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(54) Title: METHODS AND COMPOSITIONS FOR TREATING HIV

(57) Abstract: The invention features nucleic acid constructs encoding chimeric immune T-cell receptors (CIRs) that are useful for treating HIV in patients. In general, the CIRs contain an extracellular domain which targets HIV or HIV infected cells (e.g., the extracellular domain of CD4), a transmembrane domain, and a cytoplasmic domain for mediating T-cell activation (e.g., CD3 zeta and/or the partial extracellular domain of CD28). The invention also features the use of host cells expressing CIRs in the treatment of HIV.



WO 2011/130491 A2

METHODS AND COMPOSITIONS FOR TREATING HIV

Cross-Reference to Related Applications

This application claims benefit of U.S. Provisional Application No.
5 61/324,050, filed April 14, 2010, which is hereby incorporated by reference.

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10 certain rights in the invention.

Background of the Invention

The invention relates to the field of treating HIV with modified T-cells.

In 1984, HIV was shown to be the etiologic agent of AIDS. Since that
15 time, the definition of AIDS has been revised a number of times with regard to
what criteria should be included in the diagnosis. However, despite the
fluctuation in diagnostic parameters, the simple common denominator of AIDS
is the infection with HIV and subsequent development of persistent
constitutional symptoms and AIDS-defining diseases such as a secondary
20 infections, neoplasms, and neurologic disease.

HIV is a human retrovirus of the lentivirus group. The four recognized
human retroviruses belong to two distinct groups: the human T lymphotropic
(or leukemia) retroviruses, HTLV-1 and HTLV-2, and the human
immunodeficiency viruses, HIV-1 and HIV-2. The former are transforming
25 viruses whereas the latter are cytopathic viruses.

HIV-1 has been identified as the most common cause of AIDS
throughout the world. Sequence identity between HIV-2 and HIV-1 is about
40%, with HIV-2 being more closely related to some members of a group of
simian immunodeficiency viruses (SIV).

The main cause of the immune defect in AIDS has been identified as a quantitative and qualitative deficiency in the subset of thymus-derived (T) lymphocytes, the T4 population. This subset of cells is defined phenotypically by the presence of the CD4 surface molecule, which has been demonstrated to be the cellular receptor for HIV. Although the T4 cell is the major cell type infected with HIV, essentially any human cell that expresses the CD4 molecule on its surface is capable of binding to and being infected with HIV.

Previous attempts to treat patients with “designer” T-cells expressing chimeric immune receptors (CIRs) proved unsuccessful. There exists a need in the art for new therapies for HIV. The present invention addresses this issue and offers advantages over previous attempted therapies.

Summary of the Invention

In one aspect, the invention features a nucleic acid construct encoding a chimeric protein that includes (i) an extracellular domain of CD4 (e.g., amino acids 1-372 of SEQ ID NO:1) or a fragment thereof, (ii) a transmembrane domain, and (iii) a cytoplasmic domain that includes the cytoplasmic domain of the CD3 zeta chain (e.g., a polypeptide having the amino acids 31-142 of SEQ ID NO:3), or a fragment thereof, and the cytoplasmic domain of CD28 (e.g., a polypeptide having amino acids 127-234 of SEQ ID NO:2), or a fragment thereof. In one embodiment, the cytoplasmic domain has the amino acid sequence of SEQ ID NO:10.

In another aspect, the invention features a nucleic acid construct encoding a chimeric protein that includes (i) an extracellular domain of CD4 (e.g., a polypeptide having amino acids 1-372 of SEQ ID NO:1) or a fragment thereof, (ii) a transmembrane domain, and (iii) a cytoplasmic domain of the CD3 zeta chain (e.g., a polypeptide having the amino acids 31-142 of SEQ ID NO:3), or a fragment thereof.

In either of the foregoing aspects, the chimeric protein can be capable of forming a homodimer when expressed in a T-cell, e.g., through the formation of a disulfide bond.

Also in either of the foregoing aspects, the transmembrane domain can
5 be the transmembrane domain of the CD3 zeta chain (e.g., a polypeptide having amino acids 7-30 of SEQ ID NO:3) or the transmembrane/partial extracellular domain of CD28.

Also in either of the foregoing aspects, the chimeric protein can include a c-myc tag (e.g., at the N-terminus).

10 In another aspect, the invention features a vector including any of the nucleic acid constructs described above. This vector can also include a nucleic acid construct encoding an siRNA (e.g., against CCR5 or against Tat/Rev).

In yet another aspect, the invention features a host cell (e.g., a T-cell derived from an uninfected patient or T-cell derived from a patient infected
15 with HIV) containing any of the above nucleic acid constructs or vectors. This host cell can also include a nucleic acid construct encoding an siRNA (e.g., against CCR5 or against Tat/Rev).

In another aspect, the invention features a method of treating a patient infected with HIV (e.g., HIV-1 or HIV-2) by administering a composition
20 including any of the foregoing host cells. In this aspect, the host cell can be isolated from the patient being treated or from another patient.

By “specifically binds” is meant an extracellular domain which recognizes and binds an HIV protein, but that does not substantially recognize and bind other molecules in a sample, e.g., a human blood sample.

25 By “treating” is meant ameliorating a condition or symptom(s) of the condition (e.g., the symptoms of HIV infection). To “treat HIV” or refers to administering a treatment to a subject infected with HIV to improve the subject’s condition. As compared with an equivalent untreated control, such amelioration or degree of treatment is at least 5%, 10%, 20%, 30%, 40%, 50%,

60%, 70%, 80%, 90%, 95%, 99%, or 100%, as measured by the subject's HIV viral load.

By "vector" is meant a DNA molecule, usually derived from a plasmid or bacteriophage, into which fragments of DNA may be inserted or cloned. A recombinant vector will contain one or more unique restriction sites, and may be capable of autonomous replication in a defined host or vehicle organism such that the cloned sequence is reproducible. A vector contains a promoter operably-linked to a gene or coding region such that, upon transfection into a recipient cell, an RNA or an encoded protein or is expressed.

By "host T-cell" is meant a cell (e.g., a human T-cell isolated from a subject) into which one or more nucleic acid constructs is introduced.

By "chimeric immune T-cell receptor" or "CIR" is meant a fusion protein which, when expressed in a host T cell, contains an extracellular domain that specifically binds to a target protein and a cytoplasmic domain that modulates activation of the host T-cell.

By "CD4 extracellular domain" is meant a polypeptide having the N-terminal region of CD4 that is located outside the cell membrane when expressed in a T-cell, e.g., a polypeptide having the amino acid sequence of amino acids 1-372 of SEQ ID NO:1. The term "CD4 extracellular domain" is also meant to include any polypeptide fragment that binds specifically to gp120 and is substantially identical to amino acids 1-372 of SEQ ID NO:1 over the length of the polypeptide fragment.

SEQ ID NO:1 Human CD4 Amino Acid sequence

LOCUS NP_000607 458 aa linear PRI
18-MAR-2010
DEFINITION T-cell surface glycoprotein CD4 precursor [Homo sapiens].
ACCESSION NP_000607
VERSION NP_000607.1 GI:10835167
DBSOURCE REFSEQ: accession NM_000616.3

1 MNRGVPFRHL LLVLQLALLP AATQGKKVVL GKKGDTVELT CTASQKKSIIQ FHWKNSNQIK
61 ILGNQGSFLT KGPSKLNDRS DSRRLWDQGF NFPLIIKNLK IEDSDTYICE VEDQKEEVQL
121 LVFGLTANS D THLLQGQSLT LTLESPPGSS PSVQCRSPRG KNIQGGKTL S VSQLELQDSG
181 TWTCTVLQ NQ KKVEFKIDIV VLA FQKASSI VYKKEGEQVE FSFPLAFTVE KLTGSGELWW
241 QAERASSSKS WITFDLKNKE VSVKRVTDQP KLQMGKKLPL HLTLPQALPQ YAGSGNLTLA
301 LEAKTGKLHQ EVNLVVMRAT QLQKNLTCEV WGPTSPKLML SLKLENKEAK VSKREKAVVW

361 LNPEAGMWQC LLSDSGQVLL ESNIKVLPTW STPVQPMALI VLGGVAGLLL FIGLGIFFCV
 421 RCRHRRRQAE RMSQIKRLLS EKKTCQCPHR FQKTCSPI

By “CD28 cytoplasmic domain” is meant a polypeptide having the C-terminal region of CD28 that is located in the cytoplasm when expressed in a T-cell, e.g., a polypeptide having the amino acid sequence of amino acids 127-234 of SEQ ID NO:2. The term “CD28 cytoplasmic domain” is also meant to include any polypeptide fragment that maintains the ability to modulate activation of T-cells (e.g., as determined using the method titled “killing of HIV infected cells by modified T-cells” below) and is substantially identical to amino acids 127-234 of SEQ ID NO:2 over the length of the polypeptide fragment.

