TAGGED CHIMERIC EFFECTOR MOLECULES AND RECEPTORS THEREOF

CROSS REFERENCE TO RELATED APPLICATION

This application claims the benefit under 35 U.S.C. § 119(e) to U.S. Provisional Application No. 61/919,201 filed on December 20, 2013, which application is incorporated by reference herein in its entirety.

STATEMENT OF GOVERNMENT INTEREST

This invention was made with government support under Grant/Contract No. CA136551 awarded by the National Institutes of Health. The government has certain rights in this invention.

STATEMENT REGARDING SEQUENCE LISTING

The Sequence Listing associated with this application is provided in text format in lieu of a paper copy, and is hereby incorporated by reference into the specification. The name of the text file containing the Sequence Listing is 360056_426WO_SEQUENCE_LISTING.txt. The text file is 32.3 KB, was created on December 22, 2014, and is being submitted electronically via EFS-Web.

BACKGROUND

Technical Field

The present disclosure relates to fusion proteins containing a tag cassette and, more particularly, to tagged chimeric effector molecules (Key-ChEMs) and tagged chimeric antigen receptor molecules (T-ChARMs), and recombinant host cells producing such fusion proteins, wherein the recombinant host cells can be identified, isolated, sorted, induced to proliferate, tracked, eliminated, and/or used as a therapeutic (*e.g.*, in adoptive immunotherapy).

Description of the Related Art

T cell-based immunotherapies began to be developed when tumor-reactive T cells were found among a population of tumor-infiltrating lymphocytes (TILs) (Clark *et al.*, *Cancer Res. 29*:705, 1969). One strategy, known as adoptive T cell transfer, involves the isolation of tumor infiltrating lymphocytes pre-selected for tumor-reactivity, clonal expansion of the tumor-reactive T cells induced by anti-CD3 and anti-

CD28 antibodies in the presence of IL-2, and finally infusing the expanded cell population back to the tumor-bearing patient (together with chemotherapy and repetitive administration of IL-2) (Dudley *et al.*, *Science 298*:850, 2002). This form of adoptive T cell therapy with tumor infiltrating lymphocytes is technically cumbersome and leads to complete remission in only a n ' fraction of patients with melanoma and is rarely effective in other cancers (Besser *et al.*, *Clin. Cancer Res. 16*:2646, 2010).

Isolation of tumor-reactive T cell clones led to the development of another immunotherapeutic approach – the generation of recombinant T cell receptors (TCRs) specific for particular antigens, which are introduced into T cells using a vector delivery system to confer specificity for a tumor-associated peptide presented by an MHC molecule expressed on a tumor cell. A similar approach introduces a synthetic receptor, termed a chimeric antigen receptor (CAR), which contains an antigen-binding domain, which, *e.g.*, in the context of anti-tumor therapy can bind to a tumor-specific or associated antigen, linked to one or more intracellular component comprising an effector domains, such as a TCR and/or costimulatory signaling domains. Unlike TILs, the basic procedure for TCR or CAR T cell immunotherapy is to genetically modify human T cells with a transgene encoding a tumor targeting moiety, *ex vivo* expansion of the recombinant T cells, and transfusing the expanded recombinant T cells back into patients. In the case of adoptive therapy with CAR T cells, the composition of the synthetic CAR structure, as well as the quality and purity of the genetically engineered T cells, will determine therapeutic efficacy against tumors *in vivo*. But, there are challenges to expanding and selecting the recombinant cell populations, as well as making sure the cells are effective and specific enough *in vivo* to avoid serious autoimmune side effects.

Currently, there remains a need in the immunotherapy field for compositions and methods for identifying, efficiently isolating/sorting, selectively expanding, *in vivo* tracking and controlling or eliminating engineered cells, such as engineered immune cells (*e.g.*, T cells).

BRIEF SUMMARY

In certain aspects, the present disclosure is directed to a single chain fusion protein, comprising an extracellular component and an intracellular component connected by a hydrophobic portion, wherein the extracellular component comprises a binding domain that specifically binds a target, a tag cassette, and a connector region comprising a hinge, and wherein the intracellular component comprises an effector domain.

In some aspects, the present disclosure is directed to a chimeric antigen receptor molecule, comprising a fusion protein having one or more extracellular tag cassettes (a) located at the amino-terminus of an extracellular binding domain, (b) imbedded within an extracellular binding domain, or (c) disposed between and connecting an extracellular binding domain and an intracellular component comprising an effector domain.

In further aspects, the present disclosure is directed to a single chain fusion protein, comprising a hydrophobic portion disposed between and connecting an extracellular component and an intracellular component, wherein the extracellular component comprises a tag cassette and a connector region comprising a hinge, and wherein the intracellular component comprises an effector domain.

In still further aspects, the present disclosure is directed to a method for activating a cell, such as a T cell (*e.g.*, a non-natural T cell), comprising contacting a cell with a binding domain specific for a tag cassette, wherein the cell comprises a nucleic acid molecule encoding a fusion protein according to this disclosure and the binding domain specific for the tag cassette is attached to a solid surface.

In yet further aspects, the present disclosure is directed to a method for promoting cell proliferation, such as T cell proliferation, comprising contacting a cell (*e.g.*, a non-natural T cell) with a binding domain specific for a tag cassette and a growth factor cytokine for a time sufficient to allow cell growth, wherein the cell comprises a nucleic acid molecule encoding a fusion protein according to this disclosure and the binding domain specific for the tag cassette is attached to a solid surface.

In certain other aspects, the present disclosure is directed to a method for identifying cell, such as a T cell, comprising contacting a sample comprising a cell, such as a T cell (*e.g.*, a non-natural T cell) with a binding domain specific for a tag cassette, wherein the cell comprises a nucleic acid molecule encoding a fusion protein according to this disclosure and the binding domain specific for the tag cassette comprises a detectable moiety, and detecting the presence of the cell expressing a fusion protein in the sample.

In certain further aspects, the present disclosure is directed to a method for sorting a T cell, comprising contacting a sample comprising a non-natural T cell with a binding domain specific for a tag cassette, wherein the non-natural T cell comprises a nucleic acid molecule encoding a fusion protein according to this disclosure and the binding domain specific for the tag cassette comprises a detectable moiety, and sorting

the non-natural T cell expressing a fusion protein from other cells not expressing a fusion protein in the sample.

In certain aspects, the present disclosure is directed to a method for enriching or isolating a T cell, comprising contacting a sample comprising a non-natural T cell with a binding domain specific for a tag cassette, wherein the non-natural T cell comprises a nucleic acid molecule encoding a fusion protein according to this disclosure and the binding domain specific for the tag cassette comprises a detectable moiety, and enriching for or isolating the non-natural T cell expressing a fusion protein away from other cells not expressing a fusion protein in the sample.

In further aspects, the present disclosure is directed to a method for depleting certain T cells, comprising contacting a non-natural T cell with a binding domain specific for a tag cassette, wherein the non-natural T cell comprises a nucleic acid molecule encoding a fusion protein according to this disclosure and wherein binding of the binding domain specific for the tag cassette leads to cell death of the T cells expressing a fusion protein.

These and other aspects of the present invention will become apparent upon reference to the following detailed description and attached drawings. All references disclosed herein are hereby incorporated by reference in their entirety as if each was incorporated individually.

BRIEF DESCRIPTION OF THE DRAWINGS

Figures 1A – 1H show illustrations of various single chain chimeric effector molecules containing one or more affinity tag cassettes (A-D, referred to herein as a Key-ChEMs), and optionally containing one or more specific binding domains (E-G, referred to herein as a T-ChARMs). The single chain ChEMs and ChARMs contain an intracellular domain. The tag cassettes may be any type of affinity tag, such as Strep tag® II (SEQ ID NO.:1), Myc tag (SEQ ID NO.:7), V5 tag (SEQ ID NO.:8), Flag® tag (SEQ ID NO.:3), His tag, or other peptides or molecules, which are recognized by a non-endogenous cognate binding partner (*e.g.*, receptor, protein, antibody). As shown, a Key-ChEM may contain (A, B) one tag cassette, (C) two tag cassettes (Key-ChEM^2), (D) three tag cassettes (Key-ChEM^3), or more. In addition, the chimeric molecules may have multiple effector domains (*e.g.*, the molecules of A and C-G have two, while the molecule shown in B has three effector domains), and the tag cassettes may be placed in various different areas of a Key-ChEM or T-ChARM molecule. In these particular examples, T-ChARMs have one tag cassette located between the specific binding domain and the effector domain (E), at the distal end (*e.g.*, amino-terminus) of the

specific binding domain (F), integrated within the specific binding domain (G) (*e.g.*, located within the flexible linker between the VH and VL chains of an scFv), and having two different tags - one C-terminal of the binding domain and one N-terminal of the binding domain (H). The T-ChARMs may also have two, three or more tag cassettes as shown for the Key-ChEMs. As is evident in these illustrations, a tag cassette may be connected to another Key-ChEM or T-ChARM component or another tag via a linker module (*e.g.*, a flexible $(Gly_xSer)_n$ linker module). The linker length may be tailored to be longer or shorter to achieve the best interaction of a specific binding domain with a target ligand or antigen, and to achieve the best interaction between the cell expressing the ChEM or T-ChARM and the target cell.

Figures 2A – 2D show the cytolytic activity of human effector T cells expressing various kinds of anti-CD19 T-ChARMs and conventional anti-C19 CARs (lacking a tag cassette and with short, intermediate, and long spacer domains) against K562 leukemia cells transfected to express CD19 or ROR1 (control), $CD19^+/ROR1^+$ Raji lymphoma cells, and EBV transformed B cells that express a membrane bound anti-CD3 mAb single chain antibody (OKT3 scFv) to activate all effector T cells.

Figures 3A – 3F show the results of a multiplex cytokine assay (Luminex®) of supernatants obtained 24 hours after T cells expressing various anti-CD19 T-ChARMs (A-C) and conventional anti-C19 CARs (D-F) were co-cultured with K562 cells expressing either CD19 (A and D) or ROR1 (negative control; B and E), and with PMA/ionomycin (positive control; C and F).

Figures 4A and 4B show the results of a multiplex cytokine assay (Luminex®) of supernatants obtained 24 hours after T cells expressing various anti-CD19 T-ChARMs (A) and CD19 CARs (B) after co-culture with CD19+ Raji cells.

Figure 5 shows results of a T cell proliferation assay, wherein carboxyfluoroscein dye dilution indicates that anti-CD19 $CD8^+$ T cells expressing T-ChARMs (containing one, two or three tag cassettes) or a conventional CAR (CD19 (Long)) were proliferating in response to tumor cells expressing CD19 (blue), while not proliferating in the presence of tumor cells expressing ROR1 (red).

Figures 6A – 6E show that anti-CD19 human T cells expressing either a T-ChARM (containing one, two or three tag cassettes) or conventional CARs (containing short or intermediate connector regions) can eradicate established Raji tumors in NSG mice. In these experiments, the Raji cells are transfected to express the firefly luciferase gene, and tumor growth is measured by injecting the mice with luciferin and bioluminescence imaging.

Figure 7 shows that anti-CD19 CAR and T-ChARM expressing human T cells can persist in the blood following adoptive transfer into NSG mice that were inoculated with Raji lymphoma. Human T cells are distinguished by staining with monoclonal antibodies specific for the human CD8 and CD45 cell surface molecules.

Figures 8A – 8D show that T-ChARM expressing T cells can be identified by flow cytometry using a tag specific binding agent. In the examples, purified T-ChARM T cells are detected by the expression marker tEGFR (A), detected by anti-strep tag II (STII) (B), or with StrepTactin APC (C, D).

Figure 9 shows that T-ChARM expressing T cells can be sorted by flow cytometry from low purity (15% in the example) to high purity (99% in the example) with a tag-specific binding agent linked to a fluorochrome. In the example, the tag is StrepTag II and the tag-specific binding agent is anti STII mAb linked to a fluorochrome.

Figure 10 shows direct enrichment of T-ChARM expressing T cells (containing three Strep-tag tag cassettes) by using Strep-Tactin® beads of various sizes. The panels on the left show staining of the enriched fraction and the panels on the right show the effluent (un-enriched fraction).

Figure 11 shows light photomicrographs of T-ChARM (containing one, two or three tag cassettes) or conventional anti-CD19 CAR expressing T cells (CD19 Long) that have been co-cultured with beads linked to binding ligand (Strep-Tactin®) for the tag sequence. The photomicrographs demonstrate selective clustering and proliferation of T-ChARM T cells.

Figure 12 shows the growth curve of T-ChARM expressing T cells (containing one, two or three tag cassettes) over 10 days of culture with Strep-Tactin® microbeads.

Figures 13A and 13B show activation of T-ChARM expressing T cells as determined by upregulation of CD25 and CD69 after binding of the tag cassette by either Streptactin microbeads, nanobeads or anti-StrepTag II mAb alone or in combination with anti-CD28 mAb. Data is shown after (A) 24 hours and (B) 48 hours of stimulation.

Figures 14A and 14B show the selective expansion of T-ChARM expressing T cells. Unsorted T-ChARM^1/4-1BB and T-ChARM^1/CD28 transduced T cells (CD8+ and CD4+) cultured with anti-Strep tag/anti-CD28-MB for 9 days. The percentage of T-ChARM cells was assessed by (A) flow detection of Strep tag expression on T cells before and after culture. Culture cells treated with anti-CD3/anti-CD28-MB alone were used as control. (B) FACS sorted EGFR+ anti-CD19 ChARM T cells after CD19+

immortalized B cell line (TM-LCL) expansion. Stained with anti-EGFR (upper row) and anti-Streptag II (lower row) antibodies, respectively

Figure 15 shows proliferation of anti-CD19 T-ChARM expressing T cells (containing one, two or three tag cassettes) as measured by the level of Ki-67 protein 7 days after stimulation with varying amounts of Strep-Tactin® beads. In the bottom panels, the expression of Ki-67 in T-ChARM expressing T cells after stimulation through the anti-CD19 binding component of the T-ChARM with $CD19^+$ EBV-LCL (TM-LCL) is shown.

Figure 16 shows the growth curve of T-ChARM expressing T cells cultured on different kinds of Streptactin, anti-Streptag II or antiCD3/anti-CD28 conjugated beads.

Figures 17A and 17B show the selective expansion of anti-CD19 T-ChARM expressing T cells on Strep-Tactin beads (A). The anti-CD19 T-ChARM expressing T cells can subsequently be expanded by stimulation through the anti-CD19 chimeric receptor with $CD19^+$ LCL (B).

Figures 18A – 18D show that T cells can be transduced with two types of T-ChARM (effector domain of 4-1BB/CD3ζ (A and B), or CD28/CD3ζ (C and D)) after culture in the presence of IL-7 and IL-15 without prior activation with anti-CD3/anti-CD28 beads. The transduced T-ChARM expressing T cells can be selectively expanded and enriched by adding anti-Strep tag II beads to the culture (B and D) (even in the absence anti-CD3/anti-CD28 bead stimulation), but are not expanded when anti-Strep tag II beads are not added to the culture (A and C).

Figures 19A – 19D show that anti-CD19 T-$ChARM^1$ T cells that were expanded by stimulation with Strep-Tactin® microbeads retain a comparable or superior ability to produce cytokines (GM-CSF, interferon-γ, IL-2, and TNF-α) upon re-stimulation with CD19 positive tumor cells (A. K562/CD19; B- Raji) as control T cells that express the anti-CD19 CAR(short) (CD19-S). K562 cells (C) and PMA-ionomycin (D) served as negative and positive controls, respectively.

Figure 20 shows that T-ChARM expressing T cells can be induced to form clusters and to proliferate with anti-Strep tag beads alone or with beads containing anti-Strep tag and anti-CD27 antibodies or containing anti-Strep tag and anti-CD28 antibodies.

Figure 21 shows flow cytometry analysis (MFI) of FACS sorted EGFR+ anti-CD19 ChARM T cells after CD19+ immortalized B cell line (TM-LCL) expansion. Stained with anti-EGFR (upper row) and anti-Streptag II (lower row) antibodies, respectively.

Figure 22 shows chromium release assay results for examining the cytolytic effect of various anti-CD19 ChARM transduced T cells (effectors) against the K562 cells transduced with CD19 (K562/CD19), or ROR1 (K562/ROR1) or CD19+ Raji tumor cells (targets). E/T = Effector/target ratio.

Figures 23A and 23B show the cytolytic activity of T cells expressing (A) anti-CD19 short, T-ChARM^1, T-ChARM^2, T-ChARM^3 with a CD28/CD3ζ effector domain, and (B) having an anti-ROR1 R12 short and T-ChARM^1 with a 41BB/CD3ζ effector domain. The cells were tested for cytolytic activity against K562 cells transduced with CD19 (K562/CD19), or ROR1 (K562/ROR1) or CD19+ Raji tumor cells (targets). E/T = Effector/target ratio.

Figure 24 shows IL2/IFN-γ production of various anti-CD19 T-ChARM transduced T cells (Effector) against K562 cells transduced with CD19 (K562/CD19), or ROR1 (K562/ROR1) or CD19+ Raji tumor cells (Target).

Figures 25A-25C show luminex multiplex cytokine analysis of triplicate co-culture supernatants of ChARM transduced T cells with CD19+ Raji cells (1:4 ratio) after 24h. The data is derived from three independent experiments using T cells from different donors, and all data are expressed as means ± SD. Student's t test was performed. * $P<0.01$. (A) Comparison of cytokine production by CD8+ T cells expressing the anti-CD19 CAR with long (CH3-CH2-hinge), intermediate (CH3-hinge), and short (hinge only) spacers. Multiplex cytokine data from 3 independent experiments were normalized (cytokine release by CD19-CAR 'long/41BB' = 1); (B) comparison of cytokine production by CD8+ T cells expressing anti-CD19 T-ChARM^1 (1ST), T-ChARM^2 (2ST), T-ChARM^3 (3ST) with a 4-1BB/CD3ζ effector domain as compared to anti-CD19 CAR-Short with 4-1BB/CD3ζ effector domain. Multiplex cytokine data from 3 independent experiments were normalized (cytokine release by CD19-CAR-Short: Hi/4-1BB = 1); and (C) comparison of cytokine production by CD8+ T cells expressing anti-CD19 T-ChARM^1 (1ST), T-ChARM^2 (2ST), T-ChARM^3 (3ST) with a CD28/CD3ζ effector domain as compared to anti-CD19 CAR-Short with CD28/CD3ζ effector domain. Multiplex cytokine data from 3 independent experiments were normalized (cytokine release by CD19-CAR-Short: Hi/CD28 = 1).

Figure 26 shows CFSE dye dilution used to measure proliferation of anti-CD19 4-1BB or CD28 ChARM expressing T cells 5 days after stimulation with CD19+ Raji tumor cells (solid grey) or medium only (grey lines) without addition of exogenous cytokines.

Figures 27A-27D show FACS sorted EGFR+ anti-CD19 ChARM (A) CD8+ T cells (CD19-Hi/4-1BB, ST-CD19/4-1BB, CD19(VH-ST-VL)/4-1BB; CD19-1ST/4-

1BB, CD19-2ST/4-1BB, CD19-3ST/4-1BB CAR); (B) CD4+T cells (CD19-Hi/4-1BB, ST-CD19/4-1BB, CD19(VH-ST-VL)/4-1BB; CD19-1ST/4-1BB, CD19-2ST/4-1BB, CD19-3ST/4-1BB CAR); (C) anti-CD19 ChARM CD8+ T cells (CD19-Hi/CD28, CD19-1ST/CD28, CD19-2ST/CD28, CD19-3ST/CD28 CAR); and (D) anti-ROR1 R12 ChARM T cells (R12-Hi/4-1BB, R12-1ST/4-1BB), which were stimulated with StrepTactin coated microbeads (StrepTactin-MB), anti-Streptag antibody or anti-Streptag/anti-CD28 antibody coated microbeads (α*Strep* tag-MB and α*Strep* tag/CD28-MB) in the culture with IL2. After 48 hours of stimulation, the cells were harvested and T cell activation marker CD25 was assessed by flow cytometry. Untreated cells (medium) were used as controls.

Figure 28 shows representative microscopic images of FACS sorted EGFR+ anti-CD19 4-1BB ChARM T cells (CD8+) that were stimulated with StrepTactin-MB, α*Strep* tag-MB and α*Strep* tag/CD28-MB in presence of IL2. Untreated cells (medium) were used as control. Microscopic images were taken after 48h of stimulation.

Figures 29A and 29B show growth curves of ChARM T cells. FACS sorted EGFR+ anti-CD19 ChARM (A) CD8+ and (B) CD4+ T cells were cultured in CTL medium with StrepTactin-MB, α*Strep* tag-MB and α*Strep* tag/CD28-MB in presence of IL2.

Figures 30A-30F show anti-CD3/anti-CD28 microbead-stimulated CD8+ T cells transduced with anti-CD19-1ST/4-1BB or CD19-1ST/CD28 CAR; after EGFR staining and sorting, pure CAR T cells were expanded with TM-LCL or α*Strep* tag-MB or α*Strep* tag/CD28-MB for 8 days. *In vitro* functionality tests were carried out to evaluate CAR T cell function before (αCD3/CD28-MB) or after expansion (TM-LCL or α*Strep* tag-MB or α*Strep* tag/CD28-MB). (A) chromium release assays were carried out to examine cytolytic effect of ChARM T cells against target cells (K562/CD19) or control cells (K562/ROR1). E/T: Effector/target ratio; (B) cytokine production was measured by ELISA to evaluate IFN-γ and IL2 in supernatants obtained after 24 hours from co-cultures of 5×10^4 anti-CD19 ChARM T cells with target cells (K562/CD19), or control cells (K562/ROR1). PMA/Ionomycin stimulated T cells were used as positive control. (n=3; * $P<0.05$); (C) CFSE proliferation assay of ChARM T cells 5 days after stimulation with target cells (K562/CD19) (solid grey), or control cells (K562/ROR1) (grey lines) without addition of exogenous cytokines. For analysis, triplicate wells were pooled and the proliferation of live (PI-), EGFR-positive CAR T cells was analyzed.; (D) flow detection of CD45RO, CD62L, CD28 and CD27 expression on the ChARM T cells before (αCD3/CD28-MB) or after expansion (TM-LCL or α*Strep* tag-MB or α*Strep* tag/CD28-MB); (E) cohorts of mice were inoculated

with Raji-ffluc via tail vein injection at day 1, and then 5 x 10^6 CD8+ ChARM T cells (CD19-Hi/4-1BB and CD19-1ST/4-1BB), which were expanded on either CD19+ B LCL or α*Strep* tag/CD28-MB were administered 7 days after tumor engraftment. Tumor progression and distribution was evaluated by serial bioluminescence imaging after injection of luciferin substrate; and (F) persistence of anti-CD19 ChARM T cells following adoptive transfer into NSG/Raji mice. Flow cytometric analysis of ChARM T cells in the peripheral blood (eye bleeds) of the cohort of mice treated with various ChARM transduced T cells at different time points after T cell infusion. The frequency of CD8+ tEGFR+ and ChARM+ T cells was used as the percentage of live peripheral blood cells.

Figure 31 shows CFSE dye dilution used to measure proliferation of anti-CD19 CAR-Short, T-ChARM^1, T-ChARM^3, and Myc-ChARM with 4-1BB T cells 5 days after stimulation with CD19 (K562/CD19), ROR1 (K562/ROR1), medium alone, or CD19+ Raji tumor cells without addition of exogenous cytokines.

Figure 32 shows chromium release assays carried out to examine cytolytic effect of anti-CD19 CAR-Short, T-ChARM^1, T-ChARM^3, and Myc-ChARM with 4-1BB T cells against target cells (K562/CD19) or control cells (K562/ROR1). E/T: Effector/target ratio

DETAILED DESCRIPTION

The instant disclosure provides compositions and methods for generating various fusion proteins containing one or more affinity tag cassettes, which are chimeric effector molecules (ChEMs) that function like a "key" to access and manipulate (*i.e.*, turn on or off or modulate) any of a variety of biological pathways. These chimeric effector molecules are referred to herein as a Key-ChEMs. Nucleic acid molecules encoding such fusion proteins can be used to generate modified host cells in which specific cellular responses, such as proliferation or killing, are elicited, controlled, or both. For example, certain types of progenitor cells may be obtained from a subject, modified to express a fusion protein comprising a tag cassette, induced to proliferate, and then infused back into the subject for a particular therapeutic effect (*e.g.*, reconstitute a subject's depleted immune system). Alternatively, such fusion proteins containing a tag may further have a binding domain specific for a particular target (*e.g.*, a tumor antigen). In such examples, these fusion proteins are tagged chimeric antigen receptor molecules (T-ChARMs) that can be introduced into a particular cell and then used to identify, sort, activate, or expand that modified cell. In certain embodiments,

such tagged chimeric molecules are transduced into and expressed in cells, such as immune cells (*e.g.*, T cells).

In certain aspects, the present disclosure further provides methods for selectively activating, promoting proliferation, identifying, sorting, enriching, isolating, tracking, or depleting cells (*e.g.*, T cells) comprising a nucleic acid molecule encoding a fusion protein having one or more tag cassettes (Key-ChEMs or T-ChARMs). Additionally, this disclosure provides Key-ChEMs or T-ChARMs, as well as cells, compositions and methods for using the Key-ChEMs or T-ChARMs of this disclosure in various therapeutic applications, including the treatment of a disease in subject (*e.g.*, cancer, infectious disease, inflammatory disease, immune disease, aging-associated disease).

Prior to setting forth this disclosure in more detail, it may be helpful to an understanding thereof to provide definitions of certain terms to be used herein. Additional definitions are set forth throughout this disclosure.

