, in a method of treating or preventing a tumor or of making a CAR T cell. The package insert typically includes instructions customarily included in commercial packages of therapeutic products that contain information about the indications, usage, dosage, administration, contraindications and/or warnings concerning the use of such therapeutic products. The instructional materials may be written, in an electronic form (such as a computer diskette or compact disk) or may be visual (such as video files). The kits may also

include additional components to facilitate the particular application for which the kit is designed. Thus, for example, the kit may additionally contain means of detecting a label (such as enzyme substrates for enzymatic labels, filter sets to detect fluorescent labels, appropriate secondary labels such as a secondary antibody, or the like). The kits may additionally include buffers and other reagents routinely used for the practice of a particular method. Such kits and appropriate contents are well known to those of skill in the art.

EXAMPLES

This invention is further illustrated by the following examples, which are not to be construed in any way as imposing limitations upon the scope thereof. On the contrary, it is to be clearly understood that resort may be had to various other embodiments, modifications, and equivalents thereof which, after reading the description herein, may suggest themselves to those skilled in the art without departing from the spirit of the present invention and/or the scope of the appended claims.

EXAMPLE 1

Isolation of ROR1-Specific Binders from a Fully Human Phage and Yeast-Displayed ScFv library

MATERIALS AND METHODS:

a) Production of Fully Human ScFc (ScFv with Fc domain for analysis) binders against human ROR1

A naïve human ScFv (recombinant single chain fragment variable of immunoglobulin) phage display library (approximate diversity, 10^{10} unique specificities), constructed from peripheral blood B cells of 50 healthy donors (Z. Y. Zhu and D. S. Dimitrov, unpublished data), were used for selection of ScFvs for recombinant human ROR1 protein. Amplified libraries of 10^{12} phage-displayed ScFv were incubated with 5, 3, and 1, μg of coated ROR1 in a $5 \times 100\text{-}\mu\text{l}$ volume, distributed equally in 5 wells of a 96-well plate for 2 h at room temperature during the first, second and third rounds of biopanning, respectively. After each round of incubation, the wells were washed 5 times for the first round and 10 times for the later rounds with phosphate-

buffered saline containing 0.05% Tween 20 (PBST) to remove nonspecifically bound phage, the bound phage were mixed with TG1 competent cells for 1 hour at 37°C, and the phage was amplified from the infected cells and used in the next round of biopanning. After the third round of biopanning, 380 clones were randomly picked from the infected TG1 cells and each inoculated into 150 µl 2YT medium containing 100 µg/ml carbenicillin and 0.2% glucose in 96-well plates. After the bacterial cultures reached an optical density at 600 nm (OD₆₀₀) of 0.5, helper phage M13K07 at a multiplicity of infection (MOI) of 10 and kanamycin at 50 µg/ml (final concentration) were added to the medium, and the plates were further incubated at 30°C overnight in a shaker at 250 rpm. The phage supernatants were mixed with 3% nonfat milk in PBS at a 4:1 volume ratio and used for enzyme-linked immunosorbent assay (ELISA) to identify clones of phage displaying ScFvs with high ROR1 binding affinity. The supernatants were incubated for 2 h at room temperature with recombinant human ROR1 coated at 50 ng per well in 96-well plates and washed five times with PBST, (after overnight incubation at 4°C it was blocked with 3% nonfat milk in PBS and washed three times with PBS containing 0.05% Tween 20.) ROR1-bound phages were detected using horseradish peroxidase-conjugated goat anti-M13 antibody. After incubation with the target antigen, the nonspecifically bound antibody was removed by washing wells, and the 3,3',5,5'-tetramethylbenzidine (TMB) substrate was added, and solution absorbance at 450 nm (A₄₅₀) measured. Clones that bound to ROR1 with A₄₅₀ of >1.0 were selected for further characterization.

b) Expression and purification of selected soluble ScFvs.

The VH and VL of the selected clones were DNA sequenced, and the ScFvs encoded by clones with unique sequences were expressed and purified as described below. Plasmids extracted from these clones were used for transformation of HB2151 cells. A single colony was picked from the plate containing freshly transformed cells, inoculated into 200 ml 2YT medium containing 100 µg/ml ampicillin and 0.2% glucose, and incubated at 37°C with shaking at 250 rpm. When the culture OD at 600 nm reached 0.90, isopropyl-β-d-thiogalactopyranoside at a 0.5 mM final concentration was added, and the culture was further incubated overnight at 30°C. The bacterial pellet was collected after centrifugation at 8,000 × g for 20 min and resuspended in PBS buffer containing 0.5 mU polymyxin B (Sigma-Aldrich, St. Louis, MO). After 30 min incubation with rotation at 50 rpm at room temperature, the resuspended pellet was centrifuged at 25,000 × g for 25 min at 4°C, and the supernatant was used for ScFv purification using the Ni-NTA resin following vendor protocol (Qiagen).

c) ELISA binding assay

50 µl of the diluted recombinant human ROR1 in PBS at 2ug/ml was coated in a 96-well plate at 4°C overnight. Purified ScFv with His and Flag tags were serially diluted and added into the target protein coated wells. After washing, a 1:3000 diluted HRP conjugated anti-Flag antibody was added for 1 hr at RT. After washing, 3, 3', 5, 5'-Tetramethylbenzidine (TMB) substrate was added, 1N H₂SO₄ was added to stop the reaction after incubation at room temperature for 10 minutes, and the O.D. was read at 450 nm to quantify the relative ability of ScFv to bind ROR1.

RESULTS:

Two ScFv clones specific for recombinant human ROR1 were identified, and labeled as human anti-ROR1 ScFv binders ScFv4 and ScFv9. The paucity of binding results indicates that these two binders are entirely unique and important new binding moieties for ROR1 that can be formulated into CAR and immunoglobulin therapeutic constructs. The generation of chimeric antigen receptors expressing the LTG1941, LTG1942, LTG2528, and LTG2529 human anti-ROR1 binders is outlined in Example 2, *infra*.

EXAMPLE 2

CARs Expressing Anti-ROR1 Fully Human Binding sequences.

Homo sapiens ROR1 (receptor tyrosine kinase-like orphan receptor 1) is a well-investigated oncoembryonic cell surface glycoprotein expressed on chronic lymphocytic leukemia (CLL) and various solid tumors such as subsets of sarcoma, carcinomas, or adenocarcinoma of the lung. A phase one study of anti-ROR1 antibody UC-961 (Cirtuzumab) for relapsed or refractory chronic lymphocytic leukemia is currently active (Sponsor, Thomas Kipps, NCT02222688). Results for this first-in-class study are pending. Also in early stage is a phase 1 clinical trial with a CAR-T specific for ROR1 (Sponsor, Fred Hutchinson Cancer Research Center, NCT02706392). We have included a published ROR1 binder as our control (LTG1943, LTG2527), see Hudecek et al., 2013, *Clin Cancer Res* 19:3153-3164 to benchmark our studies and to demonstrate the activity of our constructs. Given the current advances with T-cell based therapy, including the recent commercial

offering of anti-CD19 CARs, the development of cell-based immunotherapy for CLL and other malignancies expressing ROR1 featuring the CAR constructs presented here are an innovative new approach to treating human disease using binding moieties derived from human sequences.

The novel anti-ROR1 CAR-T constructs described here have high levels of cell surface expression in primary human T cells and specific and potent cytotoxic and cytokine functions against ROR1-positive tumor cells. ROR1 CARs were designed using ROR1 binding sequences derived from ScFv candidates identified by phage display, as in Example 1, and for characterization were cloned into lentiviral expression vectors that contained selected structural and signaling domains under the control of the EF1a promoter and tested *in vitro* for transduction efficiency, killing function and cytokine production in both model cell lines and primary human T cells. Table 1 summarizes the nomenclature used. CAR Construct LTG1943 is the relevant comparator, as this sequence has been proposed for clinical use (See KTE-C19, Kite Pharma, and CTL019, Novartis).

Table 1 – Construct LTG numbers and corresponding ScFv binder designations used in the design of fully human ROR1 CARs

CAR Construct LTG#	huCAR19 ScFv binder
UTD	Untransduced T cell control
1538	FMC63 murine CAR19 control
1398	GFP expression vector
1941	ScFv4
1942	ScFv9
2528	ScFv4
2529	ScFv9
1943	Control-ScFv
2527	Control-ScFv

MATERIALS AND METHODS

(a) Cell Lines

All cell lines and reagents were purchased from American Tissue Culture Collection (ATCC, Manassass, VA), unless otherwise noted. The acute lymphocytic leukemia cell line REH and the mantle cell lymphoma line Jeko-1 (ACC-553 DSMZ, Leibniz Institute DSMZ, Braunschweig, Germany), as well as the chronic myelogenous leukemia line K562 were cultured

in RPMI-1640 medium supplemented with 10% heat-inactivated fetal bovine serum (FBS, Hyclone, Logan, UT) and 2mM L-Glutamax (Thermo Fisher Scientific, Grand Island, NY).

(b) Creation of Chimeric Antigen Receptor (CAR) – Expression Vectors

ROR1 CAR constructs were generated by linking each scFv in frame to either CD8 hinge and transmembrane domains (aa 141182-191, UniProt ID P01732), or IgG4 hinge domain (aa 99-110, UniProt sequence ID P01861), followed by CD8 transmembrane domain (aa 183-203, UniProt sequence ID P01732), 4-1BB (CD137, aa 214-255, UniProt sequence ID Q07011) transactivation domain and CD3 zeta signaling domain (CD247, aa 52-163, Ref sequence ID: NP_000725.1.). Leader sequence from human granulocyte macrophage colony stimulating factor receptor alpha subunit was included in all constructs in order to facilitate CAR trafficking to the T cell membrane. CAR constructs sequences were codon optimized and cloned into a third generation lentiviral plasmid backbone (Lentigen Technology Inc., Gaithersburg, MD).

(c) Primary T cell purification and transduction

Human primary T cells from healthy volunteers were purified from whole blood or buffy coats (purchased from commercial provider with donor's written consent) using immunomagnetic bead selection of CD4⁺ and CD8⁺ cells according to manufacturer's protocol (Miltenyi Biotec, Bergisch Gladbach, Germany). T cells were cultivated in TexMACS medium supplemented with 200 IU/ml IL-2 at a density of 0.3 to 2 x 10⁶ cells/ml, activated with CD3/CD28 MACS® GMP T Cell TransAct reagent (Miltenyi Biotec) and transduced on day 2 with lentiviral vectors encoding CAR constructs in the presence of 10 ug/ml protamine sulfate (Sigma-Aldrich, St. Louis, MO) overnight, and media exchanged on day 3. Cultures were propagated in TexMACS medium supplemented with 200 IU/ml IL-2 until harvest on day 8-12.

(d) Immune effector assays (CTL and cytokine)

To determine cell-mediated cytotoxicity (CTL assay), 5,000 target cells stably transduced with firefly luciferase were combined with CAR T cells at various effector to target ratios (E:T) and incubated overnight. SteadyGlo reagent (Promega, Madison WI) was added to each well and the resulting luminescence was analyzed on an EnSpire plate reader (Perkin Elmer, Shelton, Connecticut) and recorded as counts per second (sample CPS). Target only wells (max CPS) and

target only wells plus 1% Tween-20 (min CPS) were used to determine assay range. Percent specific lysis was calculated as: $(1 - (\text{sample CPS} - \text{min CPS}) / (\text{max CPS} - \text{min CPS}))$. Cytokine release assay was performed on supernatants harvested post co incubation of effector and tumor cell lines at E:T ratio of 10. Cytokines IFN γ , than and IL-2 were measured by ELISA in triplicates (Thermo Fischer, Waltham, MA).

(e) Flow Cytometric analysis

For cell staining, half a million CAR T transduced cells were harvested from culture, washed two times in cold AutoMACS buffer supplemented with 0.5% bovine serum albumin (Miltenyi Biotec), and CAR surface expression detected by staining with ROR1-Fc peptide (R&D, Minneapolis, MN) followed by anti Fc-AF647 conjugate (Jackson ImmunoResearch, West Grove, PA). Non-transduced cells were used as negative controls. Dead cells in all studies were excluded by 7AAD staining (BD Biosciences, San Jose, CA). Cells were washed twice and resuspended in 200 μ l Staining Buffer before quantitative analysis by flow cytometry. Flow cytometric analysis was performed on a MACSQuant $\text{\textcircled{R}}$ 10 Analyzer (Miltenyi Biotec), and data plots were generated using FlowJo software (Ashland, OR).

RESULTS:

Fully human CAR T constructs targeting the ROR1 tumor antigen were designed by combining in frame the sequences of leader peptide derived from GMCSFR, anti-human ROR1 ScFv, CD8 or IgG4 hinge, CD8 transmembrane domain, 4-1BB costimulatory domain and CD3 ζ activation domain. Schematic diagram of the CAR T constructs and list of constructs designed and respective ScFv targeting domains is provided (Figure 1 and Table 1). Untransduced T cells grown under the same conditions (UTD) were included as controls.

All test and control CAR constructs were cloned into LV backbone expression vectors under the control of human Efl-alpha promoter, and used to produce lentiviral vector particles by transfection into 293 cells using a standard four-plasmid system. Activated human primary T cells were transduced with LV supernatants encoding CAR test constructs or controls, and expanded to culture day 8-10. In flow cytometric analysis, using recombinant a ROR1-Fc fusion protein followed by anti-Fc APC, all test CAR constructs demonstrated surface expression in transduced human T cells (Figure 3).

Table 2: List of ROR1 – Targeting CAR Constructs

1941: FMC63-CD8 TM-41BB-CD3 zeta, control
2525: ScFv1-CD8 TM-41BB-CD3 zeta
1942: ScFv2-CD8TM-4-1BB-CD3 zeta
2529: ScFv3-CD8TM-4-1BB-CD3 zeta
1943: ScFv4-CD8TM-4-1BB-CD3 zeta
2627: ScFv5-CD8TM-4-1BB-CD3 zeta

T cells Transduced with Anti-ROR1 Chimeric Antigen Receptors Demonstrate Cytokine Expression and Cytolytic Activity.