SEQ ID NO:2 Human CD28 Amino Acid sequence:

15 LOCUS NP_006130 220 aa linear PRI
 11-APR-2010
 DEFINITION T-cell-specific surface glycoprotein CD28 precursor [Homo sapiens].
 20 ACCESSION NP_006130
 VERSION NP_006130.1 GI:5453611
 DBSOURCE REFSEQ: accession NM_006139.2

25 1 MLRLLALNL FPSIQVTGNK ILVKQSPMLV AYDNAVNLSC KYSYNLFSRE FRASLHKGLD
 61 SAVEVCVVYG NYSQQLQVYS KTGFCNDGKL GNEVTFYLQ NLYVNQTDIY FCKIEVMYPP
 21 PYLDNEKSNG TIIHVKGKHL CPSPLFPGPS KPFWVLVVVG GVLACYSLLV TVAFIIFWVR
 181 SKRSRLHSD YMNMTPRRPG PTRKHYQPYA PPRDFAAYRS

By “CD3 zeta” is meant a polypeptide having the amino acid sequence of SEQ ID NO:3. The term “CD3 zeta” is also meant to include any polypeptide fragment that maintains the ability to modulate activation of T-cells (e.g., as determined using the method titled “killing of HIV infected cells by modified T-cells” below) and is substantially identical to SEQ ID NO:3 over the length of the protein fragment.

35

SEQ ID NO:3 Human CD3 zeta Amino Acid sequence

40 LOCUS NP_000725 163 aa linear PRI
 11-APR-2010
 DEFINITION T-cell receptor zeta chain isoform 2 precursor [Homo sapiens].
 ACCESSION NP_000725
 VERSION NP_000725.1 GI:4557431

DBSOURCE REFSEQ: accession NM_000734.3

5 1 MKWKALFTAA ILQAQLPITE AQSFGLLDPK LCYLLDGILF IYGVILTALF LRVKFSRSAD
61 APAYQQGQNO LYNELNLGRR EYDVLDRRR GRDPEMGGKP RRKNPQEGLY NELQDKMAE
121 AYSEIGMKGE RRRGKGHDGL YQGLSTATKD TYDALHMQAL PPR

By “small interfering RNA” or “siRNA” is meant an isolated RNA molecule, either single-stranded or double stranded that is at least 15 nucleotides, preferably, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 10 32, 33, 34, or 35 nucleotides in length and even up to 50 or 100 nucleotides in length (inclusive of all integers in between). Preferably, the siRNA is capable of mediating RNAi. As used herein the phrase “mediates RNAi” refers to (indicates) the ability to distinguish which RNAs are to be degraded by the RNAi machinery or process. siRNAs are processed from long dsRNAs and are 15 usually double-stranded (e.g., endogenous siRNAs). siRNAs can also include short hairpin RNAs in which both strands of an siRNA duplex are included within a single RNA molecule. These terms include double-stranded RNA, single-stranded RNA, isolated RNA, as well as altered RNA that differs from naturally occurring RNA by the addition, deletion, substitution, and/or 20 alteration of one or more nucleotides.

By “substantially identical” is meant a nucleic acid or amino acid sequence that, when optimally aligned, for example using the methods described below, share at least 60%, 65%, 70%, 75%, 80%, 85%, 90%, 95%, 96%, 97%, 98%, 99%, or 100% sequence identity with a second nucleic acid or 25 amino acid sequence. “Substantial identity” may be used to refer to various types and lengths of sequence, such as full-length sequence, epitopes or immunogenic peptides, functional domains, coding and/or regulatory sequences, exons, introns, promoters, and genomic sequences. Percent identity between two polypeptides or nucleic acid sequences is determined in various 30 ways that are within the skill in the art, for instance, using publicly available computer software such as Smith Waterman Alignment (Smith and Waterman (1981) J Mol Biol 147:195-7); “BestFit” (Smith and Waterman, Advances in Applied Mathematics, (1981) 482-489) as incorporated into GeneMatcher

PlusTM, Schwarz and Dayhof, Atlas of Protein Sequence and Structure, Dayhof, M.O., Ed (1979) 353-358; BLAST program (Basic Local Alignment Search Tool; (Altschul et al. (1990) J Mol Biol 215: 403-10), BLAST-2, BLAST-P, BLAST-N, BLAST-X, WU-BLAST-2, ALIGN, ALIGN-2, CLUSTAL, or
5 Megalign (DNASTAR) software. In addition, those skilled in the art can determine appropriate parameters for measuring alignment, including any algorithms needed to achieve maximal alignment over the full length of the sequences being compared. In general, for proteins or nucleic acids, the length of comparison can be any length, up to and including full length (e.g., 5%,
10 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90%, 95%, or 100%). Conservative substitutions typically include substitutions within the following groups: glycine, alanine; valine, isoleucine, leucine; aspartic acid, glutamic acid, asparagine, glutamine; serine, threonine; lysine, arginine; and phenylalanine, tyrosine.
15 Other features and advantages of the invention will be apparent from the following Detailed Description, the drawings, and the claims.

Brief Description of the Drawings

Fig. 1 is a diagram showing the structure of the indicated chimeric
20 immune T-cell receptors (CIRs).

Fig. 2 is a diagram showing the organization of an exemplary nucleic acid construct encoding a 2nd generation CIR and siRNA construct.

Fig. 3 is a series of graphs showing the cellular surface expression of the indicated CIR. PBMCs were transduced with retrovirus and stained with anti-
25 CD4-FITC and anti-CD8-APC antibodies after four days and analyzed by flow cytometry. % CD8+ cells expressing Hege CIR is 52%, 1st generation CIR is 44%, and 2nd generation CIR is 39%. A representative experiment of four is shown.

Fig. 4A is a pair of graphs showing survival of the indicated cell type
30 when incubated with HIV-infected CEM-SS cells at the indicated ratio.

Transduced PBMCs were co-cultured with HIV-infected CEM-SS cells or uninfected CEM-SS cells at an Effector to Target (E:T) ratio of 1:1 or 1:10. Aliquots of cells were taken from the cultures at day three and stained with anti-CD4 and anti-CD8 antibodies as described above. Data shown is %
 5 modified cells (CD8+CIR+) at each time point. A representative of two experiments is shown.

Fig. 4B is a pair of graphs showing flow cytometry analysis from day three for Hege CIR cells. Hege CIR T-cells disappear (Hege+HIV, upper right quadrant) when cultured at an E:T ratio of 1:10. % Modified cells =
 10 (Q2/Q2+Q4) is shown in each plot. (Q2 is upper right quadrant and Q4 is lower right quadrant.)

Fig. 5 is a graph showing survival of Hege CIR cells when incubated with HIV-infected CEM-SS cells at the indicated ratio in the presence and absence of AZT. Transduced PBMCs were co-cultured with HIV-infected
 15 CEM-SS cells or uninfected CEM-SS cells at an Effector to Target (E:T) ratio of 1:1 or 1:10. Aliquots of cells were taken from the cultures at day three and stained with anti-CD4 and anti-CD8 antibodies as described for Fig. 3. Data shown is % modified cells (CD8+CIR+ cells) from one experiment.

Fig. 6 is a series of graphs showing expression of the indicated markers
 20 on the indicated cells when exposed to HIV. Non-transduced or 1st and 2nd generation CIR transduced T-cells were co-cultured with HIV infected CEM-SS cells for two days and stained with anti-CD8 and anti-p24gag antibodies. An aliquot of unstained cells were washed and continued to culture for another nine days and stained with anti-CD8 and anti-p24gag antibodies. A
 25 representative of two experiments is shown. At day two, infected CD8+ cells show as a distinct population (circled) in the 1st and 2nd generation T-cells compared to non-transduced cells. There is no distinct population of cells seen in non-Td CD8+ cells (day two, upper right quadrant). % modified cells for this experiment is: 1st generation = 67% and 2nd generation = 68%.