In the present description, any concentration range, percentage range, ratio range, or integer range is to be understood to include the value of any integer within the recited range and, when appropriate, fractions thereof (such as one tenth and one hundredth of an integer), unless otherwise indicated. Also, any number range recited herein relating to any physical feature, such as polymer subunits, size or thickness, are to be understood to include any integer within the recited range, unless otherwise indicated. As used herein, the term "about" means ± 20% of the indicated range, value, or structure, unless otherwise indicated. It should be understood that the terms "a" and "an" as used herein refer to "one or more" of the enumerated components. The use of the alternative (*e.g.*, "or") should be understood to mean either one, both, or any combination thereof of the alternatives. As used herein, the terms "include," "have" and "comprise" are used synonymously, which terms and variants thereof are intended to be construed as non-limiting.

In addition, it should be understood that the individual compounds, or groups of compounds, derived from the various combinations of the structures and substituents described herein, are disclosed by the present application to the same extent as if each compound or group of compounds was set forth individually. Thus, selection of particular structures or particular substituents is within the scope of the present disclosure.

The term "consisting essentially of" limits the scope of a claim to the specified materials or steps, or to those that do not materially affect the basic characteristics of a claimed invention. For example, a protein domain, region, module or cassette (*e.g.*, a

binding domain, hinge region, linker module, tag cassette) or a protein (which may have one or more domains, regions, modules or cassettes) "consists essentially of" a particular amino acid sequence when the amino acid sequence of a domain, region, module, cassette or protein includes extensions, deletions, mutations, or a combination thereof (*e.g.*, amino acids at the amino- or carboxy-terminus or between domains) that, in combination, contribute to at most 20% (*e.g.*, at most 15%, 10%, 8%, 6%, 5%, 4%, 3%, 2% or 1%) of the length of a domain, region, module, cassette or protein and do not substantially affect (*i.e.*, do not reduce the activity by more than 50%, such as no more than 40%, 30%, 25%, 20%, 15%, 10%, 5%, or 1%) the activity of the domain(s), region(s), module(s), cassette(s) or protein (*e.g.*, the target binding affinity of a binding protein or tag cassette).

A "binding domain" (also referred to as a "binding region" or "binding moiety"), as used herein, refers to a molecule, such as a peptide, oligopeptide, polypeptide, or protein that possesses the ability to specifically and non-covalently associate, unite, or combine with a target molecule (*e.g.*, CD19, CD20, CD22, ROR1, mesothelin, PD-L1, PD-L2, PSMA). A binding domain includes any naturally occurring, synthetic, semi-synthetic, or recombinantly produced binding partner for a biological molecule or other target of interest. In some embodiments, the binding domain is an antigen-binding domain, such as an antibody or T cell receptor (TCR) or functional binding domain or antigen-binding fragment thereof. Exemplary binding domains include single chain antibody variable regions (*e.g.*, domain antibodies, sFv, scFv, Fab), receptor ectodomains (*e.g.*, TNF-α), ligands (*e.g.*, cytokines, chemokines), antigen-binding regions of T cell receptors (TCRs), such as single chain TCRs (scTCRs), or synthetic polypeptides selected for the specific ability to bind to a biological molecule.

As used herein, "specifically binds" refers to an association or union of a binding domain, or a fusion protein thereof, to a target molecule with an affinity or K_a (*i.e.*, an equilibrium association constant of a particular binding interaction with units of 1/M) equal to or greater than 10^5 M^{-1}, while not significantly associating or uniting with any other molecules or components in a sample. Binding domains (or fusion proteins thereof) may be classified as "high affinity" binding domains (or fusion proteins thereof) or "low affinity" binding domains (or fusion proteins thereof). "High affinity" binding domains refer to those binding domains with a K_a of at least 10^7 M^{-1}, at least 10^8 M^{-1}, at least 10^9 M^{-1}, at least 10^{10} M^{-1}, at least 10^{11} M^{-1}, at least 10^{12} M^{-1}, or at least 10^{13} M^{-1}. "Low affinity" binding domains refer to those binding domains with a K_a of up to 10^7 M^{-1}, up to 10^6 M^{-1}, up to 10^5 M^{-1}. Alternatively, affinity may be defined as an equilibrium dissociation constant (K_d) of a particular binding interaction with units of

M (*e.g.*, 10^{-5} M to 10^{-13} M). In certain embodiments, a binding domain may have "enhanced affinity," which refers to a selected or engineered binding domain with stronger binding to a target antigen than a wild type (or parent) binding domain. For example, enhanced affinity may be due to a Ka (equilibrium association constant) for the target antigen that is higher than the wild type binding domain, or due to a K_d (dissociation constant) for the target antigen that is less than that of the wild type binding domain, or due to an off-rate (K_{off}) for the target antigen that is less than that of the wild type binding domain. A variety of assays are known for identifying binding domains of the present disclosure that specifically bind a particular target, as well as determining binding domain or fusion protein affinities, such as Western blot, ELISA, and Biacore® analysis (*see also*, *e.g.*, Scatchard *et al.*, *Ann. N.Y. Acad. Sci. 51*:660, 1949; and U.S. Patent Nos. 5,283,173, 5,468,614, or the equivalent).

As used herein, "heterologous" or "non-endogenous" or "exogenous" refers to any gene, protein, compound, molecule or activity that is not native to a host cell or a subject, or is any gene, protein, compound, molecule or activity native to a host or host cell but has been altered or mutated such that the structure, activity or both is different as between the native and mutated molecules. In certain embodiments, heterologous, non-endogenous or exogenous molecules (*e.g.*, receptors, ligands) may not be endogenous to a host cell or subject, but instead nucleic acids encoding such molecules may have been added to a host cell by conjugation, transformation, transfection, electroporation, or the like, wherein the added nucleic acid molecule may integrate into a host cell genome or can exist as extra-chromosomal genetic material (*e.g.*, as a plasmid or other self-replicating vector). The term "homologous" or "homolog" refers to a molecule or activity found in or derived from a host cell, species or strain. For example, a heterologous or exogenous molecule or gene encoding the molecule may be homologous to a native host or host cell molecule or gene that encodes the molecule, respectively, but may have an altered structure, sequence, expression level or combinations thereof. A non-endogenous molecule may be from the same species, a different species or a combination thereof.

As used herein, the term "endogenous" or "native" refers to a gene, protein, compound, molecule or activity that is normally present in a host or host cell.

As used herein, "tag cassette" refers to a unique peptide sequence affixed to, fused to, or that is part of a protein of interest, to which a heterologous or non-endogenous cognate binding molecule (*e.g.*, receptor, ligand, antibody, or other binding partner) is capable of specifically binding where the binding property can be used to detect, identify, isolate or purify, track, enrich for, or target a tagged protein or cells

expressing a tagged protein, particularly when a tagged protein is part of a heterogeneous population of proteins or other material, or when cells expressing a tagged protein are part of a heterogeneous population of cells (*e.g.*, a biological sample like peripheral blood). In certain embodiments, a cell expressing a tagged protein can be contacted with a heterologous or non-endogenous cognate binding molecule and induce a biological response, such as promote cell activation, cell proliferation or cell death. In the provided fusion proteins, the ability of the tag cassette(s) to be specifically bound by the cognate binding molecule(s) is distinct from or in addition to the ability of the binding domain(s) to specifically bind to the target molecule(s). The tag cassette generally is not an antigen-binding molecule, for example, is not an antibody or TCR or an antigen-binding portion thereof.

As used herein, a "hinge region" or a "hinge" refers to (a) an immunoglobulin hinge sequence (made up of, for example, upper and core regions) or a functional fragment or variant thereof, (b) a type II C-lectin interdomain (stalk) region or a functional fragment or variant thereof, or (c) a cluster of differentiation (CD) molecule stalk region or a functional variant thereof. As used herein, a "wild type immunoglobulin hinge region" refers to a naturally occurring upper and middle hinge amino acid sequences interposed between and connecting the CH1 and CH2 domains (for IgG, IgA, and IgD) or interposed between and connecting the CH1 and CH3 domains (for IgE and IgM) found in the heavy chain of an antibody. In certain embodiments, a hinge region is human, and in particular embodiments, comprises a human IgG hinge region.

As used herein, a "connector region" refers to one or more proteins, polypeptides, oligopeptides, peptides, domains, regions, modules, cassettes, motifs or any combination thereof that join two or more proteins, polypeptides, oligopeptides, peptides, domains, regions, modules, cassettes, motifs or any combination thereof in a fusion protein. For example, a connector region may provide a spacer function to facilitate the interaction of two single chain fusion proteins, or positioning of one or more binding domains, so that the resulting polypeptide structure maintains a specific binding affinity to a target molecule or maintains signaling activity (*e.g.*, effector domain activity) or both. In certain embodiments, a connector region may comprise a "linker module" that is an amino acid sequence having from about to two up to about 500 amino acids, which can provide flexibility and room for conformational movement between two regions, domains, motifs, cassettes or modules connected by a linker. Exemplary linker modules include those having from one to about ten repeats of Gly_xSer_y, wherein x and y are independently an integer from 0 to 10 provided that x and

y are not both 0 (*e.g.*, $(Gly_4Ser)_2$ (SEQ ID NO: 67), $(Gly_3Ser)_2$ (SEQ ID NO: 68), Gly_2Ser, or a combination thereof such as $(Gly_3Ser)_2Gly_2Ser$)(SEQ ID NO: 69). In certain other embodiments, a connector region may have a linker module that comprises one or more immunoglobulin heavy chain constant regions, such as a CH3 alone or a CH2CH3. In further embodiments, a connector region may comprise a hinge region or a tag cassette. Each such connector component is not mutually exclusive. For example, a connector region may comprise a hinge and one or more linker modules, or a connector region may comprise a hinge, one or more linker modules, and one or more tag cassettes. Exemplary connector regions can vary in length, for instance, from about five to about 500 amino acids, or from about ten to about 350 amino acids, or from about 15 to about 100 amino acids, or from about 20 to about 75 amino acids, or from about 25 to about 35 amino acids.

A "hydrophobic portion," as used herein, means any amino acid sequence having a three-dimensional structure that is thermodynamically stable in a cell membrane, and generally ranges in length from about 15 amino acids to about 30 amino acids. The structure of a hydrophobic domain may comprise an alpha helix, a beta barrel, a beta sheet, a beta helix, or any combination thereof.

As used herein, an "effector domain" is an intracellular portion of a fusion protein or receptor that can directly or indirectly promote a biological or physiological response in a cell when receiving the appropriate signal. In certain embodiments, an effector domain is part of a protein or protein complex that receives a signal when bound, or it binds directly to a target molecule, which triggers a signal from the effector domain. An effector domain may directly promote a cellular response when it contains one or more signaling domains or motifs, such as an immunoreceptor tyrosine-based activation motif (ITAM). In other embodiments, an effector domain will indirectly promote a cellular response by associating with one or more other proteins that directly promote a cellular response.

A "variable region linker" specifically refers to a five to about 35 amino acid sequence that connects a heavy chain immunoglobulin variable region to a light chain immunoglobulin variable region or connects T cell receptor $V_{\alpha/\beta}$ and $C_{\alpha/\beta}$ chains (*e.g.*, V_α-C_α, V_β-C_β, V_α-V_β) or connects each V_α-C_α, V_β-C_β, V_α-V_β pair to a hinge or hydrophobic domain, which provides a spacer function and flexibility sufficient for interaction of the two sub-binding domains so that the resulting single chain polypeptide retains a specific binding affinity to the same target molecule as an antibody or T cell receptor. In certain embodiments, a variable region linker comprises from about ten to about 30 amino acids or from about 15 to about 25 amino acids. In

particular embodiments, a variable region linker peptide comprises from one to ten repeats of Gly_xSer_y, wherein x and y are independently an integer from 0 to 10 provided that x and y are not both 0 (*e.g.*, Gly_4Ser (SEQ ID NO: 10), Gly_3Ser (SEQ ID NO: 71), Gly_2Ser, or $(Gly_3Ser)_n(Gly_4Ser)_1$ (SEQ ID NO: 72), $(Gly_3Ser)_n(Gly_2Ser)_n$, (SEQ ID NO: 73) $(Gly_3Ser)_n(Gly_4Ser)_n$ (SEQ ID NO: 72), or $(Gly_4Ser)_n$ (SEQ ID NO: 10), wherein n is an integer of 1, 2, 3, 4, 5, 6, 7, 8, 9 or 10) and wherein linked variable regions form a functional immunoglobulin-like binding domain (*e.g.*, scFv, scTCR). Exemplary variable region linkers include those amino acid sequences set forth in SEQ IDNOS.:44, 65-69, and 71-73, and $(Gly_4Ser)_n$ (SEQ ID NO: 10), wherein n is 3, as found in T-ChARM having the amino acid sequence set forth in SEQ ID NO.:57.

"Junction amino acids" or "junction amino acid residues" refer to one or more (*e.g.*, about 2-20) amino acid residues between two adjacent motifs, regions or domains of a polypeptide, such as between a binding domain and an adjacent linker region or between a hydrophobic domain and an adjacent effector domain or on one or both ends of a linker region that links two motifs, regions or domains (*e.g.*, between a linker and an adjacent binding domain and/or between a linker and an adjacent hinge). Junction amino acids may result from the construct design of a fusion protein (*e.g.*, amino acid residues resulting from the use of a restriction enzyme site during the construction of a nucleic acid molecule encoding a fusion protein). For example, a single junction amino acid, asparagine, is encoded by the AAT codon found between the nucleic acid sequence encoding the secretory signal sequence (SEQ ID NO.:63) and the sequence encoding the tag cassette (SEQ ID NO.:38) in the T-ChARM encoded by the nucleic acid sequence set forth in SEQ ID NO.:58. Similarly, an asparagine (N) junction amino acid is found between the flexible linker amino acid sequence of GGSGSG (SEQ ID NO.:65) and the amino acid tag sequence WSHPQFEK (SEQ ID NO.:1) found in the T-ChARM having the amino acid sequence set forth in SEQ ID NO.:54.

Terms understood by those in the art of antibody technology are each given the meaning acquired in the art, unless expressly defined differently herein. The term "antibody" refers to an intact antibody comprising at least two heavy (H) chains and two light (L) chains inter-connected by disulfide bonds, as well as an antigen-binding portion of an intact antibody that has or retains the capacity to bind a target molecule. A monoclonal antibody or antigen-binding portion thereof may be non-human, chimeric, humanized, or human, preferably humanized or human. Immunoglobulin structure and function are reviewed, for example, in Harlow *et al.*, Eds., Antibodies: A Laboratory Manual, Chapter 14 (Cold Spring Harbor Laboratory, Cold Spring Harbor, 1988).

For example, the terms "V_L" and "V_H" refer to the variable binding region from an antibody light and heavy chain, respectively. The variable binding regions are made up of discrete, well-defined sub-regions known as "complementarity determining regions" (CDRs) and "framework regions" (FRs). The term "CL" refers to an "immunoglobulin light chain constant region" or a "light chain constant region," *i.e.*, a constant region from an antibody light chain. The term "CH" refers to an "immunoglobulin heavy chain constant region" or a "heavy chain constant region," which is further divisible, depending on the antibody isotype into CH1, CH2, and CH3 (IgA, IgD, IgG), or CH1, CH2, CH3, and CH4 domains (IgE, IgM). A "Fab" (fragment antigen binding) is the part of an antibody that binds to antigens and includes the variable region and CH1 of the heavy chain linked to the light chain via an inter-chain disulfide bond.

As used herein, "Fc region portion" refers to the heavy chain constant region segment of the Fc fragment (the "fragment crystallizable" region or Fc region) from an antibody, which can in include one or more constant domains, such as CH2, CH3, CH4, or any combination thereof. In certain embodiments, an Fc region portion includes the CH2 and CH3 domains of an IgG, IgA, or IgD antibody or any combination thereof, or the CH3 and CH4 domains of an IgM or IgE antibody and any combination thereof. In other embodiments, a CH2CH3 or a CH3CH4 structure has sub-region domains from the same antibody isotype and are human, such as human IgG1, IgG2, IgG3, IgG4, IgA1, IgA2, IgD, IgE, or IgM (*e.g.*, CH2CH3 from human IgG1). By way of background, an Fc region is responsible for the effector functions of an immunoglobulin, such as ADCC (antibody-dependent cell-mediated cytotoxicity), CDC (complement-dependent cytotoxicity) and complement fixation, binding to Fc receptors (*e.g.*, CD16, CD32, FcRn), greater half-life *in vivo* relative to a polypeptide lacking an Fc region, protein A binding, and perhaps even placental transfer (*see* Capon *et al.*, *Nature 337*:525, 1989). In certain embodiments, an Fc region portion found in fusion proteins of the present disclosure will be capable of mediating one or more of these effector functions, or will lack one or more or all of these activities by way of, for example, one or more mutations known in the art.

In addition, antibodies have a hinge sequence that is typically situated between the Fab and Fc region (but a lower section of the hinge may include an amino-terminal portion of the Fc region). By way of background, an immunoglobulin hinge acts as a flexible spacer to allow the Fab portion to move freely in space. In contrast to the constant regions, hinges are structurally diverse, varying in both sequence and length between immunoglobulin classes and even among subclasses. For example, a human

IgG1 hinge region is freely flexible, which allows the Fab fragments to rotate about their axes of symmetry and move within a sphere centered at the first of two inter-heavy chain disulfide bridges. By comparison, a human IgG2 hinge is relatively short and contains a rigid poly-proline double helix stabilized by four inter-heavy chain disulfide bridges, which restricts the flexibility. A human IgG3 hinge differs from the other subclasses by its unique extended hinge region (about four times as long as the IgG1 hinge), containing 62 amino acids (including 21 prolines and 11 cysteines), forming an inflexible poly-proline double helix and providing greater flexibility because the Fab fragments are relatively far away from the Fc fragment. A human IgG4 hinge is shorter than IgG1 but has the same length as IgG2, and its flexibility is intermediate between that of IgG1 and IgG2.

"T cell receptor" (TCR) refers to a molecule found on the surface of T cells (or T lymphocytes) that, in association with CD3, is generally responsible for recognizing antigens bound to major histocompatibility complex (MHC) molecules. The TCR has a disulfide-linked heterodimer of the highly variable α and β chains (also known as TCRα and TCRβ, respectively) in most T cells. In a small subset of T cells, the TCR is made up of a heterodimer of variable γ and δ chains (also known as TCRγ and TCRδ, respectively). Each chain of the TCR is a member of the immunoglobulin superfamily and possesses one N-terminal immunoglobulin variable domain, one immunoglobulin constant domain, a transmembrane region, and a short cytoplasmic tail at the C-terminal end (*see* Janeway *et al.*, *Immunobiology: The Immune System in Health and Disease*, 3rd Ed., Current Biology Publications, p. 4:33, 1997). TCR, as used in the present disclosure, may be from various animal species, including human, mouse, rat, cat, dog, goat, horse, or other mammals. TCRs may be cell-bound (*i.e.*, have a transmembrane region or domain) or in soluble form.

"Major histocompatibility complex molecules" (MHC molecules) refer to glycoproteins that deliver peptide antigens to a cell surface. MHC class I molecules are heterodimers consisting of a membrane spanning α chain (with three α domains) and a non-covalently associated β2 microglobulin. MHC class II molecules are composed of two transmembrane glycoproteins, α and β, both of which span the membrane. Each chain has two domains. MHC class I molecules deliver peptides originating in the cytosol to the cell surface, where peptide:MHC complex is recognized by $CD8^+$ T cells. MHC class II molecules deliver peptides originating in the vesicular system to the cell surface, where they are recognized by $CD4^+$ T cells. An MHC molecule may be from various animal species, including human, mouse, rat, or other mammals.

A "vector" is a nucleic acid molecule that is capable of transporting another nucleic acid. Vectors may be, for example, plasmids, cosmids, viruses, or phage. An "expression vector" is a vector that is capable of directing the expression of a protein encoded by one or more genes carried by the vector when it is present in the appropriate environment.

"Retroviruses" are viruses having an RNA genome. "Gammaretrovirus" refers to a genus of the retroviridae family. Exemplary gammaretroviruses include mouse stem cell virus, murine leukemia virus, feline leukemia virus, feline sarcoma virus, and avian reticuloendotheliosis viruses.

"Lentivirus" refers to a genus of retroviruses that are capable of infecting dividing and non-dividing cells. Several examples of lentiviruses include HIV (human immunodeficiency virus: including HIV type 1, and HIV type 2); equine infectious anemia virus; feline immunodeficiency virus (FIV); bovine immune deficiency virus (BIV); and simian immunodeficiency virus (SIV).

A "hematopoietic progenitor cell" is a cell derived from hematopoietic stem cells or fetal tissue that is capable of further differentiation into mature cells types (*e.g.*, cells of the T cell lineage). In certain embodiments, $CD24^{lo}$ Lin^{-} $CD117^{+}$ hematopoietic progenitor cells are useful. As defined herein, hematopoietic progenitor cells may include embryonic stem cells, which are capable of further differentiation to cells of the T cell lineage. Hematopoietic progenitor cells may be from various animal species, including human, mouse, rat, or other mammals. A "thymocyte progenitor cell" or "thymocyte" is a hematopoietic progenitor cell present in the thymus.

"Hematopoietic stem cells" refer to undifferentiated hematopoietic cells that are capable of self-renewal either *in vivo*, essentially unlimited propagation *in vitro*, and capable of differentiation to other cell types including cells of the T cell lineage. Hematopoietic stem cells may be isolated, for example, but not limited to, from fetal liver, bone marrow, cord blood.

"Embryonic stem cells" or "ES cells" or "ESCs" refer to undifferentiated embryonic stem cells that have the ability to integrate into and become part of the germ line of a developing embryo. Embryonic stem cells are capable of differentiating into hematopoietic progenitor cells, and any tissue or organ. Embryonic stem cells that are suitable for use herein include cells from the J1 ES cell line, 129J ES cell line, murine stem cell line D3 (American Type Culture Collection), the R1 or E14K cell lines derived from 129/Sv mice, cell lines derived from Balb/c and C57Bl/6 mice, and human embryonic stem cells (*e.g.* from WiCell Research Institute, WI; or ES cell International, Melbourne, Australia).

"Cells of T cell lineage" refer to cells that show at least one phenotypic characteristic of a T cell or a precursor or progenitor thereof that distinguishes the cells from other lymphoid cells, and cells of the erythroid or myeloid lineages. Such phenotypic characteristics can include expression of one or more proteins specific for T cells (*e.g.* , $CD3^+$, $CD4^+$, $CD8^+$), or a physiological, morphological, functional, or immunological feature specific for a T cell. For example, cells of the T cell lineage may be progenitor or precursor cells committed to the T cell lineage; $CD25^+$ immature and inactivated T cells; cells that have undergone CD4 or CD8 linage commitment; thymocyte progenitor cells that are $CD4^+CD8^+$ double positive; single positive $CD4^+$ or $CD8^+$; TCRαβ or TCR γδ; or mature and functional or activated T cells.

"Nucleic acid molecule", or polynucleotides, may be in the form of RNA or DNA, which includes cDNA, genomic DNA, and synthetic DNA. A nucleic acid molecule may be double stranded or single stranded, and if single stranded, may be the coding strand or non-coding (anti-sense strand). A coding molecule may have a coding sequence identical to a coding sequence known in the art or may have a different coding sequence, which, as the result of the redundancy or degeneracy of the genetic code, or by splicing, can encode the same polypeptide.

"Treat" or "treatment" or "ameliorate" refers to medical management of a disease, disorder, or condition of a subject (*e.g.*, a human or non-human mammal, such as a primate, horse, dog, mouse, rat). In general, an appropriate dose or treatment regimen comprising a host cell expressing a Key-ChEM or T-ChARM of this disclosure, and optionally an adjuvant, is administered in an amount sufficient to elicit a therapeutic or prophylactic benefit. Therapeutic or prophylactic/preventive benefit includes improved clinical outcome; lessening or alleviation of symptoms associated with a disease; decreased occurrence of symptoms; improved quality of life; longer disease-free status; diminishment of extent of disease, stabilization of disease state; delay of disease progression; remission; survival; prolonged survival; or any combination thereof.

A "therapeutically effective amount" or "effective amount" of a fusion protein or cell expressing a fusion protein of this disclosure (*e.g.*, Key-ChEM, T-ChARM) refers to that amount of compound or cells sufficient to result in amelioration of one or more symptoms of the disease being treated in a statistically significant manner. When referring to an individual active ingredient or a cell expressing a single active ingredient, administered alone, a therapeutically effective dose refers to the effects of that ingredient or cell expressing that ingredient alone. When referring to a combination, a therapeutically effective dose refers to the combined amounts of active

ingredients or combined adjunctive active ingredient with a cell expressing an active ingredient that results in a therapeutic effect, whether administered serially or simultaneously. Another combination may be a cell expressing more than one active ingredient, such as two different T-ChARMs, a T-ChARM and a TCR, a T-ChARM and a CAR, or combinations thereof.

Additional definitions are provided throughout the present disclosure.

Key-ChEMs and T-ChARMs

In certain aspects, the present disclosure provides a single chain fusion protein, referred to as a Key-ChEM, which comprises an extracellular component and an intracellular component connected by a hydrophobic portion, wherein the extracellular component comprises a tag cassette and a connector region comprising a hinge, and wherein the intracellular component comprises an effector domain. In certain embodiments, a connector region further comprises a linker module, or one or more tag cassettes are located within the connector region. In certain other embodiments, one or more tag cassettes are linked to the connector region by a linker module.