On culture day 8-10, CAR T cells were combined with ROR1⁺ mantle cell lymphoma Jeko-1, ROR1⁺ epidermoid carcinoma A431, or ROR1⁻ Reh leukemia cells at E:T ratios of 40:1, 20:1, or 10:1 to assess CAR T cytotoxic function (Figure 3). Positive control CAR construct LTG1943, based on anti ROR1 scFv R12 (ref. 9), and negative controls T cells transduced with lentiviral vector encoding GFP (1398) or non-transduced T cells (UTD), were included for comparison. All constructs shown (LTG1941-1943) demonstrated dose-dependent, ROR1-specific tumor killing. The greatest cytotoxicity against ROR1⁺ tumor lines (80% at E:T ratio of 40:1 in Jeko-1 ROR1⁺ cells), was demonstrated by CAR construct LTG1942, which was comparable in magnitude of tumor killing to control CAR construct LTG1943, based on R12 anti ROR1 scFv (ref. 9). CAR construct, LTG1941 was also cytotoxic to ROR1⁺ tumor lines, but to a lesser degree, and achieved maximal specific lysis of 40% for Jeko-1 cells at E:T ratio of 40:1. In A431 line, which is less sensitive to CART-mediate lysis, CAR LTG1941 was ineffective, however CAR LTG1942 was equally or more effective than the positive control CAR LTG1943.

The concentration of pro-inflammatory cytokines IFN-gamma, TNF-alpha and IL-2 secreted by CAR T cells transduced with ROR1 CAR constructs, when challenged by ROR1-positive and ROR1-negative tumor cell lines, was then determined (Figure 4). CAR T cells alone were included for each construct, in order to test for basal levels of cytokine production. T cells transduced with GFP (LTG1398) were included as a negative control. Levels of TNF-alpha, IFN-gamma and IL-2 were strongly induced by CAR T cell construct LTG1942 and the positive control LTG1493, and to a lesser degree by CARLTG1491 when challenged with ROR1⁺ Jeko-1, or A431 lines, but not to ROR1⁻ Reh control line. No cytokines induction was seen in the negative control GFP or UTD groups. Notably, LTG1941 cytokine production levels were quite low indicating a differential ability to activate T cell expressing this vector. This corresponded to the lower level of cytolysis

against the Jeko cell line, but not A431, when comparing LTG1941 to LTG1942. This demonstrates first that identification of a binder is insufficient to determine the true activity of a CAR that includes this binder in its sequence. Importantly, these differences may be crucial, allowing CAR activity to be tuned in accordance with desired target antigen density. The ability to lyse tumor targets is intricately linked to both CAR expression levels on the surface of the T cells and target expression levels of tumor antigen on the target tumor cell surface (Walker, A., et al., 2017, *Mol Ther* 25:2189-2201). Thus, if ROR1 expression on normal T cell triggers CAR-T activity, for example by LTG1492, a construct like LTG1941 might be used to allow differential targeting of the cancer as opposed to low expression levels on normal tissues. Furthermore, none of the constructs demonstrated cytokine production above baseline in the absence of tumor cell targets. This is an important verification that no auto-activation exists as has been reported for some CAR constructs (Long, A.H. et al., 2015, *Nature Med* 20:581-590). Therefore, CAR T constructs LTG1941, LTG1942, and LTG1943 were specific for ROR1 tumor antigen as expressed on model tumor cell lines.

Overall, CAR LTG 1942 and LTG1941 demonstrated functional specificity manifested as tumor lytic activity and elaboration of cytokines in response to ROR1⁺ tumors. The constructs described in this application are thus promising candidates for clinical applications.

Each of the applications and patents cited in this text, as well as each document or reference cited in each of the applications and patents (including during the prosecution of each issued patent; "application cited documents"), and each of the PCT and foreign applications or patents corresponding to and/or claiming priority from any of these applications and patents, and each of the documents cited or referenced in each of the application cited documents, are hereby expressly incorporated herein by reference, and may be employed in the practice of the invention. More generally, documents or references are cited in this text, either in a Reference List before the claims, or in the text itself; and, each of these documents or references ("herein cited references"), as well as each document or reference cited in each of the herein cited references (including any manufacturer's specifications, instructions, etc.), is hereby expressly incorporated herein by reference.

The foregoing description of some specific embodiments provides sufficient information that others can, by applying current knowledge, readily modify or adapt for various applications such specific embodiments without departing from the generic concept, and, therefore, such adaptations and modifications should and are intended to be comprehended within the meaning and range of equivalents of the disclosed embodiments. It is to be understood that the phraseology or terminology employed herein is for the purpose of description and not of

limitation. In the drawings and the description, there have been disclosed exemplary embodiments and, although specific terms may have been employed, they are unless otherwise stated used in a generic and descriptive sense only and not for purposes of limitation, the scope of the claims therefore not being so limited. Moreover, one skilled in the art will appreciate that certain steps of the methods discussed herein may be sequenced in alternative order or steps may be combined. Therefore, it is intended that the appended claims not be limited to the particular embodiment disclosed herein. Those skilled in the art will recognize, or be able to ascertain using no more than routine experimentation, many equivalents to the embodiments of the invention described herein. Such equivalents are encompassed by the following claims.

SEQUENCES OF THE DISCLOSURE

The nucleic and amino acid sequences listed below are shown using standard letter abbreviations for nucleotide bases, and three letter code for amino acids, as defined in 37 C.F.R. 1.822. Only one strand of each nucleic acid sequence is shown, but the complementary strand is understood as included by any reference to the displayed strand. In the accompanying sequence listing:

SEQ ID NO: 1 Nucleotide Sequence of Anti-ROR1 binder: ScFV4

CAGGTGCAGCTGCAGGAGTCCGGCCCAGGACTGGTGAAGCCTTCGGAGAC
 CCTGTCCCTCACCTGCACTGTCTCTGGTGGCTCCATCAGCAGTAGTAGTTA
 CTACTGGGGCTGGATCCGCCAGCCCCAGGGAAGGGGCTGGAGTGGATTG
 GGAGTATCTATTATAGTGGGAGCACCTACTACAACCCGTCCTCAAGAGT
 CGAGTCACCATACCCGTAGACACGTCCAAGAACCAGTTCTCCCTGAAGCT
 GAGCTCTGTGACCGCCGCAGACACGGCTGTGTATTACTGTGCGAGACACC
 TGGGGGGTGATGCTTTTGATATCTGGGGCCAAGGGACCACGGTCACCGTC
 TCCTCAGGAGGTGGCGGGTCTGGTGGTGGCGGTAGCGGTGGAGGCGGATC
 CCTGCCTGTGCTGACTCAGCCCCCCTCGGTGTCAGTGGCCCCAGGACAGA
 CGGCCAGGATTACCTGTGGGGGGAACAACATTGGAAGTAAAAGTGTGCA
 CTGGTACCAGCAGAAGCCAGGCCAGGCCCTGTGCTGGTCGTCTATGATG
 ATAGCGACCGGCCCTCAGGGATCCCTGAGCGATTCTCTGGCTCCAACCTCT
 GGGAACACAGCCACTCTGACCATCAGCGGGACCCAGGCTATGGATGAGG
 CTGACTACTTCTGTGTCAGTCTTATGATAGCAGCAATCCCGTGGTATTCGGCG
 GAGGGACCCAGCTCACCGTTTTA

SEQ ID NO: 2 Amino Acid Sequence of Anti-ROR1 binder: ScFV4

QVQLQESGPGLVKPSETLSLTCTVSGGSISSSSYYWGWIRQPPGKGLEWIGSIY
 YSGSTYYNPSLKSRTIPVDTSKNQFSLKLSSVTAADTAVYYCARHLGGDAF
 DIWGQGTTTVTVSSGGGGSGGGGSGGGGSLPVLTPPPSVSVAPGQTARITCGG
 NNIGSKSVHWYQQKPGQAPVLLVYDDSDRPSGIPERFSGSNSGNTATLTISGT
 QAMDEADYFCQSYDSSNPVVFGGGTQLTVL

SEQ ID NO: 3 ROR1-CAR DNA SEQ LTG1941 (LP-ScFV4-CD8H/CD8TM-41BB-CD3zeta)

ATGCTGCTGCTGGTGACCAGCCTGCTGCTGTGCGAACTGCCGCATCCGGC
 GTTTCTGCTGATTCCGCAAGTTCAGCTGCAAGAATCAGGACCTGGGCTTGT
 CAAACCATCTGAAACCCTCAGCTTGACTTGTACCGTATCAGGAGGGTCAA
 TTTCAAGCTCATCCTACTATTGGGGATGGATCAGACAACCACCCGGGAAA
 GGGCTCGAGTGGATAGGGTCCATATATTACAGCGGATCTACATACTACAA
 CCCGTCATTGAAGTCCAGGGTAACGATTCCGGTGGACACTAGCAAGAATC
 AGTTTAGCCTCAAGTTGAGCAGTGTAAGTCTGCTGCGGACACGGCGGTATAT
 TATTGTGCTCGACACCTCGGTGGAGATGCTTTTGACATATGGGGTCAAGG

GACAACAGTCACCGTTAGCTCAGGTGGAGGGGGTAGCGGGGGGGGGCGGA
TCTGGGGGAGGCGGTTTATTGCCCGTACTTACACAGCCACCCTCTGTCAGC
GTCGCACCTGGACAAACCGCTCGCATCACCTGTGGCGGAAATAATATAGG
TTCCAAGTCTGTTTATTGGTATCAGCAGAAACCGGGACAGGCCCCCGTCC
TTGTGGTGTATGATGATTCTGATAGGCCATCTGGTATCCCAGAACGGTTTT
CAGGTAGCAATTACAGGGAATACTGCCACTCTCACTATTAGCGGTACTCAA
GCTATGGATGAGGCCGACTATTTTTGCCAGAGCTACGACTCTAGTAACCC
AGTCGTGTTTCGGGGGAGGGACCCAGTTGACCGTGCTGGCGGCCGCAACTA
CCACCCCTGCCCCCTCGGCCGCCGACTCCGGCCCCAACCATCGCAAGCCAA
CCCCTCTCCTTGCGCCCCGAAGCTTGCCGCCCGGCCGCGGGTGGAGCCGT
GCATACCCGGGGGCTGGACTTTGCCTGCGATATCTACATTTGGGCCCCGCT
GGCCGGCACTTGCGGCGTGCTCCTGCTGTCGCTGGTCATCACCCTTTACTG
CAAGAGGGGGCCGAAGAAGCTGCTTTACATCTTCAAGCAGCCGTTTATGC
GGCCCGTGCAGACGACTCAGGAAGAGGACGGATGCTCGTGCAGATTCCTT
GAGGAGGAAGAGGGGGGATGCGAACTGCGCGTCAAGTTCTCACGGTCCG
CCGACGCCCCCGCATATCAACAGGGGCCAGAATCAGCTCTACAACGAGCTG
AACCTGGGAAGGAGAGAGGAGTACGACGTGCTGGACAAGCGACGCGGAC
GCGACCCGGAGATGGGGGGGAAACCACGGCGGAAAAACCTCAGGAAGG
ACTGTACAACGAACCTCCAGAAAGACAAGATGGCGGAAGCCTACTCAGAA
ATCGGGATGAAGGGAGAGCGGAGGAGGGGAAAGGGTCACGACGGGCTGT
ACCAGGGACTGAGCACCGCCACTAAGGATACCTACGATGCCTTGCATATG
CAAGCACTCCCACCCCGG

SEQ ID NO: 4 ROR1-CAR AA SEQ LTG1941 (LP-ScFV4-CD8H/CD8TM-41BB-CD3zeta)

MLLLVTSLLLCELPHPAFLLIPQVQLQESGPGLVKPSSETLSLTCTVSGGSISSSS
YYWGWIRQPPGKLEWIGSIYYSGSTYYNPSLKSRTVTPVDTSKNQFSLKLSS
VTAADTAVYYCARHLGGDAFDIWQGTTVTVSSGGGGSGGGSGGGGSLP
VLTQPPSVSVAPGQTARITCGGNIGSKSVHWYQQKPGQAPVLVYDDSDRP
SGIPERFSGSNSGNTATLTISGTQAMDEADYFCQSYDSSNPVVFGGGTQLTVL
AAATTTTPAPRPPTPAPTIASQPLSLRPEACRPAAGGAVHTRGLDFACDIYIWAP
LAGTCGVLLLSLVITLYCKRGRKKLLYIFKQPFMRPVQTTQEEDGCSCRFPEE
EEGGCELRVKFSRSADAPAYQQGQNQLYNELNLGRREEYDVLDKRRGRDPE
MGGKPRRKNPQEGLYNELQKDKMAEAYSEIGMKGERRRGKGHDLGYQGLS
TATKDTYDALHMQALPPR

SEQ ID NO: 5 ROR1-CAR DNA SEQ LTG2528 (LP-ScFV4-IgG4H/CD8TM-41BB-CD3zeta)

ATGCTGCTGCTGGTGACCAGCCTGCTGCTGTGCGAACTGCCGCATCCGGC
GTTTCTGCTGATTCCGCAAGTTCAGCTGCAAGAATCAGGACCTGGGCTTGT
CAAACCATCTGAAACCCTCAGCTTGACTTGTAACCGTATCAGGAGGGTCAA
TTTCAAGCTCATCCTACTATTGGGGATGGATCAGACAACCACCCGGGAAA
GGGCTCGAGTGGATAGGGTCCATATATTACAGCGGATCTACATACTACAA
CCCGTCATTGAAGTCCAGGGTAACGATTCCGGTGGACACTAGCAAGAATC
AGTTTAGCCTCAAGTTGAGCAGTGTAAGTCTGCTGCGGACACGGCGGTATAT
TATTGTGCTCGACACCTCGGTGGAGATGCTTTTGACATATGGGGTCAAGG
GACAACAGTCACCGTTAGCTCAGGTGGAGGGGGTAGCGGGGGGGGGCGGA