Fig. 7 is a graph showing the percent of specific killing as a function of the ratio of Effector to Target cells. Hege CIR, 1st, and 2nd generation T-cells were cultured with ⁵¹Cr labeled uninfected or chronically infected with HIV-1 IIIB CEM-SS cells. Cytotoxicity is determined from ⁵¹Cr release to the culture media after 18 hrs of co-culture at the indicated ratios of Effector to Target, and % specific killing is calculated as follows: (experimental-control)/(maximal-control) x 100. % modified cells for Hege is 47%, for 1st generation is 25%, and for 2nd generation is 47%. Data shown is representative of two experiments. This is calculated by taking mean value of CEM-SS control as spontaneous release = (Expt-control)/(Max-control).

Fig. 8 is a pair of graphs showing the amount of secretion of the indicated cytokine in the indicated cells types. 1st and 2nd generation T-cells were assayed for IL2 or interferon gamma (IFN γ) secretion by culturing for 24 hrs on anti-CD4 (5 μ g/ml) coated plates. Data represented as fold change over 1st generation. IL2 data shown is average $\pm$ SEM of three experiments. IFN- γ data shown is average $\pm$ SEM of two experiments. % modified cells are similar for 1st and 2nd generation T-cells.

Detailed Description of the Invention

The invention features nucleic acid constructs encoding chimeric immune T-cell receptors (CIRs) that are useful for treating HIV in patients. In general, the CIRs contain an extracellular domain which targets HIV or HIV-infected cells (e.g., the extracellular domain of CD4), a transmembrane domain, and a cytoplasmic domain for mediating T-cell activation (e.g., CD3 zeta and/or the partial extracellular domain of CD28). The invention also features the use of host cells expressing CIRs in the treatment of HIV. When expressed in the host cells, the CIRs can be engineered to homodimerize, thereby increasing their potency. These host cells can also contain nucleic acid constructs encoding siRNA against HIV genes in order to, e.g., disrupt HIV infection of the host T-cells. The structure of a prior art CIR and the structures of CIRs

containing the transmembrane domain of CD3 zeta and partially extracellular domain of CD28 are depicted in Fig. 1.

Extracellular Domains

5 The CIRs of the invention feature an extracellular domain able to specifically bind HIV and cells infected with HIV. The HIV protein gp120 binds human CD4. Therefore, the extracellular domain of the CIRs of the invention can include the extracellular domain of CD4 (e.g., human CD4 or fragments thereof). Alternatively, the extracellular domain can include any
10 binding moiety specific for HIV and cells infected with HIV, including, HIV specific antibodies (e.g., single-chain Fv antibody fragments that are specific to gp120 or gp41).

 The extracellular domain can optionally include a further protein tag, e.g., a c-myc tag (EQKLISEEDL (SEQ ID NO:4) of human origin, at the N-terminus.
15 The c-myc tag does not obstruct CD4 binding to gp120. Inclusion of c-myc in the sFv based-CIR design does not appear to affect CIR function, but can facilitate future study of the construct.

Cytoplasmic Domains

20 The CIRs of the invention also feature a cytoplasmic domain for signaling modulating activation of the host T-cells when bound to HIV or HIV-infected cells. Cytoplasmic domains useful for use in the CIRs of the invention include CD3 zeta, or fragments thereof, and for the cytoplasmic domain of CD28, or fragments thereof. The invention also features the fusion of
25 polypeptides derived from multiple extracellular domains for potentiating activation of T-cells when bound to HIV or HIV-infected cells (e.g., a cytoplasmic domain that includes both active fragments of CD3 zeta and CD28).

Transmembrane Domains

The CIRs of the invention feature transmembrane domains derived from CD4, CD28, CD3 zeta, or another protein. Furthermore, the transmembrane domain (or the partial extracellular domains, "pEC") can be engineered to
5 facilitate homodimerization of the CIRs when expressed in host T-cells. This can be accomplished, e.g., with the addition or substitution of cysteine residues capable of forming disulfide bonds with a paired molecule.

The inclusion of the transmembrane region of the zeta chain or the transmembrane and partial extracellular domain of CD28 provides the
10 capability of intermolecular disulfide bonds. CIRs containing these transmembrane/partial extracellular domains are predicted to form disulfide-linked dimers through a cysteine residue located in the transmembrane of zeta or in the proximal cysteine residue located in the partial extracellular domain of CD28 (position 123 of CD28), mimicking the dimer configuration of native
15 zeta and CD28.

siRNA Constructs

The DNA constructs and host cells of the invention also optionally feature components to suppress HIV infection of host T-cells. Such
20 components include siRNA constructs for suppression of HIV replication. These siRNA constructs can be specific for various HIV targets (reviewed in Morris (2006) Gene Ther 13:553-558; Rossi (2006) Biotechniques Suppl:25-29; Nekhai (2006) Curr Opin Mol Ther 8:52-61; and Cullen (2005) AIDS Rev 7:22-25). One example is an siRNA targeting a highly conserved sequence in
25 an exon common to both *tat* and *rev*, has been shown to be effective to prevent virus expression and replication (See, e.g., SEQ ID No. 1). In order to prevent HIV infection of host T-cells, the invention also features components to decrease expression of T cell coreceptors (e.g., CCR5 and CCR4). Such suppression would be expected to hinder infection of host T-cells as people
30 with CCR5Δ32 mutation are resistant to HIV infection. The invention also

features the inclusion of multiple siRNA constructs (e.g., constructs against HIV genes and T-cell receptors used for HIV infection). Here, one siRNA construct can block infection and while a second siRNA construct prevents progression of infection.

5 Methods of designing and expressing siRNA constructs are well known in the art. For example, the siRNA constructs of the invention can utilize long-hairpin RNA (lhRNA) to express both CCR5 and Tat/Rev siRNAs. Use of a lhRNA is a viable approach in controlling HIV-1 replication since a single long transcript can in theory be processed into multiple siRNAs. Multiple targeting
10 can be achieved from a single long-hairpin precursor, suggesting that multiple siRNAs can be processed from the long hairpins *in vivo*. The siRNA constructs of the invention can also include a promoter directing expression in host T-cells. Examples of such promoters are U6 and tRNA promoters. Expressing shRNAs from tRNA promoters has several advantages, compared to the more
15 commonly used U6 and H1 promoters: tRNA promoters are smaller, provide a variety of options, and are typically expressed at lower levels. Smaller promoters may be desirable in the nucleic acid constructs of the invention to facilitate inclusion in a vector including a CIR expression construct. An example of a nucleic acid construct containing a CIR and siRNA is set forth in
20 Fig. 2.

shRNA sequences

tat/rev shRNA – sense strand SEQ ID NO:5

5' –GCGGAGACAGCGACGAAGAGC– 3'

25

Ref: Scherer, L. J., R. Frank, and J. J. Rossi. 2007. *Nucleic Acids Res* 35:2620-2628.

ccr5 shRNA – sense strand SEQ ID NO:6

5' – GCCUGGGAGAGCUGGGGAA – 3'

30

Ref: Ehsani, *Mol Ther* Epub ahead of print.

shRNA within CIR (SEQ ID NO:7)

5 -Myc-CD4-CD28-zeta-tcaggtggtggcgggttcaggctgcggaggtggtctggtggcggtggcggtatcg
Generic linker (G4S)3

10 GCGCGGATAGCTCAGTcGGTAGAGCACAGACTTTAATCTGAGGGTCCAGGGTCAAGTCCCTGTTCTGGGC
GCCA

15 tRNA promoter

GCCTGGGAGAGCTGGGGAATTTGTACGTAGTTCCCCAGCTCTCCCAGGC
ccr5 shRNA sense shRNA loop ccr5 shRNA antisense

20 ggtggcagtggtccggaggttcaggaagcggcggtagtgggagc
generic linker (GGSGS)3

25 GCGGAGACAGCGACGAAGAGCCTTCCTGTCTCAGAGCGGAGACAGCGACGAAGAGCTTTTTGAA
tat/rev shRNA sense shRNA loop tat/rev shRNA antisense terminator sequence

20 **Nucleic Acid Constructs**

The nucleic acid constructs of the invention are useful for expressing CIRs and siRNA constructs in host T-cells. CIRs and siRNA constructs can be included in a single nucleic acid construct or multiple nucleic acid constructs. In order to facilitate transfection of host cells, the nucleic acid construct can be included in a viral vector (e.g., a retroviral vector or adenoviral vector) or be designed to be transfected into a host cell via electroporation or chemical means (e.g., using a lipid transfection reagent).