In further Key-ChEM embodiments, the fusion protein comprises from amino-terminus to carboxy-terminus: a tag cassette, a connector region comprising a hinge, a hydrophobic portion, and an intracellular component comprising an effector domain (*see*, *e.g.*, Figures 1A and 1B). In still further Key-ChEM embodiments, the fusion protein comprises from amino-terminus to carboxy-terminus: a first connector region, a tag cassette, a second connector region comprising a hinge, a hydrophobic portion, and an intracellular component comprising an effector domain. In yet further Key-ChEM embodiments, the fusion protein comprises from amino-terminus to carboxy-terminus: a first tag cassette, a first connector region, a second tag cassette, a second connector region comprising a hinge, a hydrophobic portion, and an intracellular component comprising an effector domain (*see*, *e.g.*, Figure 1C). In even further Key-ChEM embodiments, the fusion protein comprises from amino-terminus to carboxy-terminus: a first tag cassette, a first connector region, a second tag cassette, a second connector region, a third tag cassette, a third connector region comprising a hinge, a hydrophobic portion, and an intracellular component comprising an effector domain (*see*, *e.g.*, Figure 1D).

In certain other Key-ChEM embodiments, the fusion protein further comprises a non-covalently associated binding domain, such as a binding domain associated with the tag cassette (*i.e.*, a multichain T-ChARM). In still other Key-ChEM embodiments, the non-covalently associated binding domain is bi-specific, wherein the first binding end is specific for the tag cassette and the second binding end is specific for a target

other than the tag cassette, or the first and second binding ends are both specific for the tag cassette. In yet other Key-ChEM embodiments, the non-covalently associated binding domain is multispecific, wherein a first end binds to a tag cassette and a second end is specific for one or more targets other than the tag cassette. In such embodiments, a Key-ChEM comprises a multimer protein. In some embodiments, such Key-ChEMs comprising one or more non-covalently associated binding domains comprise heteromultimers.

In other aspects, the present disclosure provides a single chain fusion protein, referred to as a T-ChARM, which comprises an extracellular component and an intracellular component connected by a hydrophobic portion, wherein the extracellular component comprises a binding domain that specifically binds a target, a tag cassette, and a connector region comprising a hinge, and wherein the intracellular component comprises an effector domain. In certain embodiments, a T-ChARM binding domain is a scFv, scTCR, receptor ectodomain, or ligand.

In further T-ChARM embodiments, the fusion protein comprises from amino-terminus to carboxy-terminus: an extracellular binding domain, a tag cassette, a connector region comprising a hinge, a hydrophobic portion, and an intracellular component comprising an effector domain (*see*, *e.g.*, Figure 1E). In still further T-ChARM embodiments, the fusion protein comprises from amino-terminus to carboxy-terminus: an extracellular binding domain, a first connector region, a tag cassette, a second connector region comprising a hinge, a hydrophobic portion, and an intracellular component comprising an effector domain. In yet further T-ChARM embodiments, the fusion protein comprises from amino-terminus to carboxy-terminus: an extracellular binding domain, a first tag cassette, a first connector region, a second tag cassette, a second connector region comprising a hinge, a hydrophobic portion, and an intracellular component comprising an effector domain. In even further T-ChARM embodiments, the fusion protein comprises from amino-terminus to carboxy-terminus: an extracellular binding domain, a first tag cassette, a first connector region, a second tag cassette, a second connector region, a third tag cassette, a third connector region comprising a hinge, a hydrophobic portion, and an intracellular component comprising an effector domain.

In certain other T-ChARM embodiments, the fusion protein comprises from amino-terminus to carboxy-terminus: a tag cassette, an extracellular binding domain, a connector region comprising a hinge, a hydrophobic portion, and an intracellular component comprising an effector domain (*see*, *e.g.*, Figure 1F). In still other T-ChARM embodiments, the fusion protein comprises from amino-terminus to carboxy-

terminus: an extracellular scFv or scTCR binding domain comprising a variable region linker containing a tag cassette disposed between the variable regions (*e.g.*, at or closer to the N-terminal end of the variable region linker, at or closer to the C-terminal end of the variable region linker, or imbedded closer to the middle of the variable region linker), a connector region comprising a hinge, a hydrophobic portion, and an intracellular component comprising an effector domain. An exemplary tag cassette imbedded in a variable region linker comprises $GGSGSG(X)_nWSHPQFEKGSGSG$ (SEQ ID NO.:45), wherein X is optional, may be any amino acid and n is 0, 1, 2, 3, 4 or 5. In SEQ ID NO.:54, such a variable region linker having an imbedded tag is present, wherein n is 1 and X is asparagine (N).

A Key-ChEM or T-ChARM may be cell-bound (*e.g.*, expressed on a cell surface) or in soluble form. In certain embodiments, nucleic acid molecules encoding Key-ChEM or T-ChARM fusion proteins may be codon optimized to enhance or maximize expression in certain types of cells, such as T cells (Scholten *et al.*, *Clin. Immunol. 119*:135, 2006).

In other embodiments, Key-ChEM or T-ChARM may further comprise a cytotoxic component (*e.g.*, chemotherapeutic drugs such as anti-mitotics (*e.g.*, vindesine), antifolates, alkylating agents (*e.g.*, temozolomide), bacterial toxins, ricin, anti-virals, radioisotopes, radiometals), which is useful for specific killing or disabling a cancer cell, infected cell or other diseased cell. In further embodiments, Key-ChEM or T-ChARM may further comprise a detectable component (*e.g.*, biotin, fluorescent moiety, radionuclide), which is useful for tracking or imaging cancer cells, infected cells, or other tissues (*e.g.*, tissue under autoimmune attack). In still further embodiments, Key-ChEM or T-ChARM may further comprise a functional component (*e.g.*, an immunostimulatory moiety, cytokine, immune modulator, immunoglobulin protein, or the like).

Component parts of the fusion proteins of the present disclosure are further described in detail herein.

Tag Cassette

A tag cassette contained in a single chain fusion protein according to the present disclosure (*e.g.*, Key-ChEM or T-ChARM) will be an extracellular component that can specifically bind to a cognate receptor or binding partner (*e.g.*, antibody) with high affinity or avidity, wherein the cognate receptor or binding partner is heterologous or non-endogenous to a host or a cell expressing a Key-ChEM or T-ChARM. Within a single chain fusion protein structure, a tag cassette may be located (a) immediately amino-terminal to a connector region, (b) interposed between and connecting linker

modules, (c) immediately carboxy-terminal to a binding domain, (d) interposed between and connecting a binding domain (*e.g.*, scFv) to an effector domain, (e) interposed between and connecting subunits of a binding domain, or (f) at the amino-terminus of a single chain fusion protein of this disclosure. In certain embodiments, one or more junction amino acids may be disposed between and connecting a tag cassette with a hydrophobic portion, or disposed between and connecting a tag cassette with a connector region, or disposed between and connecting a tag cassette with a linker module, or disposed between and connecting a tag cassette with a binding domain.

Exemplary tag cassettes include Strep tag (which refers the original Strep® tag, Strep® tag II, or any variant thereof; *see*, *e.g.*, U.S. Patent No. 7,981,632, which Strep tags are incorporated herein by reference), His tag, Flag tag (SEQ ID NO.:3), Xpress tag (SEQ ID NO.:4), Avi tag (SEQ ID NO.:5), Calmodulin tag (SEQ ID NO.:19), Polyglutamate tag, HA tag (SEQ ID NO.:6), Myc tag (SEQ ID NO.:7), Nus tag, S tag, SBP tag, Softag 1 (SEQ ID NO.:9), Softag 3 (SEQ ID NO.:32), V5 tag (SEQ ID NO.:8), CREB-binding protein (CBP), glutathione S-transferase (GST), maltose binding protein (MBP), green fluorescent protein (GFP), Thioredoxin tag, or any combination thereof. In certain embodiments, a tag cassette is a Strep tag having an amino acid sequence of Trp-Ser-His-Pro-Gln-Phe-Glu-Lys (SEQ ID NO.:1) or Trp-Arg-His-Pro-Gln-Phe-Gly-Gly (SEQ ID NO.:2). In other embodiments, a tag cassette may be a genetically engineered affinity site, such as a minimal chelation site (*e.g.*, HGGHHG, SEQ ID NO.:33)

Tag cassettes may be present in multiple copies in fusion proteins of this disclosure. For example, a fusion protein of this disclosure can have one, two, three, four or five tag cassettes (*e.g.*, Strep tag). In certain embodiments, a connector region of a Key-ChEM or T-ChARM includes one tag cassette, two tag cassettes, three tag cassettes, four tag cassettes, or five tag cassettes. Each of the plurality of tag cassettes may be the same or different. Exemplary embodiments include a Key-ChEM or T-ChARM having a Strep tag and a Strep tag cassette, or a His tag and a Strep tag cassette, or a HA tag and a Strep tag cassette, or a Myc tag and a Strep tag cassette. Alternatively, a Key-ChEM or T-ChARM will have multiple tag cassettes of the same type or same amino acid sequence, such as two, three, four or five Strep tag cassettes (*e.g.*, Strep tag II).

For example, a Key-ChEM or T-ChARM may have at least two different tag cassettes. In some embodiments, a first tag cassette can provide a stimulation signal and a distinct second tag cassette might be used to associate with a detection reagent or associate with an antibody-toxin conjugate or with an antibody-imaging agent

conjugate. In further embodiments, the two or more first tag cassettes may be located in different areas of a Key-ChEM or T-ChARM. In certain embodiments, a first tag cassette is located in the connector region and a second tag cassette is located at the amino-terminus or carboxy terminus or both of a Key-ChEM or T-ChARM (*see*, *e.g.*, Figure 1H).

In certain embodiments, a tag cassette comprises from about five to about 500 amino acids, or from about six to about 100 amino acids, or from about seven to about 50 amino acids, or from about eight to about 20 amino acids. In some embodiments, a tag cassette has seven to ten amino acids. Preferably, a tag cassette is non-immunogenic or minimally immunogenic. Essentially, a tag cassette can function as a handle or beacon to allow for the identification, enrichment, isolation, promotion of proliferation, activation, tracking, or elimination of cells expressing a Key-ChEM or T-ChARM.

In certain embodiments, a tag cassette is located within a connector region of a fusion protein of this disclosure. For example, a connector region may further comprise a linker module adjacent to a tag cassette, wherein the linker module with the tag cassette has an amino acid sequence of $(Gly\text{-}Gly\text{-}Gly\text{-}Gly\text{-}Ser)_2$-Trp-Ser-His-Pro-Gln-Phe-Glu-Lys (SEQ ID NO.:20), Trp-Ser-His-Pro-Gln-Phe-Glu-Lys-$(Gly\text{-}Gly\text{-}Gly\text{-}Gly\text{-}Ser)_2$ (SEQ ID NO.:21), $(Gly\text{-}Gly\text{-}Gly\text{-}Gly\text{-}Ser)_2$-Trp-Ser-His-Pro-Gln-Phe-Glu-Lys-$(Gly\text{-}Gly\text{-}Gly\text{-}Ser)_2$–Gly-Gly-Ser-Trp-Ser-His-Pro-Gln-Phe-Glu-Lys (SEQ ID NO.:22), Trp-Ser-His-Pro-Gln-Phe-Glu-Lys-$(Gly\text{-}Gly\text{-}Gly\text{-}Ser)_2$–Gly-Gly-Ser-Trp-Ser-His-Pro-Gln-Phe-Glu-Lys-$(Gly\text{-}Gly\text{-}Gly\text{-}Gly\text{-}Ser)_2$ (SEQ ID NO.:23), $(Gly\text{-}Gly\text{-}Gly\text{-}Gly\text{-}Ser)_2$-Trp-Ser-His-Pro-Gln-Phe-Glu-Lys-$(Gly\text{-}Gly\text{-}Gly\text{-}Ser)_2$–Gly-Gly-Ser-Trp-Ser-His-Pro-Gln-Phe-Glu-Lys-$(Gly\text{-}Gly\text{-}Gly\text{-}Gly\text{-}Ser)_2$-Trp-Ser-His-Pro-Gln-Phe-Glu-Lys (SEQ ID NO.:24), or Trp-Ser-His-Pro-Gln-Phe-Glu-Lys-$(Gly\text{-}Gly\text{-}Gly\text{-}Gly\text{-}Ser)_2$–Trp-Ser-His-Pro-Gln-Phe-Glu-Lys-$(Gly\text{-}Gly\text{-}Gly\text{-}Ser)_2$–Gly-Gly-Ser-Trp-Ser-His-Pro-Gln-Phe-Glu-Lys-$(Gly\text{-}Gly\text{-}Gly\text{-}Gly\text{-}Ser)_2$ (SEQ ID NO.:25).

A single chain fusion protein comprising one or more tag cassettes as described herein will be capable of associating with a cognate binding partner, wherein the cognate binding partner is heterologous to the host or cell expressing a fusion protein comprising a tag cassette as described herein. In certain embodiments, a tag cassette present in a single chain Key-ChEM or T-ChARM of this disclosure is a Strep tag, which has streptavidin, streptactin or both as a cognate binding partner, or is recognized by antibodies specific for a Strep tag. In certain embodiments, the cognate binding partner (*e.g.*, receptor, protein, antibody) may be soluble, part of a matrix composition,

or conjugated to a solid surface (*e.g.*, plate, bead). Exemplary solid surfaces include beads and particles (*e.g.*, micro and nano), such as magnetic beads and particles.

In single chain T-ChARM fusion protein embodiments, a protein complex can form between a fusion protein and a cognate tag cassette binding partner, which is a result of binding between the tag cassette and the binding partner. In certain embodiments, a T-ChARM comprises a scFv or scTCR binding domain where the tag cassette is located within the variable region linker (between the binding domain subunits). In other embodiments, a T-ChARM has a tag cassette located at the amino-terminus of the binding domain. In such protein complexes or fusion protein structures, a T-ChARM binding domain will retain its target specificity or its specific target binding affinity.

Connector Region and Hinge

A connector region comprising a hinge in a single chain fusion protein according to the present disclosure may be located (a) immediately amino-terminal to a hydrophobic portion, (b) interposed between and connecting a tag cassette (*e.g.*, Strep tag) and an effector domain, (c) immediately carboxy-terminal to a binding domain, or (d) interposed between and connecting a linker module and an effector domain. A single chain fusion protein comprising a connector region with a hinge as described herein will be capable of associating with another single chain fusion protein to form a dimer (*e.g.*, homodimer or heterodimer), wherein a Key-ChEM or T-ChARM dimer will contain one or more tag cassettes capable of binding a cognate binding partner, and a T-ChARM dimer will further comprise a binding domain that retains its target specificity or its specific target binding affinity.

A connector region can be comprised of a hinge only, linker modules only, a hinge and linker modules, or a hinge, one or more linker modules and one or more tag cassettes. In certain embodiments, linker modules include from about two to about 20 amino acids that form a flexible structure. Exemplary linker modules include an immunoglobulin CH2CH3, an immunoglobulin CH3, or one or more Gly_xSer_y, wherein x and y are independently an integer from 0 to 10 provided that x and y are not both 0 (*e.g.*, $(Gly_4Ser)_2$ (SEQ ID NO: 67), $(Gly_3Ser)_2$ (SEQ ID NO: 68), Gly_2Ser, or a combination thereof such as $(Gly_3Ser)_2Gly_2Ser$) (SEQ ID NO: 69). In further embodiments, a connector region comprises a tag cassette. For example, a connector region contains from one to five tag cassettes, wherein each tag cassette is connected to one or two linker modules comprising a $(Gly_xSer_y)_n$, wherein n is an integer from 1 to 10, and x and y are independently an integer from 0 to 10 provided that x and y are not both 0. Exemplary linker modules have an amino acid sequence of Gly-Gly-Gly-Gly-

Ser (SEQ ID NO.:10), $(Gly\text{-}Gly\text{-}Gly\text{-}Gly\text{-}Ser)_2$ (SEQ ID NO.:11), $(Gly\text{-}Gly\text{-}Gly\text{-}Ser)_2$-Gly-Gly-Ser (SEQ ID NO.:12), which may be present in any combination within a connector region.

In certain embodiments, a hinge present in a single chain Key-ChEM or T-ChARM of this disclosure may be an immunoglobulin hinge region, such as a wild type immunoglobulin hinge region or an altered immunoglobulin hinge region thereof. In certain embodiments, a hinge is a wild type human immunoglobulin hinge region. In certain other embodiments, one or more amino acid residues may be added at the amino- or carboxy-terminus of a wild type immunoglobulin hinge region as part of a fusion protein construct design. For example, one, two or three additional junction amino acid residues may be present at the hinge amino-terminus or carboxy-terminus, or a hinge may contain a terminal or internal deletion and have added back one, two or three additional junction amino acid residues.

In certain embodiments, a hinge is an altered immunoglobulin hinge in which one or more cysteine residues in a wild type immunoglobulin hinge region is substituted with one or more other amino acid residues. Exemplary altered immunoglobulin hinges include an immunoglobulin human IgG1, IgG2 or IgG4 hinge region having one, two or three cysteine residues found in a wild type human IgG1, IgG2or IgG4 hinge substituted by one, two or three different amino acid residues (*e.g.*, serine or alanine). In certain embodiments, a hinge polypeptide comprises or is a sequence that is at least 80%, at least 81%, at least 82%, at least 83%, at least 84%, at least 85%, at least 86%, at least 87%, at least 88%, at least 89%, at least 90%, at least 91%, at least 92%, at least 93%, at least 94%, at least 95%, at least 96%, at least 97%, at least 98%, at least 99% identical to a wild type immunoglobulin hinge region, such as a wild type human IgG1 hinge, a wild type human IgG2 hinge, or a wild type human IgG4 hinge.

In further embodiments, a hinge present in a single chain Key-ChEM or T-ChARM of this disclosure may be a hinge that is not based on or derived from an immunoglobulin hinge (*i.e.*, not a wild type immunoglobulin hinge or an altered immunoglobulin hinge). Examples of such hinges include peptides of about five to about 150 amino acids of the stalk region of type II C-lectins or CD molecules, including peptides of about eight to about 25 amino acids or peptides of about seven to about 18 amino acids, or variants thereof.

A "stalk region" of a type II C-lectin or CD molecule refers to the portion of the extracellular domain of the type II C-lectin or CD molecule that is located between the C-type lectin-like domain (CTLD; *e.g.*, similar to CTLD of natural killer cell receptors) and the hydrophobic portion (transmembrane domain). For example, the extracellular

domain of human CD94 (GenBank Accession No. AAC50291.1) corresponds to amino acid residues 34-179, but the CTLD corresponds to amino acid residues 61-176, so the stalk region of the human CD94 molecule comprises amino acid residues 34-60, which are located between the hydrophobic portion (transmembrane domain) and CTLD (*see* Boyington *et al.*, *Immunity 10*:75, 1999; for descriptions of other stalk regions, *see also* Beavil *et al.*, *Proc. Nat'l. Acad. Sci. USA 89*:753, 1992; and Figdor *et al.*, *Nat. Rev. Immunol. 2*:77, 2002). These type II C-lectin or CD molecules may also have junction amino acids between the stalk region and the transmembrane region or the CTLD. In another example, the 233 amino acid human NKG2A protein (GenBank Accession No. P26715.1) has a hydrophobic portion (transmembrane domain) ranging from amino acids 71-93 and an extracellular domain ranging from amino acids 94-233. The CTLD comprises amino acids 119-231, and the stalk region comprises amino acids 99-116, which may be flanked by additional junction amino acids. Other type II C-lectin or CD molecules, as well as their extracellular ligand-binding domains, stalk regions, and CTLDs are known in the art (*see*, *e.g.*, GenBank Accession Nos. NP_001993.2; AAH07037.1; NP_001773.1; AAL65234.1; CAA04925.1; for the sequences of human CD23, CD69, CD72, NKG2A and NKG2D and their descriptions, respectively).

A "derivative" of a stalk region hinge, or fragment thereof, of a type II C-lectin or CD molecule includes about an eight to about 150 amino acid sequence in which one, two, or three amino acids of the stalk region of a wild type type II C-lectin or CD molecule have a deletion, insertion, substitution, or any combination thereof. For instance, a derivative can comprise one or more amino acid substitutions and/or an amino acid deletion. In certain embodiments, a derivative of a stalk region is more resistant to proteolytic cleavage as compared to the wild-type stalk region sequence, such as those derived from about eight to about 20 amino acids of NKG2A, NKG2D, CD23, CD64, CD72, or CD94.

In certain embodiments, stalk region hinges may comprise from about seven to about 18 amino acids and can form an α-helical coiled coil structure. In certain embodiments, stalk region hinges contain 0, 1, 2, 3, or 4 cysteines. Exemplary stalk region hinges include fragments of the stalk regions, such as those portions comprising from about ten to about 150 amino acids from the stalk regions of CD69, CD72, CD94, NKG2A and NKG2D.

Alternative hinges that can be used in single chain Key-ChEMs or T-ChARMs of this disclosure are from portions of cell surface receptors (interdomain regions) that connect immunoglobulin V-like or immunoglobulin C-like domains. Regions between Ig V-like domains where the cell surface receptor contains multiple Ig V-like domains

in tandem and between Ig C-like domains where the cell surface receptor contains multiple tandem Ig C-like regions are also contemplated as hinges useful in single chain Key-ChEMs or T-ChARMs of this disclosure. In certain embodiments, hinge sequences comprised of cell surface receptor interdomain regions may further contain a naturally occurring or added motif, such as an IgG core hinge sequence to provide one or more disulfide bonds to stabilize the Key-ChEM or T-ChARM dimer formation. Examples of hinges include interdomain regions between the Ig V-like and Ig C-like regions of CD2, CD4, CD22, CD33, CD48, CD58, CD66, CD80, CD86, CD150, CD166, or CD244.

In certain embodiments, hinge sequences have from about 5 to about 150 amino acids, about 5 to about 10 amino acids, about 10 to about 20 amino acids, about 20 to about 30 amino acids, about 30 to about 40 amino acids, about 40 to about 50 amino acids, about 50 to about 60 amino acids, about 5 to about 60 amino acids, about 5 to about 40 amino acids, for instance, about 8 to about 20 amino acids or about 10 to about 15 amino acids. The hinges may be primarily flexible, but may also provide more rigid characteristics or may contain primarily α-helical structure with minimal β-sheet structure.

In certain embodiments, a hinge sequence is stable in plasma and serum, and is resistant to proteolytic cleavage. For example, the first lysine in an IgG1 upper hinge region may be mutated or deleted to minimize proteolytic cleavage, and hinges may include junction amino acids. In some embodiments, a hinge sequence may contain a naturally occurring or added motif, such as an immunoglobulin hinge core structure CPPCP (SEQ ID NO.:26) that confers the capacity to form a disulfide bond or multiple disulfide bonds to stabilize dimer formation.

Hydrophobic Portion

A hydrophobic portion contained in a single chain fusion protein of the present disclosure (*e.g.*, Key-ChEM or T-ChARM) will allow a fusion protein of this disclosure to associate with a cellular membrane such that a portion of the fusion protein will be located extracellularly (*e.g.*, tag cassette, connector domain, binding domain) and a portion will be located intracellularly (*e.g.*, effector domain). A hydrophobic portion will generally be disposed within the cellular membrane phospholipid bilayer. In certain embodiments, one or more junction amino acids may be disposed between and connecting a hydrophobic portion with an effector domain, or disposed between and connecting a hydrophobic portion with a connector region, or disposed between and connecting a hydrophobic portion with a tag cassette.

In certain embodiments, a hydrophobic domain is a transmembrane domain, such as one derived from an integral membrane protein (*e.g.*, receptor, cluster of differentiation (CD) molecule, enzyme, transporter, cell adhesion molecule, or the like). In particular embodiments, a hydrophobic portion is a transmembrane domain from CD4, CD8, CD27, or CD28. In certain embodiments, a transmembrane domain is a CD28 transmembrane domain having an amino acid as set forth in SEQ ID NO.:16.

Effector Domain

An effector domain contained in a single chain fusion protein of the present disclosure (*e.g.*, Key-ChEM or T-ChARM) will be an intracellular component and capable of transmitting functional signals to a cell. In certain embodiments, a single chain Key-ChEM or T-ChARM will dimerize with a second single chain Key-ChEM or T-ChARM, respectively, wherein the dimerization allows the intracellular component comprising an effector domains to be in close proximity and promote signal transduction when exposed to the proper signal. In addition to forming such dimer protein complexes, the effector domains may further associate with other signaling factors, such as costimulatory factors, to form multiprotein complexes that produce an intracellular signal. In certain embodiments, an effector domain will indirectly promote a cellular response by associating with one or more other proteins that directly promote a cellular response. An effector domain may include one, two, three or more receptor signaling domains, costimulatory domains, or combinations thereof. Any intracellular component comprising an effector domain, costimulatory domain or both from any of a variety of signaling molecules (*e.g.*, signal transduction receptors) may be used in the fusion proteins of this disclosure.

An effector domain useful in the fusion proteins of this disclosure may be from a protein of a Wnt signaling pathway (*e.g.*, LRP, Ryk, ROR2), NOTCH signaling pathway (*e.g.*, NOTCH1, NTOCH2, NOTCH3, NOTCH4), Hedgehog signaling pathway (*e.g.*, PTCH, SMO), receptor tyrosine kinases (RTKs) (*e.g.*, epidermal growth factor (EGF) receptor family, fibroblast growth factor (FGF) receptor family, hepatocyte growth factor (HGF) receptor family, Insulin receptor (IR) family, platelet-derived growth factor (PDGF) receptor family, vascular endothelial growth factor (VEGF) receptor family, tropomycin receptor kinase (Trk) receptor family, ephrin (Eph) receptor family, AXL receptor family, leukocyte tyrosine kinase (LTK) receptor family, tyrosine kinase with immunoglobulin-like and EGF-like domains 1 (TIE) receptor family, receptor tyrosine kinase-like orphan (ROR) receptor family, discoidin domain (DDR) receptor family, rearranged during transfection (RET) receptor family, tyrosine-protein kinase-like (PTK7) receptor family, related to receptor tyrosine kinase

(RYK) receptor family, muscle specific kinase (MuSK) receptor family); G-protein-coupled receptors, GPCRs (Frizzled, Smoothened); serine/threonine kinase receptors (BMPR, TGFR); or cytokine receptors (IL1R, IL2R, IL7R, IL15R).