TCTGGGGGAGGCGGTTCATTGCCCCGTACTTACACAGCCACCCTCTGTCAGC
 GTCGCACCTGGACAAACCGCTCGCATCACCTGTGGCGGAAATAATATAGG
 TTCCAAGTCTGTTTCATTGGTATCAGCAGAAACCGGGACAGGCCCCCGTCC
 TTGTGGTGTATGATGATTCTGATAGGCCATCTGGTATCCCAGAACGGTTTT
 CAGGTAGCAATTCAGGGAATACTGCCACTCTCACTATTAGCGGTACTCAA
 GCTATGGATGAGGCCGACTATTTTTGCCAGAGCTACGACTCTAGTAACCC
 AGTCGTGTTTCGGGGGAGGGACCCAGTTGACCGTGCTGGCGGCCGCAGAGT
 CAAAATACGGTCCTCCGTGCCCTCCGTGTCCGATCTACATTTGGGCCCCCGC
 TGGCCGGCACTTGCGGCGTGCTCCTGCTGTGCTGGTCATCACCTTTACT
 GCAAGAGGGGGCCGGAAGAAGCTGCTTTACATCTTCAAGCAGCCGTTTCATG
 CGGCCCGTGCAGACGACTCAGGAAGAGGACGGATGCTCGTGCAGATTCCC
 TGAGGAGGAAGAGGGGGGATGCGAACTGCGCGTCAAGTTCTCACGGTCC
 GCCGACGCCCCCGCATATCAACAGGGGCCAGAATCAGCTCTACAACGAGCT
 GAACCTGGGAAGGAGAGAGGAGTACGACGTGCTGGACAAGCGACGCGGA
 CGCGACCCGGAGATGGGGGGGAAACCACGGCGGAAAAACCCTCAGGAAG
 GACTGTACAACGAACTCCAGAAAGACAAGATGGCGGAAGCCTACTCAGA
 AATCGGGATGAAGGGAGAGCGGAGGAGGGGAAAGGGTCACGACGGGCT
 GTACCAGGGACTGAGCACCGCCACTAAGGATACCTACGATGCCTTGCATA
 TGCAAGCACTCCCACCCCGG

SEQ ID NO: 6 ROR1-CAR AA SEQ LTG2528 (LP-ScFV4-IgG4H/CD8TM-41BB-CD3zeta)

MLLLVTSLLLCELPHPAFLIPQVQLQESGPGLVKPSETLSLTCTVSGGSISSSS
 YYWGWIRQPPGKLEWIGSIYYSGSTYYNPSLKSRTVTPVDTSKNQFSLKLSS
 VTAADTAVYYCARHLGGDAFDIWQGTTVTVSSGGGGSGGGSGGGGSLP
 VLTQPPSVSVAPGQTARITCGGNNIGSKSVHWYQKPGQAPVLVYDDSDRP
 SGIPERFSGSNSGNTATLTISGTQAMDEADYFCQSYDSSNPVVFGGGTQLTVL
 AAAESKYGPPCPPIYIWAPLAGTCGVLLSLVITLYCKRGRKLLYIFKQPF
 MRPVQTTQEEDGCSRFPEEEEGGCELRVKFSRSADAPAYQQGQNQLYNELN
 LGRREEYDVLDRRRGRDPEMGGKPRRKNPQEGLYNELQKDKMAEAYSEIM
 KGERRRGKGHDGLYQGLSTATKDTYDALHMQALPPR

SEQ ID NO: 7 Nucleotide Sequence of Anti-ROR1 binder: ScFV9

CAGGCGGCCCAGGTACAGCTGCAGCAGTCAGGGGCTGAGGTGAAGAA
 GCCTGGGTCCCTCGGTGAAGGTCTCCTGCAAGGCTTCTGGAGGCACCTT
 CAGCAGCTATGCTATCAGCTGGGTGCGACAGGCCCTGGACAAGGGCT
 TGAGTGGATGGGATGGATCAACCTAACAGTGGTGGCACAACCTATGC
 ACAGAGGTTTCAGGGCAGGGTCACCATGACCAGGGACACGTCCATCA
 GCACAGCCTACATGGAGCTGAGCAGGCTGAGATCTGACGACACGGCC
 GTGTATTACTGTGCGAGTTATAATGATGCTTTTGATATCTGGGGCCAAG
 GCACCCTGGTCACCGTCTCCTCAGGAGGTGGCGGGTCTGGTGGTGGCG
 GTAGCGGTGGTGGCGGATCCAATTTTATGCTGACTCAGCCCCACTCTG
 TGTCGGAGTCTCCGGGGAAGACGGTAACCATCTCCTGCACCCGCAGCA
 GTGGCAGCATTGCCAGCAACTATGTGCAGTGGTACCAGCAGCGCCCGG
 GCAGTGCCCCCACCATTGTGATCTATGAGGATGATCAAAGACCCTCTG
 GGGTCCCTGATCGGTTCTCTGGCTCCATCGACACCTCCTCCAACCTCTGC
 CTCCTCACCATCTCTGGACTGCAGAGTGAGGACGAGGCTGACTACTA

CTGTCAGTCTTATGAGCCCGGCAATGGGGTATTCGGCGGAGGGACCAA
GGTCACCGTCCTA

SEQ ID NO: 8 Amino Acid Sequence of Anti-ROR1 binder: ScFV9

QAAQVQLQQSGAEVKKPGSSVKVSCKASGGTFSSYAIWVRQAPGQGLEW
MGWINPNSGGTNYAQRFGGRVTMTRDTSISTAYMELSRLSDDTAVYYCA
SYNDAFDIWGQGLVTVSSGGGGSGGGGSGGGGSNFMLTQPHSVSESPGKT
VTISCTRSSGSIASNYVQWYQQRPGSAPTIVYEDDQRPSGVPDRFSGSIDTSS
NSASLTISGLQSEDEADYYCQSYEPGNVFGGGTKVTVL

SEQ ID NO: 9 ROR1-CAR DNA SEQ LTG1942 (LP-ScFV9-CD8H/CD8TM-
41BB-CD3zeta)

ATGCTGCTGCTGGTGACCAGCCTGCTGCTGTGCGAACTGCCGCATCCGGC
GTTTCTGCTGATTCCGCAGGCGGCCAGGTACAGCTGCAGCAGTCAGGGG
CTGAGGTGAAGAAGCCTGGGTCTCCTCGGTGAAGGTCTCCTGCAAGGCTTCT
GGAGGCACCTTCAGCAGCTATGCTATCAGCTGGGTGCGACAGGCCCTGG
ACAAGGGCTTGAGTGGATGGGATGGATCAACCCTAACAGTGGTGGCACA
AACTATGCACAGAGGTTTCAGGGCAGGGTCACCATGACCAGGGACACGTC
CATCAGCACAGCCTACATGGAGCTGAGCAGGCTGAGATCTGACGACACGG
CCGTGTATTACTGTGCGAGTTATAATGATGCTTTTGATATCTGGGGCCAAG
GCACCCTGGTCACCGTCTCCTCAGGAGGTGGCGGGTCTGGTGGTGGCGGT
AGCGGTGGTGGCGGATCCAATTTTATGCTGACTCAGCCCCACTCTGTGTGCG
GAGTCTCCGGGGAAGACGGTAACCATCTCCTGCACCCGCAGCAGTGGCAG
CATTGCCAGCAACTATGTGCAGTGGTACCAGCAGCGCCCGGGCAGTGCCC
CCACCATTGTGATCTATGAGGATGATCAAAGACCCTCTGGGGTCCCTGAT
CGGTTCTCTGGCTCCATCGACACCTCCTCCAACCTCTGCCTCCCTCACCATC
TCTGGACTGCAGAGTGAGGACGAGGCTGACTACTACTGTCAGTCTTATGA
GCCCCGCAATGGGGTATTCGGCGGAGGGACCAAGGTCACCGTCCTAGCGG
CCGCAACTACCACCCCTGCCCTCGGCCGCCGACTCCGGCCCCCAACCATC
GCAAGCCAACCCCTCTCCTTGCGCCCCGAAGCTTGCCGCCCGGCCGCGGG
TGGAGCCGTGCATACCCGGGGGCTGGACTTTGCCTGCGATATCTACATTTG
GGCCCCGCTGGCCGGCACTTGCGGCGTGCTCCTGCTGTCGCTGGTCATCAC
CCTTTACTGCAAGAGGGGCGGGAAGAAGCTGCTTTACATCTTCAAGCAGC
CGTTCATGCGGCCCCGTGCAGACGACTCAGGAAGAGGACGGATGCTCGTGC
AGATTCCTGAGGAGGAAGAGGGGGGATGCGAACTGCGCGTCAAGTTCTC
ACGGTCCGCCGACGCCCCGCATATCAACAGGGCCAGAATCAGCTCTACA
ACGAGCTGAACCTGGGAAGGAGAGAGGAGTACGACGTGCTGGACAAGCG
ACGCGGACGCGACCCGGAGATGGGGGGGAAACCACGGCGGAAAAACCT
CAGGAAGGACTGTACAACGAACCTCCAGAAAGACAAGATGGCGGAAGCCT
ACTCAGAAATCGGGATGAAGGGAGAGCGGAGGAGGGGAAAGGGTCACG
ACGGGCTGTACCAGGGACTGAGCACCGCCACTAAGGATACCTACGATGCC
TTGCATATGCAAGCACTCCCACCCCG

SEQ ID NO: 10 ROR1-CAR AA SEQ LTG1942 (LP-ScFV9-CD8H/CD8TM-41BB-
CD3zeta)

MLLLVTSLLLCELPHPAFLIPQAAQVQLQQSGAEVKKPGSSVKVSCKASGGT
FSSYAIWVRQAPGQGLEWMGWINPNSGGTNYAQRFGGRVTMTRDTSISTA
YMELSRLSDDTAVYYCASYNDAFDIWGQGLVTVSSGGGGSGGGGSGGGG
SNFMLTQPHSVSESPGKTVTISCTRSSGSIASNYVQWYQQRPGSAPTIVYEDD

QRPSGVPDRFSGSIDTSSNSASLTISGLQSEDEADYYCQSYEPGNGVFGGGTK
 VTVLAAATTTTPAPRPPTPAPTIASQPLSLRPEACRPAAGGAVHTRGLDFACDIY
 IWAPLAGTCGVLLLSLVITLYCKRGRKKLLYIFKQPFMRPVQTTQEEDGCSCR
 FPEEEEGGCEL RVKFSRSADAPAYQQGQNQLYNELNLGRREEYDVLDRRG
 RDPENGGKPRRKNPQEGLYNELQKDKMAEAYSEIGMKGERRRGKGHDGLY
 QGLSTATKDTYDALHMQALPPR

SEQ ID NO: 11 ROR1-CAR DNA SEQ LTG2529 (LP-ScFV9-IgG4H/CD8TM-41BB-CD3zeta)

ATGCTGCTGCTGGTGACCAGCCTGCTGCTGTGCGAACTGCCGCATCCGGC
 GTTTCTGCTGATTCCGCAGGCGGCCAGGTACAGCTGCAGCAGTCAGGGG
 CTGAGGTGAAGAAGCCTGGGTCTCGGTGAAGGTCTCCTGCAAGGCTTCT
 GGAGGCACCTTCAGCAGCTATGCTATCAGCTGGGTGCGACAGGCCCTGG
 ACAAGGGCTTGAGTGGATGGGATGGATCAACCCTAACAGTGGTGGCACA
 AACTATGCACAGAGGTTTCAGGGCAGGGTCACCATGACCAGGGACACGTC
 CATCAGCACAGCCTACATGGAGCTGAGCAGGCTGAGATCTGACGACACGG
 CCGTGTATTACTGTGCGAGTTATAATGATGCTTTTGATATCTGGGGCCAAG
 GCACCCTGGTCACCGTCTCCTCAGGAGGTGGCGGGTCTGGTGGTGGCGGT
 AGCGGTGGTGGCGGATCCAATTTTATGCTGACTCAGCCCCACTCTGTGTCTG
 GAGTCTCCGGGGAAGACGGTAACCATCTCCTGCACCCGCAGCAGTGGCAG
 CATTGCCAGCAACTATGTGCAGTGGTACCAGCAGCGCCCGGCAGTGCCC
 CCACCATTGTGATCTATGAGGATGATCAAAGACCCTCTGGGGTCCCTGAT
 CGGTTCTCTGGCTCCATCGACACCTCCTCCAACCTCTGCCTCCCTCACCATC
 TCTGGACTGCAGAGTGAGGACGAGGCTGACTACTACTGTCACTTATGA
 GCCCCGCAATGGGGTATTCGGCGGAGGGACCAAGGTCACCGTCTAGCGG
 CCGCAGAGTCAAATAACGGTCCTCCGTGCCCTCCGTGTCCGATCTACATTT
 GGGCCCCGCTGGCCGGCACTTGCGGCGTGCTCCTGCTGTCGCTGGTCATCA
 CCCTTTACTGCAAGAGGGGGCCGGAAGAAGCTGCTTTACATCTTCAAGCAG
 CCGTTCATGCGGCCCGTGACAGACTCAGGAAGAGGACGGATGCTCGTG
 CAGATTCCCTGAGGAGGAAGAGGGGGGATGCCAACTGCGCGTCAAGTTCT
 CACGGTCCGCCGACGCCCCCGCATATCAACAGGGCCAGAATCAGCTCTAC
 AACGAGCTGAACCTGGGAAGGAGAGAGGAGTACGACGTGCTGGACAAGC
 GACGCGGACGCGACCCGGAGATGGGGGGGAAACCACGGCGGAAAAACCC
 TCAGGAAGGACTGTACAACGAACCTCCAGAAAGACAAGATGGCGGAAGCC
 TACTCAGAAATCGGGATGAAGGGAGAGCGGAGGAGGGGAAAGGGTCACG
 ACGGGCTGTACCAGGGACTGAGCACCGCCACTAAGGATACCTACGATGCC
 TTGCATATGCAAGCACTCCCACCCCGG

SEQ ID NO: 12 ROR1-CAR AA SEQ LTG2529 (LP-ScFV9-IgG4H/CD8TM-41BB-CD3zeta)

MLLLVTSLLLCELPHPAFLIPQAAQVQLQQSGAEVKKPGSSVKVSKASGGT
 FSSYAIWVRQAPGQGLEWMGWINPNSGGTNYAQRFGQGRVTMTRDTSISTA
 YMELSLRLSDDTAVYYCASYNDAFDIWGQGLTVTVSSGGGGSGGGSGGGG
 SNFMLTQPHSVSESPGKTVTISCTRSSGSIASNYVQWYQQRPGSAPTIVYEDD
 QRPSGVPDRFSGSIDTSSNSASLTISGLQSEDEADYYCQSYEPGNGVFGGGTK
 VTVLAAAESKYGPCCPCPIYIWAPLAGTCGVLLLSLVITLYCKRGRKKLLYIF
 KQPFMRPVQTTQEEDGCSCRFPPEEEEGGCEL RVKFSRSADAPAYQQGQNQLY

NELNLGRREEYDVLDKRRGRDPEMGGKPRRKNPQEGLYNELQKDKMAEAY
SEIGMKGERRRGKGHDGLYQGLSTATKDTYDALHMQALPPR

SEQ ID NO: 13 Nucleotide Sequence of CONTROL ANTI-ROR1 binder:

CAAGAACAGCTTGTAGAGTCCGGCGGTAGATTGGTGACACCGGGGGGGA
GCCTTACCCTGTCTTGTAAGGCATCTGGGTTCGATTTCAGTGCGTATTATA
TGAGCTGGGTTCGGCAGGCGCCCGGGAAGGGGCTGGAATGGATAGCCAC
TATATACCCGTCATCCGGCAAGACTTACTACGCGACTTGGGTAAACGGGA
GGTTTACGATAAGCTCAGATAACGCCCAAACACGGTTGATCTCCAAATG
AATAGCTTGACCGCCGCTGATAGGGCGACCTATTTCTGTGCGCGGGACTC
TTACGCTGATGACGGGGCCCTCTTCAATATATGGGGACCGGGAACGCTCG
TAACCATATCATCTGGAGGAGGTGGGAGCGGAGGCGGAGGGTCAGGTGG
GGGCGGGAGCGAACTCGTACTTACACAATCTCCAAGCGTAAGCGCAGCGT
TGGGGAGTCCAGCAAAGATCACCTGCACTTTGTCAAGCGCCACAAAACG
GATACGATAGATTGGTATCAGCAACTCCAAGGTGAAGCGCCACGATATCT
CATGCAGGTACAGAGCGACGGGAGTTATACTAAGAGGCCCGGGGTCCCA
GACAGATTCAAGTGGCAGCAGTTCAGGTGCCGACAGATACCTGATAATACC
CTCAGTTCAAGCCGATGATGAAGCCGATTACTACTGTGGGGCTGACTACA
TAGGTGGGTATGTTTTTCGGGGGCGGCACTCAATTGACAGTTACAGGG

SEQ ID NO: 14 Amino Acid Sequence of CONTROL ANTI-ROR1 binder:

QEQLVESGGRLVTPGGSLLSCKASGFDFSAYYMSWVRQAPGKGLEWIATY
PSSGKTYIATWVNGRFTISSDNAQNTVDLQMNSLTAADRATYFCARDSYAD
DGALFNIWGPGLVTISSGGGGSGGGSGGGGSELVLTQSPSVSAALGSPAKI
TCTLSSAHKTDIDWYQQLQGEAPRYLMQVQSDGSYTKRPGVPDRFSGSSSG
ADRYLIIPSVQADDEADYCYCGADYIGGYVFGGGTQLTGTG

SEQ ID NO: 15 ROR1-CAR DNA SEQ CONTROL LTG1943 (LP-ControlScFv-
CD8H/CD8TM-41BB-CD3zeta)

ATGCTGCTGCTGGTGACCAGCCTGCTGCTGTGCGAACTGCCGCATCCGGC
GTTTCTGCTGATTCCGCAAGAACAGCTTGTAGAGTCCGGCGGTAGATTGG
TGACACCGGGGGGAGCCTTACCCTGTCTTGTAAGGCATCTGGGTTCGAT
TTCAGTGCGTATTATATGAGCTGGGTTCGGCAGGCGCCCGGGAAGGGGCT
GGAATGGATAGCCACTATATACCCGTCATCCGGCAAGACTTACTACGCGA
CTTGGGTAAACGGGAGGTTTACGATAAGCTCAGATAACGCCCAAACACG
GTTGATCTCCAAATGAATAGCTTGACCGCCGCTGATAGGGCGACCTATTC
TGTGCGCGGGACTCTTACGCTGATGACGGGGCCCTCTTCAATATATGGGG
ACCGGGAACGCTCGTAACCATATCATCTGGAGGAGGTGGGAGCGGAGGC
GGAGGGTCAGGTGGGGGCGGGAGCGAACTCGTACTTACACAATCTCCAA
GCGTAAGCGCAGCGTTGGGGAGTCCAGCAAAGATCACCTGCACTTTGTCA
AGCGCCACAAAACGGATACGATAGATTGGTATCAGCAACTCCAAGGTGA
AGCGCCACGATATCTCATGCAGGTACAGAGCGACGGGAGTTATACTAAGA
GGCCCGGGGTCCCAGACAGATTCAAGTGGCAGCAGTTCAGGTGCCGACAGA
TACCTGATAATACCCTCAGTTCAAGCCGATGATGAAGCCGATTACTACTGT
GGGGCTGACTACATAGGTGGGTATGTTTTTCGGGGGCGGCACTCAATTGAC
AGTTACAGGGGCGGCCGCAACTACCACCCCTGCCCCTCGGCCGCCGACTC
CGGCCCAACCATCGCAAGCCAACCCCTCTCCTTGCGCCCCGAAGCTTGC
CGCCCGGCCGCGGGTGGAGCCGTGCATACCCGGGGGCTGGACTTTGCCTG
CGATATCTACATTTGGGCCCCGCTGGCCGGCACTTGCGGCGTGCTCCTGCT

GTCGCTGGTCATCACCCCTTTACTGCAAGAGGGGGCCGGAAGAAGCTGCTTT
ACATCTTCAAGCAGCCGTTTCATGCGGCCCCGTGCAGACGACTCAGGAAGAG
GACGGATGCTCGTGCAGATTCCCTGAGGAGGAAGAGGGGGGATGCGAAC
TGCGCGTCAAGTTCTCACGGTCCGCCGACGCCCCCGCATATCAACAGGGC
CAGAATCAGCTCTACAACGAGCTGAACCTGGGAAGGAGAGAGGAGTACG
ACGTGCTGGACAAGCGACGCGGACGCGACCCGGAGATGGGGGGGAAACC
ACGGCGGAAAAACCCTCAGGAAGGACTGTACAACGAACCTCCAGAAAGAC
AAGATGGCGGAAGCCTACTCAGAAATCGGGATGAAGGGAGAGCGGAGGA
GGGGAAGGGTCACGACGGGCTGTACCAGGGACTGAGCACCGCCACTAA
GGATACCTACGATGCCTTGCATATGCAAGCACTCCCACCCCGG

SEQ ID NO: 16 ROR1-CAR AA SEQ CONTROL LTG1943 (LP-ControlScFv-
CD8H/CD8TM-41BB-CD3zeta)

MLLLVTSLLLCELPHPAFLIPQEQLVESGGRLVTPGGSLTLCKASGDFDSAY
YMSWVRQAPGKGLEWIATIPSSGKTYATWVNGRFTISSDNAQNTVDLQM
NSLTAADRATYFCARDSYADDGALFNWGPGLVTISSGGGSGGGSGGGG
SELVLTQSPSVSAALGSPAKITCTLSSAHKTDITDQYQQLQGEAPRYLMQVQS
DGSYTKRPGVPDRFSGSSSGADRYLIIPSVQADDEADYYCGADYIGGYVFGG
GTQLTVTGAAATTPAPRPPTPAPTIASQPLSLRPEACRPAAGGAVHTRGLDF
ACDIYIWAPLAGTCGVLLLSLVITLYCKRGRKKLLYIFKQPFMRPVQTTQEED
GCSCRFPEEEEEGGCELRVKFSRSADAPAYQQGQNQLYNELNLGRREEYDVLD
KRRGRDPEMGGKPRRKNPQEGLYNELQKDKMAEAYSEIGMKGERRRGKGH
DGLYQGLSTATKDTYDALHMQALPPR

SEQ ID NO: 17 ROR1-CAR DNA SEQ CONTROL LTG2527 (LP-ControlScFv-
IgG4H/CD8TM-41BB-CD3zeta)

ATGCTGCTGCTGGTGACCAGCCTGCTGCTGTGCGAACTGCCGCATCCGGC
GTTTCTGCTGATTCCGCAAGAACAGCTTGTAGAGTCCGGCGGTAGATTGG
TGACACCGGGGGGAGCCTTACCCTGTCTTGTAAAGGCATCTGGGTTCGAT
TTCAGTGCCTATTATATGAGCTGGGTTCGGCAGGCGCCCGGGAAGGGGCT
GGAATGGATAGCCACTATATACCCGTCATCCGGCAAGACTTACTACGCGA
CTTGGGTAAACGGGAGGTTTACGATAAGCTCAGATAACGCCCAAACACG
GTTGATCTCCAAATGAATAGCTTGACCGCCGCTGATAGGGCGACCTATTTC
TGTGCGCGGGACTCTTACGCTGATGACGGGGCCCTCTTCAATATATGGGG
ACCGGGAACGCTCGTAACCATATCATCTGGAGGAGGTGGGAGCGGAGGC
GGAGGGTCAGGTGGGGGCGGGAGCGAACTCGTACTTACACAATCTCCAA
GCGTAAGCGCAGCGTTGGGGAGTCCAGCAAAGATCACCTGCACTTTGTCA
AGCGCCACAAAACGGATACGATAGATTGGTATCAGCAACTCCAAGGTGA
AGCGCCACGATATCTCATGCAGGTACAGAGCGACGGGAGTTATACTAAGA
GGCCCGGGGTCCCAGACAGATTCAGTGGCAGCAGTTCAGGTGCCGACAGA
TACCTGATAATACCCTCAGTTCAAGCCGATGATGAAGCCGATTACTACTGT
GGGGCTGACTACATAGGTGGGTATGTTTTTCGGGGGCGGCACTCAATTGAC
AGTTACAGGGGCGGCCGAGAGTCAAATAACGGTCCTCCGTGCCCTCCGT
GTCCGATCTACATTTGGGCCCCGCTGGCCGGCACTTGCGGCGTGCTCCTG
CTGTCGCTGGTCATCACCCCTTTACTGCAAGAGGGGGCCGGAAGAAGCTGCT
TTACATCTTCAAGCAGCCGTTTCATGCGGCCCCGTGCAGACGACTCAGGAAG
AGGACGGATGCTCGTGCAGATTCCCTGAGGAGGAAGAGGGGGGATGCGA
ACTGCGCGTCAAGTTCTCACGGTCCGCCGACGCCCCCGCATATCAACAGG
GCCAGAATCAGCTCTACAACGAGCTGAACCTGGGAAGGAGAGAGGAGTA

CGACGTGCTGGACAAGCGACGCGGACGCGACCCGGAGATGGGGGGGAAA
 CCACGGCGGAAAAACCCTCAGGAAGGACTGTACAACGAAGTCCAGAAAG
 ACAAGATGGCGGAAGCCTACTCAGAAATCGGGATGAAGGGAGAGCGGAG
 GAGGGGAAAGGGTCACGACGGGCTGTACCAGGGACTGAGCACC GCCACT
 AAGGATACCTACGATGCCTTGCATATGCAAGCACTCCCACCCCGG

SEQ ID NO: 18 ROR1-CAR AA SEQ CONTROL LTG2527 (LP-ControlScFv-IgG4H/CD8TM-41BB-CD3zeta)

MLLLVTSLLLCELPHPAFLIPQEQLVESGGRLVTPGGSLTLCKASGFDFSA
 YMSWVRQAPGKGLEWIATIPSSGKTYATWVNGRFTISSDNAQNTVDLQM
 NSLTAADRATYFCARDSYADDGALFNIWGPGLVTISSGGGGSGGGSGGGG
 SELVLTQSPSVSAALGSPAKITCTLSAHKTDIDWYQQLQGEAPRYLMQVQS
 DGSYTKRPGVPDRFSGSSSGADRYLIIPSVQADDEADYCYGADYIGGYVFGG
 GTQLTVTGAAAESKYGPCCPPCIYIWAPLAGTCGVLLLSLVITLYCKRGRKK
 LLYIFKQPFMRPVQTTQEEDGCSRFPEEEEGGCELRVKFSRSADAPAYQQGQ
 NQLYNELNLGRREEYDVLDRRGRDPEMGGKPRRKNPQEGLYNELQKDKM
 AEAYSEIGMKGERRRGKGHDGLYQGLSTATKDTYDALHMQALPPR

SEQ ID NO: 19 Nucleotide Sequence of leader/signal peptide sequence (LP)

ATGCTGCTGCTGGTGACCAGCCTGCTGCTGTGCGAACTGCCGCATCCGGCGTTTC
 TGCTGATTCCG

SEQ ID NO: 20 Amino Acid sequence of leader/signal peptide sequence (LP)

MLLLVTSLLLCELPHPAFLIP

SEQ ID NO: 21 Nucleotide Sequence of DNA CD8 transmembrane domain

ATTTGGGCCCCGCTGGCCGGCACTTGCGGCGTGCTCCTGCTGTCGCTGGTCATCA
 CCCTTTACTGC

SEQ ID NO: 22 Amino Acid Sequence of CD8 transmembrane domain

IWAPLAGTCGVLLLSLVITLYC

SEQ ID NO: 23 Nucleotide Sequence of DNA CD8 hinge domain

ACTACCACCCCTGCCCTCGGCCGCGACTCCGGCCCCAACCATCGCAAGCCAAC
 CCCTCTCCTTGCGCCCCGAAGCTTGCCGCCCCGGCCGCGGGTGGAGCCGTGCATAC
 CCGGGGGCTGGACTTTGCCTGCGATATCTAC

SEQ ID NO: 24 Amino Acid Sequence of CD8 hinge domain

TTTPAPRPPTPAPTIASQPLSLRPEACRPAAGGAVHTRGLDFACDIY

SEQ ID NO: 25 Amino Acid Sequence of amino acid numbers 137 TO 206 hinge and transmembrane region of CD8.alpha. (NCBI REFSEQ: NP.SUB.--001759.3)

TTTPAPRPPTPAPTIASQPLSLRPEACRPAAGGAVHTRGLDFACDIYIWAPLAG
TCGVLLLSLVITLYC

SEQ ID NO: 26 Nucleotide Sequence of signaling domain of 4-1BB

AAGAGGGGCGCGGAAGAAGCTGCTTTACATCTTCAAGCAGCCGTTTCATGCGGCCC
GTGCAGACGACTCAGGAAGAGGACGGATGCTCGTGCAGATTCCCTGAGGAGGAA
GAGGGGGGATGCGAACTG

SEQ ID NO: 27 Amino Acid Sequence of signaling domain of 4-1BB

KRGRKLLYIFKQPFMRPVQTTQEEDGCSCRFPEEEEEGGCEL

SEQ ID NO: 28 Nucleotide Sequence of intracellular signaling domain of CD3-zeta

CGCGTCAAGTTCTCACGGTCCGCCGACGCCCCGCATATCAACAGGGCCAGAAT
CAGCTCTACAACGAGCTGAACCTGGGAAGGAGAGAGGAGTACGACGTGCTGGAC
AAGCGACGCGGACGCGACCCGGAGATGGGGGGGAAACCACGGCGGAAAAACCC
TCAGGAAGGACTGTACAACGAACTCCAGAAAGACAAGATGGCGGAAGCCTACTC
AGAAATCGGGATGAAGGGAGAGCGGAGGAGGGGAAAGGGTACGACGGGCTGT
ACCAGGGACTGAGCACCGCCACTAAGGATACCTACGATGCCTTGCATATGCAAG
CACTCCCACCCCGG