Examples of nucleic acid constructs

30 **Myc-CD4-zeta (1st generation (dimer)) SEQ ID NO: 8**

ATGAACCGGGGAGTCCCTTTTAGGCACTTGCTTCTGGTGCTGCAACTGGC
 GCTCCTCCCAGCAGCCACTCAGGGAGAGCAGAAGCTGATCTCCGAGGAGG myc (underline)
 35 ACCTGAAGAAAGTGGTGCTGGGCAAAAAAGGGGATACAGTGGAAGCTGACC
 TGTACAGCTTCCCAGAAGAAGAGCATAACAATTCCACTGGAAAACTCCAA
 CCAGATAAAGATTCTGGGAAATCAGGGCTCCTTCTTAACTAAAGGTCCAT
 CCAAGCTGAATGATCGCGCTGACTCAAGAAGAAGCCTTTGGGACCAAGGA
 AACTTTCCCTGATCATCAAGAATCTTAAGATAGAAGACTCAGATACTTA
 CATCTGTGAAGTGGAGGACCAGAAGGAGGAGGTGCAATTGCTAGTGTTTCG
 40 GATTGACTGCCAACTCTGACACCCACCTGCTTCAGGGGCAGAGCCTGACC
 CTGACCTTGGAGAGCCCCCTGGTAGTAGCCCCCTCAGTGCAATGTAGGAG
 TCCAAGGGGTA AAAACATACAGGGGGGGAAGACCCCTCTCCGTGTCTCAGC
 TGGAGCTCCAGGATAGTGGCACCTGGACATGCACTGTCTTGCAGAACCAG
 AAGAAGGTGGAGTTCAAAATAGACATCGTGGTGCTAGCTTTCCAGAAGGC
 45 CTCCAGCATAGTCTATAAGAAAGAGGGGGAACAGGTGGAGTTCTCCTTCC
 CACTCGCCTTTACAGTTGAAAAGCTGACGGGCAGTGGCGAGCTGTGGTGG
 CAGGCGGAGAGGGCTTCTCTCTCCAAGTCTTGATCACCTTTGACCTGAA
 GAACAAGGAAGTGTCTGTAAACGGGTTACCCAGGACCCTAAGCTCCAGA
 TGGGCAAGAAGCTCCCGCTCCACCTCACCTGCCCCAGGCCTTGCCTCAG

TATGCTGGCTCTGGAAACCTCACCCCTGGCCCTTGAAAGCGAAAACAGGAAA
 GTTGCATCAGGAAGTGAACCTGGTGGTGATGAGAGCCACTCAGCTCCAGA
 AAAATTTGACCTGTGAGGTGTGGGGACCCACCTCCCCTAAGCTGATGCTG
 5 AGCTTGAAACTGGAGAACAAGGAGGCAAAGGTCTCGAAGCGGGAGAAGGC
 GGTGTGGGTGCTGAACCTGAGGCGGGGATGTGGCAGTGTCTGCTGAGTG
 ACTCGGGACAGGTCTCTGCTGGAATCCAACATCAAGGTTCTGCCCACATGG
 TCCACCCCGGTGCTTAGGCTGGATCCCAAACTCTGCTACCTGCTGGATGG zeta (Underline)
 AATCCTCTTCATCTATGGTGTCAATCTCACTGCCTTGTTCCTGAGAGTGA
 10 AGTTTCAGCAGGAGCGCAGACGCCCCCGCTACCAGCAGGGCCAGAACCAG
 CTCTATAACGAGCTCAATCTAGGACGAAGAGAGGAGTACGATGTTTTGGA
 CAAGAGACGTGGCCGGGACCCCTGAGATGGGGGGAAAAGCCGAGAAGGAAGA
 ACCCTCAGGAAGGCCTGTACAATGAACTGCAGAAAAGATAAGATGGCGGAG
 GCCTACAGTGAGATTGGGATGAAAGGCGAGCGCCGGAGGGGCAAGGGGCA
 CGATGGCCTTTACCAGGGTCTCAGTACAGCCACCAAGGACACCTACGACG
 15 CC

Myc-CD4-CD28-zeta (2nd generation) SEQ ID NO:9

ATGAACCGGGGAGTCCCTTTTAGGCACTTGCTTCTGGTGCTGCAACTGGC
 20 GCTCCTCCAGCAGCCACTCAGGGAGAGCAGAAGCTGATCTCCGAGGAGG myc (underline)
 ACCTGAAGAAAGTGGTGCTGGGCAAAAAGGGGATACAGTGGAAGTGAAC CD4
 TGTACAGCTTCCAGAAAGAGCATAACAATTCCACTGGAAAACTCCAA
 CCAGATAAAGATTCTGGGAAATCAGGGCTCCTTCTTAACTAAAGGTCCAT
 CCAAGCTGAATGATCGCGCTGACTCAAGAAGAAGCCTTTGGGACCAAGGA
 25 AACTTTCCCTGATCATCAAGAATCTTAAGATAGAAGACTCAGATACTTA
 CATCTGTGAAGTGGAGGACCAGAAGGAGGAGGTGCAATTGCTAGTGTTTCG
 GATTGACTGCCAACTCTGACACCCACCTGCTTCAGGGGCAGAGCCTGACC
 CTGACCTTGGAGAGCCCCCTGGTAGTAGCCCCCTCAGTGCAATGTAGGAG
 TCCAAGGGGTAAAAACATACAGGGGGGAAGACCTCTCCGTGTCTCAGC
 30 TGGAGCTCCAGGATAGTGGCACCTGGACATGCACTGTCTTGCAAGACCAG
 AAGAAGGTGGAGTTCAAAATAGACATCGTGGTGCTAGCTTTCCAGAAGGC
 CTCCAGCATAGTCTATAAGAAAAGAGGGGGAAACAGGTGGAGTTCTCCTTCC
 CACTCGCCTTTACAGTTGAAAAGCTGACGGGCAGTGCGGAGCTGTGGTGG
 CAGGCGGAGAGGGCTTCTCCTCCAAGTCTTGATCACCTTTGACCTGAA
 35 GAACAAGGAAGTGTCTGTATAAACGGGTACCCAGGACCCTAAGCTCCAGA
 TGGGCAAGAAGCTCCCGCTCCACCTCACCTGCCCCAGGCCTTGCCCTCAG
 TATGCTGGCTCTGGAAACCTCACCCCTGGCCCTTGAAAGCGAAAACAGGAAA
 GTTGCATCAGGAAGTGAACCTGGTGGTGATGAGAGCCACTCAGCTCCAG
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 40 TGAGCTTGAACTGGAGAACAAGGAGGCAAAGGTCTCGAAGCGGGAGAAG
 GCGGTGTGGGTGCTGAACCTGAGGCGGGGATGTGGCAGTGTCTGCTGAG
 TGACTCGGGACAGGTCTCTGCTGGAATCCAACATCAAGGTTCTGCCCACAT
 GGTCCACCCCGGTGCTTAGGAAAATTGAAGTTATGTATCCTCCTCCTTAC
 45 CTAGACAATGAGAAAGAGCAATGGAACCATATCCATGTGAAAAGGGAAACA
 CCTTTGTCCAAGTCCCCTATTTCCCGGACCTTCTAAGCCCTTTTGGGTGC
 TGGTGGTGGTTGGTGGAGTCTGGCTTGCTATAGCTTGCTAGTAACAGTG
 GCCTTTATTATTTCTGGGTGAGGAGTAAGAGGAGCAGGCTCCTGCACAG
 TGACTACATGAACATGACTCCCCGCCGCCCGGGCCACCCGCAAGCATT
 ACCAGCCCTATGCCCCACCACGCGACTTCGCAGCCTATCGCTCCAGAGTG
 50 AAGTTTCAGCAGGAGCGCAGACGCCCCCGGTACCAGCAGGGCCAGAACCA
 GCTCTATAACGAGCTCAATCTAGGACGAAGAGAGGAGTACGATGTTTTGG
 ACAAGAGACGTGGCCGGGACCCCTGAGATGGGGGGAAAAGCCGAGAAGGAAG
 AACCTCAGGAAGGCCTGTACAATGAACTGCAGAAAAGATAAGATGGCGGA
 GGCCTACAGTGAGATTGGGATGAAAGGCGAGCGCCGGAGGGGCAAGGGGC
 55 ACGATGGCCTTTACCAGGGTCTCAGTACAGCCACCAAGGACACCTACGAC
 GCC CD28 (underline)
zeta

The amino acid sequence for the CD28 and CD3 zeta portions of the 2nd generation construct is

60 K I E V Met Y P P P Y L D N E K S N G T I I H V K G K H L C P S P L F P G P S K P
 F W V L V V V G G V L A C Y S L L V T V A F I I F W V R S K R S R L L H S D Y Met

N Met T P R R P G P T R K H Y Q P Y A P P R D F A A Y R S R V K F S R S A D A
 P A Y Q Q G Q N Q L Y N E L N L G R R E E Y D V L D K R R G R D P E Met G G K
 P R R K N P Q E G L Y N E L Q K D K Met A E A Y S E I G Met K G E R R R G K G
 H D G L Y Q G L S T A T K D T Y D A

5

(SEQ ID NO:10)

Host T-cells

The host T-cells of the invention can be isolated from, e.g., a patient
 10 infected with HIV. The host T-cells are transfected or infected with nucleic
 acid constructs of the invention (e.g., nucleic acid constructs encoding a CIR
 and, optionally, one or more siRNA constructs). Prior to administration to a
 patient the T-cells can be expanded in cell culture. In one embodiment, the
 modified T-cells are administered to the patient from whom they were
 15 originally isolated.