In certain embodiments, an effector domain comprises a lymphocyte receptor signaling domain or comprises an amino acid sequences having one or a plurality of immunoreceptor tyrosine-based activation motifs (ITAMs). In still further embodiments, an effector domain comprises a cytoplasmic portion that associates with a cytoplasmic signaling protein, wherein the cytoplasmic signaling protein is a lymphocyte receptor or signaling domain thereof, a protein comprising a plurality of ITAMs, a costimulatory factor, or any combination thereof.

Exemplary effector domains include those from 4-1BB (*e.g.*, SEQ ID NO.:17), CD3ε, CD3δ, CD3ζ (*e.g.*, SEQ ID NO.:18), CD27, CD28 (*e.g.*, SEQ ID NO.:35), CD79A, CD79B, CARD11, DAP10, FcRα, FcRβ, FcRγ, Fyn, HVEM, ICOS, Lck, LAG3, LAT, LRP, NOTCH1, Wnt, NKG2D, OX40, ROR2, Ryk, SLAMF1, Slp76, pTα, TCRα, TCRβ, TRIM, Zap70, PTCH2, or any combination thereof.

In particular embodiments, an effector domain of a Key-ChEM or T-ChARM of the instant disclosure is CD3ζ and CD28, is CD3ζ and 4-1BB, or is CD3ζ, CD28 and 4-1BB.

Binding Domain

As described herein, a T-ChARM single chain fusion protein of the present disclosure comprises a binding domain that specifically binds a target. Binding of a target by the binding domain may block the interaction between the target (*e.g.*, a receptor or a ligand) and another molecule and, for example, interfere, reduce or eliminate certain functions of the target (*e.g.*, signal transduction), or the binding of a target may induce certain biological pathways or identify the target for elimination.

A binding domain may be any peptide that specifically binds a target of interest. Sources of binding domains include antibody variable regions from various species (which can be in the form of antibodies, sFvs, scFvs, Fabs, scFv-based grababody, or soluble VH domain or domain antibodies), including human, rodent, avian, or ovine. Additional sources of binding domains include variable regions of antibodies from other species, such as camelid (from camels, dromedaries, or llamas; Ghahroudi *et al.*, *FEBS Lett. 414*:521, 1997; Vincke *et al.*, *J. Biol. Chem. 284*:3273, 2009; Hamers-Casterman *et al.*, *Nature 363*:446, 1993 and Nguyen *et al.*, *J. Mol. Biol. 275*:413, 1998), nurse sharks (Roux *et al.*, *Proc. Nat'l. Acad. Sci. (USA) 95*:11804, 1998), spotted ratfish (Nguyen *et al.*, *Immunogen. 54*:39, 2002), or lamprey (Herrin *et al.*, *Proc. Nat'l. Acad. Sci. (USA) 105*:2040, 2008 and Alder *et al. Nat. Immunol. 9*:319, 2008). These

antibodies can form antigen-binding regions using only a heavy chain variable region, *i.e.*, these functional antibodies are homodimers of heavy chains only (referred to as "heavy chain antibodies") (Jespers *et al.*, *Nat. Biotechnol. 22*:1161, 2004; Cortez-Retamozo *et al.*, *Cancer Res. 64*:2853, 2004; Baral *et al.*, *Nature Med. 12*:580, 2006; and Barthelemy *et al.*, *J. Biol. Chem. 283*:3639, 2008).

An alternative source of binding domains of this disclosure includes sequences that encode random peptide libraries or sequences that encode an engineered diversity of amino acids in loop regions of alternative non-antibody scaffolds, such as scTCR (*see, e.g.*, Lake *et al.*, *Int. Immunol.*11:745, 1999; Maynard *et al.*, *J. Immunol. Methods 306*:51, 2005; U.S. Patent No. 8,361,794), fibrinogen domains (*see, e.g.*, Weisel *et al.*, *Science 230*:1388, 1985), Kunitz domains (*see, e.g.*, US Patent No. 6,423,498), designed ankyrin repeat proteins (DARPins) (Binz *et al.*, *J. Mol. Biol. 332*:489, 2003 and Binz *et al.*, *Nat. Biotechnol. 22*:575, 2004), fibronectin binding domains (adnectins or monobodies) (Richards *et al.*, *J. Mol. Biol. 326*:1475, 2003; Parker *et al.*, *Protein Eng. Des. Selec. 18*:435, 2005 and Hackel *et al.* (2008) *J. Mol. Biol. 381*:1238-1252), cysteine-knot miniproteins (Vita *et al.* (1995) *Proc. Nat'l. Acad. Sci. (USA) 92*:6404-6408; Martin *et al.* (2002) *Nat. Biotechnol. 21*:71, 2002 and Huang *et al.* (2005) *Structure 13*:755, 2005), tetratricopeptide repeat domains (Main *et al.*, *Structure 11*:497, 2003 and Cortajarena *et al.*, *ACS Chem. Biol. 3*:161, 2008), leucine-rich repeat domains (Stumpp *et al.*, *J. Mol. Biol. 332*:471, 2003), lipocalin domains (*see, e.g.*, WO 2006/095164, Beste *et al.*, *Proc. Nat'l. Acad. Sci. (USA) 96*:1898, 1999 and Schönfeld *et al.*, *Proc. Nat'l. Acad. Sci. (USA) 106*:8198, 2009), V-like domains (*see, e.g.*, US Patent Application Publication No. 2007/0065431), C-type lectin domains (Zelensky and Gready, *FEBS J. 272*:6179, 2005; Beavil *et al.*, *Proc. Nat'l. Acad. Sci. (USA) 89*:753, 1992 and Sato *et al.*, *Proc. Nat'l. Acad. Sci. (USA) 100*:7779, 2003), mAb^2 or Fcab™ (*see*, *e.g.*, PCT Patent Application Publication Nos. WO 2007/098934; WO 2006/072620), armadillo repeat proteins (*see*, *e.g.*, Madhurantakam *et al.*, *Protein Sci. 21*: 1015, 2012; PCT Patent Application Publication No. WO 2009/040338), affilin (Ebersbach *et al.*, *J. Mol. Biol. 372*: 172, 2007), affibody, avimers, knottins, fynomers, atrimers, cytotoxic T-lymphocyte associated protein-4 (Weidle *et al.*, *Cancer Gen. Proteo. 10*:155, 2013) or the like (Nord *et al.*, *Protein Eng. 8*:601, 1995; Nord *et al.*, *Nat. Biotechnol. 15*:772, 1997; Nord *et al.*, *Euro. J. Biochem. 268*:4269, 2001; Binz *et al.*, *Nat. Biotechnol. 23*:1257, 2005; Boersma and Plückthun, *Curr. Opin. Biotechnol. 22*:849, 2011).

Binding domains of this disclosure can be generated as described herein or by a variety of methods known in the art (*see*, *e.g.*, U.S. Patent Nos. 6,291,161 and

6,291,158). For example, binding domains of this disclosure may be identified by screening a Fab phage library for Fab fragments that specifically bind to a target of interest (*see* Hoet *et al.*, *Nat. Biotechnol. 23*:344, 2005). Additionally, traditional strategies for hybridoma development using a target of interest as an immunogen in convenient systems (*e.g.*, mice, HuMAb mouse®, TC mouse™, KM-mouse®, llamas, chicken, rats, hamsters, rabbits, *etc.*) can be used to develop binding domains of this disclosure.

In some embodiments, a binding domain is a single chain Fv fragment (scFv) that comprises VH and VL regions specific for a target of interest. In certain embodiments, the V_H and V_L regions are human. Exemplary V_H and V_L regions include the segments of anti-CD19 specific monoclonal antibody FMC63 (*see*, *e.g.*, SEQ ID NOS.:51 and 52, respectively).

In certain embodiments, a binding domain comprises or is a sequence that is at least 90%, at least 91%, at least 92%, at least 93%, at least 94%, at least 95%, at least 96%, at least 97%, at least 98%, at least 99%, at least 99.5%, or 100% identical to an amino acid sequence of a light chain variable region (V_L) (*e.g.*, from FMC63, SEQ ID NO.:52; from R12, SEQ ID NO.:56) or to a heavy chain variable region (V_H) (*e.g.*, from FMC63, SEQ ID NO.:51; from R12, SEQ ID NO.:55), or both, wherein each CDR comprises zero changes or at most one, two, or three changes, from a monoclonal antibody or fragment or derivative thereof that specifically binds to target of interest (*e.g.*, CD19, ROR1).

In certain embodiments, a binding domain V_H region of the present disclosure can be derived from or based on a V_H of a known monoclonal antibody and contains one or more (*e.g.*, 2, 3, 4, 5, 6, 7, 8, 9, 10) insertions, one or more (*e.g.*, 2, 3, 4, 5, 6, 7, 8, 9, 10) deletions, one or more (*e.g.*, 2, 3, 4, 5, 6, 7, 8, 9, 10) amino acid substitutions (*e.g.*, conservative amino acid substitutions or non-conservative amino acid substitutions), or a combination of the above-noted changes, when compared with the V_H of a known monoclonal antibody. An insertion, deletion or substitution may be anywhere in the V_H region, including at the amino- or carboxy-terminus or both ends of this region, provided that each CDR comprises zero changes or at most one, two, or three changes and provided a binding domain containing the modified V_H region can still specifically bind its target with an affinity similar to the wild type binding domain.

In further embodiments, a V_L region in a binding domain of the present disclosure is derived from or based on a V_L of a known monoclonal antibody and contains one or more (*e.g.*, 2, 3, 4, 5, 6, 7, 8, 9, 10) insertions, one or more (*e.g.*, 2, 3, 4, 5, 6, 7, 8, 9, 10) deletions, one or more (*e.g.*, 2, 3, 4, 5, 6, 7, 8, 9, 10) amino acid

substitutions (*e.g.*, conservative amino acid substitutions), or a combination of the above-noted changes, when compared with the V_L of the known monoclonal antibody. An insertion, deletion or substitution may be anywhere in the V_L region, including at the amino- or carboxy-terminus or both ends of this region, provided that each CDR comprises zero changes or at most one, two, or three changes and provided a binding domain containing the modified V_L region can still specifically bind its target with an affinity similar to the wild type binding domain.

The V_H and V_L domains may be arranged in either orientation (*i.e.*, from amino-terminus to carboxyl terminus, V_H-V_L or V_L-V_H) and may be joined by an amino acid sequence (*e.g.*, having a length of about five to about 35 amino acids) capable of providing a spacer function such that the two sub-binding domains can interact to form a functional binding domain. In certain embodiments, a variable region linker that joins the V_H and V_L domains includes those belonging to the (Gly_nSer) family, such as $(Gly_3Ser)_n(Gly_4Ser)_1$ (SEQ ID NO: 72), $(Gly_3Ser)_1(Gly_4Ser)_n$ (SEQ ID NO: 72), $(Gly_3Ser)_n(Gly_4Ser)_n$ (SEQ ID NO: 72), or $(Gly_4Ser)_n$ (SEQ ID NO: 10), wherein n is an integer of 1 to 5. In certain embodiments, the linker is $(Gly\text{-}Gly\text{-}Gly\text{-}Gly\text{-}Ser)_3$ (SEQ ID NO.:13) or $Gly\text{-}Gly\text{-}Gly\text{-}Ser)_4$ (SEQ ID NO.:14). In certain embodiments, these (Gly_nSer)-based linkers are used to link the V_H and V_L domains in a binding domain, and these linkers may also be used to link the binding domain to a connector region or to a tag cassette, or to link a tag cassette to an effector domain. In certain other embodiments, a tag cassette is a part of or is located within a (Gly_nSer)-based linker used to link the V_H and V_L domains of a binding domain. In still further embodiments, a (Gly_nSer)-based linker may be used to connect one or more tag cassettes to the N-terminal end of a T-ChARM binding domain.

In some embodiments, a binding domain is a single chain T cell receptor (scTCR) comprising $V_{\alpha/\beta}$ and $C_{\alpha/\beta}$ chains (*e.g.*, V_α-C_α, V_β-C_β, V_α-V_β) or comprising V_α-C_α, V_β-C_β, V_α-V_β pair specific for a target of interest (*e.g.*, peptide-MHC complex).

In certain embodiments, a binding domain comprises or is a sequence that is at least 90%, at least 91%, at least 92%, at least 93%, at least 94%, at least 95%, at least 96%, at least 97%, at least 98%, at least 99%, at least 99.5%, or 100% identical to an amino acid sequence of a TCR V_α, V_β, C_α, or C_β, wherein each CDR comprises zero changes or at most one, two, or three changes, from a TCR or fragment or derivative thereof that specifically binds to a target of interest.

In certain embodiments, a binding domain V_α, V_β, C_α, or C_β region of the present disclosure can be derived from or based on a V_α, V_β, C_α, or C_β of a known TCR (*e.g.*, a high-affinity TCR) and contains one or more (*e.g.*, 2, 3, 4, 5, 6, 7, 8, 9, 10)

insertions, one or more (*e.g.*, 2, 3, 4, 5, 6, 7, 8, 9, 10) deletions, one or more (*e.g.*, 2, 3, 4, 5, 6, 7, 8, 9, 10) amino acid substitutions (*e.g.*, conservative amino acid substitutions or non-conservative amino acid substitutions), or a combination of the above-noted changes, when compared with the V_α, V_β, C_α, or C_β of a known TCR. An insertion, deletion or substitution may be anywhere in a V_α, V_β, C_α, or C_β region, including at the amino- or carboxy-terminus or both ends of these regions, provided that each CDR comprises zero changes or at most one, two, or three changes and provided a binding domain containing a modified V_α, V_β, C_α, or C_β region can still specifically bind its target with an affinity similar to wild type.

A target molecule, which is specifically bound by a binding domain contained in a T-ChARM single chain fusion protein of the present disclosure, may be found on or in association with a cell of interest ("target cell"). Exemplary target cells include a cancer cell, a cell associated with an autoimmune disease or disorder or with an inflammatory disease or disorder, and an infectious organism or cell (*e.g.*, bacteria, virus, virus-infected cell). A cell of an infectious organism, such as a mammalian parasite, is also contemplated as a target cell.

In certain embodiments, binding domains of a T-ChARM single chain fusion protein of the present disclosure recognize a target selected from a tumor antigen, a B-cell target, a TNF receptor superfamily member, a Hedgehog family member, a receptor tyrosine kinase, a proteoglycan-related molecule, a TGF-β superfamily member, a Wnt-related molecule, a T-cell target, a dendritic cell target, an NK cell target, a monocyte/macrophage cell target, or an angiogenesis target. In further embodiments, the binding domains of a T-ChARM single chain fusion protein of the present disclosure bind a receptor protein, such as peripheral membrane receptor proteins or transmembrane receptor proteins.

In certain embodiments, a T-ChARM single chain fusion protein of the present disclosure specifically binds a target, such as CD3, CEACAM6, c-Met, EGFR, EGFRvIII, ErbB2, ErbB3, ErbB4, EphA2, IGF1R, GD2, O-acetyl GD2, O-acetyl GD3, GHRHR, GHR, FLT1, KDR, FLT4, CD44v6, CD151, CA125, CEA, CTLA-4, GITR, BTLA, TGFBR2, TGFBR1, IL6R, gp130, Lewis A, Lewis Y, TNFR1, TNFR2, PD1, PD-L1, PD-L2, HVEM, MAGE-A, mesothelin, NY-ESO-1, PSMA, RANK, ROR1, TNFRSF4, CD40, CD137, TWEAK-R, HLA, tumor or pathogen derived peptides bound to HLA (such as from hTERT, tyrosinase, or WT-1), LTβR, LIFRβ, LRP5, MUC1, OSMRβ, TCRα, TCRβ, CD19, CD20, CD22, CD25, CD28, CD30, CD33, CD52, CD56, CD80, CD81, CD86, CD123, CD171, CD276, B7H4, TLR7, TLR9, PTCH1, PTCH1, Robo1, α-fetoprotein (AFP), Frizzled, OX40 (also referred to as

CD134), or CD79b. In certain embodiments, a T-ChARM single chain fusion protein of the present disclosure specifically binds a pathogen specific molecule expressed on infected cells, such as molecules from an adenovirus, bunyavirus, herpesvirus (*e.g.*, Epstein Barr Virus, cytomegalocvirus), papovavirus, papillomavirus (*e.g.*, human papilloma virus, HPV), paramyxovirus, picornavirus, rhabdovirus (*e.g.*, Rabies), orthomyxovirus (*e.g.*, influenza), poxvirus (*e.g.*, Vaccinia), reovirus, retrovirus, lentivirus (*e.g.*, human immunodeficiency virus, HIV), flavivirus (*e.g.*, Hepatitis C virus, HCV; Hepatitis B virus, HBV).

Host Cells and Nucleic Acids

In certain aspects, the present disclosure provides nucleic acid molecules that encode any one or more of the Key-ChEM or T-ChARM described herein. Such nucleic acid molecules can be inserted into an appropriate vector (*e.g.*, viral vector or non-viral plasmid vector) for introduction in a host cell of interest (*e.g.*, hematopoietic progenitor cell, T cell).

As used herein, the term "recombinant" or "non-natural" refers to an organism, microorganism, cell, nucleic acid molecule, or vector that includes at least one genetic alteration or has been modified by introduction of an exogenous nucleic acid molecule, wherein such alterations or modifications are introduced by genetic engineering. Genetic alterations include, for example, modifications introducing expressible nucleic acid molecules encoding proteins, fusion proteins or enzymes, or other nucleic acid molecule additions, deletions, substitutions or other functional disruption of a cell's genetic material. Additional modifications include, for example, non-coding regulatory regions in which the modifications alter expression of a gene or operon. In certain embodiments, a cell, such as a T cell, obtained from a subject may be converted into a non-natural or recombinant cell (*e.g.*, a non-natural or recombinant T cell) by introducing a nucleic acid that encodes a Key-ChEM or T-ChARM as described herein and whereby the cell expresses a cell surface located Key-ChEM or T-ChARM.

A vector that encodes a core virus is referred to herein as a "viral vector." There are a large number of available viral vectors suitable for use with the compositions of the instant disclosure, including those identified for human gene therapy applications (*see* Pfeifer and Verma, *Ann. Rev. Genomics Hum. Genet. 2*:177, 2001). Suitable viral vectors include vectors based on RNA viruses, such as retrovirus-derived vectors, *e.g.*, Moloney murine leukemia virus (MLV)-derived vectors, and include more complex retrovirus-derived vectors, *e.g.*, lentivirus-derived vectors. HIV-1-derived vectors belong to this category. Other examples include lentivirus vectors derived from HIV-2, FIV, equine infectious anemia virus, SIV, and Maedi-Visna virus (ovine lentivirus).

Methods of using retroviral and lentiviral viral vectors and packaging cells for transducing mammalian host cells with viral particles containing chimeric antigen receptor transgenes are known in the art and have been previous described, for example, in U.S. Patent 8,119,772; Walchli *et al.*, *PLoS One 6*:327930, 2011; Zhao *et al.*, *J. Immunol. 174*:4415, 2005; Engels *et al.*, *Hum. Gene Ther. 14*:1155, 2003; Frecha *et al.*, *Mol. Ther. 18*:1748, 2010; Verhoeyen *et al.*, *Methods Mol. Biol. 506*:97, 2009. Retroviral and lentiviral vector constructs and expression systems are also commercially available.

In certain embodiments, a viral vector is used to introduce a non-endogenous nucleic acid sequence encoding a Key-ChEM or a non-endogenous nucleic acid sequence encoding a T-ChARM specific for a target. A viral vector may be a retroviral vector or a lentiviral vector. A viral vector may also include nucleic acid sequences encoding a marker for transduction. Transduction markers for viral vectors are known in the art and include selection markers, which may confer drug resistance, or detectable markers, such as fluorescent markers or cell surface proteins that can be detected by methods such as flow cytometry. In particular embodiments, a viral vector further comprises a gene marker for transduction comprising green fluorescent protein, an extracellular domain of human CD2, or a truncated human EGFR (huEGFRt; *see* Wang *et al.*, *Blood 118*:1255, 2011). When a viral vector genome comprises a plurality of nucleic acid sequences to be expressed in a host cell as separate transcripts, the viral vector may also comprise additional sequences between the two (or more) transcripts allowing bicistronic or multicistronic expression. Examples of such sequences used in viral vectors include internal ribosome entry sites (IRES), furin cleavage sites, viral 2A peptide, or any combination thereof.

Other vectors also can be used for polynucleotide delivery including DNA viral vectors, including, for example adenovirus-based vectors and adeno-associated virus (AAV)-based vectors; vectors derived from herpes simplex viruses (HSVs), including amplicon vectors, replication-defective HSV and attenuated HSV (Krisky *et al.*, *Gene Ther. 5*: 1517, 1998).

Other vectors recently developed for gene therapy uses can also be used with the compositions and methods of this disclosure. Such vectors include those derived from baculoviruses and α-viruses. (Jolly, D J. 1999. Emerging Viral Vectors. pp 209-40 in Friedmann T. ed. The Development of Human Gene Therapy. New York: Cold Spring Harbor Lab), or plasmid vectors (such as sleeping beauty or other transposon vectors). In some embodiments, a viral or plasmid vector further comprises a gene marker for transduction (*e.g.* green fluorescent protein, huEGFRt).

In certain embodiments, hematopoietic progenitor cells or embryonic stem cells are modified to comprise a non-endogenous nucleic acid molecule that encodes a Key-ChEM or T-ChARM of this disclosure. Hematopoietic progenitor cells may comprise thymocyte progenitor cells or induced pluripotent stem cells, which may be derived or originate from fetal liver tissue, bone marrow, cord blood, or peripheral blood. The hematopoietic progenitor cells may be from human, mouse, rat, or other mammals. In particular embodiments, $CD24^{lo}$ Lin^{-} $CD117^{+}$ thymocyte progenitor cells are used.

In certain embodiments, culture conditions entail culturing hematopoietic progenitor cells expressing fusion proteins of this disclosure for a sufficient time to induce proliferation or differentiation. The cells are maintained in culture generally for about 3 days to about 5 days, or about 4 to about 10 days, or about 5 to about 20 days. It will be appreciated that the cells may be maintained for an appropriate amount of time required to achieve a desired result, *i.e.*, a desired cellular composition or level of proliferation. For example, to generate a cellular composition comprising primarily immature and inactivated T cells, cells may be maintained in culture for about 5 to about 20 days. Cells may be maintained in culture for about 20 to about 30 days to generate a cellular composition comprising primarily mature T cells. Non-adherent cells may also be collected from culture at various time points, such as from about several days to about 25 days. In certain embodiments, hematopoietic stem cells are co-cultured on stromal cells lines (U.S. Patent No. 7,575,925; Schmitt *et al.*, *Nat. Immunol. 5*:410, 2004; Schmitt *et al.*, *Immunity 17*:749, 2002).

One or more cytokines that promote commitment or differentiation of hematopoietic progenitor cells may be added to the culture. The cytokines may be human or non-human. Representative examples of cytokines that may be used include all members of the FGF family, including FGF-4 and FGF-2; Flt-3-ligand, stem cell factor (SCF), thrombopoietin (TPO), and IL-7. Cytokines may be used in combination with a glycosaminoglycan, such as heparin sulfate.

In some embodiments, cells capable of expressing a fusion protein of this disclosure on the cell surface are T cells, including primary cells or cell lines derived from human, mouse, rat, or other mammals. If obtained from a mammal, a T cell can be obtained from numerous sources, including blood, bone marrow, lymph node, thymus, or other tissues or fluids. A T cell may be enriched or purified. T cell lines are well known in the art, some of which are described in Sandberg *et al.*, *Leukemia 21*:230, 2000. In certain embodiments, T cells that lack endogenous expression of TCRα and β chains are used. Such T cells may naturally lack endogenous expression of

TCRα and β chains or may have been modified to block expression (*e.g.*, T cells from a transgenic mouse that does not express TCR α and β chains or cells that have been manipulated to inhibit expression of TCR α and β chains) or to knockout TCRα chain, TCRβ chain, or both genes. In certain embodiments, cells capable of expressing a fusion protein of this disclosure on the cell surface are not T cells or cells of a T cell lineage, but cells that are progenitor cells, stem cells or cells that have been modified to express cell surface anti-CD3.

In certain embodiments, the host T cell transfected to express a Key-ChEM or T-ChARM of this disclosure is a functional T cell, such as a virus-specific T cell, a tumor antigen specific cytotoxic T cell, a naïve T cell, a memory stem T cell, a central or effector memory T cell, or a CD4+ CD25+ regulatory T cell.

One or more growth factor cytokines that promote proliferation of T cells expressing a Key-ChEM or T-ChARM of this disclosure may be added to the culture. The cytokines may be human or non-human. Exemplary growth factor cytokines that may be used promote T cell proliferation include IL2, IL15, or the like.