SEQ ID NO: 29 Amino Acid sequence of CD3-zeta

RVKFSRSADAPAYQQGQNQLYNELNLGRREEYDVLDKRRGRDPPEMGGKPR
RKNPQEGLYNELQKDKMAEAYSEIGMKGERRRGKGHDGLYQGLSTATKDT
YDALHMQALPPR

SEQ ID NO: 30 Nucleotide Sequence of intracellular signaling domain of CD3-zeta, variant

CGCGTCAAGTTCTCACGGTCCGCCGACGCCCCGCATATAAACAGGGCCAGAAT
CAGCTCTACAACGAGCTGAACCTGGGAAGGAGAGAGGAGTACGACGTGCTGGAC
AAGCGACGCGGACGCGACCCGGAGATGGGGGGGAAACCACGGCGGAAAAACCC
TCAGGAAGGACTGTACAACGAACTCCAGAAAGACAAGATGGCGGAAGCCTACTC
AGAAATCGGGATGAAGGGAGAGCGGAGGAGGGGAAAGGGTACGACGGGCTGT
ACCAGGGACTGAGCACCGCCACTAAGGATACCTACGATGCCTTGCATATGCAAG
CACTCCCACCCCGG

SEQ ID NO: 31 Amino Acid Sequence of CD3-zeta signaling domain, variant

RVKFSRSADAPAYKQGQNQLYNELNLGRREEYDVLDKRRGRDPPEMGGKPR
RKNPQEGLYNELQKDKMAEAYSEIGMKGERRRGKGHDGLYQGLSTATKDT
YDALHMQALPPR

SEQ ID NO: 32 Nucleotide Sequence of ScFV CD19 (FMC63)

GACATTCAGATGACTCAGACCACCTCTTCCTTGTCCGCGTCACTGGGAGACAGA
GTGACCATCTCGTGTGCGCAAGCCAGGATATCTCCAAGTACCTGAACTGGTA
CCAACAGAAGCCCGACGGGACTGTGAAGCTGCTGATCTACCACACCTCACGCC

TGCACAGCGGAGTGCCAAGCAGATTCTCCGGCTCCGGCTCGGGAACCGATTAC
 TCGCTTACCATTAGCAACCTCGAGCAGGAGGACATCGCTACCTACTTCTGCCAG
 CAAGGAAATACCCTGCCCTACACCTTCGGCGGAGGAACCAAATTGGAAATCAC
 CGGCGGAGGAGGCTCCGGGGGAGGAGGTTCCGGGGGCGGGGGTTCCGAAGTG
 AAGCTCCAGGAGTCCGGCCCCGGCCTGGTGGCGCCGTCGCAATCACTCTCTGT
 GACCTGTACCGTGTTCGGGAGTGTCCCTGCCTGATTACGGCGTGAGCTGGATTCTG
 GCAGCCGCCGCGGAAGGGCCTGGAATGGCTGGGTGTCATCTGGGGATCCGAGA
 CTACCTACTACAACCTCGGCCCTGAAGTCCCGCCTGACTATCATCAAAGACAACCT
 CGAAGTCCCAGGTCTTTCTGAAGATGAACTCCCTGCAAACCTGACGACACCGCC
 ATCTATTACTGTGCTAAGCACTACTACTACGGTGGAAGCTATGCTATGGACTAC
 TGGGGGCAAGGCACTTCGGTGACTGTGTCAAGC

SEQ ID NO: 33 Amino Acid Sequence of ScFV CD19 (FMC63)

DIQMTQTTSSLSASLGDRVTISCRASQDISKYLNWYQQKPDGTVKLLIYHTSR
 LHSQVPSRFSGSGSGTDYSLTISNLEQEDIATYFCQQGNTLPYTFGGGKLEIT
 GGGGSGGGGSGGGGSEVKLQESGPGLVAPSQSLSVTCTVSGVSLPDYGVSWI
 RQPPRKGLEWLGVIWGSETTYNSALKSRLTIKDNSKSQVFLKMNSLQTDD
 TAIYYCAKHYYYGGSYAMDYWGQGSTSVTVSS

SEQ ID NO: 34 Nucleotide Sequence of anti-CD33 ScFV (LTG1936)

CAGGTGCAGCTGGTGCAATCTGGGGCAGAGGTGAAAAAGCCCGGGGAGTCTCTG
 AGGATCTCCTGTAAGGGTTCTGGATTCAGTTTTCCACCTACTGGATCGGCTGGG
 TGCGCCAGATGCCCGGGAAAGGCCTGGAGTGGATGGGGATCATCTATCCTGGTG
 ACTCTGATACCAGATACAGCCCCTCCTTCCAAGGCCAGGTCACCATCTCAGCCGA
 CAAGTCCATCAGCACCGCCTACCTGCAGTGGAGCAGCCTGAAGGCCTCGGACAC
 CGCCATGTATTACTGTGCGAGACTAGTTGGAGATGGCTACAATACGGGGGCTTTT
 GATATCTGGGGCCAAGGGACAATGGTCACCGTCTCTTCAGGAGGTGGCGGGTCT
 GGTGGTGGCGGTAGCGGTGGTGGCGGATCCGATATTGTGATGACCCACACTCCA
 CTCTCTCTGTCCGTCACCCCTGGACAGCCGGCCTCCATCTCCTGCAAGTCTAGTCA
 GAGCCTCCTGCATAGTAATGGAAAGACCTATTTGTATTGGTACCTGCAGAAGCCA
 GGCCAGCCTCCACAGCTCCTGATCTATGGAGCTTCCAACCGGTTCTCTGGAGTGC
 CAGACAGGTTTCAAGTGGCAGCGGGTCAGGGACAGATTTCACACTGAAAATCAGCC
 GGGTGGAGGCTGAGGATGTTGGGGTTTATTACTGCATGCAAAGTATACAGCTTCC
 TATCACCTTCGGCCAAGGGACACGACTGGAGATTA

SEQ ID NO: 35 Amino Acid sequence of anti-CD33 ScFV (LTG1936)

QVQLVQSGAEVKKPGESLRISCKGSGFSFPTYWIGWVRQMPGKGLEWMGHIYPGDS
 DTRYSPSFQGGQVTISADKSISTAYLQWSSLKASDTAMYYCARLVGDGYNTGAFDIW
 GQGTMTVTVSSGGGGSGGGGSGGGGSDIVMTHTPLSLSVTPGQPASISCKSSQSLLHS
 NGKTYLYWYLQKPGQPPQLLIYGASNRFSQVDPDRFSGSGSGTDFTLKISRVEAEDVG
 VYYCMQSIQLPITFGQGTRLEIK

SEQ ID NO: 36 Nucleotide Sequence of anti-mesothelin ScFV (LTG1904)

GAGGTCCAGCTGGTACAGTCTGGGGGAGGCTTGGTACAGCCTGGGGGGTCCCTG
 AGACTCTCCTGTGCAGCCTCTGGATTCACCTTTGATGATTATGCCATGCACTGGG
 TCCGGCAAGCTCCAGGGAAGGGCCTGGAGTGGGTCTCAGGTATTAGTTGGAATA

GTGGTAGCATAGGCTATGCGGACTCTGTGAAGGGCCGATTACCATCTCCAGAG
 ACAACGCCAAGAACTCCCTGTATCTGCAAATGAACAGTCTGAGAGCTGAGGACA
 CGGCCTTGTATTACTGTGCAAAAGATTTATCGTCAGTGGCTGGACCCTTTAACTA
 CTGGGGCCAGGGCACCCCTGGTCACCGTCTCCTCAGGAGGTGGCGGGTCTGGTGG
 AGGCGGTAGCGGCGGTGGCGGATCCTCTTCTGAGCTGACTCAGGACCCTGCTGTG
 TCTGTGGCCTTGGGACAGACAGTCAGGATCACATGCCAAGGAGACAGCCTCAGA
 AGCTATTATGCAAGCTGGTACCAGCAGAAGCCAGGACAGGCCCTGTACTTGTC
 ATCTATGGTAAAAACAACCGGCCCTCAGGGATCCCAGACCGATTCTCTGGCTCCA
 GCTCAGGAAACACAGCTTCCTTGACCATCACTGGGGCTCAGGCGGAGGATGAGG
 CTGACTATTACTGTAACCTCCCGGGACAGCAGTGGTAACCATCTGGTATTCGGCGG
 AGGCACCCAGCTGACCGTCCTCGGT

SEQ ID NO: 37 Amino Acid sequence of anti-mesothelin ScFV (LTG1904)

EVQLVQSGGGLVQPGGSLRLSCAASGFTFDDYAMHWVRQAPGKGLEWVSGISWNS
 GSGYADSVKGRFTISRDNKNSLYLQMNSLRAEDTALYYCAKDLSSVAGPFNYWG
 QGTLVTVSSGGGSGGGGSGGGGSSSELTQDPAVSVALGQTVRITCQGDSLRSYAS
 WYQQKPGQAPVLVIYGKNNRPSGIPDRFSGSSSGNTASLTITGAQAEDEADYYCNSR
 DSSGNHLVFGGGTQLTVLG

SEQ ID NO: 38 Nucleotide Sequence of IgG4H (hinge)

GAGTCAAAATACGGTCCTCCGTGCCCTCCGTGTCCG

SEQ ID NO: 39 Amino Acid Sequence of IgG4H (hinge)

ESKYGPPCPPCP

SEQ ID NO: 40 Nucleotide Sequence of hinge domain of IgG4H linked to CD8 TM (transmembrane)

GAGTCAAAATACGGTCCTCCGTGCCCTCCGTGTCCGATCTACATTTGGGCC
 CCGCTGGCCGGCACTTGCGGCGTGCTCCTGCTGTCGCTGGTCATCACCTT
 TACTGC

SEQ ID NO: 41 Amino Acid Sequence of hinge domain of IgG4H linked to CD8 TM (transmembrane)

ESKYGPPCPPCPPIYIWAPLAGTCGVLLLSLVITLYC

CLAIMS**WHAT IS CLAIMED IS:**

1. An isolated nucleic acid molecule encoding a chimeric antigen receptor (CAR) comprising at least one extracellular antigen binding domain comprising a ROR1 antigen binding domain encoded by a nucleotide sequence comprising SEQ ID NO: 1, or SEQ ID NO: 7, at least one transmembrane domain, and at least one intracellular signaling domain.
2. The isolated nucleic acid molecule of claim 1, wherein the encoded at least one ROR1 antigen binding domain comprises at least one single chain variable fragment of an antibody that binds to ROR1.
3. The isolated nucleic acid molecule of claim 1, wherein the encoded at least one ROR1 antigen binding domain comprises at least one heavy chain variable region of an antibody that binds to ROR1.
4. The isolated nucleic acid molecule of claim 1, wherein the encoded at least one ROR1 antigen binding domain, the at least one intracellular signaling domain, or both are connected to the transmembrane domain by a linker or spacer domain.
5. The isolated nucleic acid molecule of claim 4, wherein the encoded linker or spacer domain is derived from the extracellular domain of IgG4, CD8 or CD28, and is linked to a transmembrane domain.
6. The isolated nucleic acid molecule of claim 1, wherein the encoded extracellular ROR1 antigen binding domain is preceded by a leader nucleotide sequence encoding a leader peptide.
7. The isolated nucleic acid molecule of claim 6, wherein the leader nucleotide sequence comprises a nucleotide sequence comprising SEQ ID NO: 19 encoding the leader amino acid sequence of SEQ ID NO: 20.

8. The isolated nucleic acid molecule of claim 1, wherein the transmembrane domain comprises a transmembrane domain of a protein comprising the alpha, beta or zeta chain of the T-cell receptor, CD8, CD28, CD3 epsilon, CD45, CD4, CD5, CD8, CD9, CD16, CD22, CD33, CD37, CD64, CD80, CD83, CD86, CD134, CD137, CD154, and TNFRSF19, or any combination thereof.
9. The isolated nucleic acid molecule of claim 1, wherein the nucleic acid sequence encoding the extracellular ROR1 antigen binding domain comprises a nucleic sequence comprising SEQ ID NO: 1, 3, 5, 7, 9, or 11, or a sequence with 85%, 90%, 95%, 96%, 97%, 98% or 99% identity thereof.
10. The isolated nucleic acid molecule of claim 1, wherein the encoded at least one intracellular signaling domain further comprises a CD3 zeta intracellular domain.
11. The isolated nucleic acid molecule of claim 10, wherein the encoded at least one intracellular signaling domain is arranged on a N-terminal side relative to the CD3 zeta intracellular domain.
12. The isolated nucleic acid molecule of claim 1, wherein the encoded at least one intracellular signaling domain comprises a costimulatory domain, a primary signaling domain, or any combination thereof.
13. The isolated nucleic acid molecule of claim 12, wherein the encoded at least one costimulatory domain comprises a functional signaling domain of OX40, CD70, CD27, CD28, CD5, ICAM-1, LFA-1 (CD11a/CD18), ICOS (CD278), DAP10, DAP12, and 4-1BB (CD137), or any combination thereof.
14. A chimeric antigen receptor (CAR) encoded by the isolated nucleic acid molecule of claim 1.
15. The CAR of claim 14, comprising at least one extracellular antigen binding domain comprising a ROR1 antigen binding domain comprising the amino acid sequence of SEQ ID NO. 2, or 8, at least one transmembrane domain, and at least one intracellular signaling domain.