In one embodiment, PBMCs are isolated by standard techniques and
 transduced with a CIR. Cells are administered to the patient in a dose of
 between 10^9 and 10^{10} cells (e.g., 10^9 , 5×10^9 , or 10^{10} cells). Cells can be
 isolated once and expanded for multiple administrations or a separate isolation
 20 and transduction can be performed with each round of treatment.

Treatment can be, e.g., a single treatment, monthly treatment, semi-
 annual treatment, or annual treatment.

Additional Agents

25 Additional antiviral can be, for example, a protease inhibitor, a reverse
 transcriptase inhibitor, an integrase inhibitor, a CCR5 antagonist, a fusion
 inhibitor, or a second maturation inhibitor. The additional antiviral agent can
 be, without limitation, azidovudine (AZT), didanosine (dideoxyinosine, ddl),
 d4T, zalcitabine (dideoxycytosine, ddC), nevirapine, lamivudine (epivir, 3TC),
 30 saquinavir (Invirase), ritonavir (Norvir), indinavir (Crixivan), and delavirdine
 (Rescriptor).

Additional Therapies

The methods of the invention can be combined with, e.g., lymphodepletion prior to administration of host T-cells. Furthermore, treatment can also include the administration of one or more cytokines, e.g., IL-2, IL-7,
5 and IL-15.

Experimental Results

Construction of Retroviral Vectors

The chimeric immune T-cell receptor (CIR) of the prior anti-HIV
10 designer T cell trials had the structure of extracellular domain of CD4 (a polypeptide corresponding to amino acids 1-372 of SEQ ID NO:1), transmembrane domain of CD4 (a polypeptide corresponding to amino acids 373-395 of SEQ ID NO:1) and cytoplasmic domain of zeta (a polypeptide corresponding to amino acids 31-142 of SEQ ID NO:3) (Deeks et al. (2002)
15 Mol Ther 5:788-797, Mitsuyasu et al. (2000) Blood 96:785-793) (herein "Hege CIR", Fig. 1). We also designed a signal one-only CIR that is similar to the Hege CIR except that the transmembrane domain of zeta (a polypeptide corresponding to amino acids residues 7-30 of SEQ ID NO:3) was substituted (1st generation CIR, Fig. 1). Lastly, we created a construct that integrates CD28
20 as well as zeta signaling in a two signal format (2nd generation CIR, Fig. 1). This employs the same extracellular domain of CD4 (a polypeptide corresponding to amino acids 1-372 of SEQ ID NO:1) with a partial extracellular domain/transmembrane domain/cytoplasmic domain of CD28 (a polypeptide corresponding to amino acids 127-234 of SEQ ID NO:2) and is
25 expressed as dimer.

In addition, a c-myc tag (EQKLISEEDL) of human origin is also included in our constructs at the N-terminus of CD4.

1st and 2nd generation CIRs were constructed in the MFG retrovirus vector. Retrovirus was created by ping pong between the E+86 ecotropic and
30 PG13 amphotropic cell lines. PG13 is a helper cell line derived from murine

fibroblasts that is used to create vector producer cells (VPC) for retroviral production. VPCs were sorted for the highest transgene expression and viral supernatants were harvested as described Beaudoin et al. ((2008) J Virol Methods 148:253-259).

5

Expression of CIRs

Viral supernatants from PG13 VPCs were used to transduce human PBMCs. PBMCs from normal healthy individuals were purified and activated with anti-CD3 antibody (OKT3) and 100 U/ml IL2 for two days and transduced with retrovirus by spinoculation on a retronectin coated plate. We determined the surface expression of CIRs on CD8+ T-cells by double staining for CD8 and CD4 and determined the transduction rate (as % modified cells, Fig. 3). Transduction of activated human T-cells routinely yield 40 to 70% transduction rates with these anti-HIV CIRs.

15 We co-cultured transduced or non-transduced T-cells with CEM-SS HIV+ (chronically infected with HIV-1 IIIB) or HIV- cells (at an E:T ratio of 1:1 or 1:10). We determined the presence of transduced cells in the culture by staining with anti-CD4 and anti-CD8 antibodies. Co-culture of Hege CIR T-cells with CEM-SS HIV+ cells at an E: T ratio of 1:10 induced cell death and all the Hege CIR cells disappeared from the culture by day 3 (Fig 4). At an E:T ratio of 1:1, Hege CIR T cells were still present in the culture at day 13, with killing of all target cells in the culture (observed by flow cytometry analysis). Cell death observed in the Hege CIR designer T-cells could be either due to heightened sensitivity to Activation Induced Cell Death (AICD) or to HIV infection. To test this, Hege CIR cells were treated with anti-retroviral drug AZT and co-cultured with HIV infected CEM-SS cells. AZT treated Hege CIR cells did not die when co-cultured with higher target ratio (1:10, Fig. 5). These data suggest that Hege CIR cells become infected with HIV and die by either HIV induced apoptosis or killed by other CIR containing T-cells (fratricide).
25
30 These data suggest and we hypothesize that one of the reasons for the failure of

Hege CIR in the clinical trials could be due to highest susceptibility to HIV infection and elimination from the patients.

Susceptibility of Designer T-cells to HIV Infection

5 HIV infects CD4+ T-cells by binding to CD4 receptor and a co-receptor (CXCR4 or CCR5). Since CIR has an extracellular CD4 domain, we postulated that this could be used by HIV to infect all CIR+ T-cells, including CD8+ T-cells. HIV infection of CIR+CD8+ cells was determined by co-culturing CIR containing T-cells with HIV+ CEM-SS cells and staining for p24-gag antigen,
10 an indicator of productive infection. After two days of culture, cells were stained with anti-CD8 and anti-p24 gag antibodies. In contrast to non-transduced cultures, CD8+ cells are infected with HIV in transduced cultures (1st and 2nd generation) (Fig. 6). At day 11 we did not detect any HIV infected CD8+ cells in either 1st or 2nd generation CIR containing T-cells (Fig. 6).

15 *Killing of HIV-infected Cells by Modified T-cells.*

In order to compare the potencies of Hege CIR, 1st, and 2nd generation anti-HIV CIR in killing of target cells, activated T-cells were transduced as described above. Target cells (HIV-infected or uninfected CEM-SS cells) were labeled with ⁵¹Cr for 5 hrs (50 µCi for 1 × 10⁶ cells) and co-cultured with
20 transduced T-cells at indicated E:T ratios for 18 hrs. Hege CIR T-cells and our 1st and 2nd generation designer T-cells were all equally potent in killing HIV+ target cells (Fig. 7).

Cytokine Secretion by Modified T-cells.

25 Human T-cells transduced with 1st and 2nd generation CIR containing T-cells were tested for their ability to secrete cytokines upon stimulation through the CIR. Transduced or non-transduced T-cells were cultured on anti-CD4 antibody coated plates for 24 hrs. IL2 secretion was measured with an ELISA kit. 2nd generation T-cells produced more IL2 than 1st generation T-cells when
30 stimulated with anti-CD4 antibody (Fig. 8). In contrast, IFNγ secretion is

similar with anti-CD4 stimulation of 1st and 2nd generation designer T-cells, as is typical for T cell signaling.

Conferring Resistance of Designer T-cells to HIV Infection

5 HIV infects CD4+ T-cells by binding to CD4 receptor and a co-receptor (CXCR4 or CCR5). As shown above, CD8+CIR+ cells (1st and 2nd generation) are susceptible to HIV infection (day two, Fig. 6). At day 11 we did not detect any HIV infected CD8+ cells in either 1st or 2nd generation T-cells (Fig. 6). These data suggest that modified T-cells could kill other HIV infected modified
10 T-cells. Nevertheless, this is a potential source of loss of effector cells to combat HIV and provides a new reservoir to increase patient HIV load. It is therefore becomes important to eliminate or reduce the potential for HIV to infect modified T-cells.

