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(54) Title: VIRAL VECTORS ENCODING MULTIPLE HIGHLY HOMOLOGOUS NON-VIRAL POLYPEPTIDES AND THE USE OF SAME

(57) Abstract: The present invention relates to compositions and methods for creation of vector nucleic acid sequences (e.g., retroviral nucleic acid sequences) that comprise two or more exogenous nucleic acid sequences that encode highly homologous (e.g., identical) polypeptide sequences, yet wherein at least one of the exogenous nucleic acid sequences has been mutated using degenerate codons for purpose of reducing homology between the two or more exogenous nucleic acid sequences while maintaining the encoded polypeptide sequence. Preferred nucleic acid sequences include those encoding multi-chimeric immune receptor (CIR) genes. Specific nucleic acid sequences of such CIR genes are also disclosed.

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VIRAL VECTORS ENCODING MULTIPLE HIGHLY HOMOLOGOUS NON-VIRAL POLYPEPTIDES AND THE USE OF SAME

RELATED APPLICATION

This application claims the benefit of U.S. Provisional Application No. 61/146,755,  
5 filed on January 23, 2009. The entire teachings of the above application are incorporated herein by reference.

GOVERNMENT SUPPORT

The invention was supported, in whole or in part, by a grant #AI060550 from the National Institutes of Health. The Government has certain rights in the  
10 invention.

BACKGROUND OF THE INVENTION

Recombination between nucleic acids is a well-established phenomenon in molecular biology. Genetic recombination that requires strong sequence homology between participating nucleic acid sequences to occur is generally referred to as  
15 homologous recombination. While most genetic knockout strategies employ homologous recombination to achieve a targeted knockout, in certain systems the occurrence of genetic recombination can impact genetic manipulations detrimentally. In particular, homologous recombination events can adversely impact construction and production of vectors, particularly viral vectors (*e.g.*, adenovirus,  
20 retrovirus, adeno-associated virus, herpes virus, etc.), where it is often desirable to maintain highly homologous sequences (*e.g.*, identical polypeptide sequences) within a single, stable viral vector free of homologous recombination during, *e.g.*, passage and/or propagation of viral vector through one or more host cells and/or organisms.

25 In bacteria, homologous recombination begins with a step that involves a single-stranded end (Meselson and Radding 1975 *Proc. Natl. Acad. Sci. USA*, 80:

358-361). In eukaryotes, a mechanism of double-strand break (DSB) (Szostak *et al.* 1983 *Cell* 33: 25-35) has been suggested. DSB appears to occur in two principal mechanisms of homologous recombination: one conservative, within which all the nucleic acid sequences participating in the recombination event are present in the recombination products (*ibid*), the other nonconservative, during which certain  
5 sequences are lost. In mammalian somatic cells, the majority of homologous recombination events by DSB appears to take place according to a nonconservative process (Lin *et al.* 1990 *Mol Cell Biol.* 10: 103-12).

During the production of recombinant proteins, recombination events within  
10 an expression plasmid (intramolecular homologous recombination) can, for example, lead to the excision of the expression cassette from the transgene, resulting in a loss of expression. Recombination events can also produce excision of an expression cassette which has been stably integrated into the genome of a host producer cell, thereby inducing a loss of stability. Because of the potential for  
15 deleterious impact of homologous recombination events during vector production, particularly viral vector production, a need exists for effective strategies to reduce or eliminate the occurrence of homologous recombination events during synthesis of vectors, particularly viral vectors. Accordingly, there is also a need for vector compositions that possess reduced susceptibility to the occurrence of homologous  
20 recombination events, particularly viral vectors comprising, within a single vector, nucleic acid sequences that are designed to protect against the occurrence of homologous recombination events between those sequences encoding highly homologous polypeptides.

#### SUMMARY OF THE INVENTION

25 The present invention relates, at least in part, to the discovery of a strategy for synthesis of a vector, viral vector and/or recombinant virus having two or more nucleic acid sequences encoding polypeptides that are identical or are of high homology to one another, wherein these nucleic acid sequences are, by design, of significantly lower homology to one another than their encoded polypeptide  
30 sequences. Design of such nucleic acid sequences of significantly lowered homology can be achieved *via* mutation of at least one nucleic acid sequence using

degenerate codons – an approach that exploits the degeneracy of the genetic code. Inclusion of such mutated nucleic acid sequences that still encode highly homologous polypeptides within a single vector can dramatically lessen the probability of homologous recombination events occurring between nucleic acid sequences within such a vector, as compared to the rate of homologous recombination expected and/or observed for a vector that comprises two or more native (or otherwise unaltered) nucleic acid sequences encoding highly homologous polypeptides. Thus, a vector, viral vector and/or recombinant virus of the instant invention can be generated, extensively propagated in host cells, and utilized in, *e.g.*, gene therapy of a subject, with high probability that both homologous polypeptide sequences are present and expressed within a host cell and/or target cell of the subject, even, *e.g.*, following extensive preparative passaging, replication, propagation, administration and/or chromosomal integration, excision, etc.

In certain aspects of the invention, the synthesis of viral vectors by the process of the invention is particularly advantageous for gene therapy of mammalian immune cells (*e.g.*, T cells, NK cells, macrophages), especially T cells. Accordingly, specific aspects of the present invention provide a viral vector having two or more nucleic acid sequences that each encodes a chimeric immune receptor (CIR) polypeptide, wherein the nucleic acid sequences, or fragments thereof, are, by design, of significantly lower homology to one another than their encoded polypeptide sequences. Introduction of such viral vectors to T cells allows for efficient concurrent expression of highly homologous CIRs within a T cell, which in turn allows for higher affinity targeting of a specific ligand (*e.g.*, *via* expression of both  $\alpha$  and  $\beta$  chains of an antigen binding fragment of an antibody that binds a targeted antigen with higher specificity than would be provided by a single chain antigen binding fragment), as well as enhanced T cell activation (*e.g.*, *via* simultaneous expression of co-activating molecules on a single host cell). Other aspects of the invention provide methods for therapeutic administration of such viral vectors to a host cell and/or target cell of a subject in need thereof, either *ex vivo* or *in vivo*, for the purpose of treating, *e.g.*, cancer and/or an infectious disease in the subject.

In one aspect, the instant invention provides a viral vector comprising a first nucleic acid sequence encoding a first polypeptide sequence and a second nucleic acid sequence encoding a second polypeptide sequence, wherein the first polypeptide sequence and the second polypeptide sequence comprise an identical  
5 polypeptide sequence of greater than 15 amino acids in length; and the first nucleic acid sequence and the second nucleic acid sequence contain at least one non-identical codon within the codons that encode the identical polypeptide sequence of the first and second nucleic acid sequences.

In another aspect, the instant invention provides a viral vector comprising a  
10 first nucleic acid sequence encoding a first polypeptide sequence and a second nucleic acid sequence encoding a second polypeptide sequence, wherein the first polypeptide sequence comprises a polypeptide sequence of greater than 15 amino acids in length that is greater than 90% identical to the second polypeptide sequence; and the first nucleic acid sequence and the second nucleic acid sequence contain at  
15 least one non-identical codon that encodes an identical amino acid residue, wherein the greater than 90% identical polypeptide sequence of the first and second nucleic acid sequences comprises the identical amino acid residue.

In one embodiment, at least one of the first and second nucleic acid sequences of the viral vector is a synthetic sequence. In another embodiment, the  
20 level of homology between the first and the second nucleic acid sequences of the viral vector is insufficient to cause homologous recombination between the first and the second nucleic acid sequences in a cell. In one related embodiment, the cell is a bacterial cell. In an additional related embodiment, the cell is a host cell.

In certain embodiments, the viral vector of the instant invention is selected  
25 from the group consisting of an adenovirus vector, an adeno-associated virus vector, a retrovirus vector, and a herpes virus vector.

In an additional embodiment, the first and second nucleic acid sequences of the viral vector encode non-viral polypeptide sequences. In another embodiment, the first and second nucleic acid sequences of the viral vector encode mammalian  
30 polypeptide sequences. In a further embodiment, the first and second nucleic acid sequences of the viral vector encode human polypeptide sequences.

In certain embodiments, the viral vector is a retroviral vector. In a related embodiment, the retroviral vector is selected from the group consisting of avian sarcoma-leukosis virus (ASLV), murine leukemia virus (MLV), human-, simian-, feline-, and bovine immunodeficiency viruses (HIV, SIV, FIV, BIV), equine  
5 infectious anaemia virus (EIAV), mouse mammary tumour virus (MMTV), Rous sarcoma virus (RSV), Fujinami sarcoma virus (FuSV), Moloney murine leukemia virus (Mo-MLV), MFG, FBR murine osteosarcoma virus (FBR MSV), Moloney murine sarcoma virus (Mo-MSV), Abelson murine leukemia virus (A-MLV), Avian myelocytomatosis virus-29 (MC29), Avian erythroblastosis virus (AEV), AKR  
10 (endogenous) murine leukemia virus, Avian carcinoma, Mill Hill virus 2, Avian leukosis virus--RSA, Avian myeloblastosis virus, Avian myelocytomatosis virus 29, Bovine syncytial virus, Caprine arthritis encephalitis virus, Chick syncytial virus, Equine infectious anemia virus, Feline leukemia virus, Feline syncytial virus, Finkel-Biskis-Jenkins murine sarcoma virus, Friend murine leukemia virus, Fujinami  
15 sarcoma virus, Gardner-Arnstein feline sarcoma virus, Gibbon ape leukemia virus, Guinea pig type C oncovirus, Hardy-Auckerman feline sarcoma virus, Harvey murine sarcoma virus, Human foamy virus, Human spumavirus, Human T-lymphotropic virus 1, Human T-lymphotropic virus 2, Jaagsiekte virus, Kirsten murine sarcoma virus, Langur virus, Mason-Pfizer monkey virus, Mouse mammary  
20 tumor virus, Ovine pulmonary adenocarcinoma virus, Porcine type C oncovirus, Reticuloendotheliosis virus, Rous sarcoma virus, Simian foamy virus, Simian sarcoma virus, Simian T-lymphotropic virus, Simian type D virus 1, Snyder-Theilen feline sarcoma virus, Squirrel monkey retrovirus, Trager duck spleen necrosis virus, UR2 sarcoma virus, Viper retrovirus, Visna/maedi virus, Woolly monkey sarcoma  
25 virus, and Y73 sarcoma virus.

In another embodiment, at least 20% of the codons encoding the at least one identical polypeptide domain of the first and second nucleic acid sequences are non-identical. In a further embodiment, the first nucleic acid sequence and the second nucleic acid sequence are less than 80% identical to one another within the codons  
30 that encode the at least one identical polypeptide domain of the first and second nucleic acid sequences.

In an additional embodiment, at least one of the first and second polypeptide sequences encoded by the viral vector is a chimeric immune receptor polypeptide sequence. In a related embodiment, at least one of the first and second polypeptide sequences is a chimeric immune receptor polypeptide sequence comprising a signal sequence that directs the polypeptide to the cell surface. In a further embodiment, the signal sequence that directs the polypeptide to the cell surface is selected from the group consisting of TCR- $\alpha$ , TCR- $\beta$ , TCR- $\gamma$ , TCR- $\delta$ , IgG, IgA, IgM, IgE, IgD, CD2, CD4, CD8, CD28, CD3 $\zeta$ , Fc $\epsilon$ RI $\gamma$ , and LFA-1. In another embodiment, at least one of the first and second polypeptide sequences is a chimeric immune receptor (CIR) polypeptide sequence comprising an extracellular binding domain selected from the group consisting of a surface membrane polypeptide that binds specifically to at least one ligand and a secreted polypeptide that binds specifically to at least one ligand.

In certain embodiments, at least one of the first and second polypeptide sequences is a chimeric immune receptor polypeptide sequence comprising a transmembrane domain selected from the group consisting of TCR- $\alpha$ , TCR- $\beta$ , TCR- $\gamma$ , TCR- $\delta$ , IgG, IgA, IgM, IgE, IgD, CD2, CD4, CD8, CD28, CD3 $\zeta$ , Fc $\epsilon$ RI $\gamma$ , and LFA-1. In some embodiments, at least one of the first and second polypeptide sequences is a chimeric immune receptor polypeptide sequence comprising an intracellular cytoplasmic domain selected from the group consisting of a CD3 $\zeta$  cytoplasmic domain or a functional fragment thereof, a CD28 cytoplasmic domain or a functional fragment thereof, a polypeptide that combines CD28 and CD3 $\zeta$  polypeptide sequences or a functional fragment thereof, and an Fc $\epsilon$ RI $\gamma$  cytoplasmic domain or a functional fragment thereof. In one embodiment, at least one of the first and second polypeptide sequences is a chimeric immune receptor polypeptide sequence comprising a signal sequence which directs the polypeptide to the cell surface; an extracellular binding domain that is a surface membrane polypeptide that binds specifically to at least one ligand or a secreted polypeptide that binds specifically to at least one ligand; a transmembrane domain; and an intracellular cytoplasmic domain that is a CD3 $\zeta$  cytoplasmic domain or a functional fragment thereof, a CD28 cytoplasmic domain or a functional fragment thereof, a polypeptide

that combines CD28 and CD3 $\zeta$  polypeptide sequences or a functional fragment thereof, a CD2 cytoplasmic domain or a functional fragment thereof, a LFA-1 polypeptide sequence or a functional fragment thereof, or an Fc $\epsilon$ RI $\gamma$  cytoplasmic domain or a functional fragment thereof.

5           In one embodiment, the viral vector comprises an altered (mutant) nucleic acid sequence that is the mutant sequence shown in Figure 2, the mutant sequence shown in Figure 4, the mutant sequence shown in Figure 6, the mutant sequence shown in Figure 16, the mutant sequence shown in Figure 19, the mutant sequence shown in Figure 21, or the mutant sequence shown in Figure 22.

10           In another embodiment, one of the first and second nucleic acid sequences is the mutant sequence shown in Figure 2, the mutant sequence shown in Figure 4, the mutant sequence shown in Figure 6, the mutant sequence shown in Figure 16, the mutant sequence shown in Figure 19, the mutant sequence shown in Figure 21, or the mutant sequence shown in Figure 22, or a functional fragment thereof.