16. The CAR of claim 15, wherein the ROR1 antigen binding domain comprises at least one single chain variable fragment of an antibody that binds to ROR1.
17. The CAR of claim 15, wherein the ROR1 antigen binding domain comprises at least one heavy chain variable region of an antibody that binds to ROR1.
18. The CAR of claim 15, wherein the transmembrane domain comprises a transmembrane domain of a protein comprising the alpha, beta or zeta chain of the T-cell receptor, CD8, CD28, CD3 epsilon, CD45, CD4, CD5, CD8, CD9, CD16, CD22, CD33, CD37, CD64, CD80, CD86, CD134, CD137, CD154, and TNFRSF19 or any combination thereof.
19. The CAR of claim 18, wherein the CD8 transmembrane domain comprises the amino acid sequence of SEQ ID NO: 22, or an amino acid sequence with 85%, 90%, 95%, 96%, 97%, 98% or 99% identity to an amino acid sequence of SEQ ID NO: 22.
20. The CAR of claim 15, wherein the at least one extracellular antigen binding domain comprising a ROR1 antigen binding domain comprising the amino acid sequence of SEQ ID NO. 2, or 8, and the at least one intracellular signaling domain, or both are connected to the transmembrane domain by a linker or spacer domain.
21. The CAR of claim 20, wherein the linker or spacer domain is derived from the extracellular domain of IgG4, CD8 or CD28, and is linked to a transmembrane domain.
22. The CAR of claim 15, wherein the at least one intracellular signaling domain comprises a costimulatory domain and a primary signaling domain.
23. The CAR of claim 22, wherein the at least one intracellular signaling domain comprises a costimulatory domain comprising a functional signaling domain of a protein selected from the group consisting of OX40, CD70, CD27, CD28, CD5, ICAM-1, LFA-1 (CD11a/CD18), ICOS (CD278), DAP10, DAP12, and 4-1BB (CD137), or a combination thereof.
24. A vector comprising a nucleic acid molecule of claim 1.

25. The vector of claim 24, wherein the vector is selected from the group consisting of a DNA vector, an RNA vector, a plasmid vector, a cosmid vector, a herpes virus vector, a measles virus vector, a lentivirus vector, adenoviral vector, or a retrovirus vector, or a combination thereof.
26. The vector of claim 24, further comprising a promoter.
27. The vector of claim 26, wherein the promoter is an inducible promoter, a constitutive promoter, a tissue specific promoter, a suicide promoter or any combination thereof.
28. A cell comprising the vector of claim 24.
29. The cell of claim 28, wherein the cell is a T cell.
30. The cell of claim 29, wherein the T cell is a CD8⁺ T cell.
31. The cell of claim 28, wherein the cell is a human cell.
32. A method of making a cell comprising transducing a T cell with a vector of claim 24.
33. A method of generating a population of RNA-engineered cells comprising introducing an in vitro transcribed RNA or synthetic RNA into a cell, where the RNA comprises a nucleic acid molecule of claim 1.
34. A method of providing an anti-tumor immunity in a mammal comprising administering to the mammal an effective amount of a cell of claim 28.
35. A method of treating or preventing cancer in a mammal, comprising administering to the mammal the CAR of claim 15, in an amount effective to treat or prevent cancer in the mammal.
36. A pharmaceutical composition comprising an anti-tumor effective amount of a population of human T cells, wherein the T cells comprise a nucleic acid sequence that encodes a chimeric antigen receptor (CAR), wherein the CAR comprises at least one extracellular antigen

binding domain comprising a ROR1 antigen binding domain comprising the amino acid sequence of SEQ ID NO. 2, or 8, at least one linker domain, at least one transmembrane domain, at least one intracellular signaling domain, and wherein the T cells are T cells of a human having a cancer.

37. The pharmaceutical composition of claim 36, wherein the at least one transmembrane domain comprises a transmembrane domain of a protein comprising the alpha, beta or zeta chain of the T-cell receptor, CD8, CD28, CD3 epsilon, CD45, CD4, CD5, CD8, CD9, CD16, CD22, CD33, CD37, CD64, CD80, CD86, CD134, CD137 and CD154, or any combination thereof.
38. The pharmaceutical composition of claim 36, wherein the T cells are T cells of a human having a hematological cancer.
39. The pharmaceutical composition of claim 38, wherein the hematological cancer is leukemia or lymphoma.
40. The pharmaceutical composition of claim 39, wherein the leukemia is chronic lymphocytic leukemia (CLL), acute lymphocytic leukemia (ALL), or chronic myelogenous leukemia (CML).
41. The pharmaceutical composition of claim 39, wherein the lymphoma is mantle cell lymphoma, non-Hodgkin's lymphoma or Hodgkin's lymphoma.
42. The pharmaceutical composition of claim 38, wherein the hematological cancer is multiple myeloma.
43. The pharmaceutical composition of claim 36, wherein the human cancer includes an adult carcinoma comprising oral and pharynx cancer (tongue, mouth, pharynx, head and neck), digestive system cancers (esophagus, stomach, small intestine, colon, rectum, anus, liver, interhepatic bile duct, gallbladder, pancreas), respiratory system cancers (larynx, lung and bronchus), bones and joint cancers, soft tissue cancers, skin cancers (melanoma, basal and squamous cell carcinoma), pediatric tumors (neuroblastoma, rhabdomyosarcoma, osteosarcoma, Ewing's sarcoma), tumors of the central nervous system (brain, astrocytoma, glioblastoma, glioma), and cancers of the breast, the genital system (uterine cervix, uterine

corpus, ovary, vulva, vagina, prostate, testis, penis, endometrium), the urinary system (urinary bladder, kidney and renal pelvis, ureter), the eye and orbit, the endocrine system (thyroid), and the brain and other nervous system, or any combination thereof.

44. A method of treating a mammal having a disease, disorder or condition associated with an elevated expression of a tumor antigen, the method comprising administering to the subject a pharmaceutical composition comprising an anti-tumor effective amount of a population of T cells, wherein the T cells comprise a nucleic acid sequence that encodes a chimeric antigen receptor (CAR), wherein the CAR comprises at least one extracellular antigen binding domain comprising a ROR1 antigen binding domain comprising the amino acid sequence of SEQ ID NO. 2, or 8, at least one linker or spacer domain, at least one transmembrane domain, at least one intracellular signaling domain, wherein the T cells are T cells of the subject having cancer.
45. A method of treating cancer in a subject in need thereof, the method comprising administering to the subject a pharmaceutical composition comprising an anti-tumor effective amount of a population of T cells, wherein the T cells comprise a nucleic acid sequence that encodes a chimeric antigen receptor (CAR), wherein the CAR comprises at least one extracellular antigen binding domain comprising a ROR1 antigen binding domain comprising the amino acid sequence of SEQ ID NO. 2, or 8, at least one linker or spacer domain, at least one transmembrane domain, at least one intracellular signaling domain, wherein the T cells are T cells of the subject having cancer.
46. The method of claim 44 or 45, wherein the at least one transmembrane domain comprises a transmembrane domain of a protein comprising the alpha, beta or zeta chain of the T-cell receptor, CD8, CD28, CD3 epsilon, CD45, CD4, CD5, CD8, CD9, CD16, CD22, CD33, CD37, CD64, CD80, CD86, CD134, CD137 and CD154, or any combination thereof.
47. A process for producing a chimeric antigen receptor-expressing cell, the process comprising introducing the isolated nucleic acid of claim 1 into a cell.
48. The process for producing a chimeric antigen receptor-expressing cell according to claim 47, wherein the cell is a T cell or a cell population containing a T cell.

FIGURE 1



FIGURE 2A

LTG1941: LP-ScFV4-CD8H/CD8TM-41BB-CD3zeta nucleic acid sequence (SEQ ID NO: 3):

ATGCTGCTGCTGGTGACCAGCCTGCTGCTGTGCGAACTGCCGCATCCGGC
GTTTCTGCTGATTCCGCAAGTTCAGCTGCAAGAATCAGGACCTGGGCTTGT
CAAACCATCTGAAACCCTCAGCTTGACTTGTACCGTATCAGGAGGGTCAA
TTTCAAGCTCATCCTACTATTGGGGATGGATCAGACAACCACCCGGGAAA
GGGCTCGAGTGGATAGGGTCCATATATTACAGCGGATCTACATACTACAA
CCCGTCATTGAAGTCCAGGGTAACGATTCCGGTGGACACTAGCAAGAATC
AGTTTAGCCTCAAGTTGAGCAGTGTAAGTCTGCTGCGGACACGGCGGTATAT
TATTGTGCTCGACACCTCGGTGGAGATGCTTTTGACATATGGGGTCAAGG
GACAACAGTCACCGTTAGCTCAGGTGGAGGGGGTAGCGGGGGGGGCGGA
TCTGGGGGAGGCGGTTCATTGCCCGTACTTACACAGCCACCCTCTGTCAGC
GTCGCACCTGGACAAACCGCTCGCATCACCTGTGGCGGAAATAATATAGG
TTCCAAGTCTGTTCATTGGTATCAGCAGAAACCGGGACAGGCCCCCGTCC
TTGTGGTGTATGATGATTCTGATAGGCCATCTGGTATCCAGAACGGTTTT
CAGGTAGCAATTCAGGGAATACTGCCACTCTCACTATTAGCGGTACTCAA
GCTATGGATGAGGCCGACTATTTTTGCCAGAGCTACGACTCTAGTAACCC
AGTCGTGTTCCGGGGGAGGGACCCAGTTGACCGTGCTGGCGGCCGCAACTA
CCACCCCTGCCCTCGGCCGCCGACTCCGGCCCCAACCATCGCAAGCCAA
CCCCTCTCCTTGCGCCCCGAAGCTTGCCGCCCGGCCGCGGGTGGAGCCGT
GCATACCCGGGGGCTGGACTTTGCCTGCGATATCTACATTGGGCCCCGCT
GGCCGGCACTTGCGGCGTGCTCCTGCTGTCGCTGGTCATCACCCTTTACTG
CAAGAGGGGCCGGAAGAAGCTGCTTTACATCTTCAAGCAGCCGTTTCATGC
GGCCCGTGCAGACGACTCAGGAAGAGGACGGATGCTCGTGCAGATTCCCT
GAGGAGGAAGAGGGGGGATGCGAACTGCGCGTCAAGTTCTCACGGTCCG
CCGACGCCCCCGCATATCAACAGGGGCCAGAATCAGCTCTACAACGAGCTG
AACCTGGGAAGGAGAGAGGAGTACGACGTGCTGGACAAGCGACGCGGAC
GCGACCCGGAGATGGGGGGGAAACCACGGCGGAAAAACCTCAGGAAGG
ACTGTACAACGAACCTCCAGAAAGACAAGATGGCGGAAGCCTACTCAGAA
ATCGGGATGAAGGGAGAGCGGAGGAGGGGAAAGGGTCACGACGGGCTGT
ACCAGGGACTGAGCACCGCCACTAAGGATACCTACGATGCCTTGCATATG
CAAGCACTCCACCCCGG

LTG1941: LP-ScFV4-CD8H/CD8TM-41BB-CD3zeta amino acid sequence (SEQ ID NO : 4)

MLLLVTSLLLCELPHPAFLIPQVQLQESGPGLVKPSETLSLTCTVSGGSISSSS
YYWGWIRQPPGKLEWIGSIYYSGSTYYNPSLKSRTIPVDTSKNQFSLKLSS
VTAADTAVYYCARHLGGDAFDIWGQGTITVTVSSGGGGSGGGSGGGGSLP
VLTQPPSVSVAPGQTARITCGGNNIGSKSVHWYQQKPGQAPVLVYDDSDRP
SGIPERFSGSNSGNTATLTISGTQAMDEADYFCQSYDSSNPVVFGGGTQLTVL
AAATTTTPAPRPPTPAPTIASQPLSLRPEACRPAAGGAVHTRGLDFACDIYIWAP
LAGTCGVLLLSLVITLYCKRGRKKLLYIFKQPFMRPVQTTQEEDGCSCRFPEE
EEGGCELRVKFSRSADAPAYQQGQNQLYNELNLGRREEYDVLDKRRGRDPE
MGGKPRRKNPQEGLYNELQKDKMAEAYSEIGMKGERRRGKGHDGLYQGLS
TATKDTYDALHMQALPPR

FIGURE 2B

LTG2528: LP-ScFV4-IgG4H/CD8TM-41BB-CD3zeta nucleic acid sequence (SEQ ID NO : 5)

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ATGCTGCTGCTGGTGACCAGCCTGCTGCTGTGCGAACTGCCGCATCCGGC
GTTTCTGCTGATTCCGCAAGTTCAGCTGCAAGAATCAGGACCTGGGCTTGT
CAAACCATCTGAAACCCTCAGCTTGACTTGTACCGTATCAGGAGGGTCAA
TTTCAAGCTCATCCTACTATTGGGGATGGATCAGACAACCACCCGGGAAA
GGGCTCGAGTGGATAGGGTCCATATATTACAGCGGATCTACATACTACAA
CCCGTCATTGAAGTCCAGGGTAACGATTCCGGTGGACACTAGCAAGAATC
AGTTTAGCCTCAAGTTGAGCAGTGTAAGTGTGCGGACACGGCGGTATAT
TATTGTGCTCGACACCTCGGTGGAGATGCTTTTGACATATGGGGTCAAGG
GACAACAGTCACCGTTAGCTCAGGTGGAGGGGGTAGCGGGGGGGGGCGGA
TCTGGGGGAGGCGGTTCATTGCCCCTACTTACACAGCCACCCTCTGTCAGC
GTCGCACCTGGACAAACCGCTCGCATCACCTGTGGCGGAAATAATATAGG
TTCCAAGTCTGTTTATTGGTATCAGCAGAAACCGGGACAGGCCCCCGTCC
TTGTGGTGTATGATGATTCTGATAGGCCATCTGGTATCCCAGAACGGTTTT
CAGGTAGCAATTCAAGGAATACTGCCACTCTCACTATTAGCGGTACTCAA
GCTATGGATGAGGCCGACTATTTTTGCCAGAGCTACGACTCTAGTAACCC
AGTCGTGTTTCGGGGGAGGGACCCAGTTGACCGTGCTGGCGGCCGCAGAGT
CAAATACGGTCCTCCGTGCCCTCCGTGTCCGATCTACATTTGGGCCCCCGC
TGGCCGGCACTTGCGGCGTGCTCCTGCTGTCGCTGGTCATCACCTTTACT
GCAAGAGGGGGCCGGAAGAAGCTGCTTTACATCTTCAAGCAGCCGTTTCATG
CGGCCCGTGACAGCAGCTCAGGAAGAGGACGGATGCTCGTGACAGATTCCC
TGAGGAGGAAGAGGGGGGATGCGAACTGCGCGTCAAGTTCTCACGGTCC
GCCGACGCCCCCGCATATCAACAGGGCCAGAATCAGCTCTACAACGAGCT
GAACCTGGGAAGGAGAGAGGAGTACGACGTGCTGGACAAGCGACGCGGA
CGCGACCCGGAGATGGGGGGGAAACCACGGCGGAAAAACCCTCAGGAAG
GACTGTACAACGAACTCCAGAAAGACAAGATGGCGGAAGCCTACTCAGA
AATCGGGATGAAGGGAGAGCGGAGGAGGGGAAAGGGTCACGACGGGCT
GTACCAGGGACTGAGCACCGCCACTAAGGATACCTACGATGCCTTGCATA
TGCAAGCACTCCCACCCCGG
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LTG2528: LP-ScFV4-IgG4H/CD8TM-41BB-CD3zeta amino acid sequence (SEQ ID NO : 6)