Uses

Diseases that may be treated with cells expressing Key-ChEM or T-ChARM as described in the present disclosure include cancer, infectious diseases (viral, bacterial, protozoan infections), immune diseases (*e.g.*, autoimmune), or aging-related diseases (*e.g.*, senescence). Adoptive immune and gene therapy are promising treatments for various types of cancer (Morgan *et al.*, *Science 314*:126, 2006; Schmitt *et al.*, *Hum. Gene Ther. 20*:1240, 2009; June, *J. Clin. Invest. 117*:1466, 2007) and infectious disease (Kitchen *et al.*, *PLoS One 4*:38208, 2009; Rossi *et al.*, *Nat. Biotechnol. 25*:1444, 2007; Zhang *et al.*, *PLoS Pathog. 6*:e1001018, 2010; Luo *et al.*, *J. Mol. Med. 89*:903, 2011).

A wide variety of cancers, including solid tumors and leukemias are amenable to the compositions and methods disclosed herein. Exemplary types of cancer that may be treated include adenocarcinoma of the breast, prostate, and colon; all forms of bronchogenic carcinoma of the lung; myeloid leukemia; melanoma; hepatoma; neuroblastoma; papilloma; apudoma; choristoma; branchioma; malignant carcinoid syndrome; carcinoid heart disease; and carcinoma (*e.g.*, Walker, basal cell, basosquamous, Brown-Pearce, ductal, Ehrlich tumor, Krebs 2, Merkel cell, mucinous, non-small cell lung, oat cell, papillary, scirrhous, bronchiolar, bronchogenic, squamous cell, and transitional cell). Additional types of cancers that may be treated include histiocytic disorders; malignant histiocytosis; leukemia; Hodgkin's disease; immunoproliferative small; non-Hodgkin's lymphoma; plasmacytoma; reticuloendotheliosis; melanoma; chondroblastoma; chondroma; chondrosarcoma;

fibroma; fibrosarcoma; giant cell tumors; histiocytoma; lipoma; liposarcoma; mesothelioma; myxoma; myxosarcoma; osteoma; osteosarcoma; chordoma; craniopharyngioma; dysgerminoma; hamartoma; mesenchymoma; mesonephroma; myosarcoma; ameloblastoma; cementoma; odontoma; teratoma; thymoma; trophoblastic tumor. Further, the following types of cancers are also contemplated as amenable to treatment: adenoma; cholangioma; cholesteatoma; cyclindroma; cystadenocarcinoma; cystadenoma; granulosa cell tumor; gynandroblastoma; hepatoma; hidradenoma; islet cell tumor; Leydig cell tumor; papilloma; sertoli cell tumor; theca cell tumor; leimyoma; leiomyosarcoma; myoblastoma; myomma; myosarcoma; rhabdomyoma; rhabdomyosarcoma; ependymoma; ganglioneuroma; glioma; medulloblastoma; meningioma; neurilemmoma; neuroblastoma; neuroepithelioma; neurofibroma; neuroma; paraganglioma; paraganglioma nonchromaffin. The types of cancers that may be treated also include angiokeratoma; angiolymphoid hyperplasia with eosinophilia; angioma sclerosing; angiomatosis; glomangioma; hemangioendothelioma; hemangioma; hemangiopericytoma; hemangiosarcoma; lymphangioma; lymphangiomyoma; lymphangiosarcoma; pinealoma; carcinosarcoma; chondrosarcoma; cystosarcoma phyllodes; fibrosarcoma; hemangiosarcoma; leiomyosarcoma; leukosarcoma; liposarcoma; lymphangiosarcoma; myosarcoma; myxosarcoma; ovarian carcinoma; rhabdomyosarcoma; sarcoma; neoplasms; nerofibromatosis; and cervical dysplasia.

Exemplifying the variety of hyperproliferative disorders amenable to Key-ChEM or T-ChARM therapy are B-cell cancers, including B-cell lymphomas (such as various forms of Hodgkin's disease, non-Hodgkins lymphoma (NHL) or central nervous system lymphomas), leukemias (such as acute lymphoblastic leukemia (ALL), chronic lymphocytic leukemia (CLL), Hairy cell leukemia, B cell blast transformation of chronic myeloid leukemia) and myelomas (such as multiple myeloma). Additional B cell cancers include small lymphocytic lymphoma, B-cell prolymphocytic leukemia, lymphoplasmacytic lymphoma, splenic marginal zone lymphoma, plasma cell myeloma, solitary plasmacytoma of bone, extraosseous plasmacytoma, extra-nodal marginal zone B-cell lymphoma of mucosa-associated (MALT) lymphoid tissue, nodal marginal zone B-cell lymphoma, follicular lymphoma, mantle cell lymphoma, diffuse large B-cell lymphoma, mediastinal (thymic) large B-cell lymphoma, intravascular large B-cell lymphoma, primary effusion lymphoma, Burkitt's lymphoma/leukemia, B-cell proliferations of uncertain malignant potential, lymphomatoid granulomatosis, and post-transplant lymphoproliferative disorder.

Inflammatory and autoimmune diseases include arthritis, rheumatoid arthritis, juvenile rheumatoid arthritis, osteoarthritis, polychondritis, psoriatic arthritis, psoriasis, dermatitis, polymyositis/dermatomyositis, inclusion body myositis, inflammatory myositis, toxic epidermal necrolysis, systemic scleroderma and sclerosis, CREST syndrome, inflammatory bowel disease, Crohn's disease, ulcerative colitis, respiratory distress syndrome, adult respiratory distress syndrome (ARDS), meningitis, encephalitis, uveitis, colitis, glomerulonephritis, allergic conditions, eczema, asthma, conditions involving infiltration of T cells and chronic inflammatory responses, atherosclerosis, autoimmune myocarditis, leukocyte adhesion deficiency, systemic lupus erythematosus (SLE), subacute cutaneous lupus erythematosus, discoid lupus, lupus myelitis, lupus cerebritis, juvenile onset diabetes, multiple sclerosis, allergic encephalomyelitis, neuromyelitis optica, rheumatic fever, Sydenham's chorea, immune responses associated with acute and delayed hypersensitivity mediated by cytokines and T-lymphocytes, tuberculosis, sarcoidosis, granulomatosis including Wegener's granulomatosis and Churg-Strauss disease, agranulocytosis, vasculitis (including hypersensitivity vasculitis/angiitis, ANCA and rheumatoid vasculitis), aplastic anemia, Diamond Blackfan anemia, immune hemolytic anemia including autoimmune hemolytic anemia (AIHA), pernicious anemia, pure red cell aplasia (PRCA), Factor VIII deficiency, hemophilia A, autoimmune neutropenia, pancytopenia, leukopenia, diseases involving leukocyte diapedesis, central nervous system (CNS) inflammatory disorders, multiple organ injury syndrome, myasthenia gravis, antigen-antibody complex mediated diseases, anti-glomerular basement membrane disease, anti-phospholipid antibody syndrome, allergic neuritis, Behcet disease, Castleman's syndrome, Goodpasture's syndrome, Lambert-Eaton Myasthenic Syndrome, Reynaud's syndrome, Sjorgen's syndrome, Stevens-Johnson syndrome, solid organ transplant rejection, graft versus host disease (GVHD), bullous pemphigoid, pemphigus, autoimmune polyendocrinopathies, seronegative spondyloarthropathies, Reiter's disease, stiff-man syndrome, giant cell arteritis, immune complex nephritis, IgA nephropathy, IgM polyneuropathies or IgM mediated neuropathy, idiopathic thrombocytopenic purpura (ITP), thrombotic throbocytopenic purpura (TTP), Henoch-Schonlein purpura, autoimmune thrombocytopenia, autoimmune disease of the testis and ovary including autoimmune orchitis and oophoritis, primary hypothyroidism; autoimmune endocrine diseases including autoimmune thyroiditis, chronic thyroiditis (Hashimoto's Thyroiditis), subacute thyroiditis, idiopathic hypothyroidism, Addison's disease, Grave's disease, autoimmune polyglandular syndromes (or polyglandular endocrinopathy syndromes), Type I diabetes also referred to as insulin-dependent

diabetes mellitus (IDDM) and Sheehan's syndrome; autoimmune hepatitis, lymphoid interstitial pneumonitis (HIV), bronchiolitis obliterans (non-transplant), non-specific interstitial pneumonia (NSIP), Guillain-BarréSyndrome, large vessel vasculitis (including polymyalgia rheumatica and giant cell (Takayasu's) arteritis), medium vessel vasculitis (including Kawasaki's disease and polyarteritis nodosa), polyarteritis nodosa (PAN) ankylosing spondylitis, Berger's disease (IgA nephropathy), rapidly progressive glomerulonephritis, primary biliary cirrhosis, Celiac sprue (gluten enteropathy), cryoglobulinemia, cryoglobulinemia associated with hepatitis, amyotrophic lateral sclerosis (ALS), coronary artery disease, familial Mediterranean fever, microscopic polyangiitis, Cogan's syndrome, Whiskott-Aldrich syndrome and thromboangiitis obliterans.

In particular embodiments, a method of treating a subject with the Key-ChEM or T-ChARM as disclosed herein include acute myelocytic leukemia, acute lymphocytic leukemia, and chronic myelocytic leukemia.

Infectious diseases include those associated with infectious agents and include any of a variety of bacteria (*e.g.*, pathogenic *E. coli, S. typhimurium, P. aeruginosa, B. anthracis, C. botulinum, C. difficile, C. perfringens, H. pylori, V. cholerae, Listeria spp., Rickettsia spp., Chlamydia spp.*, and the like), mycobacteria, and parasites (including any known parasitic member of the Protozoa). Infectious viruses include eukaryotic viruses, such as adenovirus, bunyavirus, herpesvirus, papovavirus, papillomavirus (*e.g.*, HPV), paramyxovirus, picornavirus, rhabdovirus (*e.g.*, Rabies), orthomyxovirus (*e.g.*, influenza), poxvirus (*e.g.*, Vaccinia), reovirus, retrovirus, lentivirus (*e.g.*, HIV), flavivirus (*e.g.*, HCV, HBV) or the like. In certain embodiments, infection with cytosolic pathogens whose antigens are processed and displayed with MHC Class I molecules, are treated with Key-ChEM or T-ChARM of this disclosure.

A Key-ChEM or T-ChARM of this disclosure may be administered to a subject in cell-bound form (*e.g.*, gene therapy of target cell population (mature T cells (*e.g.*, $CD8^+$ or $CD4^+$ T cells) or other cells of T cell lineage)). In a particular embodiment, cells of T cell lineage expressing Key-ChEM or T-ChARM administered to a subject are syngeneic, allogeneic, or autologous cells. In other embodiments, Key-ChEM or T-ChARM may be administered to a subject in soluble form. Soluble TCRs are known in the art (*see*, *e.g.*, Molloy *et al.*, *Curr. Opin. Pharmacol. 5*:438, 2005; U.S. Patent No. 6,759,243).

Pharmaceutical compositions including Key-ChEM or T-ChARM of this disclosure may be administered in a manner appropriate to the disease or condition to be treated (or prevented) as determined by persons skilled in the medical art. An

appropriate dose, suitable duration, and frequency of administration of the compositions will be determined by such factors as the condition of the patient, size, type and severity of the disease, particular form of the active ingredient, and the method of administration. The present disclosure provides pharmaceutical compositions comprising cells expressing a Key-ChEM or T-ChARM as disclosed herein and a pharmaceutically acceptable carrier, diluents, or excipient. Suitable excipients include water, saline, dextrose, glycerol, or the like and combinations thereof.

An advantage of the instant disclosure is that Key-ChEM or T-ChARM expressing cells administered to a patient can be depleted using the cognate binding partner to a tag cassette. In certain embodiments, the present disclosure provides a method for depleting a T cell expressing a Key-ChEM or T-ChARM by using an antibody specific for the tag cassette, using a cognate binding partner specific for the tag cassette, or by using a second T cell expressing a CAR and having specificity for the tag cassette. In certain embodiments, a tag cassette allows for immunodepletion of a T cell expressing a Key-ChEM or T-ChARM of this disclosure. Elimination of engineered T cells may be accomplished using depletion agents specific for a tag cassette. For example, if a Strep tag is used, then an anti-Strep tag antibody, anti-Strep tag scFv, or Streptactin each fused to or conjugated to a cell-toxic reagent (such as a toxin, radiometal) may be used, or an anti-Strep tag /anti-CD3 bispecific scFv, or an anti-Strep tag CAR T cell may be used.

In certain other embodiments, cells expressing a Key-ChEM or T-ChARM of this disclosure can be identified, sorted, enriched or isolated by binding to antibodies having specificity to a tag cassette (*e.g.*, anti-tag antibodies), or by other proteins that specifically bind a tag cassette (*e.g.*, Streptactin binding to the Strep tag), which are conjugated to beads, a cell culture plate, agarose, or any other solid surface matrix. In certain embodiments, such cells are sorted, enriched or isolated by using an affinity column.

In certain embodiments, the present disclosure provides a method for selectively activating a T cell by contacting a non-natural or recombinant T cell expressing a Key-ChEM or T-ChARM with a binding domain specific for a tag cassette and attached to a solid surface or as part of a biocompatible matrix (*e.g.*, alginate, basement membrane matrix (Matrigel®), biopolymer). The recombinant T cell comprises an exogenous nucleic acid molecule encoding a Key-ChEM or T-ChARM fusion protein of this disclosure. For example, a T cell expressing a Key-ChEM or T-ChARM may be activated with beads coated or conjugated with a cognate binding partner (*e.g.*, antibody) specific for the tag cassette. For example, if the tag cassette is a Strep tag,

then StrepTactin coated beads or anti-Strep tag antibody conjugated beads can be used to induce T cell activation. In certain embodiments, the method comprises activating *ex vivo* recombinant T cells expressing a Key-ChEM or T-ChARM of this disclosure and is optionally further expressing a chimeric antigen receptor (CAR). Such activated T cells are useful in the disease treatment methods described herein.

In another aspect, the present disclosure provides a method for selectively promoting proliferation of a recombinant T cell expressing a Key-ChEM or T-ChARM of this disclosure. In certain embodiments, the method comprises selective *ex vivo* proliferation of T cells expressing a Key-ChEM or T-ChARM using a tag binding partner, such as an antibody. In further embodiments, the method comprises expanding functional T cells (*e.g.*, virus-specific, TAA (tumor-associated antigen) specific CTL, or specific T cell subsets, such as naïve T cells, memory stem T cells, central or effector memory T cells, CD4+ CD25+ regulatory T cells) with a tag binding partner, such as an antibody, which may optionally be done in the presence of a costimulatory molecule binding partner (such as an anti-CD27 or antiCD28 antibody). In certain embodiments, anti-tag binding partners may be used to activate a Key-ChEM (*e.g.*, a Wnt or Notch Key-ChEM) transduced hematopoietic stem cell, embryonic stem cell, or tissue stem cell (*e.g.*, neural stem cell) to self-renew, proliferate or differentiate into one or more desired phenotype for therapeutic use.

In still further embodiments, a Key-ChEM or T-ChARM allows for selective promotion of T cell proliferation *in vivo* when expressing a Key-ChEM or T-ChARM of this disclosure. In certain embodiments, a T cell expressing a CAR comprising a tag cassette allows for expansion of the CAR T cells *in vivo* when contacting cells expressing a ligand (*e.g.*, including T cell suppressor cell ligands PD-L1, PD-L2). Such expanded T cells are useful in the disease treatment methods described herein. In certain embodiments, proliferation or expansion of cells expressing Key-ChEM or T-ChARM as disclosed herein is induced *in vivo*, which may be induced with a tag cassette binding partner (such as an anti-tag antibody) and optionally a costimulatory molecule binding partner (such as an anti-CD27 or antiCD28 antibody).

In certain further embodiments, cells expressing Key-ChEM or T-ChARM as disclosed herein are activated *in vivo*, such as at the site of a tumor. For example, a composition (*e.g.*, alginate, basement membrane matrix (Matrigel®), biopolymer, or other matrix) or a carrier (*e.g.,* microbead, nanoparticle, or other solid surface) comprising a tag cassette binding partner (such as an anti-tag antibody) and a costimulatory molecule binding partner (such as an anti-CD27 or antiCD28 antibody)

may be used to locally activate at the site of a tumor (*e.g.*, a solid tumor) a T cell expressing a Key-ChEM or T-ChARM as disclosed herein.

In certain embodiments, recombinant cells expressing a Key-ChEM or T-ChARM may be detected or tracked *in vivo* by using antibodies that bind with specificity to a tag cassette (*e.g.*, anti-Tag antibodies), or by other cognate binding proteins that specifically bind the tag cassette sequence (*e.g.*, Streptactin binding to Strep tag), which binding partners for the tag cassette are conjugated to a fluorescent dye, radio-tracer, iron-oxide nanoparticle or other imaging agent known in the art for detection by X-ray, CT-scan, MRI-scan, PET-scan, ultrasound, flow-cytometry, near infrared imaging systems, or other imaging modalities (*see*, *e.g.*, Yu *et al.*, *Theranostics* *2*:3, 2012).

In further embodiments, cells expressing Key-ChEM or T-ChARM of the instant disclosure may be used in diagnostic methods or imaging methods, including methods used in relation to the indications or conditions identified herein.

EXAMPLES

EXAMPLE 1
KEY-CHIMERIC EFFECTOR MOLECULES (KEY-CHEMS) AND TAGGED CHIMERIC ANTIGEN RECEPTOR MOLECULES (T-CHARMS), AND DERIVATIVES THEREOF

Exemplary chimeric fusion proteins containing one or more affinity tag cassettes are illustrated in Figure 1. The tag cassettes are generally small (*i.e.*, minimally immunogenic or non-immunogenic) and do not associate with or bind to any molecules endogenous to a host or host cell. The tags do specifically bind to a heterologous cognate receptor (*e.g.*, ligand, antibody, or other binding partner), which binding can be used in the context of these chimeric effector molecules (ChEMs) as a "key" to access and manipulate (*i.e.*, turn on or off or modulate) any of a variety of cellular pathways (referred to herein as a Key-ChEMs). These tagged chimeric fusion proteins may further comprise a binding domain specific for a particular target (*e.g.*, a tumor antigen). For example, the tagged chimeric fusion proteins include chimeric antigen receptor molecules (referred to herein as T-ChARMs).

An exemplary nucleic acid molecule encoding a Key-ChEM (Figure 1A) comprises the following elements (5' to 3'): Strep tag® II (SEQ ID NO.:38 encoding peptide Trp-Ser-His-Pro-Gln-Phe-Glu-Lys as set forth in SEQ ID NO.:1), a connector portion including a linker module (SEQ ID NO.:42 encoding peptide (Gly-Gly-Gly-

Gly-Ser)$_2$ as set forth in SEQ ID NO.:11) and a modified IgG4 hinge (SEQ ID NO.:27 encoding peptide Glu-Ser-Lys-Tyr-Gly-Pro-Pro-Cys-Pro-Pro-Cys-Pro as set forth in SEQ ID NO.:15), a CD28 transmembrane domain (SEQ ID NO.:27 encoding a peptide as set forth in SEQ ID NO.:16), and an intracellular component comprising an effector domain comprising a 4-1BB portion (SEQ ID NO.:29 encoding a peptide as set forth in SEQ ID NO.:17) and a CD3ζ portion (SEQ ID NO.:30 encoding a peptide as set forth in SEQ ID NO.:18; Kowolik *et al.*, *Cancer Res.66*:10995, 2006). This Key-ChEM (single tag) encoding nucleic acid molecule was cloned into an epHIV7 lentiviral vector, as described by Yam *et al.* (*Mol. Ther. 5*:479, 2002) and Wang *et al.* (*Blood 118*:1255, 2011).

The epHIV7 lentiviral vector was derived from the pHIV7 vector by replacing the cytomegalovirus promoter of pHIV7 with an EF-1 promoter (Wang *et al.*, 2011; Yam *et al.*, 2002). The lentiviral vector also encodes a truncated human EGFR polypeptide (huEGFRt) that is devoid of extracellular N-terminal ligand binding domains and intracellular receptor tyrosine kinase activity but retains the native amino acid sequence, type I transmembrane cell surface localization, and a conformationally intact binding epitope for anti-EGFR monoclonal antibody, cetuximab (Wang *et al.*, 2011). The lentiviral vectors coordinately express a Key-ChEM and huEGFRt separated by a self-cleaving *T2A* sequence (Szymczak *et al.*, *Nat. Biotechnol. 22*:589, 2004), wherein the huEGFRt serves as an alternative selection epitope for Key-ChEM positive cells by using biotinylated cetuximab in conjunction with anti-biotin immunomagnetic microbeads.

An exemplary nucleic acid molecule encoding a T-ChARM (Figure 1E) comprises the following elements: a scFv containing VH and VL gene segments of the CD19-specific FMC63 monoclonal antibody (SEQ ID NO.:36; Wang *et al.*, 2011), a Strep tag® II (SEQ ID NO.:38, encoding peptide Trp-Ser-His-Pro-Gln-Phe-Glu-Lys as set forth in SEQ ID NO.:1), a connector portion including a linker module (SEQ ID NO.:39, 40, or 41, encoding peptide (Gly-Gly-Gly-Gly-Ser)$_2$ as set forth in SEQ ID NO.:11) and an IgG4 hinge (SEQ ID NO.:27), a CD28 transmembrane domain (SEQ ID NO.:28), and an intracellular component comprising an effector domain comprising a 4-1BB portion (SEQ ID NO.:29) and a CD3ζ portion (SEQ ID NO.:30). An exemplary T-ChARM comprising two tags (T-ChARM^2) differs from the single tag T-ChARM (T-ChARM^1) by including a second linker module (encoding peptide (Gly-Gly-Gly-Ser)$_2$-Gly-Gly-Ser as set forth in SEQ ID NO.:12) between first and second Strep tags. An exemplary T-ChARM comprising three tags (T-ChARM^3) differs from the double tag T-ChARM by including a third linker module (encoding peptide (Gly-Gly-Gly-Gly-

Ser)$_2$ as set forth in SEQ ID NO.:11) between second and third Strep tags. In certain embodiments, an scFv includes VH and VL regions of the ROR1-specific R12 monoclonal antibody (Yang *et al.*, *PLoS One 6*:e21018, 2011) as set forth in SEQ ID NO.:57) and a variable domain linker as set forth in SEQ ID NO.:13. In addition, both anti-CD19 and anti-ROR1 T-ChARMs were alternatively constructed with an intracellular component comprising an effector domain comprising a CD28 portion (SEQ ID NO.:35) in place of a 4-1BB portion.

In certain embodiments, any of the fusion proteins described herein comprise from amino-terminus to carboxy-terminus: an extracellular scFv or scTCR binding domain, a tag cassette, a connector region comprising an IgG hinge, a transmembrane domain, and an intracellular component comprising an effector domain. In some embodiments, an effector domain comprises a pairing of 4-1BB and CD3ζ, CD27 and CD3ζ, CD28 and CD3ζ, OX40 and CD3ζ, CD28, 4-1BB and CD3ζ, OX40, 4-1BB and CD3ζ, or CD28, OX40 and CD3ζ. As defined herein, an effector domain for any of these molecules may the entire intracellular portion or may include only a effector portion of the selected molecule.

An exemplary nucleic acid molecule encoding a T-ChARM (^{N1}ChARM; Figure 1F; SEQ ID NO.:58) having an N-terminal tag comprises the following elements: a secretory signal sequence (SEQ ID NO.:63, encoding peptide MLLLVTSLLLCELPHPAFLLIP as set forth in SEQ ID NO.:47, which is cleaved from the mature protein), an asparagine junction amino acid, a Strep tag® II (SEQ ID NO.:38, encoding peptide Trp-Ser-His-Pro-Gln-Phe-Glu-Lys as set forth in SEQ ID NO.:1), a linker module (SEQ ID NO.:42, encoding peptide (Gly-Gly-Gly-Gly-Ser)$_2$ as set forth in SEQ ID NO.:11), scFv of the VH and VL gene segments of the CD19-specific FMC63 monoclonal antibody (SEQ ID NO.:36; Wang *et al.*, 2011), an IgG4 hinge (SEQ ID NO.:27), a CD28 transmembrane domain (SEQ ID NO.:28), and an intracellular component comprising an effector domain comprising a 4-1BB portion (SEQ ID NO.:29) and a CD3ζ portion (SEQ ID NO.:30).

An exemplary nucleic acid molecule encoding a T-ChARM (Ch^{1}ARM; Figure 1G; SEQ ID NO.:59) having a tag imbedded in the variable region linker comprises the following elements: a secretory signal sequence (SEQ ID NO.:63, encoding peptide MLLLVTSLLLCELPHPAFLLIP as set forth in SEQ ID NO.:47, which is cleaved from the mature protein), the VH gene segment of CD19-specific FMC63 monoclonal antibody (encoding the amino acid sequence as set forth in SEQ ID NO.:51), a first linker module (encoding peptide Gly-Gly-Ser-Gly-Ser-Gly as set forth in SEQ ID NO.:65), an asparagine junction amino acid, a Strep tag® II (SEQ ID NO.:38, encoding

peptide Trp-Ser-His-Pro-Gln-Phe-Glu-Lys as set forth in SEQ ID NO.:1), a second linker module (encoding peptide Gly-Ser-Gly-Ser-Gly as set forth in SEQ ID NO.:66), the VL gene segment of CD19-specific FMC63 monoclonal antibody (encoding the amino acid sequence as set forth in SEQ ID NO.:52), an IgG4 hinge (SEQ ID NO.:27), a CD28 transmembrane domain (SEQ ID NO.:28), and an intracellular component comprising an effector domain comprising a 4-1BB portion (SEQ ID NO.:29) and a CD3ζ portion (SEQ ID NO.:30).