15           In additional embodiments, the instant invention provides a cell or recombinant virus comprising the viral vector.

          Another aspect of the instant invention provides a host cell comprising a viral vector comprising a first nucleic acid sequence encoding a first polypeptide sequence and a second nucleic acid sequence encoding a second polypeptide  
20           sequence, wherein the first and second polypeptide sequences comprise at least one identical polypeptide domain of greater than 15 amino acids in length and the first nucleic acid sequence and the second nucleic acid sequence do not undergo homologous recombination with one another.

          In one embodiment, at least one of the first and second polypeptide  
25           sequences is a mammalian polypeptide sequence. In another embodiment, the viral vector is integrated in the host cell genome.

          In an additional embodiment, the viral vector is a retroviral vector. In a related embodiment, the retroviral vector is a lentiviral vector.

          In a further embodiment, at least 20% of the codons of the host cell viral  
30           vector encoding the identical polypeptide sequence of the first and second nucleic acid sequences contain at least one non-identical nucleic acid that reduces identity between the first and second nucleic acid sequences. In another embodiment, the



first nucleic acid sequence and the second nucleic acid sequence of the host cell viral vector are less than 80% identical.

In another embodiment, the host cell is an immune cell. In a related embodiment the host cell is an immune cell that is a natural killer cell, a lymphokine  
5 activated cell, a cytotoxic T cell, or a helper T cell or a subtype thereof. In one embodiment, the host cell is a human T cell. In an additional embodiment, the host cell is a hematopoietic stem cell. In a further embodiment, the host cell is a tumor infiltrating lymphocyte.

In certain embodiments, at least one of the first and second polypeptide  
10 sequences of the host cell viral vector is a chimeric immune receptor sequence. In one embodiment, the chimeric immune receptor sequence of the host cell viral vector comprises a signal sequence that directs the polypeptide to the cell surface. In a related embodiment, the signal sequence that directs the polypeptide to the cell surface is that of a TCR- $\alpha$ , TCR- $\beta$ , TCR- $\gamma$ , TCR- $\delta$ , IgG, IgA, IgM, IgE, IgD, CD2,  
15 CD4, CD8, CD28, CD3 $\zeta$ , Fc $\epsilon$ RI $\gamma$ , or LFA-1.

In an additional embodiment, the chimeric immune receptor of the host cell viral vector comprises an extracellular binding domain selected from the group consisting of a surface membrane polypeptide that binds specifically to at least one ligand and a secreted polypeptide that binds specifically to at least one ligand. In  
20 one embodiment, the chimeric immune receptor comprises a transmembrane domain of TCR- $\alpha$ , TCR- $\beta$ , TCR- $\gamma$ , TCR- $\delta$ , IgG, IgA, IgM, IgE, IgD, CD2, CD4, CD8, CD28, CD3 $\zeta$ , Fc $\epsilon$ RI $\gamma$ , or LFA-1.

In another embodiment, the chimeric immune receptor of the host cell viral vector comprises an intracellular cytoplasmic domain of a CD3 $\zeta$  cytoplasmic  
25 domain or a functional fragment thereof, a CD28 cytoplasmic domain or a functional fragment thereof, a polypeptide that combines CD28 and CD3 $\zeta$  polypeptide sequences or a functional fragment thereof, a CD2 cytoplasmic domain or a functional fragment thereof, a LFA-1 polypeptide sequence or a functional fragment thereof, or an Fc $\epsilon$ RI $\gamma$  cytoplasmic domain or a functional fragment thereof.

30 In certain embodiments of the instant invention, the chimeric immune receptor of the host cell viral vector comprises a signal sequence which directs the

polypeptide to the cell surface; an extracellular binding domain of a surface membrane polypeptide that binds specifically to at least one ligand or a secreted polypeptide that binds specifically to at least one ligand; a transmembrane domain; and an intracellular cytoplasmic domain of a CD3 $\zeta$  cytoplasmic domain or a functional fragment thereof, a CD28 cytoplasmic domain or a functional fragment thereof, a polypeptide that combines CD28 and CD3 $\zeta$  polypeptide sequences or a functional fragment thereof, a CD2 cytoplasmic domain or a functional fragment thereof, a LFA-1 polypeptide sequence or a functional fragment thereof, or an Fc $\epsilon$ RI $\gamma$  cytoplasmic domain or a functional fragment thereof. In one embodiment, the host cell viral vector comprises a mutant nucleic acid sequence selected from the group consisting of the mutant sequence shown in Figure 2, the mutant sequence shown in Figure 4, the mutant sequence shown in Figure 6, the mutant sequence shown in Figure 16, the mutant sequence shown in Figure 19, the mutant sequence shown in Figure 21, and the mutant sequence shown in Figure 22. In another embodiment, one of the first and second nucleic acid sequences of the host cell viral vector is a mutant nucleic acid sequence selected from the group consisting of the mutant sequence shown in Figure 2, the mutant sequence shown in Figure 4, the mutant sequence shown in Figure 6, the mutant sequence shown in Figure 16, the mutant sequence shown in Figure 19, the mutant sequence shown in Figure 21, and the mutant sequence shown in Figure 22, or a functional fragment thereof.

Another aspect of the instant invention provides a cell comprising a recombinant virus comprising an altered (mutant) nucleic acid sequence that is the mutant sequence shown in Figure 2, the mutant sequence shown in Figure 4, the mutant sequence shown in Figure 6, the mutant sequence shown in Figure 16, the mutant sequence shown in Figure 19, the mutant sequence shown in Figure 21, or the mutant sequence shown in Figure 22.

An additional aspect of the instant invention provides a viral vector comprising a first nucleic acid sequence encoding a first polypeptide sequence and a second nucleic acid sequence encoding a second polypeptide sequence, wherein the first polypeptide sequence and the second polypeptide sequence each comprises an identical CD3 $\zeta$  polypeptide sequence or functional fragment thereof; and the first

nucleic acid sequence and the second nucleic acid sequence contain at least one non-identical codon within the codons encoding the identical CD3 $\zeta$  polypeptide sequence or functional fragment thereof of the first and second nucleic acid sequences. In one embodiment, the identical CD3 $\zeta$  polypeptide sequence encoded  
5 by the viral vector is cytoplasmic.

A further aspect of the instant invention provides a viral vector comprising a first nucleic acid sequence encoding a first polypeptide sequence and a second nucleic acid sequence encoding a second polypeptide sequence, wherein the first polypeptide sequence and the second polypeptide sequence each comprises an  
10 identical CD28 polypeptide sequence or functional fragment thereof; and the first nucleic acid sequence and the second nucleic acid sequence contain at least one non-identical codon within the codons encoding the identical CD28 polypeptide sequence or functional fragment thereof of the first and second nucleic acid sequences.

Another aspect of the instant invention provides a viral vector comprising a  
15 first nucleic acid sequence encoding a first polypeptide sequence and a second nucleic acid sequence encoding a second polypeptide sequence, wherein the first polypeptide sequence and the second polypeptide sequence each comprises an identical Fc $\epsilon$ R1 polypeptide sequence or functional fragment thereof; and the first  
20 nucleic acid sequence and the second nucleic acid sequence contain at least one non-identical codon within the codons encoding the identical Fc $\epsilon$ R1 polypeptide sequence or functional fragment thereof of the first and second nucleic acid sequences.

An additional aspect of the instant invention provides a viral vector  
25 comprising a first nucleic acid sequence encoding a first polypeptide sequence and a second nucleic acid sequence encoding a second polypeptide sequence, wherein the first polypeptide sequence and the second polypeptide sequence each comprises an identical single chain antibody polypeptide sequence or functional fragment thereof; and the first nucleic acid sequence and the second nucleic acid sequence contain at  
30 least one non-identical codon within the codons encoding the identical single chain antibody polypeptide sequence or functional fragment thereof of the first and second

nucleic acid sequences. In one embodiment, the single chain antibody polypeptide sequence is an anti-CEA scFv or an anti-PSMA scFv.

A further aspect of the instant invention provides a viral vector comprising a first nucleic acid sequence encoding a first polypeptide sequence and a second  
5 nucleic acid sequence encoding a second polypeptide sequence wherein the first polypeptide sequence and the second polypeptide sequence each comprises an identical polypeptide sequence comprising a target-binding domain or functional  
10 fragment thereof; and the first nucleic acid sequence and the second nucleic acid sequence contain at least one non-identical codon within the codons that encode the identical target-binding domain or functional fragment thereof of the first and  
second nucleic acid sequences. In one embodiment, the target-binding domain of the viral vector binds an antigen. In one embodiment, the antigen is HIV-1 gp120, for which the target-binding domain or functional fragment thereof is a human CD4  
15 extracellular domain or functional fragment thereof. In a further embodiment, the target-binding domain or functional fragment thereof is a single chain antibody, or fragment antigen-binding (Fab). In a related embodiment, the antigen is a viral  
antigen or a tumor antigen. In a related embodiment, the antigen is selected from the group consisting of MHC presented peptides as tumor antigens (such as MAGE-1) or viral antigens (such as JC virus VP1) for which CIR are created with target  
20 binding domains of TCR or antibody in single chain or other format.

Another embodiment of the instant invention provides a method for inhibiting growth of a tumor in a subject comprising administering a virus comprising the viral vector of the invention to the subject, thereby inhibiting the growth of the tumor.

25 An additional embodiment of the instant invention provides a method for reducing the size of a tumor in a subject comprising administering a virus comprising the viral vector of the invention to the subject, thereby reducing the size of the tumor. In one embodiment, the tumor is a prostate cancer tumor, a lung cancer tumor, a breast cancer tumor, or a colorectal cancer tumor.

30 A further embodiment of the instant invention provides a method for inhibiting proliferation of a cancer cell in a subject comprising administering a virus comprising the viral vector of the invention to the subject, thereby inhibiting

proliferation of the cancer cell in the subject. In certain embodiments, the cancer cell is selected from the group consisting of a leukemia cancer cell, an AML cancer cell, and an ALL cancer cell.

In one embodiment, the virus is administered with a pharmaceutically  
5 acceptable carrier.

In another embodiment, the instant invention provides a method for inhibiting the proliferation of an infectious agent in a subject comprising administering a virus comprising the viral vector of the invention to the subject, thereby inhibiting proliferation of the infectious agent. In a related embodiment, the  
10 infectious agent is polyomavirus JC (JCV), HIV, HBV, HCV, CMV, or EBV.

In an additional embodiment, the instant invention provides a method for killing a virus-infected cell of a subject comprising administering a virus comprising the viral vector of the invention to the subject, thereby killing the virus-infected cell of the subject.

In another embodiment, the instant invention provides a method for  
15 treatment of a tumor or infectious disease in a subject comprising transforming lymphocyte cells with the viral vector of the invention, wherein the extracellular binding domain is a scFv domain of an antibody directed against the tumor or infectious disease, and administering the transformed cells to the subject, wherein  
20 the transformed lymphocyte cells are targeted to the tumor cells or infectious disease, thereby treating the subject. In one embodiment, the lymphocyte cells are lymphocyte cells of the subject. In an additional embodiment, peripheral blood cells of the subject are transformed. In a further embodiment, hematopoietic stem cells of the subject are transformed. In another embodiment, primary T cells of the subject  
25 are transformed.

A further embodiment of the instant invention provides a method for generating a host cell that contains a viral vector comprising at least two non-viral nucleic acid sequences encoding at least one identical polypeptide sequence of greater than 15 amino acids in length comprising introducing the viral vector of the  
30 invention into a host cell, thereby generating the host cell. In one embodiment, the method further comprises selecting for the presence of the viral vector in the host cell. In an additional embodiment, the step of selecting for presence of the viral

vector in the host cell includes identifying viral particles in the host cell media. In another embodiment, at least one of the first or second polypeptide is a CIR or a functional fragment thereof.

In an additional embodiment, at least one of the CIR polypeptide sequences  
5 contains a transmembrane domain (TMD) sequence of CD3 $\zeta$  TMD sequence, CD28 TMD sequence, CD8 TMD sequence, CD4 TMD sequence, or Fc $\epsilon$ RI $\gamma$  TMD sequence, or a variant polypeptide or functional fragment thereof.

In another embodiment, at least one of the CIR polypeptides contains an N-terminal signal sequence of TCR- $\alpha$ , TCR- $\beta$ , TCR- $\gamma$ , TCR- $\delta$ , IgG, IgA, IgM, IgE,  
10 IgD, CD2, CD4, CD8, CD28, CD3 $\zeta$ , Fc $\epsilon$ RI $\gamma$ , or LFA-1.

In a further embodiment, at least one of the CIR polypeptides contains an extracellular binding domain of a surface membrane polypeptide. In certain embodiments, the extracellular binding domain of the surface membrane polypeptide binds specifically to at least one ligand or antigen.

15 In an additional embodiment, at least one of the CIR polypeptides contains an extracellular binding domain of a secreted polypeptide that binds specifically to at least one ligand or antigen.

In a further embodiment, at least one of the CIR polypeptides contains an intracellular cytoplasmic domain that is the CD3zeta intracellular cytoplasmic  
20 domain sequence, CD28 intracellular cytoplasmic domain sequence, CD8 intracellular cytoplasmic domain sequence, CD4 intracellular cytoplasmic domain sequence or Fc(e)RI $\gamma$  intracellular cytoplasmic domain sequence, or a variant polypeptide or functional fragment thereof. In certain embodiments, the ligand or antigen is a cancer cell ligand or antigen. In one embodiment, the cancer cell ligand  
25 or antigen is cyclin-dependent kinase-4,  $\beta$ -catenin, Caspase-8, MAGE-1, MAGE-3, Tyrosinase, Surface Ig idiotype, Her-2/neu, MUC-1, HPV E6, HPV E7, CD5, idiotype, CAMPATH-1, CD20, CEA, mucin-1, Lewis<sup>x</sup>, CA-125, EGFR, p185<sup>HER2</sup>, IL-2R, FAP- $\alpha$ , Tenascin, or a metalloproteinase. In another embodiment, the ligand  
30 or antigen is an infectious disease ligand or antigen. In a related embodiment, the infectious disease ligand or antigen is selected from the group consisting of CTL

epitopes of HIV, CMV, EBV, HBV, and HCV. In one embodiment, the infectious disease ligand or antigen is HIV gp120 or HIV gp41.