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MLLLVTSLLLCELPHPAFLLIPQVQLQESGPGLVKPSETLSLTCTVSGGSISSS
YYWGWIRQPPGKLEWIGSIYYSGSTYYNPSLKSRTVTPVDTSKNQFSLKLLS
VTAADTAVYYCARHLGGDAFDIWGQGTTVTVSSGGGGSGGGSGGGGSLP
VLTQPPSVSVAPGQTARITCGGNNIGSKSVHWYQQKPGQAPVLVYDDSDRP
SGIPERFSGSNSGNTATLTISGTQAMDEADYFCQSYDSSNPVVFGGGTQLTVL
AAAESKYGPPCPPIYIWAPLAGTCGVLLSLVITLYCKRGRKLLYIFKQPF
MRPVQTTQEEDGCSCRFPEEEEGGCELRVKFSRSADAPAYQQGQNQLYNELN
LGRREEYDVLDKRRGRDPEMGGKPRRKNPQEGLYNELQKDKMAEAYSEIM
KGERRRGKGHDGLYQGLSTATKDTYDALHMQALPPR
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FIGURE 2C

LTG1942 : LP-ScFV9-CD8H/CD8TM-41BB-CD3zeta nucleic acid sequence (SEQ ID NO : 9)

ATGCTGCTGCTGGTGACCAGCCTGCTGCTGTGCGAACTGCCGCATCCGGC
GTTTCTGCTGATTCCGCAGGCGGCCAGGTACAGCTGCAGCAGTCAGGGG
CTGAGGTGAAGAAGCCTGGGTCCTCGGTGAAGGTCTCCTGCAAGGCTTCT
GGAGGCACCTTCAGCAGCTATGCTATCAGCTGGGTGCGACAGGCCCTGG
ACAAGGGCTTGAGTGGATGGGATGGATCAACCCTAACAGTGGTGGCACA
AACTATGCACAGAGGTTTCAGGGCAGGGTCACCATGACCAGGGACACGTC
CATCAGCACAGCCTACATGGAGCTGAGCAGGCTGAGATCTGACGACACGG
CCGTGTATTACTGTGCGAGTTATAATGATGCTTTTGATATCTGGGGCCAAG
GCACCCTGGTCACCGTCTCCTCAGGAGGTGGCGGGTCTGGTGGTGGCGGT
AGCGGTGGTGGCGGATCCAATTTTATGCTGACTCAGCCCCACTCTGTGTCTG
GAGTCTCCGGGGAAGACGGTAACCATCTCCTGCACCCGCAGCAGTGGCAG
CATTGCCAGCAACTATGTGCAGTGGTACCAGCAGCGCCCGGGCAGTGCCC
CCACCATTGTGATCTATGAGGATGATCAAAGACCCTCTGGGGTCCCTGAT
CGGTTCTCTGGCTCCATCGACACCTCCTCCAACCTCTGCCTCCCTCACCATC
TCTGGACTGCAGAGTGAGGACGAGGCTGACTACTACTGTCAGTCTTATGA
GCCCCGCAATGGGGTATTTCGGCGGAGGGACCAAGGTCACCGTCCTAGCGG
CCGCAACTACCACCCCTGCCCTCGGCCGCCGACTCCGGCCCCCAACCATC
GCAAGCCAACCCCTCTCCTTGCGCCCCGAAGCTTGCCGCCCGGCCGCGGG
TGGAGCCGTGCATACCCGGGGGCTGGACTTTGCCTGCGATATCTACATTG
GGCCCCGCTGGCCGGCACTTGCGGCGTGCTCCTGCTGTCTGCTGGTCATCAC
CCTTTACTGCAAGAGGGGCCGGAAGAAGCTGCTTTACATCTTCAAGCAGC
CGTTCATGCGGCCCGTGACAGCAGCTCAGGAAGAGGACGGATGCTCGTGC
AGATTCCTTGAGGAGGAAGAGGGGGGATGCGAACTGCGCGTCAAGTTCTC
ACGGTCCGCCGACGCCCCCGCATATCAACAGGGCCAGAATCAGCTCTACA
ACGAGCTGAACCTGGGAAGGAGAGAGGAGTACGACGTGCTGGACAAGCG
ACGCGGACGCGACCCGGAGATGGGGGGGAAACCACGGCGGAAAAACCCT
CAGGAAGGACTGTACAACGAACCTCCAGAAAGACAAGATGGCGGAAGCCT
ACTCAGAAATCGGGATGAAGGGAGAGCGGAGGAGGGGAAAGGGTCACG
ACGGGCTGTACCAGGGACTGAGCACCGCCACTAAGGATACCTACGATGCC
TTGCATATGCAAGCACTCCCACCCCGG

LTG1942: LP-ScFV9-CD8H/CD8TM-41BB-CD3zeta amino acid sequence (SEQ ID NO : 10)

MLLLVTSLLLCELPHPAFLLIPQAAQVQLQQSGAEVKKPGSSVKVSCKASGGT
FSSYAISWVRQAPGQGLEWMGWINPNSGGTNYAQRFGGRVTMTRDTSISTA
YMELSLRSDDTAVYYCASYNDAFDIWGQGTLLTVSSGGGSGGGGSGGGG
SNFMLTQPHSVSESPGKTVTISCTRSSGSIASNYVQWYQQRPGSAPTIVYEDD
QRPSGVPDRFSGSIDTSSNSASLTISGLQSEDEADYYCQSYEPNGVFGGGTK
VTVLAAATTPAPRPPTAPTASQPLSLRPEACRPAAGGAVHTRGLDFACDIY
IWAPLAGTCGVLLLSLVITLYCKRGRKKLLYIFKQPFMRPVQTTQEEDGCSCR
FPEEEEGGCELRVKFSRSADAPAYQQGQNQLYNELNLGRREEYDVLDRRG
RDPEMGGKPRRKNPQEGLYNELQKDKMAEAYSEIGMKGERRRGKGHDGLY
QGLSTATKDTYDALHMQALPPR

FIGURE 2D

LTG2529: (LP-ScFV9-IgG4H/CD8TM-41BB-CD3zeta) (SEQ ID NO: 11)

ATGCTGCTGCTGGTGACCAGCCTGCTGCTGTGCGAACTGCCGCATCCGGC
GTTTCTGCTGATTCCGCAGGCGGCCAGGTACAGCTGCAGCAGTCAGGGG
CTGAGGTGAAGAAGCCTGGGTCTCTCGGTGAAGGTCTCCTGCAAGGCTTCT
GGAGGCACCTTCAGCAGCTATGCTATCAGCTGGGTGCGACAGGCCCTGG
ACAAGGGCTTGAGTGGATGGGATGGATCAACCCTAACAGTGGTGGCACA
AACTATGCACAGAGGTTTCAGGGCAGGGTCACCATGACCAGGGACACGTC
CATCAGCACAGCCTACATGGAGCTGAGCAGGCTGAGATCTGACGACACGG
CCGTGTATTACTGTGCGAGTTATAATGATGCTTTTGATATCTGGGGCCAAAG
GCACCCTGGTCACCGTCTCTCAGGAGGTGGCGGGTCTGGTGGTGGCGGT
AGCGGTGGTGGCGGATCCAATTTTATGCTGACTCAGCCCCACTCTGTGTCG
GAGTCTCCGGGGAAGACGGTAACCATCTCCTGCACCCGCAGCAGTGGCAG
CATTGCCAGCAACTATGTGCAGTGGTACCAGCAGCGCCCGGGCAGTGCCC
CCACCATTGTGATCTATGAGGATGATCAAAGACCCTCTGGGGTCCCTGAT
CGGTTCTCTGGCTCCATCGACACCTCCTCCAACCTCTGCCTCCCTCACCATC
TCTGGACTGCAGAGTGAGGACGAGGCTGACTACTACTGTCAGTCTTATGA
GCCCCGCAATGGGGTATTCGGCGGAGGGACCAAGGTCACCGTCTAGCGG
CCGCAGAGTCAAATAACGGTCCTCCGTGCCCTCCGTGTCCGATCTACATTT
GGGCCCCGCTGGCCGGCACTTGCGGCGTGCTCCTGCTGTCGCTGGTCATCA
CCCTTTACTGCAAGAGGGGCGCGGAAGAAGCTGCTTTACATCTTCAAGCAG
CCGTTTCATGCGGCCCGTGACAGACGACTCAGGAAGAGGACGGATGCTCGTG
CAGATTCCCTGAGGAGGAAGAGGGGGGATGCGAACTGCGCGTCAAGTTCT
CACGGTCCGCCGACGCCCCCGCATATCAACAGGGCCAGAATCAGCTCTAC
AACGAGCTGAACCTGGGAAGGAGAGAGGAGTACGACGTGCTGGACAAGC
GACGCGGACGCGACCCGGAGATGGGGGGGAAACCACGGCGGAAAAACCC
TCAGGAAGGACTGTACAACGAACCTCCAGAAAGACAAGATGGCGGAAGCC
TACTCAGAAATCGGGATGAAGGGAGAGCGGAGGAGGGGAAAGGGTCACG
ACGGGCTGTACCAGGGACTGAGCACCGCCACTAAGGATACCTACGATGCC
TTGCATATGCAAGCACTCCCACCCCGG

LTG2529: (LP-ScFV9-IgG4H/CD8TM-41BB-CD3zeta) (SEQ ID NO: 12)

MLLLVTSLLLCELPHPAFLIPQAAQVQLQQSGAEVKKPGSSVKVSKASGGT
FSSYAISWVRQAPGQGLEWMGWINPNSGGTNYAQRFGGRVTMTRDTSISTA
YMELSLRLSDDTAVYYCASYNDAFDIWGQGLVTVSSGGGSGGGGSGGGG
SNFMLTQPHSVSESPGKTVTISCTRSSGSIASNYVQWYQQRPGSAPTIVYEDD
QRPSGVPDRFSGSIDTSSNSASLTISGLQSEDEADYYCQSYEPGNGVFGGGTK
VTVLAAAESKYGPCCPPCIYIWAPLAGTCGVLLLSLVITLYCKRGRKKLLYIF
KQPFMRPVQTTQEEDGCSCRFEEEEGGCELRVKFSRSADAPAYQQGQNQLY
NELNLGRREEYDVLDKRRGRDPEMGGKPRRKNPQEGLYNELQDKMAEAY
SEIGMKGERRRGKGHDGLYQGLSTATKDTYDALHMQALPPR

FIGURE 2E

LTG1943: (LP-ControlScFv-CD8H/CD8TM-41BB-CD3zeta) (SEQ ID NO: 15)

ATGCTGCTGCTGGTGACCAGCCTGCTGCTGTGCGAACTGCCGCATCCGGC
GTTTCTGCTGATTCCGCAAGAACAGCTTGTAGAGTCCGGCGGTAGATTGG
TGACACCGGGGGGAGCCTTACCCTGTCTTGTAAGGCATCTGGGTTCGAT
TTCAGTGCGTATTATATGAGCTGGGTTCGGCAGGCGCCCGGGAAGGGGCT
GGAATGGATAGCCACTATATACCCGTCATCCGGCAAGACTTACTACGCGA
CTTGGGTAAACGGGAGGTTTACGATAAGCTCAGATAACGCCCAAACACG
GTTGATCTCCAAATGAATAGCTTGACCGCCGCTGATAGGGCGACCTATTTC
TGTGCGCGGGACTCTTACGCTGATGACGGGGCCCTCTTCAATATATGGGG
ACCGGGAACGCTCGTAACCATATCATCTGGAGGAGGTGGGAGCGGAGGC
GGAGGGTCAGGTGGGGGCGGGAGCGAACTCGTACTTACACAATCTCCAA
GCGTAAGCGCAGCGTTGGGGAGTCCAGCAAAGATCACCTGCACTTTGTCA
AGCGCCCAAAAACGGATACGATAGATTGGTATCAGCAACTCCAAGGTGA
AGCGCCACGATATCTCATGCAGGTACAGAGCGACGGGAGTTATACTAAGA
GGCCCGGGGTCCCAGACAGATTCACTGGCAGCAGTTCAGGTGCCGACAGA
TACCTGATAATACCCTCAGTTCAAGCCGATGATGAAGCCGATTACTACTGT
GGGGCTGACTACATAGGTGGGTATGTTTTCGGGGGCGGCACTCAATTGAC
AGTTACAGGGGCGGCCGCAACTACCACCCCTGCCCTCGGCCGCCGACTC
CGCCCCCAACATCGCAAGCCAACCCCTCTCCTTGCGCCCCGAAGCTTGC
CGCCCGGCCGCGGGTGGAGCCGTGCATACCCGGGGGCTGGACTTTGCCTG
CGATATCTACATTTGGGCCCCGCTGGCCGGCACTTGCGGCGTGCTCCTGCT
GTCGCTGGTCATACCCCTTACTGCAAGAGGGGCGCGAAGAAGCTGCTTT
ACATCTTCAAGCAGCCGTTTCATGCGGCCCGTGACAGCACTCAGGAAGAG
GACGGATGCTCGTGACAGATTCCCTGAGGAGGAAGAGGGGGGATGCGAAC
TGCGCGTCAAGTTCTCACGGTCCGCCGACGCCCCCGCATATCAACAGGGC
CAGAATCAGCTCTACAACGAGCTGAACCTGGGAAGGAGAGAGGAGTACG
ACGTGCTGGACAAGCGACGCGGACGCGACCCCGGAGATGGGGGGGAAACC
ACGGCGGAAAAACCCTCAGGAAGGACTGTACAACGAACCTCCAGAAAGAC
AAGATGGCGGAAGCCTACTCAGAAATCGGGATGAAGGGAGAGCGGAGGA
GGGGAAAGGGTCACGACGGGCTGTACCAGGGACTGAGCACCGCCACTAA
GGATACCTACGATGCCTTGATATGCAAGCACTCCCACCCCGG

LTG1943: (LP-ControlScFv-CD8H/CD8TM-41BB-CD3zeta) (SEQ ID NO: 16)