Nucleic acid molecules encoding each of these exemplary T-ChARM (*e.g.*, single, double or triple tagged, N-terminal tagged, imbedded tag, indicated scFvs) were individually cloned into an epHIV7 lentiviral vector, as described by Yam *et al.* (*Mol. Ther. 5*:479, 2002), and used to transduce T cells as described in the examples herein. In certain embodiments, the nucleic acid molecules encoding Key-ChARMs of the instant disclosure were codon optimized before cloning into the epHIV7 lentiviral vector. The T-ChARM-encoding lentivirus supernatants were produced in 293T cells co-transfected with each of the lentiviral vector plasmids and the packaging vectors pCHGP-2, pCMV-Rev2 and pCMV-G using Calphos transfection reagent (Clontech, Mountain View, CA). Medium was changed 16 hours post transfection, and lentivirus collected after 24, 48 and 72 hours.

EXAMPLE 2

PRODUCTION OF RECOMBINANT T CELLS AND EXPRESSION OF T-CHARMS

CD8+ and CD4+ were isolated from PBMC of normal donors using CD8+/CD4+ T Cell Isolation Kit (Miltenyi Biotec), activated with anti-CD3/CD28 beads (Life Technologies) according to the manufacturer's instructions, and transduced with a lentiviral supernatant (as indicated in each Example) (MOI = 3) supplemented with 0.8 μg/mL polybrene (Millipore, Bedford, MA) on day 3 after activation by centrifugation at 2,100 rpm for 45 min at 32°C. T cells were expanded in RPMI, 10% human serum, 2 mM L-glutamine and 1% penicillin-streptomycin (CTL medium), supplemented with recombinant human (rh) IL-2 to a final concentration of 50 U/mL every 48 hours. After expansion, an aliquot of each transduced T cell line was stained with biotin-conjugated anti-EGFR antibody and streptavidin-PE (Miltenyi, Auburn, CA). The tEGFR+ T cells were isolated by sorting on a FACS-Aria cell sorter (Becton Dickinson). The tEGFR+ T cell subset was then stimulated with irradiated (8,000 rad) CD19+ B-LCL at a T cell:LCL ratio of 1:7, and expanded for 8 days in CTL medium

with addition of 50 U/mL rh IL-2 every 48 hours or using a rapid expansion protocol for R12 T-ChARMs (Riddell and Greenberg, *J. Immunol. Methods 128*:189, 1990).

The following conjugated antibodies were used for flow cytometric phenotyping and analysis: CD4, CD8, CD25, CD137, CD45, Annexin V, CD62L, CD27, CD28 (BD Biosciences), anti-Streptag II antibody (Genscript), EGFR antibody (ImClone Systems Incorporated, Branchburg, NJ); strepTavidin-PE (BD Biosciences, San Jose, CA). Staining with propidium iodide (PI, BD Biosciences) was performed for live/dead cell discrimination as directed by the manufacturer. Flow analyses were done on a FACS Canto II, sort-purifications on a FACS AriaII (Becton Dickinson, Franklin Lakes, NJ) and data analyzed using FlowJo software (Treestar, Ashland, OR).

To examine cell surface expression of T-ChARMs, transduced T cells were sorted for EGFRt expression and evaluated by staining with fluorochrome labeled anti-Streptag mAb. The mean fluorescence intensity (MFI) of EGFR staining was similar on T cells transduced with each of the T-ChARMs and the CD19-Short CAR, which indicates that introducing a tag into a CAR to produce a ChARM did not interfere with transgene expression (Figure 21). An anti-Streptag mAb specifically stained T cells transduced with the various T-ChARMs, independent of the position or number of tag sequences in each ChARM. The MFI of anti-Streptag staining was higher for T cells transduced with T-ChARM^2 and T-ChARM^3 as compared to T-ChARM^1, presumably due to more sites on each T-ChARM^2 and T-ChARM^3 for binding the antibody-fluorochrome conjugate (Figure 21).

EXAMPLE 3
CYTOLYTIC ACTIVITY OF T CELLS EXPRESSING T-CHARMS

The *in vitro* effector function of CD8+ bulk T cells engineered to express anti-CD19 (scFv) T-ChARM^1, T-ChARM^2, or T-ChARM^3 were compared to the effector function of T cells engineered to express anti-CD19 CARs containing connector regions of different lengths – an IgG4 hinge only (short), an IgG4 CH3 and hinge (intermediate), and an IgG4 CH2CH3 and hinge (long), respectively – in a chromium release assay. Briefly, target cells were labeled with ^{51}Cr (PerkinElmer, Norwalk, CT) overnight, washed and incubated in triplicate at 1-2 x 10^3 cells/well with effector T cells at various effector to target (E:T) ratios. Supernatants were harvested for γ-counting after incubating for 4 hours and specific lysis calculated using a standard formula. The target cells used were Raji/ROR1 (naturally CD19+, transduced to express unrelated antigen ROR1) and K562/CD19 (transduced to express CD19), with K562/ROR1

(naturally CD19-, transduced to express unrelated antigen ROR1) used as a negative control and LCL-OKT3 cells (transduced to express cell surface anti-CD3) used as a positive control. Lymphoblastoid cell line (LCL) cells engineered to express a membrane bound anti-CD3 scFv (LCL-OKT3) was used as a reference standard for the maximal activation potential of a T cell line since these OKT3 expressing cells activate T cells by binding the CD3 complex.

T cells expressing each of the different anti-CD19 T-ChARM and CAR constructs were not cytotoxic for K562/ROR1 cells (Figure 2C), but were activated to be cytolytic in the presence of the anti-CD3 expressing LCL/OKT3 cells (Figure 2D). Moreover, the T-ChARM or CAR expressing T cells conferred specific cytolytic activity against CD19+ cells, Raji cells (Figure 2B) and K562/CD19 (Figure 2A). Similar results were obtained when the tag was located at the amino-terminus of the T-ChARM (^{N1}ChARM) or imbedded in the scFv (VH-tag-VL; Ch^{1}ARM) (*see* Figure 22). In addition, the efficiency of lysis was not affected by effector domain (CD28 instead of 4-1BB; *see* Figure 23A), binding domain (anti-ROR1 instead of anti-CD19; *see* Figure 23B), or the tag used (Figure 32 shows the cytolytic effect of a Myc tagged ChARM). The T-ChARM expressing cells killed tumor cells as efficiently as the CARs containing the short, intermediate and long IgG4 Fc spacers.

EXAMPLE 4

CYTOKINE RELEASE BY T CELLS EXPRESSING T-CHARMS CO-CULTURED WITH K562 CELLS

For analysis of cytokine secretion, effector (E) cells (T cells expressing anti-CD19 T-ChARMs and CARs) and target (T) cells (K562/CD19 and K562/ROR1, negative control) were co-cultured in triplicate at an E:T ratio of 4:1, incubated 24 hours, and then the supernatants were measured for GM-CSF,IFN-γ, IL-2, and TNF-α levels using a multiplex cytokine immunoassay (Luminex®).

The results (Figure 3D) show that cells expressing anti-CD19 CARs with a short connector region produce larger amounts of cytokine after engaging target cells than T cells expressing anti-CD19 CARs with intermediate or long connector regions. A similar pattern was observed with anti-CD19 T-ChARM expressing cells, wherein (Figure 3A) T-ChARM^{1} cells having a shorter linker and a single tag produce greater amounts of cytokine after engaging target cells than T-ChARM^{2} or T-ChARM^{3} cells having two tags and three tags, respectively. The levels of cytokines produced were similar for the anti-CD19 T-ChARM and anti-CD19 CAR cells, although the

T-ChARM expressing cells induced a significantly higher level of IFN-γ production than did the CAR expressing cells. Figures 3B and 3E show that cytokine production was not induced in K562 cells that do not express CD19. Figures 3C and 3F show the results from the positive control, which is stimulation with PMA / Ionomycin. Similar results were observed when examining ^{N1}ChARM and Ch^{1}ARM constructs (*see* Figure 24). In addition, the hierarchy of cytokine production and proliferation of T cells transduced with the anti-CD19 ChARM was independent of the co-stimulatory domain (4-1BB or CD28) used in the ChARM (Figure 25).

EXAMPLE 5

CYTOKINE RELEASE BY T CELLS EXPRESSING T-CHARM MOLECULES CO-CULTURED WITH RAJI B CELL LYMPHOMA CELLS

T cells expressing various anti-CD19 T-ChARMs or CARs were co-cultured with CD19+ Raji cells for 24 hours and the supernatants were examined in a multiplex cytokine assay (Luminex®). For analysis of cytokine secretion, effector (E) cells (T cells expressing anti-CD19 T-ChARMs and CARs) and target (T) cells (Raji) were co-cultured in triplicate at an E:T ratio of 2:1, incubated 24 hours, and then the supernatants were measured for GM-CSF,IFN-γ, IL-2, and TNF-α levels using a multiplex cytokine immunoassay (Luminex®).

The results indicate that T cells expressing anti-CD19 T-ChARMs with one, two or three tag cassettes were able to produce much higher levels of IFN-γ and GM-CSF when co-cultured with Raji cells (Figure 4A) as compared to T cells expressing any of the conventional anti-CD19 CARs (Figure 4B).

EXAMPLE 6

PROLIFERATION OF T CELLS EXPRESSING T-CHARM MOLECULES

For analysis of cell proliferation, T cells expressing anti-CD19 T-ChARMs or CARs were labeled with 0.2 μM carboxyfluorescein succinimidyl ester (CFSE, Invitrogen), which binds to intracellular proteins and makes the cells visible by flow cytometry in the FITC channel. After labeling, the cells were washed and plated in triplicate with stimulator cells at a ratio of 4:1 (K562/CD19 or K562/ROR1, negative control) in CTL medium without exogenous cytokines. After incubating 72 hours, cells were labeled with PI to exclude dead cells from the analysis. Samples were analyzed by flow cytometry and cell division of live CD3+ T cells was assessed by the degree of

CFSE dilution (*i.e.*, dye dilution is an indicator of proliferation since the strength of label is diluted by half with each cell division).

For analysis, triplicate wells were pooled and proliferation of live CD8+ T cells was measured. The left-most column is a forward scatter/side scatter plot of the total number of cells, the middle column is a plot gated on CD8+ T cells, and the right-most column is a histogram showing CFSE dilution in the $CD8^+$ T cell subset (increased dilution to the left). The red peak in the right-most column indicates no cell division, and the blue peaks represent indicate ≥3, 2, or 1 cell division and the three numbers in each of the histograms indicate the percent of cells that have diluted CFSE and undergone more than 3, 2, or 1 cell division, respectively. The histogram shows that T-ChARM and CAR expressing T cells proliferated vigorously during the 72 hours after co-culture stimulation with K562/CD19 cells (blue), but not with the negative control cells K562/ROR1 (red) (Figure 5). The average number of cell divisions was higher in $T\text{-}ChARM^1$ and $T\text{-}ChARM^2$ expressing T cells as compared to either $T\text{-}ChARM^3$ or CAR(long) expressing T cells. Similarly, the level of proliferation was independent of the co-stimulatory domain (4-1BB or CD28) used in the ChARM (Figure 26) and independent of the tag used (Figure 31 shows equal proliferation when a Myc tag is used).

EXAMPLE 7

IN VIVO ADOPTIVE TRANSFER OF T CELLS EXPRESSING T-CHARM MOLECULES

Six- to eight-week old female NOD.CB17-Prkdcscid/J (NOD/SCID) or NOD.Cg-$Prkdc^{scid}Il2rg^{tm1Wjl}$/SzJ (NSG) mice were obtained from Jackson Laboratory or bred in-house. Mice were injected intravenously (i.v.) with $0.5x10^6$ Raji lymphoma tumor cells transfected with firefly luciferase (Raji-ffluc) via the tail vein and tumor engraftment was allowed to occur for 6 days. On day 7, mice received a single intra-venous (i.v.) injection of 5×10^6 of T cells transduced with one of anti-CD19 (scFv) $T\text{-}ChARM^1$, $T\text{-}ChARM^2$, $T\text{-}ChARM^3$, CAR (short), CAR (medium), and CAR (long) human T cells. To verify tumor engraftment, bioluminescence imaging was performed on day 6 after Raji-ffluc inoculation (Figure 6A). To monitor anti-tumor activity of the adoptive T cell therapy, bioluminescence imaging was performed on day 7 (Figure 6B), day 11 (Figure 6C), day 18 (Figure 6D), and day 26 (Figure 6E) after T cell administration.

For bioluminescence imaging of tumor cells, mice received intraperitoneal (i.p.) injections of luciferin substrate (CaliperLife Sciences, Hopkinton, MA) resuspended in

PBS (15 μg/g body weight). Mice were anesthetized with isoflurane in an induction chamber and imaged using an Xenogen IVIS In Vivo Imaging System (Caliper Life Sciences) 10, 12 and 14 minutes after the injection of luciferin in small binning mode at an acquisition time of 1 second -1 minute to obtain unsaturated images. Luciferase activity was analyzed using Living Image Software (Caliper Life Sciences) and photon flux was analyzed within regions of interest that encompassed the entire body of each individual mouse.

The bioluminescence images show that T cells expressing anti-CD19 T-ChARM^1, T-ChARM^2, or T-ChARM^3 eradicated tumor as efficiently as T cells expressing anti-CD19 CAR (short) or CAR (intermediate), while the T cells expressing CAR (long) were not very effective for this particular construct and/or target (Figure 6).

EXAMPLE 8

IN VIVO PERSISTENCE OF T CELLS EXPRESSING T-CHARM MOLECULES

A cohort of NSG mice bearing Raji tumors were treated with 5 x 10^6 anti-CD19 CAR/huEGFRt or T-ChARM/huEGFRt expressing human T cells, and 3 weeks later peripheral blood (eye bleeds) was analyzed by flow cytometry using anti-huEGFR, anti-human CD8, and anti-human CD45 monoclonal antibodies. The frequency of CD8+ huEGFRt+ (Wang *et al.*, 2011) T cells is shown as a percentage of live peripheral blood cells in Figure 7. The level of detectable huEGFRt correlates to the level of T-ChARM expressing T cells.

Although anti-CD19 CAR (long) expressing T cells were not consistently prominent after 3 weeks, all other anti-CD19 CAR and T-ChARM expressing T cells were easily detected in the peripheral blood of NSG mice for at least 3 weeks after adoptive transfer and tumor eradication. These results indicate that anti-CD19 CAR and T-ChARM expressing T cells can persist for an extended period of time *in vivo* and mediate antitumor activity.

EXAMPLE 9

IDENTIFICATION OF T CELLS EXPRESSING T-CHARM MOLECULES

Anti-CD19 T-ChARM/huEFRt expressing T cells were stained with EGFR Ab-biotin/StrepTavidin-PE, anti-Strep tag II-FITC, Strep-Tactin®-APC (allophycocyanin), and then analyzed by flow cytometry. Anti-CD19 CAR(short) transduced T cells were used as a control. All of the transduced T-ChARM and anti-CD19 CAR (short) T cells

stained positively with the anti-EGFR mAb indicating they were transduced and expressed the huEGFRT (Figure 8A).

The results show that T-ChARM^2 and T-ChARM^3 transduced T cells could be easily distinguished from non-transduced cells with reagents that stained the tag sequence expressed in the T-ChARM cells (Figure 8B,C). The T-ChARM^1, T-ChARM^2 and T-ChARM^3 transduced T cells, but not the anti-CD19 CAR (short), stained positive with the anti-Strep tag II-FITC antibody (Figure 8B). Those with more copies of the tag sequence had an increased staining signal. The T-ChARM cells also stained with Streptactin APC (Figure 8C), demonstrating that in the case of Strep tag, more than one staining reagent can be used to detect the T cells.

EXAMPLE 10
SORTING T CELLS EXPRESSING T-CHARM MOLECULES

T-ChARM^2 transduced T cells were stained with anti-Strep tag-FITC labeled antibody and then sorted using a benchtop FACS cell sorter (BD FACSAria II cell sorter, BD Biosciences, San Jose, CA). Figure 9 shows the cell populations before sorting (top row) and after sorting (bottom row). The furthest right panel (after sorting) shows that T-ChARM^2 expressing T cells were enriched from a cell population of 15.8% to a cell population that is greater than 99% T-ChARM^2 T cells.

EXAMPLE 11
ENRICHMENT OF T CELLS EXPRESSING T-CHARM MOLECULES USING IMMUNOMAGNETIC SELECTION

Cells were incubated with Streptactin-microbeads or Nanobeads (IBA, Goettingen, Germany), then loaded onto a MACS column (Miltenyi Biotec) in a Magnetic separator. The column was washed 3 times with 3 ml MACS buffer. The column was then removed from the separator and the Streptactin® magnetic beads with the attached T cells expressing the strep tag were flushed out by firmly pushing a plunger into the column. T-ChARM^3 transduced T cells mixed with control T cells were labeled with one of the following types of beads: Strep-Tactin Microbeads 1# (generally used for protein purification, size of about 0.5 to 1.5 μm); Strep-Tactin Microbeads 2# (generally used for cell isolation with Fab Streptamers® [Strep-tagged Fab fragment], size of about 0.5 μm); Strep-Tactin Nanobeads 3# (generally used for cell isolation with MHC I Streptamers [Strep-tagged MHCI monomer], size of about

100 nm); loaded onto a MACS® column (Miltenyi) and inserted into a magnetic separator. The direct effluent and retained fractions were individually stained with an anti-Strep tag-FITC labeled antibody and analyzed by flow cytometry.

The first row of Figure 10 shows cell populations before being applied to a Strep-Tactin bead column, while the second, third and fourth rows of Figure 10 show the cell populations from each sample after passage through bead column 1#, 2#, and 3#, respectively. The second row shows there was some cell loss, which may be due to the size of Strep-Tactin Microbeads 1# not allowing some cells to pass through the column. Overall, the data show that any type of Strep-Tactin bead tested was useful for directly enriching T-ChARM expressing T cells.

EXAMPLE 12
ACTIVATION OF T CELLS EXPRESSING CELL SURFACE T-CHARMS WITH TAG BINDING REAGENTS

T cell activation and proliferation requires two signals mediated through engagement of the T cell antigen-specific receptor (TCR) and a costimulatory signal, most typically binding of CD28 by CD80 and CD86 (Ledbetter *et al.*, *Blood 75*:1531, 1990). Accordingly, anti-CD3/CD28 mAb coated microbeads have been developed to provide both requisite signals, and non-specifically activate and expand T cells for clinical applications (Riddell and Greenberg, 1990). Anti CD3/CD28 stimulation of T cells also facilitates transduction with retroviral or lentiviral vectors that encode CARs, but does not selectively expand transduced T cells.

T cells transduced with anti-CD19 T-ChARM^3 were cultured for 48h in CTL medium with either no treatment (negative control) or with one of the following treatments: (a) Strep-Tactin® Microbeads 1#; (b) Strep-Tactin Microbeads 2#; (c) Strep-Tactin Nanobeads 3#; (d) anti-Strep tag antibody conjugated to protein G beads (size of about 2 μm); (e) anti-Strep tag antibody /anti-CD28 antibody dual conjugated protein G beads, or (f) co-cultured with irradiated TM-LCL cells plus 50 U/ml IL2 (positive control). To determine whether the cells were being activated after culturing for 24h and 48h, cells were examined for the presence of CD25/CD69 using immunofluorescence staining and flow cytometry. T cells express *de novo* activation molecules, including CD69 and CD 25, after activation through the T cell surface receptor or by signaling through a CAR that expresses CD3ζ. CD69 is one of the earliest cell surface activation markers and may be involved with the ongoing activation

process. CD25 synthesis (the IL2 receptor α chain), along with IL2 itself, is induced by T cell activation when initially encountering an antigen.

The data unexpectedly show that Strep tag binding of T-ChARM expressing T cells through either Strep-Tactin or anti-Strep tag antibody coated beads significantly activated these T cells, and further show that bead size may also have an effect on the level of T cell activation (Figure 13).

In further experiments with additional constructs, Strep-Tactin microbeads induced CD25 upregulation on CD8+ (Figure 27A) and CD4+ (Figure 27B) T cells that expressed ChARM^2 and ChARM^3, but not T cells that expressed ChARM^1 or CARs that lacked a tag, indicating that ChARM^1 affinity for binding Strep-Tactin microbeads is suboptimal in ChARM-based T cell activation. But, anti-Strep tag antibody-coated microbeads, which have a binding affinity to Strep tag (K_D = ~10nm) 100 fold higher than Strep-Tactin (K_D = ~1uM), activated various ChARM T cells, independent of the copy number or location of the tag in the ChARM (Figures 27A and B). Notably, Strep-tag binding-mediated activation could be found in both 4-1BB and CD28 ChARM T cells (Figure 27C) and non-CD19 targeting ChARM T cells (Figure 27D, ROR1-targeting R12 ChARM^1).

EXAMPLE 13

PROLIFERATION OF T CELLS EXPRESSING CELL SURFACE T-CHARMS WITH TAG BINDING REAGENTS

Anti-CD19 T-ChARM^1, T-ChARM^2, T-ChARM^3 and CAR (long) (negative control) transduced T cells that were individually cultured in CTL medium with Strep-Tactin® microbeads and 50 U/ml IL2. Microscopy imaging on day 5 reveals that T-ChARM^2 and T-ChARM^3 expressing T cells surprisingly developed large clusters around the beads, indicative of cell proliferation on the Strep-Tactin beads, which was not evident with the anti-CD19 CAR (long) expressing T cells (Figure 11). The T-ChARM^1 expressing T cells showed less expansive cell clusters, but there was clearly cell expansion since there were more cells visible on the plate as compared to the negative control. In further experiments, various different ChARM expressing T cells (including ^{N1}ChARM and Ch^{1}ARM) had proliferation clusters appear within just 48 hours after stimulation with either StrepTactin microbeads or anti-Streptag antibody microbeads (Figure 28). The conventional short spacer CAR T cells (CD19-Hi) were used as negative control.

The growth curve of T-ChARM expressing T cells cultured on Strep-Tactin® microbeads was determined (*see* Figures 12 and 29). A total of about 1 x 10^6 anti-CD19 T-ChARM^1, T-ChARM^2, and T-ChARM^3 transduced T cells were individually plated in CTL medium with Strep-Tactin microbeads, anti-Strep tag mAb, or anti- Strep tag/anti-CD28 mAb coated microbeads (Figure 28) in the presence of 50 U/ml IL2 and 5ng/ml IL15, and cultured for 10 days. Cell numbers for each well was counted at day 3, 6 and 9. The data show that T-ChARM^3 transduced T cells had the highest growth rate over 9 days when stimulated by Strep-Tactin beads. With Strep-Tactin bead stimulation, $CD8^+$ or $CD4^+$ anti-CD19 ChARM-T cells expanded about 20 to about 100-fold, and the greatest expansion was observed in ChARM^3 T cells (Figures 29A and B). Anti-Strep tag and anti-Strep tag /anti-CD28 mAb coated beads induced even greater expansion (100 to 250-fold) in total ChARM T cell numbers, and unlike StrepTactin bead stimulation, $CD8^+$ and $CD4^+$ T cells expressing a ChARM^1 exhibited a trend towards greater expansion than T cells expressing ChARM^2 or ChARM^3. T cells that expressed a CD28 ChARM or anti-ROR1 ChARM were also effectively expanded with anti-Strep tag/anti-CD28 beads, demonstrating the applicability of this approach for expanding ChARM T cells with different co-stimulatory domains and specificity for different tumor targets (data not shown).

In another growth curve assay, a total of about 5 x 10^5 anti-CD19 T-ChARM^3 transduced T cells were plated in CTL medium with 50 U/ml IL2; one of the following beads: (a) Strep-Tactin Microbeads 1#, (b) Strep-Tactin Microbeads 2#, (c) Strep-Tactin Nanobeads 3#, (d) anti-Strep tag antibody conjugated to protein G beads, (e) anti-Strep tag antibody / anti-CD28 antibody dual conjugated protein G beads, or (f) anti-CD3 / anti-CD28 dual antibody beads (positive control); and cultured for 7 days. Cell numbers for each well was counted at day 3, day 5 and day 7. The data show that anti-Strep tag antibody/anti-CD28 antibody dual conjugated protein G beads promoted maximal T-ChARM^3 expressing T cell proliferation by day 5, which was significantly better that the anti-CD3/anti-CD28 positive control (Figure 16). The Strep tag engaging reagents, other than Strep-Tactin Microbeads 2#, promoted proliferation of T-ChARM expressing T cells to about the same level as the anti-CD3/anti-CD28 positive control.

To further verify proliferation of T-ChARM expressing T cells, the level of Ki-67 protein was measured as a surrogate measure of proliferation. Ki-67 is a nuclear protein associated with and possibly required for cellular proliferation. T cells transduced with anti-CD19 T-ChARM^3 were cultured for 5 days in CTL medium in the presence of one of the following treatments: (a) Strep-Tactin® Microbeads 1#; (b) Strep-Tactin Microbeads 2#; (c) Strep-Tactin Nanobeads 3#; (d) anti-Strep tag antibody

conjugated to protein G beads; (e) anti-Strep tag antibody /anti-CD28 antibody dual conjugated protein G beads, or (f) anti-CD3/anti-CD28 dual antibody beads (positive control). After culturing for 5 days, the cells were fixed, permeabilized, stained with anti-Ki-67-FITC conjugated antibody, and analyzed by flow cytometry.

These data show that Strep-Tactin beads or anti-Strep tag beads can promote selective cell proliferation and the proliferation as measured by Ki-67 staining was better than that observed with the anti-CD3/anti-CD28 positive control (Figure 14).