In another embodiment, the extracellular domains of the first and second polypeptide sequences comprise the immunoglobulin heavy and light chains of an antibody, or functional fragments thereof. In an additional embodiment, the  
5 extracellular domain of the first polypeptide sequence or the second polypeptide sequence comprises a single chain antibody, or a functional fragment thereof. In a further embodiment, both the first and the second polypeptide is a CIR or a functional fragment thereof. In certain embodiments, both CIR polypeptides contain  
10 an extracellular binding domain of a surface membrane polypeptide. In another embodiment, the extracellular domains of the first and second polypeptide sequences comprise the alpha and beta chains of an antibody, or a functional fragment thereof.

In an additional embodiment, the extracellular domains of the first and polypeptide sequences comprise the gamma and beta chains of a TCR, or a  
15 functional fragment thereof.

A further embodiment of the instant invention provides a method for expressing in a subject at least two polypeptides encoding at least one identical polypeptide sequence of greater than 15 amino acids in length and wherein the nucleic acid sequences encoding the two polypeptides are contained on a single viral  
20 vector comprising introducing the viral vector of the invention into a host cell; and exposing the subject to virions of the host cell media, thereby expressing the polypeptides in the subject.

In one embodiment, the method further comprises selecting for a host cell that produces virions comprising the viral vector in the host cell media.

25 In certain embodiments, the at least two polypeptides are multi-chimeric immune receptor (CIR) polypeptides.

In another embodiment, the instant invention features a method for expressing in a subject at least two polypeptides encoding at least one identical polypeptide sequence of greater than 15 amino acids in length, wherein the nucleic  
30 acid sequences encoding the at least two polypeptides are contained on a single viral vector comprising introducing the viral vector of the invention into a host cell; and

exposing the subject to the host cell, thereby expressing the polypeptides in the subject.

In certain embodiments, the host cell is an immune cell. In a related embodiment, the immune cell is a T cell. In another embodiment, the immune cell  
5 is a human immune cell.

In a further embodiment, the step of introducing the viral vector of the invention into an immune cell occurs *ex vivo*. In another embodiment, the step of introducing the viral vector of the invention into an immune cell occurs *in vivo*.

In certain embodiments, the subject is a mammal. In one embodiment, the  
10 mammal is a human.

In another embodiment, the virions are retrovirus virions. In a related embodiment, the retrovirus is a recombinant retrovirus selected from the group consisting of avian sarcoma-leukosis virus (ASLV), murine leukemia virus (MLV), human-, simian-, feline-, and bovine immunodeficiency viruses (HIV, SIV, FIV,  
15 BIV), equine infectious anaemia virus (EIAV), mouse mammary tumour virus (MMTV), Rous sarcoma virus (RSV), Fujinami sarcoma virus (FuSV), Moloney murine leukemia virus (Mo-MLV), FBR murine osteosarcoma virus (FBR MSV), Moloney murine sarcoma virus (Mo-MSV), Abelson murine leukemia virus (A-MLV), Avian myelocytomatosis virus-29 (MC29), Avian erythroblastosis virus  
20 (AEV), AKR (endogenous) murine leukemia virus, Avian carcinoma, Mill Hill virus 2, Avian leukosis virus--RSA, Avian myeloblastosis virus, Avian myelocytomatosis virus 29, Bovine syncytial virus, Caprine arthritis encephalitis virus, Chick syncytial virus, Equine infectious anemia virus, Feline leukemia virus, Feline syncytial virus, Finkel-Biskis-Jinkins murine sarcoma virus, Friend murine leukemia virus, Fujinami  
25 sarcoma virus, Gardner-Arnstein feline sarcoma virus, Gibbon ape leukemia virus, Guinea pig type C oncovirus, Hardy-Auckerman feline sarcoma virus, Harvey murine sarcoma virus, Human foamy virus, Human spumavirus, Human T-lymphotropic virus 1, Human T-lymphotropic virus 2, Jaagsiekte virus, Kirsten murine sarcoma virus, Langur virus, Mason-Pfizer monkey virus, Mouse mammary  
30 tumor virus, Ovine pulmonary adenocarcinoma virus, Porcine type C oncovirus, Reticuloendotheliosis virus, Rous sarcoma virus, Simian foamy virus, Simian sarcoma virus, Simian T-lymphotropic virus, Simian type D virus 1, Snyder-Theilen



feline sarcoma virus, Squirrel monkey retrovirus, Trager duck spleen necrosis virus, UR2 sarcoma virus, Viper retrovirus, Visna/maedi virus, Woolly monkey sarcoma virus, and Y73 sarcoma virus. In one embodiment, the retrovirus is an MFG-based recombinant retrovirus. In an additional embodiment, the retrovirus is a lentivirus  
5 selected from the group consisting of HIV-1, HIV-2, FIV, and SIV.

A further aspect of the invention provides a pharmaceutical composition comprising a recombinant retrovirus that contains a first nucleic acid sequence encoding a first CIR polypeptide and a second nucleic acid sequence encoding a second CIR polypeptide, wherein the first CIR polypeptide and the second CIR  
10 polypeptide comprise at least one identical polypeptide sequence of greater than 15 amino acids in length and wherein the first nucleic acid sequence and the second nucleic acid sequence contain at least one non-identical codon within the codons encoding the at least one identical polypeptide sequence of the first and second nucleic acid sequences, and a pharmaceutically acceptable carrier.

15 Another embodiment of the instant invention provides a kit comprising a virus comprising the viral vector of the invention, and instructions for use.

#### BRIEF DESCRIPTION OF THE DRAWINGS

The patent or application file contains at least one drawing executed in color. Copies of this patent or patent application publication with color drawing(s) will be  
20 provided by the Office upon request and payment of the necessary fee.

Figure 1 shows the nucleotide (SEQ ID NO: 1) and amino acid (SEQ ID NO: 2) sequences of partial human CD3 $\zeta$  that are mutated at the nucleotide level as described *infra*. The nucleotide sequence from nucleotides 10-420 encodes the polypeptide sequence of a partial CD3 $\zeta$  extracellular domain and the entire  
25 transmembrane and cytoplasmic domains of CD3 $\zeta$ . This encoded polypeptide sequence is 100% identical to the corresponding polypeptide sequence contained within the human CD3 $\zeta$  polypeptide sequence of GenBank ID X55510.1.

Figure 2 displays an alignment of nucleotide sequences of partial human CD3 $\zeta$  (GenBank ID X55510.1; SEQ ID NO: 3) with mutated CD3 $\zeta$  (SEQ ID NO:

1). The overall homology between these two sequences is 60.4%. Identical amino acid residues are denoted with an asterisk (\*).

Figure 3 shows the nucleotide (SEQ ID NO: 4) and amino acid (SEQ ID NO: 5) sequences of a fusion polypeptide construct comprising partial human CD28 and CD3 $\zeta$  sequences that are altered at the nucleotide level (mutated chimeric CD28CD3 $\zeta$ ). Nucleotides 7-330 encode a polypeptide sequence comprising a partial CD28 extracellular domain and the entire transmembrane and cytoplasmic domain of CD28. The polypeptide sequence encoded by nucleotides 7-330 is 100% identical to the corresponding polypeptide sequence contained within the human CD28 polypeptide sequence of GenBank ID J02988.1. Nucleotides 331-666 encode a polypeptide sequence comprising the entire cytoplasmic domain of CD3 $\zeta$  that is 100% identical to the corresponding polypeptide sequence contained within the human CD3 $\zeta$  polypeptide sequence of GenBank ID X55510.1. The first six nucleotides (cctagg), which comprise a cleavage site of restriction enzyme AvrII and encode two of the two amino acid residues P and R, respectively, are included for subcloning utility.

Figure 4 shows an alignment of nucleotide sequences of chimeric CD28CD3 $\zeta$  (SEQ ID NO: 6) with mutated chimeric CD28CD3 $\zeta$  (SEQ ID NO: 4). The corresponding nucleotide sequences encoding partial CD28 and CD3 $\zeta$  are from native human CD28 (GenBank ID J02988.1) and CD3Zeta (GenBank ID X55510.1). The overall homology between these two sequences is 61.3%.

Figure 5 shows the nucleotide (SEQ ID NO: 7) and amino acid (SEQ ID NO: 8) sequences of a mutated gene that encodes a partial extracellular domain and the entire transmembrane and cytoplasmic domains of human FC $\epsilon$ RI $\gamma$ . The amino acid sequence encoded by the mutated partial FC $\epsilon$ RI $\gamma$  gene is 100% identical to the corresponding polypeptide sequence within human FC $\epsilon$ RI $\gamma$  of GenBank ID M33195.1.

Figure 6 displays an alignment of nucleotide sequences of partial human FC $\epsilon$ RI $\gamma$  (SEQ ID NO: 9; GenBank ID M33195.1) with the mutated FC $\epsilon$ RI $\gamma$  polypeptide (SEQ ID NO: 7). The overall homology between these two sequences is 59.1%. Identical amino acid residues are denoted with an asterisk (\*).

Figure 7 depicts a schematic diagram of a viral vector comprising sequences encoding two chimeric immune receptor (CIR) polypeptides linked by an IRES sequence. Sequence encoding the first polypeptide comprises native sequences encoding the extracellular VaCa domain of TCR $\alpha$ , fused to the partial extracellular domain, TMD and cytoplasmic domain of CD28, which is fused to cytoplasmic CD3 $\zeta$  sequence. Sequence encoding the second polypeptide comprises sequence that encodes the TCR $\beta$  extracellular sequence fused to mutated sequence (modified with degenerate codons) encoding the partial extracellular domain, TMD and cytoplasmic domain of CD28 which is fused to mutated sequence encoding the cytoplasmic CD3 $\zeta$  sequence.

Figure 8 displays a schematic diagram of a viral vector comprising sequences encoding two chimeric immune receptor (CIR) polypeptides linked by an IRES sequence. Sequence encoding the first polypeptide comprises native sequences encoding the extracellular VaCa domain of TCR $\alpha$ , fused to the partial extracellular domain, TMD and cytoplasmic domain of CD3 $\zeta$ . Sequence encoding the second polypeptide comprises sequence that encodes the TCR $\beta$  extracellular sequence fused to mutated sequence (modified with degenerate codons) encoding the partial extracellular domain, TMD and cytoplasmic domain of CD3 $\zeta$ .

Figure 9 displays a schematic diagram of a viral vector comprising sequences encoding two chimeric immune receptor (CIR) polypeptides linked by an IRES sequence. Sequence encoding the first polypeptide comprises native sequences encoding the extracellular VaCa domain of TCR $\alpha$ , fused to the partial extracellular domain, TMD and cytoplasmic domain of Fc $\epsilon$ RI $\gamma$ . Sequence encoding the second polypeptide comprises sequence that encodes the TCR $\beta$  extracellular sequence fused to mutated sequence (modified with degenerate codons) encoding the partial extracellular domain, TMD and cytoplasmic domain of Fc $\epsilon$ RI $\gamma$ .

Figure 10 depicts a schematic diagram of a viral vector comprising sequences encoding two chimeric immune receptor (CIR) polypeptides linked by an IRES sequence. Sequence encoding the first polypeptide comprises native sequences encoding anti-CEA sFv, fused to the partial extracellular domain, TMD and cytoplasmic domain of CD28, which is fused to cytoplasmic CD3 $\zeta$  sequence.

Sequence encoding the second polypeptide comprises sequence that encodes anti-PMSA sFv fused to mutated sequence (modified with degenerate codons) encoding the partial extracellular domain, TMD and cytoplasmic domain of CD28, which is fused to mutated sequence encoding the cytoplasmic CD3 $\zeta$  sequence.

5           Figure 11 depicts a schematic diagram of a viral vector comprising sequences encoding two chimeric immune receptor (CIR) polypeptides linked by an IRES sequence. Sequence encoding the first polypeptide comprises native sequences encoding anti-CEA sFv, fused to the partial extracellular domain, TMD and cytoplasmic domain of CD3 $\zeta$ . Sequence encoding the second polypeptide  
10           comprises mutated sequence (using degenerate codon sequences) that encodes anti-CEA sFv fused to native sequence encoding the partial extracellular domain, TMD and cytoplasmic domain of CD28.

          Figure 12 shows the nucleotide sequence encoding Tctv\_p36A\_Z (SEQ ID NO: 10). The sequence of CD3 $\zeta$  (TMD and cytoplasmic) is underlined. An internal  
15           BamHI (GGATCC) cloning site located in the CD3 $\zeta$  seq. is bolded, and the TAA stop codon is also bolded. The location of anti-p36 TCR $\alpha$  sequence within the CIR sequence is indicated.

          Figure 13 displays the nucleotide sequence (SEQ ID NO: 11) also from Figure 12, along with the encoded amino acid (SEQ ID NO: 12) sequence of  
20           Tctv\_p36A\_Z. A BamHI site (GGATCC) is underlined; the 28 amino acid TMD of CD3 $\zeta$  is underlined and italicized; and the TMD and cytoplasmic domains of CD3 $\zeta$  are italicized. The location of anti-p36 TCR $\alpha$  sequence within the CIR sequence is indicated.

          Figure 14 displays the nucleotide sequence encoding Tctv\_p36B\_Z (SEQ ID  
25           NO: 13). The location of anti-p36 TCR $\beta$  sequence within the CIR sequence is indicated.

          Figure 15 displays the nucleotide sequence (SEQ ID NO: 14) from Figure 14, along with the amino acid (SEQ ID NO: 15) sequences of Tctv\_p36B\_Z. The BamHI site (GGATCC) is underlined; the 28 residue amino acid sequence of the  
30           transmembrane domain (TMD) of CD3 $\zeta$  is bolded and *italicized*; and the TMD and

cytoplasmic domain of CD3 $\zeta$  is *italicized*. The location of anti-p36 TCR $\beta$  sequence within the CIR sequence is indicated.

Figure 16 shows the nucleotide sequence encoding Tctv\_p36b\_muZ (SEQ ID NO: 16). The mutated nucleotide sequence comprising degenerate codons and encoding the transmembrane domain (TMD) and cytoplasmic domain of human  
5 CD3 $\zeta$  is in bold and italicized. The location of anti-p36 TCR $\beta$  sequence within the CIR sequence is indicated.