MLLLVTSLLLCELPHPAFLIPQEQLVESGGRLVTPGGSLTLCKASGFDFSA
YMSWVRQAPGKGLEWIATIPSSGKTYATWVNGRFTISSDNAQNTVDLQM
NSLTAADRATYFCARDSYADDGALFNIWGPGLVTISSGGGSGGGGSGGGG
SELVLTQSPSVSAALGSPAKITCTLSAHKTDIDWYQQLQGEAPRYLMQVQS
DGSYTKRPGVPDRFSGSSSGADRYLIIPSVQADDEADYYCGADYIGGYVFGG
GTQLTGTGAAATTPAPRPPTPAPTIASQPLSLRPEACRPAAGGAVHTRGLDF
ACDIYIWAPLAGTCGVLLSLVITLYCKRGRKKLLYIFKQPFMRPVQTTQEED
GCSCRFPEEEEGGCELRVKFSRSADAPAYQQGQNQLYNELNLGRREEYDVLD
KRRGRDPGEMGGKPRRKNPQEGLYNELQKDKMAEAYSEIGMKGERRRGKH
DGLYQGLSTATKDTYDALHMQALPPR

FIGURE 2F

LTG2527: (LP-ControlScFv-IgG4H/CD8TM-41BB-CD3zeta) (SEQ ID NO: 17)

ATGCTGCTGCTGGTGACCAGCCTGCTGCTGTGCGAACTGCCGCATCCGGC
GTTTCTGCTGATTCCGCAAGAACAGCTTGTAGAGTCCGGCGGTAGATTGG
TGACACCGGGGGGAGCCTTACCCTGTCTTGTAAGGCATCTGGGTTCGAT
TTCAGTGC GTATTATATGAGCTGGGTTCGGCAGGCGCCCGGGAAGGGGCT
GGAATGGATAGCCACTATATACCCGTCATCCGGCAAGACTTACTACGCGA
CTTGGGTAAACGGGAGGTTTACGATAAGCTCAGATAACGCCCAAAACACG
GTTGATCTCAAATGAATAGCTTGACCGCCGCTGATAGGGCGACCTATTTC
TGTGCGCGGGACTCTTACGCTGATGACGGGGCCCTCTTCAATATATGGGG
ACCGGGAACGCTCGTAACCATATCATCTGGAGGAGGTGGGAGCGGAGGC
GGAGGGTCAGGTGGGGGCGGGAGCGAACTCGTACTTACACAATCTCCAA
GCGTAAGCGCAGCGTTGGGGAGTCCAGCAAAGATCACCTGCACTTTGTCA
AGCGCCACAAAACGGATACGATAGATTGGTATCAGCAACTCCAAGGTGA
AGCGCCACGATATCTCATGCAGGTACAGAGCGACGGGAGTTATACTAAGA
GGCCCGGGGTCCCAGACAGATTCAGTGGCAGCAGTTCAGGTGCCGACAGA
TACCTGATAATACCCTCAGTTCAAGCCGATGATGAAGCCGATTACTACTGT
GGGGCTGACTACATAGGTGGGTATGTTTTCGGGGGCGGCACTCAATTGAC
AGTTACAGGGGCGGCCGAGAGTCAAAATACGGTCCTCCGTGCCCTCCGT
GTCCGATCTACATTTGGGCCCCGCTGGCCGGCACTTGCGGCGTGCTCCTG
CTGTCGCTGGTCATCACCTTTACTGCAAGAGGGGGCCGGAAGAAGCTGCT
TTACATCTTCAAGCAGCCGTTTCATGCGGCCCGTGCAGACGACTCAGGAAG
AGGACGGATGCTCGTGCAGATTCCTTGAGGAGGAAGAGGGGGGATGCGA
ACTGCGCGTCAAGTTCTCACGGTCCGCCGACGCCCCCGCATATCAACAGG
GCCAGAATCAGCTCTACAACGAGCTGAACCTGGGAAGGAGAGAGGAGTA
CGACGTGCTGGACAAGCGACGCGGACGCGACCCGGAGATGGGGGGGAAA
CCACGGCGGAAAAACCCCTCAGGAAGGACTGTACAACGAACTCCAGAAAG
ACAAGATGGCGGAAGCCTACTCAGAAATCGGGATGAAGGGAGAGCGGAG
GAGGGGAAAGGGTCACGACGGGCTGTACCAGGGACTGAGCACCGCCACT
AAGGATACCTACGATGCCTTG CATATGCAAGCACTCCCACCCCG

LTG2527: (LP-ControlScFv-IgG4H/CD8TM-41BB-CD3zeta) (SEQ ID NO: 18)

MLLLVTSLLLCELPHPAFLIPQEQLVESGGRLVTPGGSLTSLCKASGFDFSAY
YMSWVRQAPGKGLEWIATIPSSGKTYATWVNGRFTISSDNAQNTVDLQM
NSLTAADRATYFCARDSYADDGALFNIWPGTLVTISSGGGSGGGGSGGGG
SELVLTQSPSVSAALGSPAKITCTLSAHKTDIDWYQQLQGEAPRYLMQVQS
DGSYTKRPGVPDRFSGSSSGADRYLIIPSVQADDEADYYCGADYIGGYVFGG
GTQLTVTGAAESKYGPPCPPCIYIWAPLAGTCGVLLSLVITLYCKRGRKK
LLYIFKQPFMRPVQTTQEEDGCSCRFPEEEEGGCEL RVKFSRSADAPAYQQGQ
NQLYNELNLGRREEYDVLDKRRGRDPEMGGKPRRKNPQEGLYNELQKDKM
AEAYSEIGMKGERRRGKGHDGLYQGLSTATKDTYDALHMQALPPR

FIGURE 3

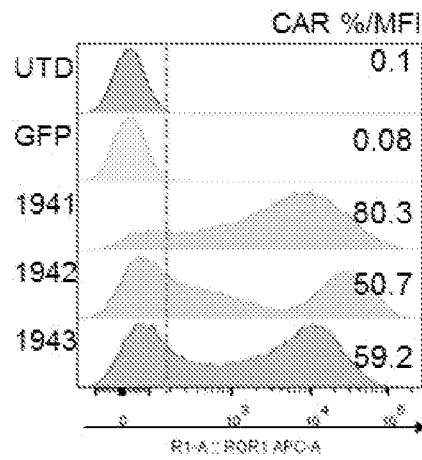


FIGURE 4

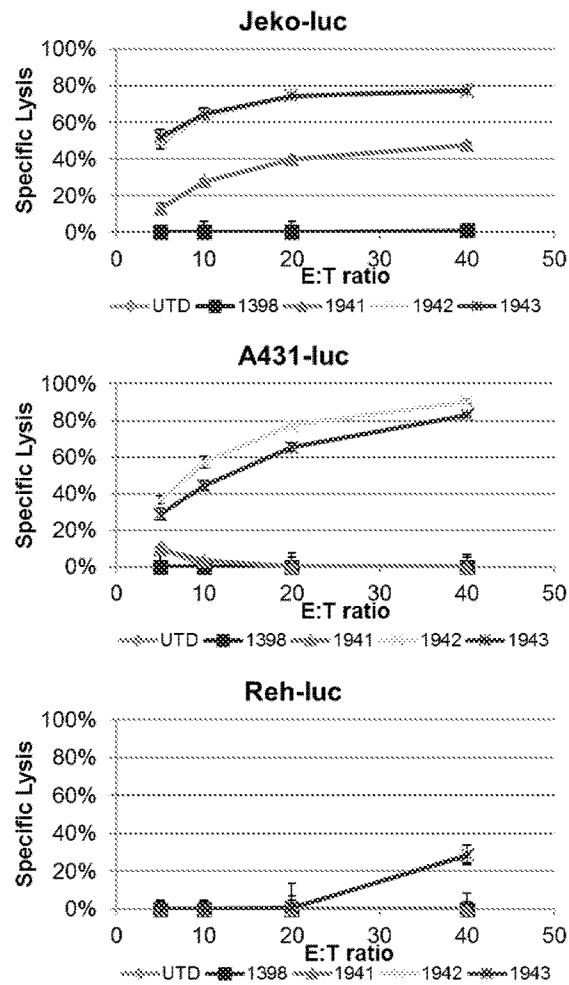
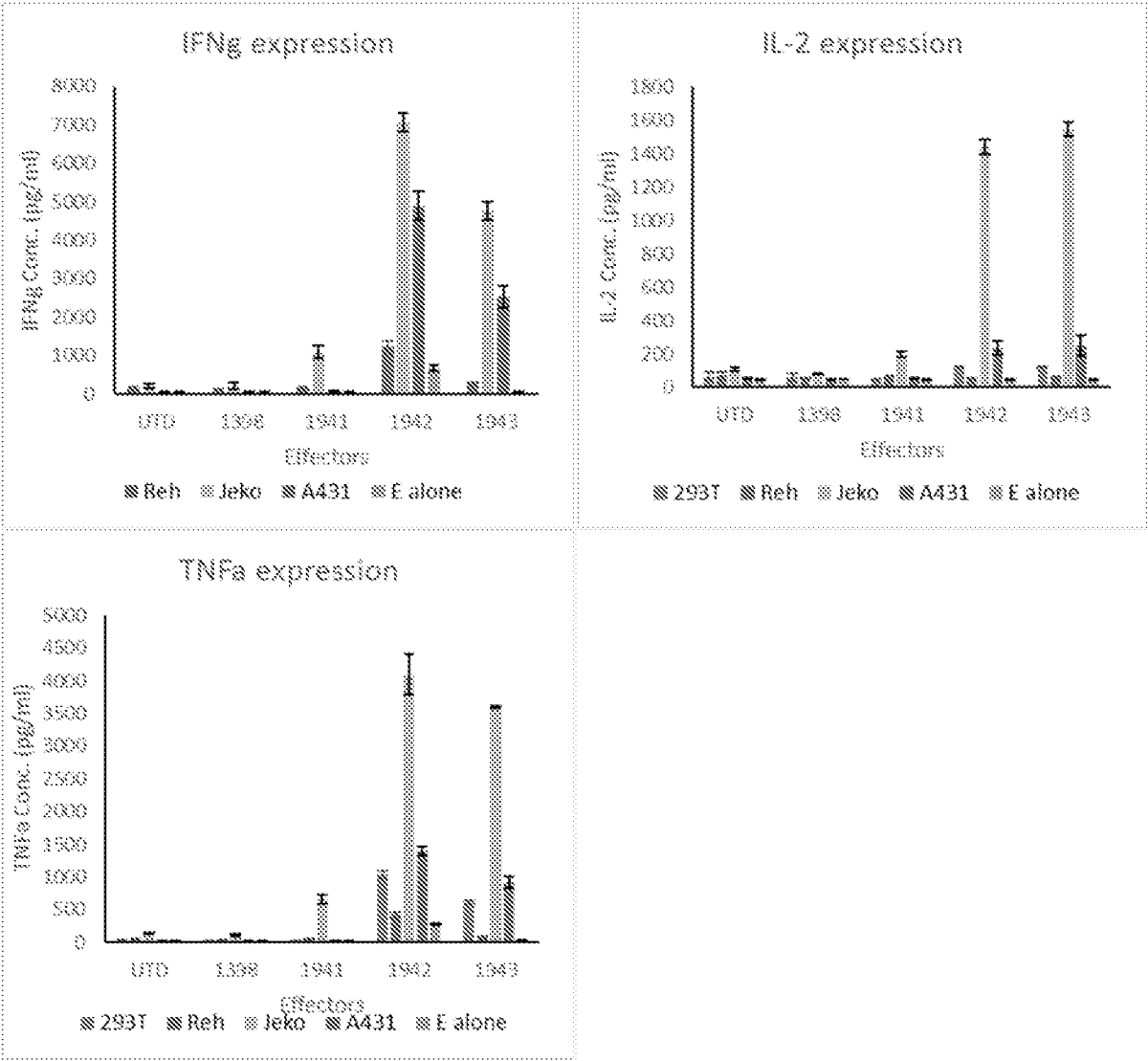


FIGURE 5



INTERNATIONAL SEARCH REPORT

International application No.

PCT/US2018/059003

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - A61K 35/17; A61K 38/00; A61P 31/00; A61P 31/04; A61P 31/10 (2019.01)

CPC - A61K 35/17; C07K 14/4746; C07K 14/4748; C07K 14/70517; C07K 2319/00 (2019.01)

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

See Search History document

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

USPC - 424/135.1; 435/328; 536/23.53 (keyword delimited)

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

See Search History document

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2017/0183407 A1 (BOARD OF REGENTS, THE UNIVERSITY OF TEXAS SYSTEM) 29 June 2017 (29.06.2017) entire document	1-48
A	WO 2016/016343 A1 (CELLECTIS) 04 February 2016 (04.02.2016) entire document	1-48
A	US 2015/0306141 A1 (FRED HUTCHINSON CANCER RESEARCH CENTER et al) 29 October 2015 (29.10.2015) entire document	1-48
A	WO 2014/031687 A1 (JENSEN) 27 February 2014 (27.02.2014) entire document	1-48
A	SCHNEIDER et al. "A tandem CD19/CD20 CAR lentiviral vector drives on-target and off-target antigen modulation in leukemia cell lines," Journal for ImmunoTherapy of Cancer, 16 May 2017 (16.05.2017), Vol. 5, Iss. 42, Pgs. 1-17. entire document	1-48

☐ Further documents are listed in the continuation of Box C.☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

10 January 2019

Date of mailing of the international search report

23 JAN 2019

Name and mailing address of the ISA/US

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PCT OSP: 571-272-7774

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US2018/059003

Box No. I Nucleotide and/or amino acid sequence(s) (Continuation of item 1.c of the first sheet)

1. With regard to any nucleotide and/or amino acid sequence disclosed in the international application, the international search was carried out on the basis of a sequence listing:

a. ☒ forming part of the international application as filed:

☒ in the form of an Annex C/ST.25 text file.

☐ on paper or in the form of an image file.

b. ☐ furnished together with the international application under PCT Rule 13ter.1(a) for the purposes of international search only in the form of an Annex C/ST.25 text file.

c. ☐ furnished subsequent to the international filing date for the purposes of international search only:

☐ in the form of an Annex C/ST.25 text file (Rule 13ter.1(a)).

☐ on paper or in the form of an image file (Rule 13ter.1(b) and Administrative Instructions, Section 713).

2. ☐ In addition, in the case that more than one version or copy of a sequence listing has been filed or furnished, the required statements that the information in the subsequent or additional copies is identical to that forming part of the application as filed or does not go beyond the application as filed, as appropriate, were furnished.

3. Additional comments:

SEQ ID NOs: 1-11, 19, 20, and 22 were searched.