A further level of Ki-67 protein as was performed on T cells transduced with anti-CD19 T-ChARM^1, T-ChARM^2, or T-ChARM^3 and cultured for 7 days in CTL medium in the presence of: (a) no treatment; (b) Strep-Tactin® Microbeads 1# at a dose of 15μg, 50μg, or 150μg per 1 x 10^6 cells; or (c) co-cultured with irradiated TM-LCL cells plus 50 U/ml IL2 (positive control). After culturing for 7 days, the cells were fixed, permeabilized, stained with anti-Ki-67-FITC conjugated antibody, and analyzed by flow cytometry. These results also show that Strep-Tactin beads can promote proliferation in T-ChARM expressing T cells regardless of the amount of the beads used, particularly for the T-ChARM^2 and T-ChARM^3 cells (Figure 15). Moreover, each of the T-ChARM expressing T cells proliferated in the presence of Strep-Tactin beads as well as or better than the TM-LCL positive control stimulation.

EXAMPLE 14

SELECTIVE EXPANSION OF T CELLS EXPRESSING T-CHARM MOLECULES

A total of about 5 x 10^5 human CD8+ T cells were stimulated with anti-CD3/anti-CD28 beads. On day 2, the treated cells were transduced with a lentivirus containing a nucleic acid molecule encoding an anti-CD19 T-ChARM^1/huEGFRt. On day 5, the anti-CD3/anti-CD28 beads were removed. At this point, the treated cells were split into two groups, one group was not treated any further and the other group was treated with Strep-Tactin® microbeads (about 0.5 μm to about 1.5 μm). On day 10, the cells from each group were harvested, stained with immunofluorescent anti-Strep tag antibody and analyzed by flow cytometry. The growth curve shows that, after the removal of the anti-CD3/anti-CD28 beads, the addition of Strep-Tactin microbeads continued to promote significant T cell proliferation (Figure 17A). The flow cytometry analysis shows that the cells that were proliferating were in fact T-ChARM expressing T cells since there was a significantly higher percentage of T-ChARM expressing T cells (as measured by huEGFRt staining) in the Strep-Tactin microbead treated group (bottom panel) as compared to the control

group (top panel) (Figure 17B). The cells from each group were then further sorted using the huEGFRt marker, then 5.0 x 10^5 cells were expanded by stimulation with CD19+ TM-LCL. The cells previously treated with the StrepTactin microbeads underwent significant and quick proliferation to a level of about 8.0 x 10^7 cells in 7 days as compared to only 4.0 x 10^6 cells in the control group. This demonstrates that after Strep-Tactin microbead stimulation through the tag sequence of the T-ChARM, subsequent re-stimulation through the anti-CD19 scFv component of the T-ChARM is highly effective.

To determine whether anti-CD3/anti-CD28 bead stimulation was needed at all to expand T-ChARM expressing T cells, we examined whether T cells could be transduced to express the T-ChARM with cytokine stimulation alone and then selectively expanded by treatment with anti-Strep tag beads only. A total of about 5 x 10^5 human CD8+ T cells were cultured with 5ng/mL IL-7 and 10 ng/mL IL-15 for 24 h and then transduced with the same titer of virus encoding two types of anti-CD19 T-ChARM[3] (41BB or CD28 effector domains). The transduced cells were treated with anti-Strep tag antibody conjugated to protein G beads on day 2, and then on day 7 were harvested, stained with immunofluorescent anti-Strep tag II antibody, and analyzed by flow cytometry.

The data show that anti-Strep tag antibody conjugated to protein G beads promoted proliferation of T-ChARM expressing T cells to greater than 60% of the cells in the culture (Figures 18B and 18D) in the absence of anti-CD3/anti-CD28 bead stimulation. When transduced cells were not exposed to anti-Strep tag antibody beads, then less than 1% of the transduced cells would proliferate (Figures 18A and 18C).

The functionality of ChARM T cells after expansion on anti-Strep tag alone or anti-Strep tag/anti-CD28 mAb coated microbeads was tested to ensure that stimulation through the ChARM would not have detrimental effects on tumor recognition *in vitro* or *in vivo*. Independent of the co-stimulatory domain in the design, ChARM T cells expanded on anti-Strep tag microbeads displayed potent cytolytic activity, efficiently release cytokines and retained extensive proliferation capacity among antigen stimulation compared the cells before expansion or after antigen-driven expansion (TM-LCL) (Figures 30A-30C). After selective expansion, the ChARM T cells had high viability (>90%), a large proportion retained expression of co-stimulatory receptors (CD27/CD28) and central memory T cell markers CD45RO and CD62L (Figure 30D), were able to eliminated Raji tumors in NSG mice (Figure 30E), and were able to persist as well as CAR T cells expanded by stimulation with $CD19^+$ B cells (Figure 30F).

EXAMPLE 15

EFFECT OF ENGAGEMENT OF TAG BINDING REAGENTS ON CYTOKINE RELEASE BY T CELLS EXPRESSING T-CHARMS

Anti-CD19 CAR (short) (expanded by TM-LCL stimulation) or T-ChARM^{1} expressing T cells (expanded by TM-LCL or StrepTactin microbead stimulation) were co-cultured for 24 hours with Raji cells (Figure 19C) or K562 cells expressing either CD19 (Figure 19A) or ROR1 (negative control) (Figure 19B). PMA / Ionomycin were used as the positive control (Figure 19D). Supernatants were harvested and analyzed using a multiplex cytokine assay (Luminex®). The level of cytokine release by the anti-CD19 T-ChARM^{1} expressing T cells cultured on Strep-Tactin microbeads was higher (except for IFN-γ) than observed for T-ChARM^{1} expressing T cells stimulated with TM-LCL cells (Figure 19A, C, and D). Regardless of conditions, the K562/ROR1 cell co-culture group (negative control) did not produce any detectable cytokines (Figure 19B). Interestingly, there was a significantly higher level of IL2 production in the Strep-Tactin bead induced cultures (more than a 10-fold increase) as compared to the TM-LCL stimulated group.

EXAMPLE 16

PROLIFERATION ENHANCED WITH ANTI-STREP TAG ANTIBODY COMBINED WITH ANTI-CD27 OR ANTI-CD28 ANTIBODIES

Purified anti-CD19 T-ChARM^{3} expressing T cells (5 x 10^{5}) were placed in CTL medium plus 50U/ml IL2 at day 0, and then 2 μg G protein Magnetic Beads (NEB), anti-Strep tag II (0.5μg)/ anti-CD27 antibody (0.5μg) conjugated G protein beads, or anti-Strep tag II (0.5μg)/ anti-CD28 antibody (0.5μg) conjugated G protein beads, were added to the cell culture. The cells in culture medium only were used as a negative control. At day 5, the cells were examined under a microscope.

Figure 20 shows that anti- Strep tag II antibody conjugated protein G beads promoted expansion of T-ChARM expressing T cells, and that combining anti- Strep tag II with either anti-CD28 or anti-CD27 antibodies would promote T-ChARM expressing T cell expansion even more efficiently.

The various embodiments described above can be combined to provide further embodiments. All of the U.S. patents, U.S. patent application publications, U.S. patent applications, foreign patents, foreign patent applications and non-patent publications

referred to in this specification and/or listed in the Application Data Sheet are incorporated herein by reference, in their entirety. Aspects of the embodiments can be modified, if necessary to employ concepts of the various patents, applications and publications to provide yet further embodiments.

These and other changes can be made to the embodiments in light of the above-detailed description. In general, in the following claims, the terms used should not be construed to limit the claims to the specific embodiments disclosed in the specification and the claims, but should be construed to include all possible embodiments along with the full scope of equivalents to which such claims are entitled. Accordingly, the claims are not limited by the disclosure.

CLAIMS

What is claimed is:

1. A single chain fusion protein, comprising an extracellular component and an intracellular component connected by a hydrophobic portion, wherein the extracellular component comprises a binding domain that specifically binds a target, a tag cassette, and a connector region comprising a hinge, and wherein the intracellular component comprises an effector domain.

2. The single chain fusion protein according to claim 1, wherein the binding domain is a scFv, scTCR, receptor ectodomain, or ligand.

3. The single chain fusion protein according to claim 1 or 2, wherein the target comprises CD3, CEACAM6, c-Met, EGFR, EGFRvIII, ErbB2, ErbB3, ErbB4, EphA2, IGF1R, GD2, O-acetyl GD2, O-acetyl GD3, GHRHR, GHR, FLT1, KDR, FLT4, CD44v6, CD151, CA125, CEA, CTLA-4, GITR, BTLA, TGFBR2, TGFBR1, IL6R, gp130, Lewis A, Lewis Y, TNFR1, TNFR2, PD1, PD-L1, PD-L2, HVEM, MAGE-A, mesothelin, NY-ESO-1, PSMA, RANK, ROR1, TNFRSF4, CD40, CD137, TWEAK-R, HLA, tumor or pathogen associated peptide bound to HLA, hTERT peptide bound to HLA, tyrosinase peptide bound to HLA, WT-1 peptide bound to HLA, LTβR, LIFRβ, LRP5, MUC1, OSMRβ, TCRα, TCRβ, CD19, CD20, CD22, CD25, CD28, CD30, CD33, CD52, CD56, CD80, CD81, CD86, CD123, CD171, CD276, B7H4, TLR7, TLR9, PTCH1, WT-1, Robo1, α-fetoprotein (AFP), Frizzled, OX40, or CD79b.

4. The single chain fusion protein according to any one of claims 1-3, wherein the connector region further comprises a linker module.

5. The single chain fusion protein according to claim 4, wherein the linker module is a $(Gly_xSer_y)_n$, wherein n is an integer from 1 to 10, and x and y are independently an integer from 0 to 10 provided that x and y are not both 0.

6. The single chain fusion protein according to claim 4, wherein the linker module is a CH2CH3 or a CH3.

7. The single chain fusion protein according to any one of claims 1-6, wherein the connector region comprises one or more of the tag cassettes.

8. The single chain fusion protein according to any one of claims 1-6, wherein the connector region comprises from one to five tag cassettes.

9. The single chain fusion protein according to claim 7 or 8, wherein the connector region comprises from one to five tag cassettes, wherein each tag cassette is connected to one or two linker modules comprising a $(Gly_xSer_y)_n$, wherein n is an integer from 1 to 10, and x and y are independently an integer from 0 to 10 provided that x and y are not both 0.

10. The single chain fusion protein according to claim 9, wherein the linker module has an amino acid sequence of Gly-Gly-Gly-Gly-Ser (SEQ ID NO.:10), $(Gly\text{-}Gly\text{-}Gly\text{-}Gly\text{-}Ser)_2$ (SEQ ID NO.:11), $(Gly\text{-}Gly\text{-}Gly\text{-}Ser)_2$-Gly-Gly-Ser (SEQ ID NO.:12), or any combination thereof.

11. The single chain fusion protein according to any one of claims 1-10, wherein the binding domain comprises one or more tag cassettes.

12. The single chain fusion protein according to any one of claims 1-10, wherein the tag cassette is located amino-terminal to the binding domain, carboxy-terminal to the binding domain, or both.

13. The single chain fusion protein according to claim 11, wherein the binding domain is a scFv or scTCR comprising a variable region linker, wherein the variable region linker comprises one or more tag cassettes.

14. The single chain fusion protein according to any one of claims 1-13, wherein the tag cassette is or comprises a Strep tag, His tag, Flag tag, Xpress tag, Avi tag, Calmodulin tag, Polyglutamate tag, HA tag, Myc tag, Nus tag, S tag, X tag, SBP tag, Softag, V5 tag, CBP, GST, MBP, GFP, Thioredoxin tag, or any combination thereof.

15. The single chain fusion protein according to claim 14, wherein the tag cassette is or comprises a Strep tag having amino acid sequence Trp-Ser-His-Pro-Gln-Phe-Glu-Lys (SEQ ID NO.:1) or Trp-Arg-His-Pro-Gln-Phe-Gly-Gly (SEQ ID NO.:2).

16. The single chain fusion protein according to any one of claims 1-15, wherein the connector region further comprises a linker module adjacent to one or more tag cassettes, wherein the linker module and adjacent tag cassette collectively have an amino acid sequence of $(Gly\text{-}Gly\text{-}Gly\text{-}Gly\text{-}Ser)_2$-Trp-Ser-His-Pro-Gln-Phe-Glu-Lys (SEQ ID NO.:20), Trp-Ser-His-Pro-Gln-Phe-Glu-Lys-$(Gly\text{-}Gly\text{-}Gly\text{-}Gly\text{-}Ser)_2$ (SEQ ID NO.:21), $(Gly\text{-}Gly\text{-}Gly\text{-}Gly\text{-}Ser)_2$-Trp-Ser-His-Pro-Gln-Phe-Glu-Lys-$(Gly\text{-}Gly\text{-}Gly\text{-}Ser)_2$–Gly-Gly-Ser-Trp-Ser-His-Pro-Gln-Phe-Glu-Lys (SEQ ID NO.:22), Trp-Ser-His-Pro-Gln-Phe-Glu-Lys-$(Gly\text{-}Gly\text{-}Gly\text{-}Ser)_2$–Gly-Gly-Ser-Trp-Ser-His-Pro-Gln-Phe-Glu-Lys-$(Gly\text{-}Gly\text{-}Gly\text{-}Gly\text{-}Ser)_2$ (SEQ ID NO.:23), $(Gly\text{-}Gly\text{-}Gly\text{-}Gly\text{-}Ser)_2$-Trp-Ser-His-Pro-Gln-Phe-Glu-Lys-$(Gly\text{-}Gly\text{-}Gly\text{-}Ser)_2$–Gly-Gly-Ser-Trp-Ser-His-Pro-Gln-Phe-Glu-Lys-$(Gly\text{-}Gly\text{-}Gly\text{-}Gly\text{-}Ser)_2$-Trp-Ser-His-Pro-Gln-Phe-Glu-Lys (SEQ ID NO.:24), or Trp-Ser-His-Pro-Gln-Phe-Glu-Lys-$(Gly\text{-}Gly\text{-}Gly\text{-}Gly\text{-}Ser)_2$–Trp-Ser-His-Pro-Gln-Phe-Glu-Lys-$(Gly\text{-}Gly\text{-}Gly\text{-}Ser)_2$–Gly-Gly-Ser-Trp-Ser-His-Pro-Gln-Phe-Glu-Lys-$(Gly\text{-}Gly\text{-}Gly\text{-}Gly\text{-}Ser)_2$ (SEQ ID NO.:25).

17. The single chain fusion protein according to any one of claims 1-16, wherein the hydrophobic portion is a transmembrane domain.

18. The single chain fusion protein according to claim 17, wherein the transmembrane domain is a CD4, CD8, CD28 or CD27 transmembrane domain.

19. The single chain fusion protein according to any one of claims 1-18, wherein the effector domain or effector portion thereof is a 4-1BB (CD137), CD3ε, CD3δ, CD3ζ, CD25, CD27, CD28, CD79A, CD79B, CARD11, DAP10, FcRα, FcRβ, FcRγ, Fyn, HVEM, ICOS, Lck, LAG3, LAT, LRP, NKG2D, NOTCH1, NOTCH2, NOTCH3, NOTCH4, OX40 (CD134), ROR2, Ryk, SLAMF1, Slp76, pTα, TCRα, TCRβ, TRIM, Zap70, PTCH2, or any combination thereof.

20. The single chain fusion protein according to any one of claims 1-19, wherein the effector domain or effector portion thereof comprises CD3ζ and one or more of 4-1BB (CD137), CD27, CD28, and OX40 (CD134).

21. The single chain fusion protein according to any one of claims 1-20, wherein the fusion protein comprises from amino-terminus to carboxy-terminus: an extracellular binding domain, a tag cassette, a connector region comprising a hinge, a hydrophobic portion, and an intracellular component comprising an effector domain.

22. The single chain fusion protein according to any one of claims 1-20, wherein the fusion protein comprises from amino-terminus to carboxy-terminus: an extracellular binding domain, a first connector region, a tag cassette, a second connector region comprising a hinge, a hydrophobic portion, and an intracellular component comprising an effector domain.

23. The single chain fusion protein according to any one of claims 1-20, wherein the fusion protein comprises from amino-terminus to carboxy-terminus: an extracellular binding domain, a first tag cassette, a first connector region, a second tag cassette, a second connector region comprising a hinge, a hydrophobic portion, and an intracellular component comprising an effector domain.

24. The single chain fusion protein according to any one of claims 1-20, wherein the fusion protein comprises from amino-terminus to carboxy-terminus: an extracellular binding domain, a first tag cassette, a first connector region, a second tag cassette, a second connector region, a third tag cassette, a third connector region comprising a hinge, a hydrophobic portion, and an intracellular component comprising an effector domain.

25. The single chain fusion protein according to any one of claims 1-20, wherein the fusion protein comprises from amino-terminus to carboxy-terminus: a tag cassette, an extracellular binding domain, a connector region comprising a hinge, a hydrophobic portion, and an intracellular component comprising an effector domain.

26. The single chain fusion protein according to any one of claims 1-20, wherein the fusion protein comprises from amino-terminus to carboxy-terminus: an extracellular binding domain, two to five tag cassettes, a connector region comprising a hinge, a hydrophobic portion, and an intracellular component comprising an effector domain.

27. The single chain fusion protein according to any one of claims 1-20, wherein the fusion protein comprises from amino-terminus to carboxy-terminus: an extracellular scFv or scTCR binding domain comprising a variable region linker disposed between the variable regions and containing a tag cassette, a connector region comprising a hinge, a hydrophobic portion, and an intracellular component comprising an effector domain.

28. The single chain fusion protein according to any one of claims 1-20, wherein the fusion protein comprises from amino-terminus to carboxy-terminus: an extracellular scFv or scTCR binding domain, a tag cassette, a connector region comprising an IgG hinge, a transmembrane domain, and an intracellular component comprising an effector domain, wherein the effector domain comprises 4-1BB and CD3ζ, CD27 and CD3ζ, CD28 and CD3ζ, OX40 and CD3ζ, CD28, 4-1BB and CD3ζ, OX40, 4-1BB and CD3ζ, or CD28, OX40 and CD3ζ.

29. The single chain fusion protein according to any one of claims 1-20, wherein the fusion protein comprises from amino-terminus to carboxy-terminus: an extracellular binding domain comprising a receptor ectodomain, a tag cassette, a connector region comprising a hinge, a hydrophobic portion, and an intracellular component comprising an effector domain, wherein the effector domain comprises 4-1BB, CD27, CD28, or OX40.

30. A chimeric antigen receptor molecule, comprising a fusion protein having one or more extracellular tag cassettes disposed between and connecting an extracellular binding domain that specifically binds to an antigen and an intracellular component comprising an effector domain.

31. The chimeric antigen receptor molecule according to claim 30, wherein the one or more tag cassettes comprises one tag cassette.

32. The chimeric antigen receptor molecule according to claim 30, wherein the one or more tag cassettes comprises two to five tag cassettes.

33. The chimeric antigen receptor molecule according to any one of claims 30-32, wherein the chimeric antigen receptor molecule further comprises one or more

linker modules comprising a $(Gly_xSer_y)_n$, wherein n is an integer from 1 to 10, and x and y are independently an integer from 0 to 10 provided that x and y are not both 0.

34. The chimeric antigen receptor molecule according to any one of claims 30-32, wherein the fusion protein further comprises a $(Gly_xSer)_n$ linker module disposed between the binding domain and the one or more tag cassettes, wherein x is an integer from 2 to 4 and n is an integer from 1 to 3.

35. The chimeric antigen receptor molecule according to any one of claims 30-32, wherein the fusion protein further comprises an extracellular $(Gly_xSer)_n$ linker module disposed between the one or more tag cassettes and the intracellular component comprising an effector domain, wherein x is an integer from 2 to 4 and n is an integer from 1 to 3.

36. The chimeric antigen receptor molecule according to any one or more of claims 30-32, wherein the fusion protein further comprises two extracellular $(Gly_xSer)_n$ linker modules, wherein x is an integer from 2 to 4 and n is an integer from 1 to 3, and wherein the first linker module is amino-terminal to at least one of the one or more tag cassettes and the second linker module is carboxy-terminal to at least one of the one or more tag cassettes.

37. The chimeric antigen receptor molecule according to claim 30, wherein the one or more tag cassettes comprises two tag cassettes and the molecule further comprises two extracellular $(Gly_xSer)_n$ linker modules, wherein x is an integer from 2 to 4 and n is an integer from 1 to 3, and wherein a first tag cassette is disposed between the binding domain and the first linker module, a second tag cassette is disposed between the first and second linker modules, and the second linker module disposed between the second tag cassette and the effector domain.

38. The chimeric antigen receptor molecule according to claim 37, wherein the fusion protein further comprises a third tag cassette and a third extracellular $(Gly_xSer)_n$ linker module, wherein the third tag cassette is disposed between the second linker module and the third linker module, and the third linker module is disposed between the third tag cassette and the effector domain.

39. The chimeric antigen receptor molecule according to any one of claims 30-38, wherein the fusion protein further comprises an extracellular hinge and extracellular CH2CH3 linker module, wherein the hinge is adjacent to the binding domain, the CH2CH3 linker module is adjacent to the intracellular component comprising an effector domain, and at least one of the one or more tag cassettes is disposed between the hinge and the CH2CH3 linker module.

40. The chimeric antigen receptor molecule according to any one of claims 30-38, wherein the fusion protein further comprises an extracellular hinge and extracellular CH3 linker module, wherein the hinge is adjacent to the binding domain, the CH3 linker module is adjacent to the intracellular component comprising an effector domain, and at least one of and/or each of the one or more tag cassette is disposed between the hinge and the CH3 linker module.

41. The chimeric antigen receptor molecule according to any one of claims 30-40, wherein at least one of the one or more tag cassettes is or comprises a Strep tag, His tag, Flag® tag, Xpress® tag, Avi tag, Calmodulin tag, Polyglutamate tag, HA tag, Myc tag, Nus tag, S tag, X tag, SBP tag, Softag, V5 tag, CBP, GST, MBP, GFP, Thioredoxin tag, or any combination thereof.

42. The chimeric antigen receptor molecule according to claim 41, wherein at least one of the one or more tag cassette is or comprises a Strep tag having amino acid sequence Trp-Ser-His-Pro-Gln-Phe-Glu-Lys (SEQ ID NO.:1) or Trp-Arg-His-Pro-Gln-Phe-Gly-Gly (SEQ ID NO.:2).

43. The chimeric antigen receptor molecule according to any one of claims 30-40, wherein the binding domain is a scFv, scTCR, receptor ectodomain, or ligand.

44. The chimeric antigen receptor molecule according to any one of claims 30-43, wherein the antigen is or comprises CD3, CEACAM6, c-Met, EGFR, EGFRvIII, ErbB2, ErbB3, ErbB4, EphA2, IGF1R, GD2, O-acetyl GD2, O-acetyl GD3, GHRHR, GHR, FLT1, KDR, FLT4, CD44v6, CD151, CA125, CEA, CTLA-4, GITR, BTLA, TGFBR2, TGFBR1, IL6R, gp130, Lewis A, Lewis Y, TNFR1, TNFR2, PD1, PD-L1, PD-L2, HVEM, MAGE-A, mesothelin, NY-ESO-1, PSMA, RANK, ROR1, TNFRSF4, CD40, CD137, TWEAK-R, HLA, tumor or pathogen associated peptide bound to HLA,

hTERT peptide bound to HLA, tyrosinase peptide bound to HLA, WT-1 peptide bound to HLA, LTβR, LIFRβ, LRP5, MUC1, OSMRβ, TCRα, TCRβ, CD19, CD20, CD22, CD25, CD28, CD30, CD33, CD52, CD56, CD80, CD81, CD86, CD123, CD171, CD276, B7H4, TLR7, TLR9, PTCH1, WT-1, Robo1, α-fetoprotein (AFP), Frizzled, OX40, or CD79b.

45. The chimeric antigen receptor molecule according to any one of claims 30-44, wherein the effector domain is a 4-1BB, CD3ε, CD3δ, CD3ζ, CD27, CD28, CD79A, CD79B, CARD11, DAP10, FcRα, FcRβ, FcRγ, Fyn, HVEM, ICOS, Lck, LAG3, LAT, NKG2D, OX40, SLAMF1, Slp76, pTα, TCRα, TCRβ, TRIM, Zap70, PTCH2, or any combination thereof.

46. The chimeric antigen receptor molecule according to any one of claims 30-45, wherein the effector domain comprises CD3ζ and one or more of 4-1BB, CD27, CD28, and OX40.

47. The chimeric antigen receptor molecule according to any one of claims 30-45, wherein the effector domain comprises 4-1BB and CD3ζ, CD27 and CD3ζ, CD28 and CD3ζ, or CD28, 4-1BB and CD3ζ.

48. The chimeric antigen receptor molecule according to any one of claims 30-45, wherein the binding domain comprises a receptor ectodomain and the effector domain comprising 4-1BB, CD27, CD28, or OX40.

49. The chimeric antigen receptor molecule according to claim 48, wherein the tag cassette is located carboxy-terminal to the receptor ectodomain.

50. A single chain fusion protein, comprising a hydrophobic portion disposed between an extracellular component and an intracellular component, wherein the extracellular component comprises a tag cassette and a connector region comprising a hinge, and wherein the intracellular component comprises an effector domain.

51. The single chain fusion protein according to claim 50, wherein the connector region further comprises a linker module.

52. The single chain fusion protein according to claim 51, wherein the linker module is a $(Gly_xSer)_n$, wherein x is an integer from 1 to 5 and n is an integer from 1 to 10.

53. The single chain fusion protein according to claim 51, wherein the linker module is a CH2CH3 or a CH3.

54. The single chain fusion protein according to any one of claims 50-53, wherein one or more tag cassettes are amino terminal to the connector region.

55. The single chain fusion protein according to any one of claims 50-54, wherein the fusion protein comprises from one to five tag cassettes.

56. The single chain fusion protein according to claim 55, wherein each tag cassette is connected to one or two linker modules comprising a $(Gly_xSer_y)_n$, wherein n is an integer from 1 to 10, and x and y are independently an integer from 0 to 10 provided that x and y are not both 0.