Figure 17 displays the nucleotide sequence encoding Tcsv\_p36A\_28Z (SEQ ID NO: 17). Sequence encoding the extracellular domain and transmembrane  
10 domain (TMD) of CD28 and cytoplasmic domain of CD28 and CD3 $\zeta$  are in bold and italicized. An AvrII site (CCTAAG) immediately prior to the 5' end of the CD28CD3 $\zeta$  sequence is underlined; and the stop codon (TAA) is also underlined. The location of anti-p36 TCR $\alpha$  sequence within the CIR sequence is indicated.

Figure 18 shows the nucleotide (SEQ ID NO: 18) and amino acid (SEQ ID  
15 NO: 19) sequences of Tctv\_p36A\_28Z. The cloning site of AvrII (cctagg, encoding "PR") immediately upstream of CD28CD3 $\zeta$  is bolded; the 29 residue amino acid sequence of the TMD of CD28 is bolded and underlined; and the amino acid sequence of the cytoplasmic domain of CD3 $\zeta$  is *italicized*. The location of anti-p36 TCR $\alpha$  sequence within the CIR sequence is indicated.

Figure 19 shows the nucleotide sequence of Tctsv\_p36B\_mu28Z (SEQ ID  
20 NO: 20). The mutated nucleotide sequence, which comprises degenerated codons and encodes the TMD and cytoplasmic domain of human CD28 and the cytoplasmic domain of CD3 $\zeta$ , is italicized. The location of anti-p36 TCR $\beta$  sequence within the CIR sequence is indicated.

Figure 20 shows the nucleotide sequence encoding hu\_CD4SigalpepECD  
25 (SEQ ID NO: 21). This sequence comprises the signal peptide and extracellular domain of human CD4.

Figure 21 shows the nucleotide sequence encoding  
Mu\_hu\_CD4SigalpepECD (SEQ ID NO: 22). This sequence comprises mutated  
30 signal peptide and the extracellular domain of human CD4.

Figure 22 displays an alignment of the nucleotide sequences CD4\_SignalpepECD (SEQ ID NO: 21) and Mu\_CD4\_SignalECD (SEQ ID NO: 22). Both DNA sequences encode an identical polypeptide sequence comprising the signal peptide and extracellular domain of native human CD4.

5           Figure 23 shows the nucleotide sequence encoding CD4\_SignalpepECD\_Z (SEQ ID NO: 23). The original cDNA encoding signal peptide and ECD of human CD4 is linked to the 5' end of an original cDNA encoding the native human CD3 $\zeta$  TMD and cytoplasmic domains. The cDNA encoding the CD3 $\zeta$  is italicized.

          Figure 24 shows the nucleotide sequence encoding  
10 Mu\_CD4\_SignalpepECD\_28 (SEQ ID NO: 24). The mutated nucleotide sequence (replaced with degenerate codons) encoding signal peptide and ECD of human CD4 is italicized. This sequence is linked to the 5' end of an original cDNA encoding the TMD and cytoplasmic domain of native human CD28.

          Figure 25 displays exemplary structures of CIRs designed to target JC virus  
15 and HIV. "Tctv" denotes two-chain two-vector, while "Tcsv" denotes two-chain single-vector.

          Figure 26 displays nucleotide sequences of the eight overlapping oligonucleotide DNA primers that were used in PCR to generate a DNA fragment encoding mutated partial ECD, TMD and cytoplasmic domains of human CD3 $\zeta$  (Z).

20           Figure 27 depicts a schematic diagram of the eight overlapping primers used in PCR to produce a DNA fragment of mutated CD3 $\zeta$  (muZ) that comprises degenerate codons yet encodes the native TMD and cytoplasmic domain polypeptide sequences of human CD3 $\zeta$ .

          Figure 28 depicts a model of a chimeric immune receptor (CIR) molecule,  
25 located at the plasma membrane of a "designer T cell."

          Figure 29 depicts a schematic diagram showing the domain structure of TCR  $\alpha$  and TCR  $\beta$  chain polypeptides.

          Figure 30 depicts a schematic diagram of a two-chain two-vector (Tctv) approach to CIR use, and displays a Venn diagram illustrating certain problems  
30 associated with such approaches, as they are reliant upon the occurrence of two different transfection and/or transformation events of potentially low probability.

Figure 31 depicts a flow chart showing the viral transduction procedure.

Figure 32 shows cell sorting results demonstrating that some cells transduced with Tctv CIRs of TCR  $\alpha$  and TCR  $\beta$  chains express the  $\beta$  chain on the cell surface but are not bound by the  $\alpha$  chain antigen, P36/A2, indicating a lack of TCR  $\alpha$  chain  
5 expression in these cells.

Figure 33 depicts a schematic diagram that illustrates and compares two vector (Tctv) and single vector (Tcsv) approaches to CIR synthesis.

Figure 34 shows cell sorting results for no vector (nv), two chain two vector (Tctv), and two chain single vector (Tcsv) CIRs of TCR  $\alpha$  and TCR  $\beta$  chains, which  
10 demonstrate that the Tcsv approach (involving mutation of the nucleic acid sequence encoding a cytoplasmic  $\zeta$  (z) chain with degenerate codon usage) efficiently yields “designer T cells” that robustly express both TCR  $\alpha$  and TCR  $\beta$  chains.

Figure 35 is a schematic of strategies for generation of anti-JVC designer T cells and tetramer staining to test for heterodimer.

Figure 36 is a schematic of two chain two vector (TcTv) CIRs and the results showing transduction of cells with two separate vectors.  
15

Figure 37 is a schematic of a two chain single vector (TcSv) CIR and the results showing transduction of cells with the vector.

Figure 38 is a schematic of engineering degenerate nucleotides in repeated  
20 sequence to prevent homologous recombination and deletion.

Figure 39 shows the results of transfection and transducing of TcTv TcSv which were run in parallel with equal ratio chains used for transfection and the alignment of nucleotide sequences of chimeric CD28CD3Zeta (SEQ ID NO: 33) with mutated chimeric CD28CD3Zeta (SEQ ID NO: 34). The corresponding nucleotide  
25 sequences encoding partial CD28 and CD3Zeta are from native human CD28.

Figure 40 is a schematic of TcSv anti-JCV constructs.

Figure 41 is a schematic and tetramer staining results of the potential for homologous recombination and deletion of sequences in a TcSv anti-JVC construct.

Figure 42 shows degenerate codon TcSv anti-JCV TCR constructs for  
30 wtCD3z (SEQ ID NO: 35) and dCD3z (SEQ ID NO: 36).

Figure 43 show degenerate codon TcSv anti-JCV TCRs.

Figure 44 shows the results of tetramer staining for degenerate codon TcSv anti-JCV TCR expression.

#### DETAILED DESCRIPTION OF THE INVENTION

The present invention relates, at least in part, to vectors, *e.g.*, viral vectors, that comprise highly homologous polypeptides (*e.g.*, chimeric immune receptors (CIRs)) yet reduce the likelihood of homologous recombination events between the nucleic acid sequences that encode such highly homologous polypeptides *via* directed alteration (mutation) of the underlying nucleic acid sequences that encode the highly homologous polypeptides. Directed alteration (mutation) of such nucleic acid sequences employs degenerate codons, which allow for nucleotide homology between two nucleic acid sequences that encode highly homologous polypeptides or even the same polypeptide (*e.g.*, an identical polypeptide domain within two CIRs contained within the same viral vector) to be significantly reduced.

The invention, at least in part, additionally provides methods of design and synthesis of such vectors, including, in certain embodiments, design and synthesis of viral vectors that comprise two or more nucleic acid sequences that encode CIRs possessing at least one polypeptide sequence domain that is highly homologous and/or identical (*e.g.*, a polypeptide domain comprising a span of 15 amino acid residues or greater that is identical and present in each of the two or more CIR polypeptide sequences.).

The instant invention, at least in part, also relates to therapeutic applications of the the vectors, *e.g.*, viral vectors described *infra*. Exemplary therapeutic applications include:

modification of immune cells (*e.g.*, lymphocytes, such as T cells and NK cells) and/or stem cells *via* introduction of CIRs through retroviral transduction or DNA and/or RNA transfection, useful for immunotherapy of cancers, infectious diseases (*e.g.*, PML, HIV/AIDS) and autoimmune diseases (*e.g.*, CIRs may be used to target autoreactive immune cells);



correction of genetic defects *via* introduction of correct or missing genes to stem cells and/or tissues or organs of target patients and/or individuals; and

introduction of multiple suicide genes *via* retroviral transduction or DNA  
5 and/or RNA transfection locally or systematically for treatment of cancer and/or autoimmune diseases or disorders.

So that the invention may be more readily understood, certain terms are first defined.

## 10 DEFINITIONS

Unless further defined below, all terms as used herein are given their customary meaning. In the case of terms specifically defined below, the definitions include their customary meaning but are expanded to include the additional context of the specific definition.

15 As used herein, the term “vector” refers to a nucleic acid molecule as introduced into a host cell, thereby producing a transformed host cell. A vector may include nucleic acid sequences that permit it to replicate in the host cell, such as an origin of replication. A vector may also include one or more selectable marker genes and other genetic elements known in the art. A vector can transduce,  
20 transform or infect a cell, thereby causing the cell to express nucleic acids and/or proteins other than those native to the cell. A vector optionally includes materials to aid in achieving entry of the nucleic acid into the cell, such as a viral particle, liposome, protein coating or the like.

Accordingly, the term “viral vector,” as used herein, refers to a vector that  
25 can be passaged in a virus, that can be used to transduce, transform or infect a cell, thereby causing the cell to express nucleic acids and/or proteins other than those native to the cell.

As used herein, the term “chimeric immune receptor” or “CIR” refers to tumor- or virus-specific ligand molecules and/or antibody molecules that are fused  
30 to the signaling domains of either the T cell receptor (TCR) or the Fc receptor. T cells expressing such receptors recapitulate the cytopathic effects mediated by the T

cell receptor and allow for the targeting of tumor or virus-infected cells in an MHC-independent manner. Exemplary CIRs of the invention comprise extracellular domains that bind to target antigens, *e.g.*, infectious disease or tumor antigens, a transmembrane domain (TMD), and a cytoplasmic domain of CD28 and/or CD3 $\zeta$ .

5 The use of CIRs can allow for production of large numbers of T cells possessing redirected target specificity, including possession of heightened sensitivity and/or response to a target antigen when bound.

The term "T helper (Th) cells" as used herein, refers to a functional subclass of T cells which help to generate cytotoxic T cells and which cooperate with B cells to stimulate antibody production. Helper T cells recognize antigen in association

10 with class II MHC molecules and provide contact dependent and contact independent (cytokine) signals to effector cells.

A protein "domain" is a relatively small (*i.e.*, between about 10 and 200 amino acids) globular unit that is part of a protein. A protein can comprise two or more domains that are linked by relatively flexible stretches of amino acids. In addition to having a semi-independent structure, a given domain can be largely or wholly responsible for carrying out functions that are normally carried out by the intact protein. In addition to domains that have been determined by *in vitro* manipulations of protein molecules, it is understood in the art that a "domain" may

15 also have been identified *in silico*, *i.e.*, by software designed to analyze the amino acid sequences encoded by a nucleic acid in order to predict the limits of domains. The latter type of domain is more accurately called a "predicted" or "putative" domain but, in the present disclosure, the term domain encompasses both known and predicted domains unless stated otherwise. Examples of CIR polypeptide domains

20 include, but are not limited to, the extracellular, transmembrane and cytoplasmic domains, which may be readily predicted *in silico* using art-recognized hydropathy analyses that are especially effective in identification of transmembrane domains (TMDs) of proteins.

The terms "variant", "homologue" or "fragment" in relation to the nucleotide

30 sequence coding for the homologous polypeptides, *e.g.*, CIR polypeptides, of the present invention include any substitution of, variation of, modification of, replacement of, deletion of or addition of one or more nucleic acid from or to the

sequence providing the resultant nucleotide sequence codes for or is capable of coding for a polypeptide. In particular, the term "homologue" covers homology with respect to structure and/or function providing the resultant nucleotide sequence codes for or is capable of coding for a polypeptide, *e.g.*, CIR polypeptide. With  
5 respect to sequence homology, preferably there is less than 99%, more preferably less than 98%, more preferably less than 95%, more preferably less than 85%, more preferably less than 75% homology between nucleic acid sequences of the vector construct (*e.g.*, retroviral vector construct) encoding for homologous polypeptides of the invention. More preferably, there is less than 70% homology, more preferably  
10 less than 69%, 68%, 67%, 66%, 65%, 64%, 63%, 62%, 61%, 60%, 59%, 58%, 57%, 56%, 55%, 54%, 53%, 52% or 51% homology between two nucleic acid sequences that encode homologous polypeptide sequences of the constructs of the present invention.

In particular, the term "homology" as used herein may be equated with the  
15 term "identity". Relative sequence homology (*i.e.* sequence identity) can be determined by commercially available computer programs that can calculate % homology between two or more sequences. A typical example of such a computer program is CLUSTAL.

Homology of polypeptide or nucleic acid sequences may be assessed  
20 globally (*e.g.*, across the entire expanse of aligned polypeptide sequences) or locally (*e.g.*, *via* inspection of a domain or subdomain of aligned polypeptide sequences). Sequence identity may be determined by sequence comparison and alignment algorithms known in the art. To determine the percent identity of two nucleic acid sequences (or of two amino acid sequences), the sequences are aligned for optimal  
25 comparison purposes (*e.g.*, gaps can be introduced in the first sequence or second sequence for optimal alignment). The nucleotides (or amino acid residues) at corresponding nucleotide (or amino acid) positions are then compared. When a position in the first sequence is occupied by the same residue as the corresponding position in the second sequence, then the molecules are identical at that position.  
30 The percent identity between the two sequences is a function of the number of identical positions shared by the sequences (*i.e.*, % homology = (# of identical

positions/total # of positions) x 100), optionally penalizing the score for the number of gaps introduced and/or length of gaps introduced.