Other Embodiments

15 Various modifications and variations of the described methods and compositions of the invention will be apparent to those skilled in the art without departing from the scope and spirit of the invention. Although the invention has been described in connection with specific desired embodiments, it should be understood that the invention as claimed should not be unduly limited to
20 such specific embodiments. Indeed, various modifications of the described modes for carrying out the invention that are obvious to those skilled in the fields of medicine, immunology, pharmacology, endocrinology, or related fields are intended to be within the scope of the invention.

All publications mentioned in this specification are herein incorporated
25 by reference to the same extent as if each independent publication was specifically and individually incorporated by reference.

What is claimed is:

1. A nucleic acid construct encoding a chimeric protein comprising
 - (i) an extracellular domain of CD4, or a fragment thereof,
 - (ii) a transmembrane domain, and
 - (iii) a cytoplasmic domain comprising
 - a) the cytoplasmic domain of the CD3 zeta chain, or a fragment thereof and
 - b) the cytoplasmic domain of CD28, or a fragment thereof.
2. The nucleic acid construct of claim 1, wherein said chimeric protein is capable of forming a homodimer when expressed in a T cell.
3. The nucleic acid construct of claim 2, wherein the dimerized chimeric proteins are capable of forming at least one disulfide bond.
4. The nucleic acid construct of claim 1, wherein said transmembrane domain comprises a polypeptide selected from the group consisting of the transmembrane domain of the CD3 zeta chain and the transmembrane domain of CD28.
5. The nucleic acid construct of claim 4, wherein said transmembrane domain comprises amino acids 7-30 of SEQ ID NO:3.
6. The nucleic acid construct of claim 1, wherein said chimeric protein further comprises a c-myc tag.
7. The nucleic acid construct of claim 1, wherein said extracellular domain of CD4 comprises amino acids 1-372 of SEQ ID NO:1.
8. The nucleic acid construct of claim 1, wherein said cytoplasmic domain of the CD3 zeta chain comprises amino acids 31-142 of SEQ ID NO:3.

9. The nucleic acid construct of claim 1, wherein said cytoplasmic domain of CD28 comprises amino acids 127-234 of SEQ ID NO:2.

10. The nucleic acid construct of claim 1, wherein said cytoplasmic domain comprises the amino acid sequence of SEQ ID NO:10.

11. A nucleic acid construct encoding a chimeric protein comprising
(i) an extracellular domain of CD4, or a fragment thereof,
(ii) a transmembrane domain, and
(iii) a cytoplasmic domain of the CD3 zeta chain, or a fragment thereof,
wherein said chimeric protein is capable of forming a homodimer when expressed in a T cell.

12. The nucleic acid construct of claim 11, wherein the chimeric protein, when in a homodimer, is capable of forming at least one disulfide bond with the chimeric protein with which it is dimerized.

13. The nucleic acid construct of claim 11, wherein said transmembrane domain comprises the transmembrane domain of the CD3 zeta chain or the transmembrane domain of CD28.

14. The nucleic acid construct of claim 13, wherein said transmembrane domain comprises amino acids 7-30 of SEQ ID NO:3.

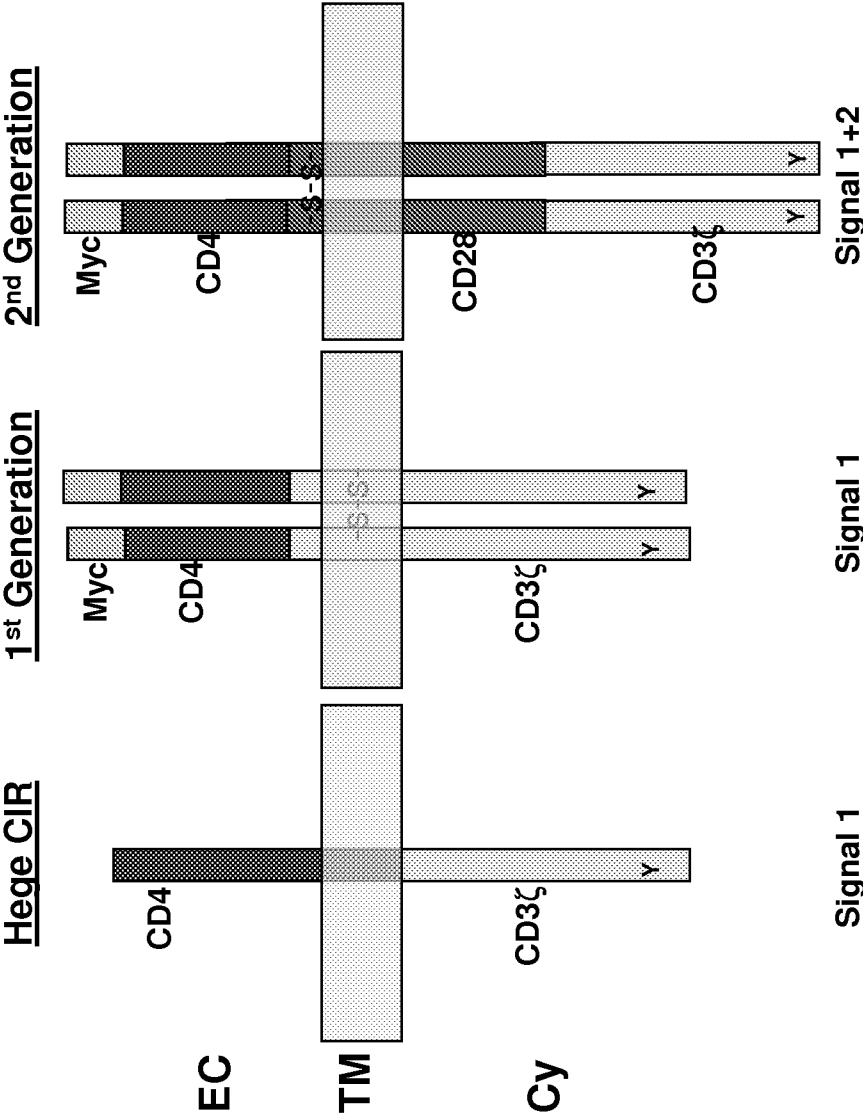
15. The nucleic acid construct of claim 11, wherein said chimeric protein further comprises a c-myc tag.

16. The nucleic acid construct of claim 11, wherein said extracellular domain of CD4 comprises amino acids 1-372 of SEQ ID NO:1.

17. The nucleic acid construct of claim 11, wherein said cytoplasmic domain of the CD3 zeta chain comprises amino acids 31-142 of SEQ ID NO:3.
18. A vector comprising the nucleic acid construct of any of claims 1-17.
19. The vector of claim 18 further comprising a nucleic acid construct encoding an siRNA.
20. The vector of claim 19 wherein said siRNA is against CCR5.
21. The vector of claim 19 wherein said siRNA is against Tat/Rev.
22. A host cell comprising the nucleic acid construct of any of claims 18-21.
23. The host cell of claim 22, wherein said host cell is a T cell.
24. The host cell of claim 23, wherein said T cell is isolated from a patient infected with HIV.
25. A host cell comprising the nucleic acid construct any of claims 1-17 and a nucleic acid construct encoding an siRNA.
26. The host cell of claim 25, wherein said siRNA is against CCR5.
27. The host cell of claim 25, wherein said siRNA is against Tat/Rev.
28. A method of treating a patient infected with HIV by administering a composition comprising host cell of any of claims 22-26.