57. The single chain fusion protein according to claim 56, wherein the linker module has an amino acid sequence of Gly-Gly-Gly-Gly-Ser (SEQ ID NO.:10), $(Gly\text{-}Gly\text{-}Gly\text{-}Gly\text{-}Ser)_2$ (SEQ ID NO.:11), $(Gly\text{-}Gly\text{-}Gly\text{-}Ser)_2$-Gly-Gly-Ser (SEQ ID NO.:12), or any combination thereof.

58. The single chain fusion protein according to any one of claims 50-57, wherein one or more tag cassettes are linked to the connector region by a linker module.

59. The single chain fusion protein according to claim 58, wherein the linker module is or comprises a $(Gly_xSer)_n$, wherein x is an integer from 1 to 5 and n is an integer from 1 to 10.

60. The single chain fusion protein according to claim 58, wherein the linker module is or comprises $(Gly\text{-}Gly\text{-}Gly\text{-}Gly\text{-}Ser)_2$ (SEQ ID NO.:11).

61. The single chain fusion protein according to any one of claims 50-60, wherein one or more tag cassettes are or comprise a Strep tag, His tag, Flag® tag,

Xpress® tag, Avi tag, Calmodulin tag, Polyglutamate tag, HA tag, Myc tag, Nus tag, S tag, X tag, SBP tag, Softag, V5 tag, CBP, GST, MBP, GFP, Thioredoxin tag, or any combination thereof.

62. The single chain fusion protein according to claim 61, wherein one or more tag cassettes are or comprise a Strep tag having amino acid sequence Trp-Ser-His-Pro-Gln-Phe-Glu-Lys (SEQ ID NO.:1) or Trp-Arg-His-Pro-Gln-Phe-Gly-Gly (SEQ ID NO.:2).

63. The single chain fusion protein according to any one of claims 50-62, wherein the fusion protein further comprises a linker module adjacent to one or more tag cassettes, wherein the linker module and the adjacent tag cassette have an amino acid sequence of $(Gly\text{-}Gly\text{-}Gly\text{-}Gly\text{-}Ser)_2$-Trp-Ser-His-Pro-Gln-Phe-Glu-Lys (SEQ ID NO.:20), Trp-Ser-His-Pro-Gln-Phe-Glu-Lys-$(Gly\text{-}Gly\text{-}Gly\text{-}Gly\text{-}Ser)_2$ (SEQ ID NO.:21), $(Gly\text{-}Gly\text{-}Gly\text{-}Gly\text{-}Ser)_2$-Trp-Ser-His-Pro-Gln-Phe-Glu-Lys-$(Gly\text{-}Gly\text{-}Gly\text{-}Ser)_2$–Gly-Gly-Ser-Trp-Ser-His-Pro-Gln-Phe-Glu-Lys (SEQ ID NO.:22), Trp-Ser-His-Pro-Gln-Phe-Glu-Lys-$(Gly\text{-}Gly\text{-}Gly\text{-}Ser)_2$–Gly-Gly-Ser-Trp-Ser-His-Pro-Gln-Phe-Glu-Lys-$(Gly\text{-}Gly\text{-}Gly\text{-}Gly\text{-}Ser)_2$ (SEQ ID NO.:23), $(Gly\text{-}Gly\text{-}Gly\text{-}Gly\text{-}Ser)_2$-Trp-Ser-His-Pro-Gln-Phe-Glu-Lys-$(Gly\text{-}Gly\text{-}Gly\text{-}Ser)_2$–Gly-Gly-Ser-Trp-Ser-His-Pro-Gln-Phe-Glu-Lys-$(Gly\text{-}Gly\text{-}Gly\text{-}Gly\text{-}Ser)_2$-Trp-Ser-His-Pro-Gln-Phe-Glu-Lys (SEQ ID NO.:24), or Trp-Ser-His-Pro-Gln-Phe-Glu-Lys-$(Gly\text{-}Gly\text{-}Gly\text{-}Gly\text{-}Ser)_2$–Trp-Ser-His-Pro-Gln-Phe-Glu-Lys-$(Gly\text{-}Gly\text{-}Gly\text{-}Ser)_2$–Gly-Gly-Ser-Trp-Ser-His-Pro-Gln-Phe-Glu-Lys-$(Gly\text{-}Gly\text{-}Gly\text{-}Gly\text{-}Ser)_2$ (SEQ ID NO.:25).

64. The single chain fusion protein according to any one of claims 50-63, wherein the hydrophobic portion is a transmembrane domain.

65. The single chain fusion protein according to claim 64, wherein the transmembrane domain is a CD4, CD8, CD28 or CD27 transmembrane domain.

66. The single chain fusion protein according to any one of claims 1-18, wherein the effector domain is a CD3ε, CD3δ, CD3ζ, CD27, CD28, CD79A, CD79B, CD134, CD137, CARD11, DAP10, FcRα, FcRβ, FcRγ, Fyn, HVEM, ICOS, Lck, LAG3, LAT, LRP, NKG2D, NOTCH1, NOTCH2, NOTCH3, NOTCH4, ROR2, Ryk,

SLAMF1, Slp76, pTα, TCRα, TCRβ, TRIM, Zap70, PTCH2, or any combination thereof.

67. The single chain fusion protein according to any one of claims 50-66, wherein the effector domain comprises CD3ζ and one or more of 4-1BB (CD137), CD27, CD28, and OX40 (CD134).

68. The single chain fusion protein according to any one of claims 50-66, wherein the effector domain comprises LRP, NOTCH1, NOTCH2, NOTCH3, NOTCH4, ROR2, or Ryk.

69. The single chain fusion protein according to any one of claims 50-68, wherein the fusion protein comprises from amino-terminus to carboxy-terminus: a tag cassette, a connector region comprising a hinge, a hydrophobic portion, and an intracellular component comprising an effector domain.

70. The single chain fusion protein according to any one of claims 50-68, wherein the fusion protein comprises from amino-terminus to carboxy-terminus: a first connector region, a tag cassette, a second connector region comprising a hinge, a hydrophobic portion, and an intracellular component comprising an effector domain.

71. The single chain fusion protein according to any one of claims 50-68, wherein the fusion protein comprises from amino-terminus to carboxy-terminus: a first tag cassette, a first connector region, a second tag cassette, a second connector region comprising a hinge, a hydrophobic portion, and an intracellular component comprising an effector domain.

72. The single chain fusion protein according to any one of claims 50-68, wherein the fusion protein comprises from amino-terminus to carboxy-terminus: a first tag cassette, a first connector region, a second tag cassette, a second connector region, a third tag cassette, a third connector region comprising a hinge, a hydrophobic portion, and an intracellular component comprising an effector domain.

73. The single chain fusion protein according to any one of claims 50-68, wherein the fusion protein comprises from amino-terminus to carboxy-terminus: two to

five tag cassettes, a connector region comprising a hinge, a hydrophobic portion, and an intracellular component comprising an effector domain.

74. The single chain fusion protein according to any one of claims 50-68, wherein the fusion protein comprises from amino-terminus to carboxy-terminus: a tag cassette, a connector region comprising an IgG hinge, a transmembrane domain, and an intracellular component comprising an effector domain comprising 4-1BB and CD3ζ, CD27 and CD3ζ, CD28 and CD3ζ, or CD28, 4-1BB and CD3ζ.

75. The single chain fusion protein according to any one of claims 50-68, wherein the fusion protein comprises from amino-terminus to carboxy-terminus: a tag cassette, a connector region comprising a hinge, a hydrophobic portion, and an intracellular component comprising an effector domain comprising LRP, NOTCH1, NOTCH2, NOTCH3, NOTCH4, ROR2, or Ryk.

76. The single chain fusion protein according to any one of claims 50-75, wherein the fusion protein further comprises a non-covalently associated binding domain.

77. The single chain fusion protein according to claim 76, wherein the non-covalently associated binding domain associates with a tag cassette.

78. The single chain fusion protein according to claim 76 or 77, wherein the non-covalently associated binding domain is a scFv, scTCR, receptor ectodomain, or ligand.

79. The single chain fusion protein according to any one of claims 76-78, wherein the non-covalently associated binding domain is bi-specific, wherein the first binding end is specific for the tag cassette and the second binding end is specific for a target other than the tag cassette.

80. The single chain fusion protein according to claim 79, wherein the non-covalently associated binding domain is specific for CD3, CEACAM6, c-Met, EGFR, EGFRvIII, ErbB2, ErbB3, ErbB4, EphA2, IGF1R, GD2, O-acetyl GD2, O-acetyl GD3, GHRHR, GHR, FLT1, KDR, FLT4, CD44v6, CD151, CA125, CEA, CTLA-4, GITR,

BTLA, TGFBR2, TGFBR1, IL6R, gp130, Lewis A, Lewis Y, TNFR1, TNFR2, PD1, PD-L1, PD-L2, HVEM, MAGE-A, mesothelin, NY-ESO-1, PSMA, RANK, ROR1, TNFRSF4, CD40, CD137, TWEAK-R, HLA, tumor or pathogen associated peptide bound to HLA, hTERT peptide bound to HLA, tyrosinase peptide bound to HLA, WT-1 peptide bound to HLA, LTβR, LIFRβ, LRP5, MUC1, OSMRβ, TCRα, TCRβ, CD19, CD20, CD22, CD25, CD28, CD30, CD33, CD52, CD56, CD80, CD81, CD86, CD123, CD171, CD276, B7H4, TLR7, TLR9, PTCH1, WT-1, Robo1, α-fetoprotein (AFP), Frizzled, OX40, or CD79b.

81. The single chain fusion protein according to any one of claims 76-78, wherein the binding domain is bi-specific, wherein the first and second binding ends are specific for the tag cassette.

82. The single chain fusion protein according to any one of claims 76-78, wherein the binding domain is multispecific, wherein a first end binds to the tag cassette and a second end is specific for one or more targets other than the tag cassette.

83. The single chain fusion protein according to claim 82, wherein at least one binding domain is specific for CD3, CEACAM6, c-Met, EGFR, EGFRvIII, ErbB2, ErbB3, ErbB4, EphA2, IGF1R, GD2, O-acetyl GD2, O-acetyl GD3, GHRHR, GHR, FLT1, KDR, FLT4, CD44v6, CD151, CA125, CEA, CTLA-4, GITR, BTLA, TGFBR2, TGFBR1, IL6R, gp130, Lewis A, Lewis Y, TNFR1, TNFR2, PD1, PD-L1, PD-L2, HVEM, MAGE-A, mesothelin, NY-ESO-1, PSMA, RANK, ROR1, TNFRSF4, CD40, CD137, TWEAK-R, HLA, tumor or pathogen associated peptide bound to HLA, hTERT peptide bound to HLA, tyrosinase peptide bound to HLA, WT-1 peptide bound to HLA, LTβR, LIFRβ, LRP5, MUC1, OSMRβ, TCRα, TCRβ, CD19, CD20, CD22, CD25, CD28, CD30, CD33, CD52, CD56, CD80, CD81, CD86, CD123, CD171, CD276, B7H4, TLR7, TLR9, PTCH1, WT-1, Robo1, α-fetoprotein (AFP), Frizzled, OX40, or CD79b.

84. The single chain fusion protein according to claim 76, wherein the binding domain is an antibody.

85. The single chain fusion protein according to claim 76, wherein the tag cassette is a Strep tag having amino acid sequence Trp-Ser-His-Pro-Gln-Phe-Glu-Lys

(SEQ ID NO.:1) or Trp-Arg-His-Pro-Gln-Phe-Gly-Gly (SEQ ID NO.:2), and the associated binding domain is a biotin binding protein.

86. The single chain fusion protein according to any one of claims 76-85, wherein the binding domain further comprises a cytotoxic, radioisotope, radiometal, or detectable agent.

87. A fusion protein according to any one of claims 1-85, wherein the fusion protein further comprises a cytotoxic, radioisotope, radiometal, or detectable agent.

88. A nucleic acid molecule encoding a fusion protein according to any one of claims 1-85 or 50-87, or a chimeric antigen receptor according to any one of claims 30-49.

89. A vector comprising a nucleic acid molecule according to claim 88.

90. The vector according to claim 89, wherein the vector is a viral vector.

91. The vector according to claim 90, wherein the viral vector is a retroviral vector or lentiviral vector.

92. A host cell, comprising a nucleic acid molecule encoding a fusion protein or chimeric antigen receptor according to any one of claims 1-85.

93. The host cell according to claim 92, wherein the host cell is a T cell.

94. A method for activating a cell, comprising contacting a cell comprising a fusion protein or chimeric antigen receptor according to any one of claims 1-85 and/or the nucleic acid molecule of claim 88 with a binding domain specific for the tag cassette.

95. The method of claim 94, wherein the binding domain specific for the tag cassette is attached to a solid surface and/or the binding domain specific for the tag cassette is a cognate receptor, an anti-tag antibody, and/or an anti-tag scFv.

96. The method according to claim 94 or 95, wherein the tag cassette is a Strep tag having amino acid sequence Trp-Ser-His-Pro-Gln-Phe-Glu-Lys (SEQ ID NO.:1) or Trp-Arg-His-Pro-Gln-Phe-Gly-Gly (SEQ ID NO.:2).

97. The method according to one of claims 94-96, wherein the binding domain specific for the tag cassette is a biotin binding protein or an anti-Strep tag antibody.

98. The method according to any one of claims 94-97, wherein the binding domain is attached to a planar surface, agarose, resin, 3D fabric matrix, or a bead.

99. The method according to any one of claims 94-98, wherein the binding domain is attached to a microbead or a nanobead.

100. The method according to any one of claims 94-99, wherein the activation is performed *in vivo* or *ex vivo*.

101. The method according to any one of claims 94-100, wherein the cell is a T cell and/or is a human T cell.

102. A method for promoting cell proliferation, comprising contacting a non-natural cell comprising a fusion protein or chimeric antigen receptor of any one of claims 1-85 and/or the nucleic acid molecule of claim 88 with a binding domain specific for the tag cassette and a growth factor cytokine for a time sufficient to allow cell growth.

103. The method of claim 102, wherein the binding domain specific for the tag cassette is attached to a solid surface and/or the binding domain specific for the tag cassette is a cognate receptor, an anti-tag antibody, or an anti-tag scFv.

104. The method according to claim 102 or 103, wherein the tag cassette is a Strep tag having amino acid sequence Trp-Ser-His-Pro-Gln-Phe-Glu-Lys (SEQ ID NO.:1) or Trp-Arg-His-Pro-Gln-Phe-Gly-Gly (SEQ ID NO.:2).

105. The method according to one of claims 102-104, wherein the binding domain specific for the tag cassette is a biotin binding protein or an anti-Strep tag antibody.

106. The method according to any one of claims 102-105, wherein the binding domain is attached to a planar surface, agarose, resin, 3D fabric matrix, or a bead.

107. The method according to any one of claims 102-106, wherein the binding domain is attached to a microbead or a nanobead.

108. The method according to any one of claims 102-107, wherein the growth factor cytokine is IL2, IL15, or both.

109. The method according to any one of claims 102-108, wherein the method further comprises incubating the cells with an anti-CD27 binding domain, an anti-CD28 binding domain, an anti-CD137 binding domain, an anti-OX40 binding domain or any combination thereof, wherein the binding domains are attached to a solid surface.

110. The method according to claim 109, wherein the anti-CD27, anti-CD28, anti-CD137 binding domain, anti-OX40 binding domain or any combination thereof are attached to a planar surface, agarose, resin, 3D fabric matrix, or a bead.

111. The method according to any one of claims 102-110, wherein the proliferation is induced *in vivo* or *ex vivo*.

112. The method according to any one of claims 102-111, wherein the cell is a T cell and/or the cell is a human T cell.

113. The method according to claim 112, wherein the T cell is a functional T cell.

114. The method according to claim 113, wherein the functional T cell is a virus-specific T cell, a tumor antigen specific cytotoxic T cell, a memory stem T cell, a central memory T cell, or a CD4+ CD25+ regulatory T cell.

115. The method according to any one of claims 102-114, wherein the proliferation is induced *in vivo* when the binding domain of a fusion protein or chimeric antigen receptor of any one of claims 1-85 binds a target cell ligand.

116. The method according to claim 115, wherein the target cell ligand is a T cell suppressor cell ligand.

117. The method according to claim 116, wherein the T cell suppressor cell ligand is PD-L1 or PD-L2.

118. A method for identifying a cell, comprising:

contacting a sample comprising a cell comprisings aa fusion protein or chimeric antigen receptor of any one of claims 1-85 and/or the nucleic acid molecule of claim 88 with a binding domain specific for the tag cassette, wherein the binding domain specific for the tag cassette comprises a detectable moiety, and

detecting the presence of the cell in the sample.

119. A method for sorting or selecting a cell or population of cells, the methodcomprising:

contacting a sample comprising a T cell comprising a fusion protein or chimeric antigen receptor of any one of claims 1-85 and/or the nucleic acid molecule of claim 88, with a binding domain specific for the tag cassette, and

selecting or sorting away from other cells cell(s) that are specifically bound by the binding domain, thereby selecting or sorting away from other cells the cell or population of cells.

120. The method according to claim 118 or 119, wherein the binding domain comprises a detectable moiety, which moiety is fluorescent marker.

121. The method according to any one of claims 118-120, wherein the binding domain comprises a detectable moiety, which is APC or FITC.

122. The method according to any one of claims 118-121, wherein the sample is blood.

123. The method according to any one of claims 118-122, wherein the cell is detected or sorted using flow cytometry.

124. The method according to any one of claims 118-123, wherein the cell is a non-natural cell, is a T cell, and/or is a human T cell.

125. A method for enriching for or isolating a cell or population thereof, the mehtoed comprising contacting a sample comprising the cell comprising the nucleic acid molecule of claim 88 and/or the protein or receptor of any of claims 1-85 with a binding domain specific for the tag cassette and enriching for or isolating the cell away from other cells not expressing the fusion protein or receptor in the sample.

126. The method according to claim 125, wherein the binding domain specific for the tag cassette is a cognate receptor, an anti-tag antibody, or an anti-tag scFv.

127. The method according to claim 125 or 126, wherein the tag cassette is a Strep tag having amino acid sequence Trp-Ser-His-Pro-Gln-Phe-Glu-Lys (SEQ ID NO.:1) or Trp-Arg-His-Pro-Gln-Phe-Gly-Gly (SEQ ID NO.:2).

128. The method according to one of claims 125-127, wherein the binding domain specific for the tag cassette is a biotin binding protein or an anti-Strep tag antibody.

129. The method according to any one of claims 125-128, wherein the binding domain is attached to a planar surface, agarose, resin, 3D fabric matrix, or a bead.

130. The method according to any one of claims 125-129, wherein the binding domain is attached to a microbead or a nanobead.

131. The method according to any one of claims 125-130, wherein the activation is performed *ex vivo*.

132. The method according to any one of claims 125-131, further comprising a step of expanding the population of cells in the sample according to any one of claims 102-117 prior to enrichment or isolation.

133. The method according to any one of claims 125-132, wherein the cell is a non-natural cell, is a T cell, and/or is a human T cell.

134. The method according to any one of claims 125-132, whereinthe cell is enriched or isolated from other components of the sample by magnetic column chromatography.

135. The method according to any one of claims 125-134, further comprising a step of identifying the enriched or isolated cell or population of cells, wherein the step of identifying comprises contacting the cells with a binding domain specific for the tag cassette and having a detectable moiety.

136. The method according to claim 135, wherein the detectable moiety is fluorescent marker.

137. The method according to claim 135 or 136, wherein the detectable moiety is APC, PE, Pacific blue, Alex fluor, or FITC.

138. The method according to any one of claims 135-137, wherein cell or populationis detected using flow cytometry.

139. The method according to any one of claims 125-138, wherein the sample is blood or a blood-derived sample.

140. A method for depleting cells, comprising contacting a cell comprising a nucleic acid molecule of claim 88 or the protein or receptor of any of claims 1-85 with a binding domain specific for the tag cassette, wherein binding of the binding domain

specific for the tag cassette leads to cell death of the cells expressing the fusion protein or chimeric receptor.

141. The method according to claim 140, wherein the binding domain specific for the tag cassette is a cognate receptor, an anti-tag antibody, an anti-tag scFv, or a cell with an anti-tag binding domain on its cell surface.

142. The method according to claim 140 or 141, wherein the tag cassette is a Strep tag having amino acid sequence Trp-Ser-His-Pro-Gln-Phe-Glu-Lys (SEQ ID NO.:1) or Trp-Arg-His-Pro-Gln-Phe-Gly-Gly (SEQ ID NO.:2).

143. The method according to one of claims 140-142, wherein the binding domain specific for the tag cassette is a biotin binding protein, an anti-Strep tag antibody, or a cell expressing an anti-Strep tag binding domain on its cell surface.

144. The method according to one of claims 140-143, wherein the binding domain specific for the tag cassette is a bispecific binding domain, wherein a first binding domain is specific for the tag cassette and the second binding domain is specific for CD3.

145. The method according to any one of claims 140-143, wherein the binding domain specific for the tag cassette further comprises a cytotoxic, radioisotope, radiometal, or detectable agent.

146. The method according to claim 145, further comprising tracking the non-natural T cell *in vivo*, wherein the binding domain specific for the tag cassette comprises a detectable agent.

147. The method according to any one of claims 140-146, wherein the binding domain specific for a tag cassette is administered to a subject.

148. The method according to claim 147, wherein the subject is human.

149. The method according to claim 147 or 148, wherein the method further comprises monitoring cytokine levels in the subject after administering the binding domain specific for the tag cassette.

150. The method according to any one of claims 147-149, wherein the method further comprises tracking the cells in the subject.

151. The method according to claim 150, wherein the *in vivo* tracking comprises the use of the binding domain specific for the tag cassette conjugated to magnetic particles, superparamagnetic iron oxide (SPIO), fluorodeoxyglucose (18F), fluorescent compounds, or any combination thereof.

152. The method according to claim 150 or 151, wherein the *in vivo* tracking comprises use of MRI, PET, or near infrared imaging.

153. A method for generating a desired cell population, comprising contacting a sample comprising a non-natural progenitor cell with a binding domain specific for a tag cassette and a growth factor for a time sufficient to allow cell growth and differentiation, wherein the non-natural progenitor cell comprises a nucleic acid molecule encoding a fusion protein according to any one of claims 50-85 and the binding domain specific for the tag cassette is attached to a solid surface.

154. The method according to claim 153, wherein the progenitor cell is a stem cell.

155. The method according to claim 153, wherein the expanded progenitor cell population is further isolated or enriched using a method according to any one of claims 125-139.

156. A method of treating a disease in a subject, comprising administering to a subject a host cell according to claim 92 or 93.

157. The method according to claim 156, wherein the disease is a viral, bacterial, cancer, inflammatory, immune, or aging-associated disease.

158. The method according to claim 156 or 157, wherein the subject is human.

159. The method according to any one of claims 156-158, wherein the host cell is a T cell or an autologous T cell.

160. The method according to claim 159, wherein the T cell is a regulatory T cell.

161. The method according to claim 159, wherein the T cell is a $CD8^+$ T cell or a $CD4^+$ T cell.

162. The method according to any one of claims 156-158, wherein the host cell is a stem cell.

163. A *in vivo* method for local activation of an immune cell, comprising administering to a subject a matrix composition comprising a binding domain for a tag cassette and a binding domain for a co-stimulatory molecule, and administering a host cell according to claim 92, wherein association of the binding domains in the matrix composition with the host cell activates of the host cell.

164. The *in vivo* method for local activation, wherein the matrix composition comprises alginate, basement membrane matrix, or bioploymer.

165. The *in vivo* method for local activation, wherein the immune cell is a T cell.

166. A *in vivo* method for local activation of an immune cell, comprising administering to a subject a device comprising a binding domain for a tag cassette and a binding domain for a co-stimulatory molecule, and administering a host cell according to claim 92, wherein association of the binding domains in the matrix composition with the host cell activates of the host cell.

167. The *in vivo* method for local activation, wherein the device comprises a planar surface, an agarose bead, a resin, a 3D fabric matrix, or a bead.

168. The *in vivo* method for local activation, wherein the immune cell is a T cell.

169. A method of tracking cells, comprising administering to a subject a binding molecule comprising a detectable moiety, wherein said subject has been administered cells according to claim 92 or 93, or the method further comprises administration of cells according to claim 92 or 93, and said binding molecule specifically binds to the tag cassette(s) comprised within the fusion protein or chimeric receptor, and detecting the presence of said molecule in said subject *in vivo* or in a sample obtained from said subject subsequent to said administration, thereby detecting said cells in said subject or a tissue or fluid thereof.

170. The method of claim 169, wherein the method further comprises said administration of said cells, wherein said cells and said binding molecule are administered simultaneously.

171. The method of claim 170, wherein said binding molecule and said cells are administered as a complex.

172. The method according to claim 150, wherein the binding molecule is conjugated to magnetic particles, superparamagnetic iron oxide (SPIO), fluorodeoxyglucose (18F), fluorescent compounds, or any combination thereof.

173. The method according to claim 150 or 151, wherein the tracking is carried out *in vivo* and comprises use of MRI, PET, or near infrared imaging.

174. A matrix composition comprising a binding domain for a tag cassette and a binding domain for an immune cell co-stimulatory molecule.

175. The matrix composition of claim 174, further comprising alginate, basement membrane matrix, or bioploymer.

176. A device comprising a binding domain for a tag cassette and a binding domain for an immune cell co-stimulatory molecule.

177. The device of claim 176, wherein one or both of said binding domains are disposed on a surface, an agarose bead, a resin, a 3D fabric matrix, or a bead.