The comparison of sequences and determination of percent identity between two sequences can be accomplished using a mathematical algorithm. In one  
5 embodiment, the alignment is generated over a certain portion of the sequence aligned having sufficient identity but not over portions having low degree of identity (*i.e.*, a local alignment). A preferred, non-limiting example of a local alignment algorithm utilized for the comparison of sequences is the algorithm of Karlin and Altschul (1990) *Proc. Natl. Acad. Sci. USA* 87: 2264-68, modified as in Karlin and  
10 Altschul (1993) *Proc. Natl. Acad. Sci. USA* 90: 5873-77. Such an algorithm is incorporated into the BLAST programs (version 2.0) of Altschul *et al.* (1990) *J. Mol. Biol.* 215: 403-10.

In another embodiment, the alignment is optimized by introducing appropriate gaps and percent identity is determined over the length of the aligned  
15 sequences (*i.e.*, a gapped alignment). To obtain gapped alignments for comparison purposes, Gapped BLAST can be utilized as described in Altschul *et al.*, (1997) *Nucleic Acids Res.* 25(17): 3389-3402. In another embodiment, the alignment is optimized by introducing appropriate gaps and percent identity is determined over the entire length of the sequences aligned (*i.e.*, a global alignment). A preferred,  
20 non-limiting example of a mathematical algorithm utilized for the global comparison of sequences is the algorithm of Myers and Miller, CABIOS (1989). Such an algorithm is incorporated into the ALIGN program (version 2.0) which is part of the GCG sequence alignment software package. When utilizing the ALIGN program for comparing amino acid sequences, a PAM120 weight residue table, a gap length  
25 penalty of 12, and a gap penalty of 4 can be used.

The NCBI Basic Local Alignment Search Tool (BLAST) (Altschul *et al.* 1990 *J. Mol. Biol.* 215: 403-10) is available from several sources, including the National Center for Biotechnology Information (NCBI, Bethesda, Md.) and on the Internet, for use in connection with the sequence analysis programs blastp, blastn,  
30 blastx, tblastn and tblastx. It can be accessed at [www.ncbi.nlm.nih.gov/BLAST/](http://www.ncbi.nlm.nih.gov/BLAST/). A description of how to determine sequence identity using this program is available at [www.ncbi.nlm.nih.gov/BLAST/blast\\_help.html](http://www.ncbi.nlm.nih.gov/BLAST/blast_help.html).

For comparisons of amino acid sequences of greater than about 30 amino acids, the Blast 2 sequences function can be employed using the default BLOSUM62 matrix set to default parameters, (gap existence cost of 11, and a per residue gap cost of 1). When aligning short peptides (fewer than around 30 amino acids), the alignment should be performed using the Blast 2 sequences function, employing the PAM30 matrix set to default parameters (open gap 9, extension gap 1 penalties). Proteins with even greater similarity to the reference sequence will show increasing percentage identities when assessed by this method, such as at least 70%, 75%, 80%, 90%, 95%, 98%, or 99% sequence identity. When less than the entire sequence is being compared for sequence identity, homologs will typically possess at least 75% sequence identity over short windows of 10-20 amino acids, and may possess sequence identities of at least 85% or at least 90% or 95% depending on their similarity to the reference sequence. Methods for determining sequence identity over such short windows are described at [www.ncbi.nlm.nih.gov/BLAST/blast\\_FAQs.html](http://www.ncbi.nlm.nih.gov/BLAST/blast_FAQs.html).

Alternatively, one may manually align the sequences and count the number of identical amino acids in the original sequence and a reference sequence that is compared to the original sequence. This number of identical amino acids is divided by the total number of amino acids in the reference sequence and multiplied by 100 to result in the percent identity.

One of ordinary skill in the art will appreciate that these sequence identity ranges are provided for guidance only; it is entirely possible that strongly significant homologs could be obtained that fall outside of the ranges provided.

The term "Fc domain" of an antibody refers to a part of the molecule comprising the hinge, CH2 and CH3 domains, but lacking the antigen binding sites. The term is also meant to include the equivalent regions of an IgM or other antibody isotype.

The term "retrovirus," as used herein, refers to any virus belonging to the family *Retroviridae*. Retroviruses are enveloped viruses that possess an RNA genome and replicate *via* a DNA intermediate. Retroviruses rely on the enzyme reverse transcriptase to perform reverse transcription of the retroviral genome from

RNA into DNA, which can then be integrated into a host cell genome using the integrase enzyme.

Lentiviruses are characterized by long incubation periods between infection of the host and the manifestation of clinical disease. Lentiviruses infect a wide  
5 variety of mammals, including humans, monkeys, sheep, goats, and horses. Lentiviruses include, for example, immunodeficiency retroviruses, such as HIV-1, HIV-2, FIV, and SIV.

A recombinant nucleic acid is one that has a sequence that is not naturally occurring or has a sequence that is made by an artificial combination of two  
10 otherwise separated segments of sequence. This artificial combination is often accomplished by chemical synthesis or, more commonly, by the artificial manipulation of isolated segments of nucleic acids, *e.g.*, by genetic engineering techniques.

The term “supernatant,” as used herein, refers to the culture medium in  
15 which a cell is grown. The culture medium includes material from the cell, including, *e.g.*, viral particles, *e.g.*, retroviral particles which bud off from the cell membrane and enter the culture medium.

A virus or vector “transduces” a cell when it transfers nucleic acid into the cell. A cell is “transformed” by a nucleic acid transduced into the cell when the  
20 DNA becomes stably replicated by the cell, either by incorporation of the nucleic acid into the cellular genome, or by episomal replication. As used herein, the term transformation encompasses all techniques by which a nucleic acid molecule might be introduced into such a cell, including transfection with viral vectors, transformation with plasmid vectors, and introduction of naked DNA by  
25 electroporation, lipofection, calcium-DNA precipitates, and particle gun acceleration.

A “transfer” vector or “transducing” vector, as used herein, refers to a vector which shuttles a transgene.

A “transformed” cell is a cell into which has been introduced a nucleic acid  
30 molecule by molecular biology techniques. As used herein, the term transformation encompasses all techniques by which a nucleic acid molecule might be introduced into such a cell, including transfection with viral vectors, transformation with

plasmid vectors, and introduction of naked DNA by electroporation, lipofection, and particle gun acceleration.

The term "transgene," as used herein, refers to an exogenous gene supplied by a vector. Examples of such genes include CIRs, single chain antibodies, and any  
5 other genes introduced *via* vector.

The term "transgenic cell," as used herein, refers to transformed cells which contain foreign, non-native DNA.

As used herein, the term "subject" includes a human or nonhuman mammal.

The production of proteins can be accomplished in a variety of ways. DNA  
10 sequences which encode for the protein, or a fragment or variant of the protein, can be engineered such that they allow the protein to be expressed in eukaryotic cells, bacteria, insects, and/or plants. In order to accomplish this expression, the DNA sequence can be altered and operably linked to other regulatory sequences. The final product, which contains the regulatory sequences and the therapeutic protein, is  
15 referred to as a vector. This vector can then be introduced into the eukaryotic cells, bacteria, insect, and/or plant. Once inside the cell the vector allows the protein to be produced.

One of ordinary skill in the art will appreciate that the DNA can be altered in numerous ways without affecting the biological activity of the encoded protein. For  
20 example, PCR may be used to produce variations in the DNA sequence which encodes a CIR. Such variants may be variants that are optimized for codon preference in a host cell that is to be used to express the protein, other sequence changes that facilitate expression, or sequences as described herein that are made non-identical at the nucleic acid level in order to reduce homologous recombination  
25 events.

At least two types of cDNA sequence variants may be produced. In one type, the variation in the cDNA sequence is not manifested as a change in the amino acid sequence of the encoded polypeptide. These silent variations are simply a reflection of the degeneracy of the genetic code, and are a preferred form of  
30 variation for practice of the methods of the present invention. In the second type, the cDNA sequence variation does result in a change in the amino acid sequence of the encoded protein. In such cases, the variant cDNA sequence produces a variant

polypeptide sequence. In order to optimize preservation of the functional and immunologic identity of the encoded polypeptide, any such amino acid substitutions may be conservative. Conservative substitutions replace one amino acid with another amino acid that is similar in size, hydrophobicity, etc. Such substitutions  
5 generally are conservative when it is desired to finely modulate the characteristics of the protein. Examples of amino acids which may be substituted for an original amino acid in a protein and which are regarded as conservative substitutions include: Ser for Ala; Lys for Arg; Gln or His for Asn; Glu for Asp; Ser for Cys; Asn for Gin; Asp for Glu; Pro for Gly; Asn or Gin for His; Leu or Val for Ile; Ile or Val for Leu;  
10 Arg or Gln for Lys; Leu or Ile for Met; Met, Leu or Tyr for Phe; Thr for Ser; Ser for Thr; Tyr for Trp; Trp or Phe for Tyr; and Ile or Leu for Val.

Variations in the cDNA sequence that result in amino acid changes, whether conservative or not, are minimized to enhance preservation of the functional and immunologic identity of the encoded protein. In particular embodiments, any cDNA  
15 sequence variant will introduce no more than 20, for example fewer than 10 amino acid substitutions into the encoded polypeptide. Variant amino acid sequences can, for example, be greater than 75%, greater than 80%, greater than 90% or even greater than 95%, greater than 96%, greater than 97%, greater than 98%, or greater than 99% identical (though not perfectly identical at the level of amino acid  
20 sequence to be considered a variant amino acid sequence) to the original (*e.g.*, native) amino acid sequence.

Conserved residues in the same or similar nucleic acids or proteins from different species can provide guidance about possible locations for making substitutions in the nucleic acid or amino acid sequence. A residue which is highly  
25 conserved across several species is more likely to be important to the function of the nucleic acid or protein than a residue that is less conserved across several species.

By "reduce" or "inhibit" is meant the ability to cause an overall decrease preferably of 10% or greater, 20% or greater, 50% or greater, 75% or greater, 85% or greater, 90% or greater, 95% or greater, 96% or greater, 97% or greater, 98% or  
30 greater, or 99% or greater in the level of an assessed effect (*e.g.*, homologous recombination between nucleic acid sequences, cancer cell and/or tumor proliferation, etc.) for a vector, cell, sample, tumor, etc. that has been altered from a



native state (*e.g.*, mutated in nucleic acid sequence) and/or contacted with an agent or otherwise employed in creating a composition of the invention or utilizing a method of the invention, as compared to an appropriate vector, control cell, sample, tumor, etc. (*e.g.*, a vector comprising nucleic acid sequences that have not been  
5 mutated to decrease homology while retaining homology of the encoded polypeptides, a cell that has not been contacted with an agent or employed in a method of the invention, etc.). In certain aspects of the instant invention, especially those related to reduction of homologous recombination events between nucleic acid sequences that encode homologous polypeptide sequences, as well as those aspects  
10 of the invention related, *e.g.*, to reduction of binding affinities of an antigen binding fragment, "reduce" or "inhibit" can refer to a decrease in the rate of occurrence of such events (and/or decrease in binding affinity) that is logarithmic in scale, *e.g.*, 10-fold or greater, 100-fold or greater, 1000-fold or greater, 10,000-fold or greater, 100,000-fold or greater, or a million-fold or greater.

15 The term "cancer" or "neoplasia" refers in general to any malignant neoplasm or spontaneous growth or proliferation of cells. The term as used herein encompasses both fully developed malignant neoplasms, as well as premalignant lesions. A subject having "cancer", for example, may have a tumor or a white blood cell proliferation such as leukemia. In certain embodiments, a subject having cancer  
20 is a subject having a tumor, such as a solid tumor.

The term "solid tumor" refers to a carcinoma, sarcoma, adenoma, cancers of neuronal origin or, in fact, to any type of cancer which does not originate from the hematopoietic cells. Cancers involving a solid tumor include but are not limited to brain cancer, glioma, astrocytoma, medulloblastoma, craniopharyngioma,  
25 ependymoma, pinealoma, retinoblastoma, carcinoma, sarcoma, adenoma, hepatocellular cancer, hepatoblastoma, rhabdomyosarcoma, gastric cancer, stomach cancer, esophageal cancer, thyroid cancer, ganglioblastoma, fibrosarcoma, myxosarcoma, liposarcoma, chondrosarcoma, osteogenic sarcoma, chordoma, angiosarcoma, endotheliosarcoma, lymphangiosarcoma, synovioma, Ewing's tumor,  
30 leiomyosarcoma, rhabdotheriosarcoma, colon cancer, pancreatic cancer, breast cancer, ovarian cancer, uterine cancer, prostate cancer, squamous cell carcinoma, basal cell carcinoma, adenocarcinoma, renal cell carcinoma, hematoma, bile duct

carcinoma, melanoma, choriocarcinoma, seminoma, embryonal carcinoma, Wilms' tumor, skin cancer, cervical cancer, testicular cancer, lung cancer, small cell lung cancer (SCLC), non small cell lung cancer (NSCLC), colorectal cancer (CRC), bladder cancer, epithelial cancer, multiple myeloma, rectal cancer, thyroid cancer,  
5 head and neck cancer, cancer of the peripheral nervous system, cancer of the central nervous system, neuroblastoma, cancer of the endometrium, as well as metastasis of all the above.

As used herein, the term "tumor" refers to a proliferation of cells (*e.g.*, a neoplasia, a growth, a polyp) resulting from neoplastic growth and is most typically  
10 a malignant tumor. In the case of a neoplastic transformation, a neoplasia is malignant or is predisposed to become malignant. Malignant tumors are typically characterized as being anaplastic (primitive cellular growth characterized by a lack of differentiation), invasive (moves into and destroys surrounding tissues) and/or metastatic (spreads to other parts of the body).

15 Various methodologies of the invention include a step that involves comparing a value, level, feature, characteristic, property, etc. to a "suitable control", referred to interchangeably herein as an "appropriate control". A "suitable control" or "appropriate control" is any control or standard familiar to one of ordinary skill in the art useful for comparison purposes. In one embodiment, a "suitable control" or  
20 "appropriate control" is a value, level, feature, characteristic, property, etc. determined prior to performing a vector synthesis and/or treatment methodology, as described herein. For example, a homologous recombination rate, a transcription rate, mRNA level, translation rate, protein level, biological activity, cellular characteristic or property, genotype, phenotype, etc. can be determined for an  
25 unmodified vector and compared with the recombination rate, transcription rate, etc., of a vector modified in the manner described herein. Such comparisons can be performed for methods and/or therapies performed *in vitro* or *in vivo*. In another embodiment, a "suitable control" or "appropriate control" is a value, level, feature, characteristic, property, etc. determined in a cell or organism, *e.g.*, a control or  
30 normal cell or organism, exhibiting, for example, normal traits. In yet another embodiment, a "suitable control" or "appropriate control" is a predefined value, level, feature, characteristic, property, etc.