29. The method of claim 28, wherein said host cell is a T cell isolated from said patient.

Figure 1



Construct	Description	Form
(1) CD4ζ (Hege CIR)	Ec/Tm of CD4 -Cy of ζ	Monomer
(2) mCD4ζ (1st generation CIR)	myc-Ec of CD4-pEc/Tm/Cy of ζ	Dimer
(3) mCD4CD28ζ (2nd generation CIR)	myc-Ec of CD4-pEc/Tm/Cy of CD28-Cy of ζ	Dimer

Figure 2

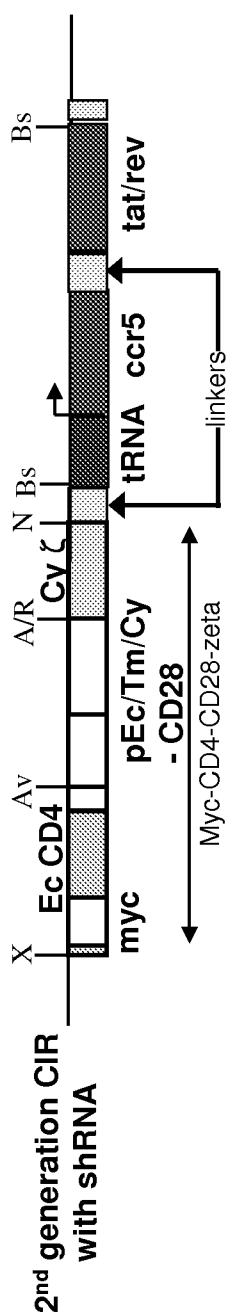


Figure 3

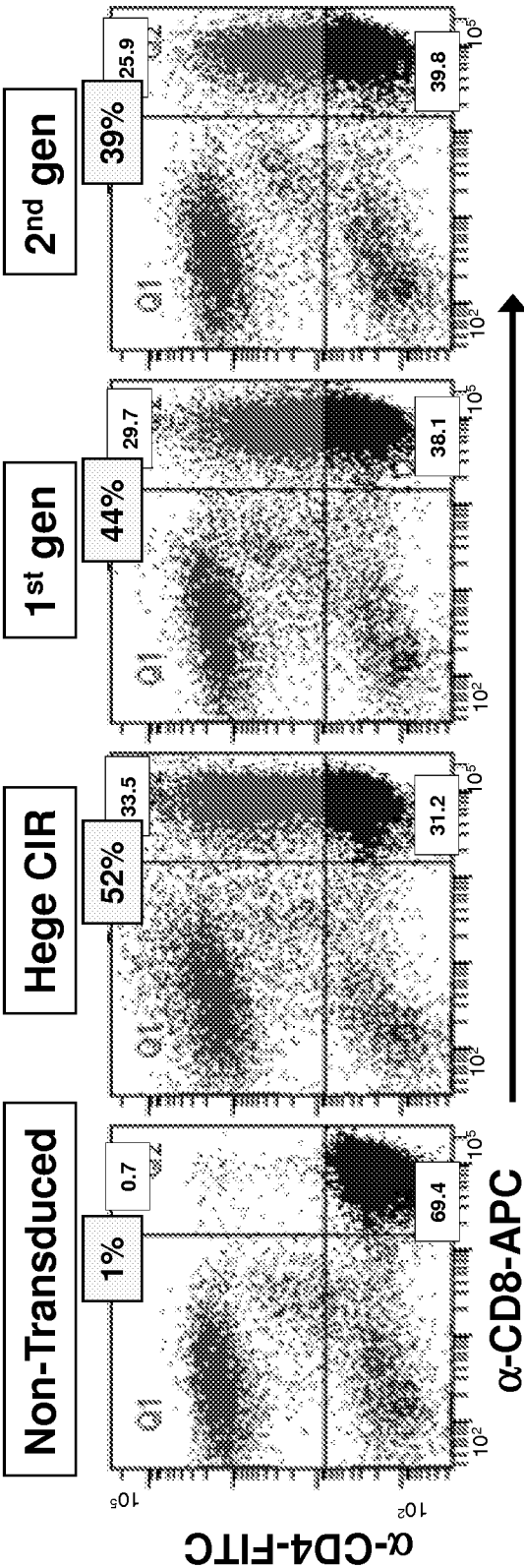


Figure 4

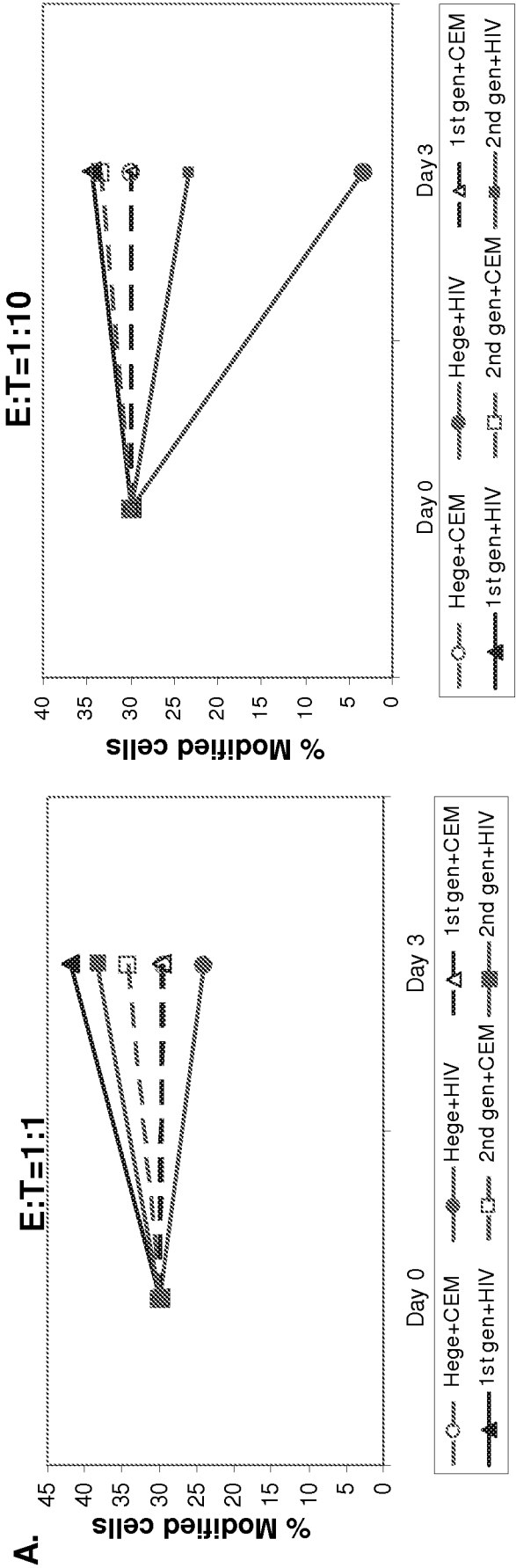
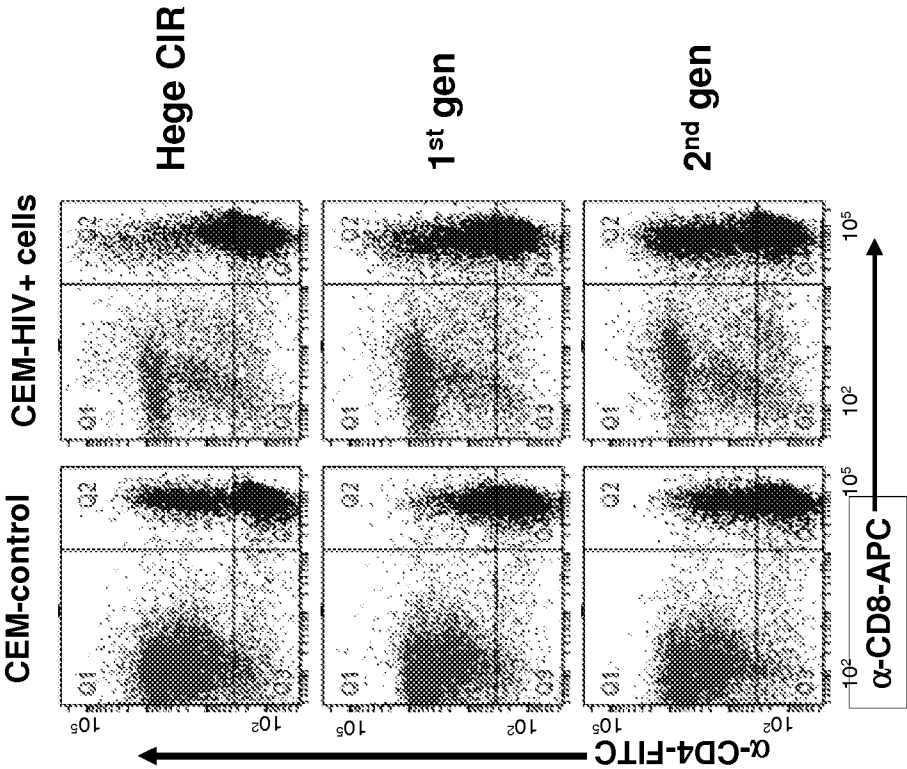


Figure 4

B.