Additional definitions of terms commonly used in molecular genetics can be found in Benjamin Lewin, Genes V, published by Oxford University Press, 1994 (ISBN 0-19-854287-9); Kendrew *et al* (eds.), The Encyclopedia of Molecular Biology, published by Blackwell Science Ltd., 1994 (ISBN 0-632-02182-9); and  
5 Robert A. Meyers (ed.), Molecular Biology and Biotechnology: a Comprehensive Desk Reference, published by VCH Publishers, Inc., 1995 (ISBN 1-56081-569-8).

Various aspects of the invention are described in further detail in the following subsections.

Certain aspects of the instant invention provide viral vectors comprising two  
10 or more homologous polypeptides (*e.g.*, CIR polypeptides) and/or polypeptide domains that are used in the treatment of a disease and/or disorder. In certain embodiments, homologous polypeptide-expressing (*e.g.*, CIR-expressing) viral vectors of the instant invention are employed in gene therapy and immunotherapy approaches. For example, the compositions and methods of this invention can be  
15 used to treat cancer in a subject (*e.g.*, a human subject), through use of T cells that express antigen-specific CIRs. In such embodiments, the extracellular domains of homologous polypeptides (*e.g.*, CIR polypeptides) are designed to bind specifically to a tumor and/or cancer cell antigen(s), thereby inducing activation of the CIR-presenting T cell ("designer T cell") upon binding of the T cell to the tumor and/or  
20 cancer cell antigen, in turn inducing a specific immune response to cancer and/or tumor antigen-presenting cells. Accordingly, the polypeptide-expressing (*e.g.*, CIR-expressing) viral vector(s) of the instant invention can be designed to bind to any art-recognized cancer-specific and/or tumor-specific antigen (*e.g.*, *via* synthesis of CIR molecules comprising extracellular tumor antigen-binding fragment(s), *e.g.*,  
25 extracellular sFv polypeptides, alpha and/or beta chain antibody polypeptides, etc.). Such cancer and/or tumor antigens include, but are not limited to, *e.g.*, cyclin-dependent kinase-4,  $\beta$ -catenin, Caspase-8, MAGE-1, MAGE-3, Tyrosinase, Surface Ig idiotype, Her-2/neu, MUC-1, HPV E6, HPV E7, CD5, idiotype, CAMPATH-1, CD20, CEA, mucin-1, Lewis<sup>x</sup>, CA-125, EGFR, p185<sup>HER2</sup>, IL-2R, FAP- $\alpha$ , Tenascin,  
30 metalloproteinases, pHCG, gp100 or Pmel17, HER2/neu, CEA, gp100, MART1, TRP-2, melan-A, NY-ESO-1, MN (gp250), idiotype, MAGE-1, MAGE-3, Tyrosinase, Telomerase, MUC-1 antigens, and germ cell-derived tumor antigens, the

blood group antigens, for example, Lea, Leb, LeX, LeY, H-2, B-1, B-2 antigens. In certain embodiments, more than one cancer and/or tumor antigens can be bound by the same CIR-expressing T cell; for example, binding of one CIR of a T cell to a MAGE antigen can be combined with binding of another CIR of the T cell to  
5 another antigen, such as melanin A, tyrosinase, or gp100. For example, CD20 is a pan B antigen that is found on the surface of both malignant and non-malignant B cells that has proved to be an extremely effective target for immunotherapeutic antibodies for the treatment of non-Hodgkin's lymphoma. In this respect, pan T cell antigens such as CD2, CD3, CD5, CD6 and CD7 also comprise tumor-associated  
10 antigens within the meaning of the present invention. Still other exemplary tumor-associated antigens comprise, but are not limited to, MAGE-1, MAGE-3, MUC-1, HPV 16, HPV E6 & E7, TAG-72, CEA, L6-Antigen, CD19, CD22, CD37, CD52, HLA-DR, EGF Receptor and HER2 Receptor. In many cases immunoreactive antibodies (and/or immunoreactive antigen-binding fragments) for each of these  
15 antigens have been reported in the literature.

The viral vectors of the invention can also be used as immunotherapeutics in treatment of infectious disease; for example, in procedures that employ CIRs that recognize infectious disease antigens. Accordingly, homologous polypeptides (*e.g.*, CIR polypeptides) of the invention can be made that bind to any of a number of  
20 forms of infectious disease antigen, thereby inducing an immune response to the infectious disease antigen upon binding. Infectious disease antigens to which homologous polypeptides (*e.g.*, CIR polypeptides) of the instant invention can be designed to bind include, but are not limited to, bacterial antigens, viral antigens, fungal antigens, parasitic antigens, and microbial toxins. Exemplary forms of each  
25 class of antigen are considered in greater detail below.

### *Bacteria*

Examples of bacteria (specifically, epitopes thereof) to which homologous polypeptides (*e.g.*, CIR polypeptides) of the instant invention may bind include, but  
30 are not limited to: *Pseudomonas aeruginosa*, *Pseudomonas fluorescens*, *Pseudomonas acidovorans*, *Pseudomonas alcaligenes*, *Pseudomonas putida*, *Stenotrophomonas maltophilia*, *Burkholderia cepacia*, *Aeromonas hydrophilia*,

Escherichia coli, Citrobacterfreundii, Salmonella enterica Typhimurium, Salmonella enterica Typhi, Salmonella enterica Paratyphi, Salmonella enterica Enteritidis, Shigella dysenteriae, Shigella flexneri, Shigella sonnei, Enterobacter cloacae, Enterobacter aerogenes, Klebsiella pneumoniae, Klebsiella oxytoca, Serratia marcescens, Francisella tularensis, Morganella morganii, Proteus mirabilis, Proteus vulgaris, Providencia alcalifaciens, Providencia rettgeri, Providencia stuartii, Acinetobacter calcoaceticus, Acinetobacter haemolyticus, Yersinia enterocolitica, Yersinia pestis, Yersinia pseudotuberculosis, Yersinia intermedia, Bordetella pertussis, Bordetella parapertussis, Bordetella bronchiseptica, Haemophilus influenzae, Haemophilus parainfluenzae, Haemophilus haemolyticus, Haemophilus parahaemolyticus, Haemophilus ducreyi, Pasteurella multocida, Pasteurella haemolytica, Branhamella catarrhalis, Helicobacter pylori, Campylobacter fetus, Campylobacter jejuni, Campylobacter coli, Borrelia burgdorferi, Vibrio cholerae, Vibrio parahaemolyticus, Legionella pneumophila, Listeria monocytogenes, Neisseria gonorrhoeae, Neisseria meningitidis, Gardnerella vaginalis, Bacteroides fragilis, Bacteroides distasonis, Bacteroides 3452A homology group, Bacteroides vulgatus, Bacteroides ovalus, Bacteroides thetaiotaomicron, Bacteroides uniformis, Bacteroides eggerthii, Bacteroides splanchnicus, Clostridium difficile, Mycobacterium tuberculosis, Mycobacterium avium, Mycobacterium intracellulare, Mycobacterium leprae, Corynebacterium diphtheriae, Corynebacterium ulcerans, Streptococcus pneumoniae, Streptococcus agalactiae, Streptococcus pyogenes, Enterococcus faecalis, Enterococcus faecium, Staphylococcus aureus, Staphylococcus epidermidis, Staphylococcus saprophyticus, Staphylococcus intermedius, Staphylococcus hyicus subsp. hyicus, Staphylococcus haemolyticus, Staphylococcus hominis, and Staphylococcus saccharolyticus. In a particular embodiment, a construct of the invention comprises a binding molecule which binds to Staphylococcal protein A.

#### *Viruses*

Examples of viruses (or epitopes thereof) which may be bound by homologous polypeptides (*e.g.*, CIR polypeptides) of the instant invention include, but are not limited to: polyomavirus JC (JCV), human immunodeficiency virus type

I (HIV I), hepatitis B virus (HBV), hepatitis C virus (HCV), cytomegalovirus (CMV), Epstein Barr virus (EBV), influenza virus hemagglutinin (Genbank accession no. J02132; Air, 1981, Proc. Natl. Acad. Sci. USA 78:7639-7643; Newton et al., 1983, Virology 128:495-501), human respiratory syncytial virus G  
5 glycoprotein (Genbank accession no. Z33429; Garcia et al., 1994, J. Virol.; Collins et al., 1984, Proc. Natl. Acad. Sci. USA 81:7683), measles virus hemagglutinin (Genbank accession no. M81899; Rota et al., 1992, Virology 188:135-142), herpes simplex virus type 2 glycoprotein gB (Genbank accession no. M14923; Bzik et al., 1986, Virology 155:322-333), poliovirus I VP1 (Emini et al., 1983, Nature  
10 304:699), envelope glycoproteins of HIV I (Putney et al., 1986, Science 234:1392-1395), hepatitis B surface antigen (Itoh et al., 1986, Nature 308:19; Neurath et al., 1986, Vaccine 4:34), diphtheria toxin (Audibert et al., 1981, Nature 289:543), streptococcus 24M epitope (Beachey, 1985, Adv. Exp. Med. Biol. 185:193), gonococcal pilin (Rothbard and Schoolnik, 1985, Adv. Exp. Med. Biol. 185:247),  
15 pseudorabies virus g50 (gpD), pseudorabies virus II (gpB), pseudorabies virus gIII (gpC), pseudorabies virus glycoprotein H, pseudorabies virus glycoprotein E, transmissible gastroenteritis glycoprotein 195, transmissible gastroenteritis matrix protein, swine rotavirus glycoprotein 38, swine parvovirus capsid protein, Serpulina hydodysenteriae protective antigen, bovine viral diarrhea glycoprotein 55,  
20 Newcastle disease virus hemagglutinin neuraminidase, swine flu hemagglutinin, swine flu neuraminidase, foot and mouth disease virus, hog colera virus, swine influenza virus, African swine fever virus, Mycoplasma hyopneumoniae, infectious bovine rhinotracheitis virus (e.g., infectious bovine rhinotracheitis virus glycoprotein E or glycoprotein G), or infectious laryngotracheitis virus (e.g., infectious  
25 laryngotracheitis virus glycoprotein G or glycoprotein I), a glycoprotein of La Crosse virus (Gonzales Scarano et al., 1982, Virology 120 :42), neonatal calf diarrhea virus (Matsuno and Inouye, 1983, Infection and Immunity 39:155), Venezuelan equine encephalomyelitis virus (Mathews and Roehrig, 1982, J. Immunol. 129:2763), punta toro virus (Dalrymple et al., 1981, Replication of  
30 Negative Strand Viruses, Bishop and Compans (eds.), Elsevier, NY, p. 167), murine leukemia virus (Steeves et al., 1974, J. Virol. 14:187), mouse mammary tumor virus (Massey and Schochetman, 1981, Virology 115:20), hepatitis B virus core protein

and/or hepatitis B virus surface antigen or a fragment or derivative thereof (see, e.g., U.K. Patent Publication No. GB 2034323A published Jun. 4, 1980; Ganem and Varmus, 1987, *Ann. Rev. Biochem.* 56:651-693; Tiollais et al., 1985, *Nature* 317:489-495), of equine influenza virus or equine herpesvirus (e.g., equine influenza virus type A/Alaska 91 neuraminidase, equine influenza virus type A/Miami 63 neuraminidase, equine influenza virus type A/Kentucky 81 neuraminidase, equine herpesvirus type 1 glycoprotein B, and equine herpesvirus type I glycoprotein D, antigen of bovine respiratory syncytial virus or bovine parainfluenza virus (e.g., bovine respiratory syncytial virus attachment protein (BRSV G), bovine respiratory syncytial virus fusion protein (BRSV F), bovine respiratory syncytial virus nucleocapsid protein (BRSV N), bovine parainfluenza virus type 3 fusion protein, the bovine parainfluenza virus type 3 hemagglutinin neuraminidase), bovine viral diarrhea virus glycoprotein 48 or glycoprotein 53, hepatitis type A, influenza, varicella, adenovirus, herpes simplex type I (HSV I), herpes simplex type II (HSV II), rinderpest, rhinovirus, echovirus, rotavirus, respiratory syncytial virus, papilloma virus, papova virus, echinovirus, arbovirus, hantavirus, coxsackie virus, mumps virus, measles virus, rubella virus, polio virus, human immunodeficiency virus type II (HIV II), any picornaviridae, enteroviruses, caliciviridae, any of the Norwalk group of viruses, togaviruses, such as alphaviruses, flaviviruses, coronaviruses, rabies virus, Marburg viruses, ebola viruses, parainfluenza virus, orthomyxoviruses, bunyaviruses, arenaviruses, reoviruses, rotaviruses, orbiviruses, human T cell leukemia virus type I, human T cell leukemia virus type II, simian immunodeficiency virus, lentiviruses, polyomaviruses, parvoviruses, human herpesvirus 6, cercopithecine herpes virus I (B virus), and poxviruses.

25 In certain embodiments, homologous polypeptides (e.g., CIR polypeptides) of the instant invention bind to HIV, inducing an immune response to the virus in a subject to whom the viral vector is administered. Various antigenic domains (e.g., epitopes) of HIV are known in the art and such domains include structural domains such as Gag, Gag-polymerase, Gag-protease, reverse transcriptase (RT), integrase  
30 (IN) and Env. The structural domains of HIV are often further subdivided into polypeptides, for example, p55, p24, p6 (Gag); p160, p10, p15, p31, p65 (pol, prot, RT and IN); and gp160, gp120 and gp41 (Ems) or Ogp140 as constructed by Chiron

Corporation. Molecular variants of such polypeptides can also be targeted for binding by the homologous polypeptides (*e.g.*, CIR polypeptides) of the instant invention, for example, variants such as those described in PCT/US99/31245; PCT/US99/31273 and PCT/US99/31272.

5

#### *Fungi*

Examples of fungi (or epitopes thereof) which may be bound by homologous polypeptides (*e.g.*, CIR polypeptides) of the instant invention include, but are not limited to fungi from the genus *Mucor*, *Candida*, and *Aspergillus*, *e.g.*, *Mucor racemosus*, *Candida albicans*, and *Aspergillus niger*.

10

#### *Parasites*

Examples of parasites (or epitopes thereof) which may be bound by homologous polypeptides (*e.g.*, CIR polypeptides) of the instant invention include, but are not limited to: *Toxoplasma gondii*, *Treponema pallidum*, Malaria, and *Cryptosporidium*.

15

#### *Microbial Toxins*

Examples of microbial toxins (or epitopes thereof) which may be bound by homologous polypeptides (*e.g.*, CIR polypeptides) of the instant invention include, but are not limited to: toxins produced by *Bacillus anthracis*, *Bacillus cereus*, *Bordetella pertussis*, *Clostridium botulinum*, *Clostridium perfringens*, *Clostridium tetani*, *Corynebacterium diphtheriae*, *Salmonella sp.*, *Shigella sp.*, *Staphylococcus sp.*, and *Vibrio cholerae*. Toxins such as ricin from jack bean and other naturally-occurring (*e.g.*, produced by an organism) and man-made toxins or portions thereof may also be bound by the homologous polypeptides (*e.g.*, CIR polypeptides) of the instant invention.

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#### Chimeric Immune Receptors

Genetically modified immune function cells, such as T cells and NK cells engineered to express foreign chimeric immune receptors (CIRs) are effective immunotherapeutics for cancer and infectious diseases. Isolation of autologous

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antigen specific immune cells, such as T cells, for therapeutic application is a laborious task, and is not possible where such cells are absent or rare. Therefore, strategies have been developed to genetically transfer immune receptors specific to tumor or virus into patients' T cells. To this end, chimeric immune receptors (CIRs) have been constructed that join antigen (Ag)-recognition domains to signaling domains of the T-cell receptor (TCR) or Fc receptor. T cells expressing such CIRs recapitulate the immune specific responses mediated by the introduced receptor.

In a prior exemplary description of therapeutic use of CIR molecules, Severino *et al.* (2003 *Virology* 306: 371-75) proposed transduction of T cells with a CIR as a strategy for generation of cellular immunity against viral pathogens such as HIV-1. Specifically, for the CD4-CD3-zeta chain (CD4-zeta) CIR, specificity for HIV-1 is conferred by binding of the CD4 moiety to gp120 on the surface of infected cells. However, it is unclear whether CD4-zeta-T cells may differ from naturally-derived CD8<sup>+</sup> cytotoxic T cells (CTL) in their susceptibility to viral escape mechanisms or the ability to recognize different cell types that support viral replication.

In general, a chimeric immune receptor (CIR) consists of three portions:

1. An "extracellular domain" comprising an antigen binding or target marker binding domain, including, *e.g.*, a variable region of antibody or functional fragment thereof, an extracellular domain of T cell receptor (TCR; *e.g.*, Va or Vb; VaCa or VbCb) or functional fragment thereof, or an extracellular domain of CD4 (binding to HIV gp120) or functional fragment thereof;
2. A "transmembrane domain (TMD)" comprising an art-recognized, functional TMD (in certain embodiments of the present invention, the TMD of the CIR is, *e.g.*, the CD3 $\zeta$  TMD, CD28 TMD, CD8 TMD, CD4 TMD or Fc $\epsilon$ R1 $\gamma$  TMD, or a variant polypeptide or functional fragment thereof); and
3. An "intracellular signaling domain," comprising, *e.g.*, the cytoplasmic portion of CD3 $\zeta$  or a functional fragment thereof, Fc $\epsilon$ R1 $\gamma$  or a functional fragment thereof, and/or CD28 (CD28 may be used to provide co-stimulatory signaling) or a functional fragment thereof.

In certain embodiments of the instant invention, the extracellular portion of an antibody-based CIR (IgCIR) consists of a single chain Fv or a fragment thereof ("sFv" or "scFv," used interchangeably herein). Similar to IgCIR, a TCRCIR is  
5 comprised of TCR variable antigen binding fragments ( $V\alpha$  and  $V\beta$ , or antigen binding fragments thereof) in the context of specific MHC molecules, linked to nucleic acid molecules (or functional fragments thereof) that encode signaling domains of the T-cell receptor (TCR) or Fc receptor. TCRCIR can be constructed in two basic forms: as a single chain TCRCIR (scTCRCIR), or as a two chain TCRCIR  
10 (tcTCRCIR). For a scTCRCIR, both TCR  $V\alpha$  and  $V\beta$  are present within the same single chain TCR protein, while in a tcTCRCIR, the  $V\alpha$  and  $V\beta$  are in separate chains which form heterodimers (Willemsen *et al.*, 2000 *Gene Ther.* 7: 1369).

A number of published reports have described the fact that TCRs (alpha and beta chains) have around 100- to 1,000-fold lower binding affinities for their cognate  
15 antigens (peptide/MHC complex), as compared to antibodies directed to the same cognate antigens. In addition, it has been reported in the literature that the single chain format T cell receptors generally have greatly reduced affinities for cognate antigens, as compared to the affinities of their corresponding parental two chain forms for such antigens, with some single chain T cell receptors completely losing  
20 antigen binding affinity. Higher binding affinities of TCRs, including chimeric TCRs, have been shown to be associated with higher potency of modified T cells expressing such receptors, with regard to the function of such cells in T cell activation, including induction of proliferation, killing of target cells and induction of cytokine secretion. Several reports in the literature have indicated that single  
25 chain formats of TCRCIRs possess binding affinities that are too low to be of therapeutic or diagnostic value. Therefore, to create functional TCRCIRs with reasonably high antigen binding affinities, the two chain format for natural TCRs possesses significant advantages over a single chain format.

In certain embodiments, the instant invention provides means and  
30 compositions designed to exploit the advantages associated with two chain formats for TCRCIR delivery (as well as those advantages associated with co-delivery

and/or co-expression of two or more heterologous proteins comprising one or more highly homologous domains – *e.g.*, co-stimulation of both CD3 $\zeta$  (T cell antigen receptor) and CD28-dependent signaling pathways in T cells using CIRs that possess, *e.g.*, highly homologous (*e.g.*, identical) extracellular domains). In specific  
5 embodiments, the instant invention overcomes problems associated with low host cell transduction efficiencies by enabling delivery of two or more nucleic acid sequences encoding for highly homologous (*e.g.*, identical) polypeptides on a single viral vector. In such embodiments of the instant invention, methods as described in greater detail below are employed to produce viral vector sequences comprising  
10 nucleic acid sequences encoding two or more highly homologous (*e.g.*, identical) polypeptides or polypeptide domains thereof, yet that possess reduced risk of homologous recombination between such nucleic acid sequences, even during, *e.g.*, extended passage in host cells and/or multiple infection, chromosomal integration, and/or excision events. Such reduced rates of homologous recombination are  
15 attributable, at least in part, to exploitation of the degeneracy of the genetic code during synthesis of the viral vectors as described herein.

Certain aspects of the instant invention relate to synthesis of fusion proteins and/or polypeptides (*e.g.*, CIRs). Methods of producing fusion proteins are well known in the art of genetic engineering, with such methods including, *e.g.*, gene  
20 splicing methods that rely upon the use of restriction enzymes, cloning vectors and, optionally, site directed mutagenesis procedures; and amplification-reliant methods of gene splicing (*e.g.*, gene splicing by overlap extension (“gene SOE”)).

Immune cells that express multiple different CIRs can possess enhanced recognition and killing of the same types of target cells *via* binding of different  
25 surface antigens, or, alternatively, may be capable of recognizing and killing distinct classes of target cells possessing different surface antigens. For example, as described in certain embodiments of the instant invention, T cells that express two different anti-tumor CIRs, anti-CEAsFvCD3Zeta and anti-PSMAFcCD3Zeta, will be capable of targeting tumor cells that express either CEA or PSMA, or a  
30 combination of both antigens on their cell surface.

Two protein molecules comprising highly homologous polypeptide sequences that are encoded by similarly highly homologous nucleic acid sequences

can be transduced to a single cell using a two vector approach as a means of reducing possible viral recombination events. For example, TCRCIRs of two-chain format, which consist of various VaCa and VbCb, respectively, but share identical signaling element polypeptide sequences (*e.g.*, cytoplasmic domains of CD28 and/or CD3 $\zeta$ ). The two different vectors, each encoding one of the two homologous proteins of interest, might be generated from separate VPCs. However, the successful transduction rate of a single vector into mammalian cells, such as activated T cells exposed to a retrovirus, is often limited.

A number of additional CIRs that can be used in the methods and compositions of the present invention have been described in the literature, including U.S. Patent Numbers 6,407,221 (Extracellular CD4-CD7TMD-Cytoplasmic  $\zeta$  (CD3 $\zeta$ )); 5,912,172 (Extracellular antibody-TMD and cytoplasmic  $\zeta$  (CD3 $\zeta$ )); 5,830,755 (native TCR alpha and TCR beta in one vector), 7,094,599 (CD4-based anti-HIV CIR); and 6,770,749 (anti-tumor TCRs).

#### 15 Therapeutic Use of CIRs

The following list provides a number of examples of the uses of the molecules of the present invention. These examples should not be viewed as limiting.

#### 20 A. Anti-JCV T Cell Receptors (TCRs) for Recognition of Polyomavirus JC (JCV) derived antigenic peptides

Progressive multifocal leukoencephalopathy (PML) is a deadly brain disease caused by the polyomavirus JC (JCV). The disease mainly arises in immunodeficient subjects. The ability to mount a cellular immune response against JCV has been shown to correlate with survival in PML, as evidenced in survivors by the presence of T cells expressing T cell receptors (TCRs) that recognize JCV peptides. Patients without such T cells have a rapidly fatal outcome. "Designer T cells" possessing anti-JCV TCRs by gene modification can provide a genuine therapy for PML by providing patients with otherwise missing T cells possessing anti-viral specificity.

Accordingly, in one aspect, the instant invention provides a viral vector comprising two nucleic acid sequences encoding homologous CIR polypeptides that each possesses an identical TCRZeta (CD3 $\zeta$ ) cytoplasmic domain, yet together comprise both the alpha and beta chain of an anti-JCV antibody. A designer T cell  
5 comprising this viral vector of the instant invention can be used in treatment of a subject infected with polyomavirus JC (JCV), as both alpha and beta chains of the anti-JCV antibody will be expressed on a single T cell, and JCV antigen binding will elicit a specific anti-JCV immune response *via* signalling through the TCRZeta (CD3 $\zeta$ ) signaling pathway of the T cell. The instant invention, therefore, also  
10 provides therapeutic methods of using such viral vectors against polyomavirus JC (JCV) and/or other antigen of an infective agent.

#### B. Anti-CEA CIRs

Carcinoembryonic antigen (CEA) is a human tumor antigen. (Schwartz *et al.* 1993 Cancer: Principles and Practice of Oncology. Lippincott. 929-77). A single  
15 chain anti-CEA sFv has been previously described (Nolan *et al.* 1999 *Clin Cancer Res.* 5: 3928-41). Anti-CEA molecules, *e.g.*, an anti-CEA sFv as previously described, can be used in a CIR format to impart CEA binding to modified T cells.

Accordingly, “designer T cells” possessing anti-CEA antigen binding fragments (*e.g.*, anti-CEA sFv molecules) that have been manipulated using the gene  
20 modification techniques described herein, can provide a therapy for CEA-expressing cancers by allowing such “designer T cells” to recognize such cancers. For example, in one aspect, the instant invention provides a viral vector comprising two nucleic acid sequences encoding homologous CIR polypeptides that each possess identical TCRZeta (CD3 $\zeta$ ) and CD28 cytoplasmic domains, yet together comprise  
25 both the alpha and beta chain of an anti-CEA antibody. A designer T cell comprising and expressing this viral vector of the instant invention can be used in treatment of a subject with a CEA-expressing cancer, as both alpha and beta chains of the anti-CEA antibody will be expressed on the single T cell, allowing for specific, high affinity binding, and such CEA antigen binding will elicit a specific  
30 immune response *via* signalling through both the TCRZeta (CD3 $\zeta$ ) and CD28

signaling pathways of the T cell, thereby inducing a specific immune response against CEA-expressing cancer cells. The instant invention, therefore, also provides cancer therapeutic methods that involve use of such viral vectors.

### C. Anti-PSMA CIRs

5 Prostate specific membrane antigen (PSMA) is a human tumor antigen (Ma *et al.* 2004 *Prostate* 6: 12-25). A single chain anti-PSMA sFv has been previously described (*ibid*). Anti-PSMA molecules, *e.g.*, an anti-PSMA sFv as previously described, can be used in a CIR format to impart PSMA binding to modified T cells. Accordingly, “designer T cells” possessing anti-PSMA antigen binding fragments  
10 (*e.g.*, anti-PSMA sFv molecules) that have been manipulated using the gene modification techniques described herein, can provide a therapy for PSMA-expressing cancers by allowing such “designer T cells” to recognize such cancers.

For example, in one aspect, the instant invention provides a viral vector comprising two nucleic acid sequences encoding homologous CIR polypeptides that  
15 each possess identical TCRZeta (CD3 $\zeta$ ) and CD28 cytoplasmic domains, yet together comprise both the alpha and beta chain of an anti-PSMA antibody. A designer T cell comprising and expressing this viral vector can be used in treatment of a subject with a PSMA-expressing (*e.g.*, prostate) cancer, as both alpha and beta chains of the anti-PSMA antibody will be expressed on the single T cell, allowing  
20 for specific, high affinity binding. Such PSMA antigen binding will, in turn, elicit a specific immune response *via* signalling through both the TCRZeta (CD3 $\zeta$ ) and CD28 signaling pathways of the T cell, thereby inducing a specific immune response against PSMA-expressing cancer cells. The instant invention, therefore, also provides cancer therapeutic methods that involve use of such viral vectors.

### 25 D. CIRs Possessing Enhanced TCR Stimulation Properties

T cells require both primary and costimulatory signals for optimal activation. The primary antigen-specific signal is delivered by engagement of the TCR. The second antigen-independent costimulatory signal is mediated by engagement of the T cell surface costimulatory molecule CD28 with its target cell ligand, B7.