E:T=1:1



E:T=1:10

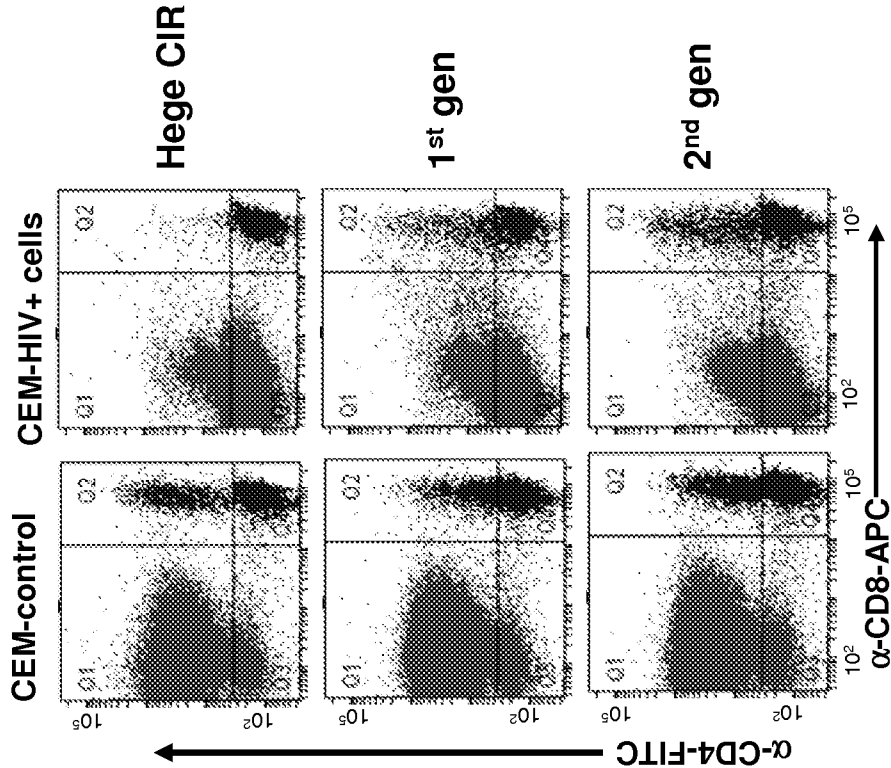


Figure 5

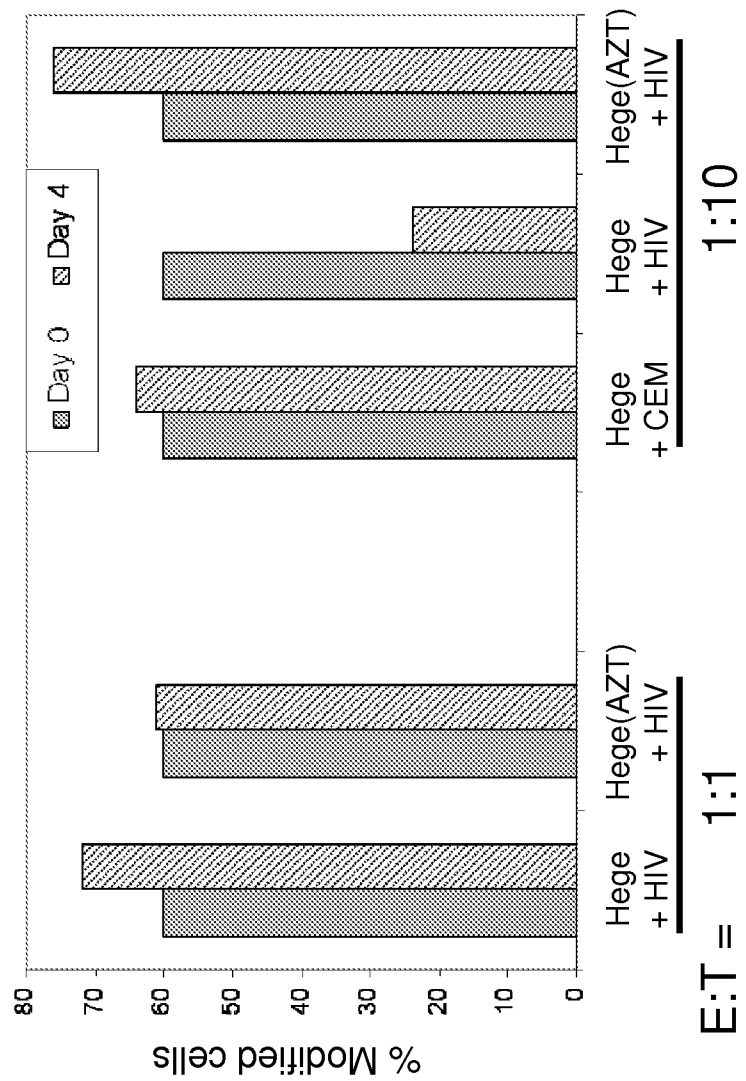
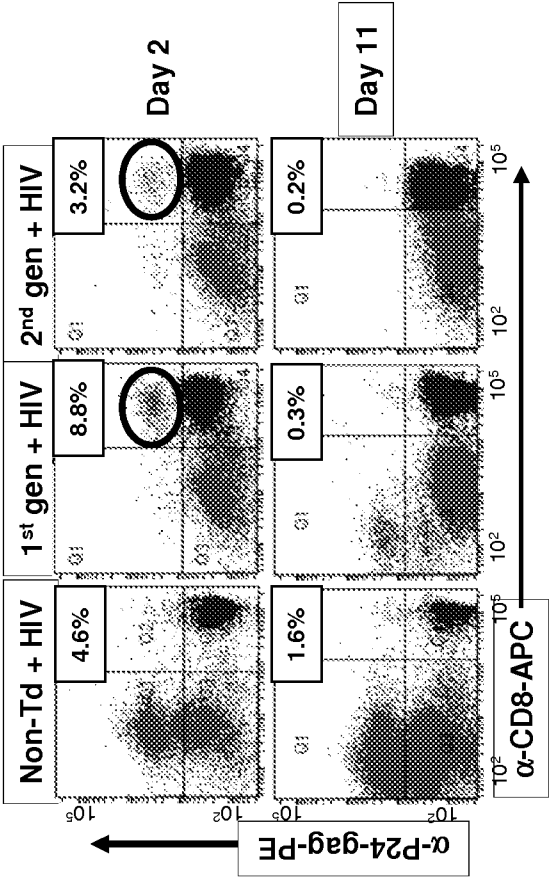


Figure 6



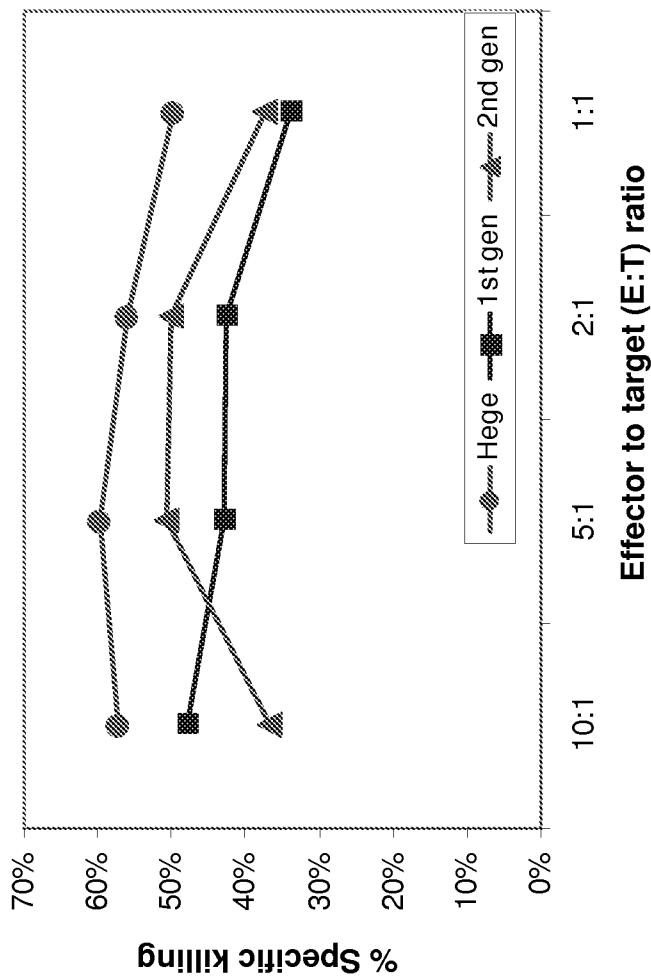


Figure 7

Figure 8