However, many tumor cells do not express these costimulatory molecules (Willemsen *et al.* 2005 *J. Immunol.* 174: 7853-58).

CD28 co-stimulation (signal 2) during T cell activation through TCR (signal 1) has been shown to promote sustained T cell proliferation (Shahinian *et al.* 1993 *Science* 261: 609-12; Lenschow *et al.* 1996 *Annu Rev Immunol.* 14: 233-58),  
5 decreased activation-induced cell death (AICD) and improved long-term lymphocyte survival (Sperling *et al.* 1996 *J Immunol.* 157: 3909-17). To combine activation and co-stimulatory functions within a single receptor, CIRs can be constructed that are comprised of both TCRZeta (CD3 $\zeta$ ) and CD28 sequences in the  
10 same molecule (Hombach *et al.* 2001 *Cancer Res* 61: 1976-82; Haynes *et al.* 2002 *Blood.* 100: 3155-63 (Erratum in: *Blood.* 2003; 101: 3808); Haynes *et al.* 2002 *J Immunol.* 2002;169:5780-6. (Erratum in: *J Immunol.* 2003; 170: 3440)). Such IgCD28Z molecules have been demonstrated to possess superior function in T cells for cytotoxicity, proliferation, and IL2 and IFN $\gamma$  production (Hombach *et al.* 2001  
15 *Cancer Res* 61: 1976-82; Haynes *et al.* 2002 *Blood.* 100: 3155-63 (Erratum in: *Blood.* 2003; 101: 3808); Haynes *et al.* 2002 *J Immunol.* 169:5780-6. (Erratum in: *J Immunol.* 2003 170: 3440)).

Accordingly, in one aspect, the instant invention provides a viral vector comprising two or more nucleic acid sequences encoding CIR polypeptides that  
20 possess highly homologous (*e.g.*, identical) extracellular antigen-binding domains, yet comprise distinct cytoplasmic domains. For example, one viral vector-encoded CIR polypeptide can comprise a TCRZeta (CD3 $\zeta$ ) cytoplasmic domain, while another CIR polypeptide encoded by the same viral vector comprises a CD28 cytoplasmic domain, thereby allowing for the binding of a single type of antigen to a  
25 T cell that expresses both CIR polypeptides to signal through both the T cell receptor pathway and the normally antigen-independent CD28 signaling pathway, resulting in an enhanced immune response to, *e.g.*, a cancer or infectious disease antigen.

#### E. CIRs Comprising Fc $\epsilon$ RI

30 The Fc $\epsilon$ RI complex is the high affinity cell surface receptor for the Fc region of antigen specific immunoglobulin E (IgE) molecules. Fc $\epsilon$ RI is composed of three

distinct polypeptides. The  $\alpha$  chain (Fc $\epsilon$ RI $\alpha$ ) binds the Fc portion of IgE with high affinity, and the  $\beta$  chain (Fc $\epsilon$ RI $\beta$ ) has four transmembrane domains between amino- and carboxyl-terminal cytoplasmic tails. A homodimer of two disulfide-linked  $\gamma$  chains (Fc $\epsilon$ RI $\gamma$ ) completes the tetrameric structure. In humans, Fc $\epsilon$ RI controls the  
5 activation of mast cells and basophils, and participates in IgE-mediated antigen presentation. Multivalent antigens bind and crosslink IgE molecules held at the cell surface by Fc $\epsilon$ RI. Receptor aggregation induces multiple signaling pathways that control diverse effector responses, including secretion of allergic mediators and the induction of cytokine gene transcription (such as IL-4, IL-6, TNF $\alpha$  and GM-CSF).  
10 Fc $\epsilon$ RI, therefore, is central to the induction and maintenance of an allergic response and physiologically may confer protection in parasitic infections.

In one aspect, the instant invention provides a viral vector comprising two or more nucleic acid sequences encoding CIR polypeptides that possess distinct extracellular TCR $\alpha$  and TCR $\beta$  domains, respectively, yet each comprise identical  
15 Fc $\epsilon$ RI $\gamma$  cytoplasmic domains. The expression of both such fusion proteins on a single T cell allows for the activation of either TCR $\alpha$  or TCR $\beta$  to induce the Fc $\epsilon$ RI $\gamma$  signaling pathway of the designer T cell, which, in turn, induces multiple signaling pathways that control diverse effector responses, including secretion of allergic mediators and the induction of cytokine gene transcription (such as IL-4, IL-6,  
20 TNF $\alpha$  and GM-CSF).

Other protein domains for signaling are by extension covered under this invention with further examples as provided in the Summary section, page 5.

#### CIRs Comprising Antigen Binding Fragments

In certain embodiments of the present invention, CIRs that comprise antigen  
25 binding fragments (*e.g.*, single chain Fv molecules) are employed. While specific anti-CEA and anti-PSMA sFv molecules have been previously described, one of skill in the art will recognize that the present invention is not limited to only constructs that employ such sFv molecules. The sFv (interchangably referred to as “scFv” herein) molecules can be replaced by any number of different antigen  
30 binding domains commonly known in the art, ranging from a minimal peptide



binding domain, to a structured antigen binding domain from a phase library, to antibody-like domains using different methods to hold the heavy and light chain (or peptide-binding domains of each) together. The arrangement can be multimeric such as in a diabody format. It is possible that the T cell receptor variant is also a  
5 multimer. Multimers are most likely caused by cross pairing of the variable portion of the light and heavy chains into what has been referred to by Winters as a diabody. Additionally and/or alternatively, antigen binding fragments employed in CIR polypeptides of the present invention can include non-immunoglobulin scaffold proteins (*e.g.*, fibronectin molecules, lipocalin molecules, etc.) adapted and/or  
10 selected for recognition of target antigens *via* art-recognized methods.

#### Exploitation of the Degeneracy of the Genetic Code

The 64 codons of the eukaryotic genetic code encode for only the 20 naturally-occurring amino acids and three stop codons, rendering the genetic code degenerate with respect to the encoding of amino acid residues. Specific codon  
15 sequences and their corresponding encoded amino acid residues or stop codons are shown below.

	T	C	A	G
T	TTT Phe (F) TTC " TTA Leu (L) TTG "	TCT Ser (S) TCC " TCA " TCG "	TAT Tyr (Y) TAC TAA <b>Ter</b> TAG <b>Ter</b>	TGT Cys (C) TGC TGA <b>Ter</b> TGG Trp (W)
C	CTT Leu (L) CTC " CTA " CTG "	CCT Pro (P) CCC " CCA " CCG "	CAT His (H) CAC " CAA Gln (Q) CAG "	CGT Arg (R) CGC " CGA " CGG "
A	ATT Ile (I) ATC " ATA " ATG Met (M)	ACT Thr (T) ACC " ACA " ACG "	AAT Asn (N) AAC " AAA Lys (K) AAG "	AGT Ser (S) AGC " AGA Arg (R) AGG "
G	GTT Val (V) GTC " GTA " GTG "	GCT Ala (A) GCC " GCA " GCG "	GAT Asp (D) GAC " GAA Glu (E) GAG "	GGT Gly (G) GGC " GGA " GGG "

While methionine (Met, M) and tryptophan (Trp, W) are uniquely encoded by ATG and TTG, respectively, all other amino acid residues may be encoded by two or more distinct codons, often differing by a single base, but in some cases  
5 differing from one another at two of three nucleic acid residues. This degeneracy of the genetic code allows for the encoding of identical polypeptides by non-identical nucleic acid sequences. The present invention, at least in some respects, relies upon introducing (and, in some embodiments, maximizing) non-identity between two  
nucleic acid sequences that encode the same or highly homologous polypeptides  
10 (*e.g.*, CIR polypeptides). By maximizing the difference between nucleic acid sequences present in a single vector (*e.g.*, a viral vector comprising viral genomic RNA possessing genes of interest), the possibility of homologous recombination-directed viral recombination between such sequences is minimized. Accordingly,

*via* directed use of degenerate codons in design of viral vectors, genes encoding identical and/or highly homologous polypeptide sequences can be propagated on a single vector with dramatically reduced possibility of homologous recombination events occurring between nucleic acid sequences encoding the highly homologous  
5 polypeptides.

Thus, in at least one embodiment, the degeneracy of the genetic code may be exploited through alteration of the codons that encode CIRs, thereby facilitating viral gene transduction of mammalian cells and minimizing viral recombination events, particularly within highly homologous (e.g., identical) TMD and intracellular  
10 portions of the CIRs.

#### Selection of Degenerate Nucleic Acid Sequences

To determine which codons within a nucleic acid sequence can be varied without impact on an encoded polypeptide sequence, the nucleic acid sequence can be inspected to determine reading frame and codons, and one or more degenerate  
15 nucleic acid sequences that encode for an identical polypeptide sequence can be determined *via* use of the genetic code (e.g., if an original, e.g., native, nucleic acid sequence encodes a glycine residue with a “GGT” codon in a polypeptide-encoding reading frame, degenerate nucleic acid sequences that encode for an identical  
20 polypeptide sequence would include the three additional sequences that encode the same glycine residue with “GGC,” “GGA,” and “GGG”). As few as a single codon within a nucleic acid sequence can be replaced by a degenerate codon for purpose of forming a variant nucleic acid sequence that encodes the same polypeptide sequence as the original nucleic acid sequence. However, in preferred embodiments of the present invention, multiple codons of the first nucleic acid sequence are replaced by  
25 degenerate codons, to an extent sufficient to dramatically reduce homologous recombination events between the original nucleic acid sequence and the variant (degenerate) nucleic acid sequence, as further described *infra*.

Selection of nucleic acid sequences that contain degenerate codon sequences can be performed manually and/or randomly for a chosen nucleic acid sequence to  
30 be altered. In addition to manual and/or random selection of alternative sequences that contain degenerate codons, a variety of resources are available for generation of

nucleic acid sequences containing degenerate codons, including, *e.g.*, a program that allows for selection of commonly used, but degenerate codons according to previously published information, which may be found on the internet at [www.kazusa.or.jp/codon/](http://www.kazusa.or.jp/codon/) (Nakamura *et al.* 2000 *Nucleic Acids Res.* 28(1): 292).

5 Additionally and/or alternatively, software that facilitates the design of artificial DNA (and corresponding RNA) segments, such as Gene Designer (available from [www.dna20.com](http://www.dna20.com); Villalobos *et al.* 2006 *BMC Bioinformatics* 7: 285.) can be used.

Selection of nucleic acid sequences comprising degenerate codons can be performed upon a single nucleic acid sequence (including, *e.g.*, performance upon an  
10 identical nucleic acid sequence encoding an identical polypeptide domain within two distinct polypeptide sequences (*e.g.*, two distinct CIRs)) or upon two homologous nucleic acid sequences encoding highly homologous polypeptide sequences (*e.g.*, polypeptide sequences greater than 80% identical, more preferably greater than 85% identical, more preferably greater than 90% identical, greater than 95% identical,  
15 greater than 96% identical, greater than 97% identical, greater than 98% identical, or greater than 99% identical). In certain embodiments of the invention, such highly homologous polypeptide sequences may constitute a polypeptide domain within a chimeric polypeptide/protein sequence (*e.g.*, a TMD within a CIR polypeptide). For such highly homologous polypeptides, use of degenerate codons within nucleic acid  
20 sequences encoding such polypeptides may be applied to either sequence individually or to both sequences in order to enhance homology reduction between the nucleic acid sequences encoding the highly homologous polypeptides. The extent of degeneracy that can be incorporated in certain nucleic acid sequences of the invention that encode highly homologous peptides is considered in greater detail  
25 below (refer to “Inhibition of Homologous Recombination *via* Homology Reduction”).

#### Determination and Use of Polypeptide Domains

In certain embodiments of the present invention, the domain structure of polypeptides is determined and/or utilized for synthesis of chimeric polypeptides,  
30 *e.g.*, CIRs. Accordingly, certain vectors of the present invention encode two or more polypeptides, *e.g.*, CIRs, that possess highly homologous and/or identical

polypeptide domain structures, though regions of the polypeptides outside of the highly homologous and/or identical domain structures may be less homologous (e.g., unrelated and/or more distantly related polypeptides). Because unaltered nucleic acids that encode highly homologous and/or identical domains within two  
5 otherwise unrelated and/or distantly related polypeptides can also drive homologous recombination events, it is within the scope of the present invention to introduce degenerate codons across such potentially limited, highly homologous domain regions within a chimeric polypeptide(s), for purpose of reducing the probability of homologous recombination events occurring between chimeric polypeptides  
10 contained within a single vector. Accordingly, determination of the domain structure(s) of polypeptides is an art-recognized facet of certain embodiments of the present invention.

The domain structure of polypeptides can be determined by a number of art-recognized methods. For example, determination of the location of a  
15 transmembrane domain (TMD) of a polypeptide can be determined using traditional hydrophathy analysis, which, for single pass transmembrane proteins that localize to the cell surface, can divide a protein into extracellular domain, TMD, and cytoplasmic domain fragments (with overall orientation within the plasma membrane determined based upon whether the polypeptide is a type I or type II  
20 membrane protein). Additional examples of resources that can be used to determine the domain structure of a polypeptide include the SOSUI system, which can be used for prediction of transmembrane helices and signal sequences of protein sequences, and other protein domain architectures can be analysed using Pfam (Protein families database of alignments and HMMs).

25 Protein domain descriptions can be obtained from Prosite (contains 1030 documentation entries that describe 1366 different patterns, rules and profiles/matrices), and Pfam. A description of the Pfam database can be found in Sonhammer *et al.* (1997) *Proteins* 28(3): 405-420.

30 A "portion" of a protein refers to that length of amino acid sequence which would retain at least one biological activity, a domain identified by PFAM or PRINTS analysis or an antigenic determinant of the protein identified using Kate-Doolittle algorithms of the PROTEAN program (DNASTAR, Madison, Wis.).

As mentioned above, hydropathy analysis can most readily be used to predict and/or determine transmembrane domains (TMDs) within a polypeptide. TMDs are among the shortest domains readily discerned by domain recognition programs. In general, the individual domain structures within a polypeptide will tend to be at least  
5 10 amino acid residues in length, more commonly at least 15 amino acid residues in length, commonly at least 16 amino acid residues in length, commonly at least 17 amino acid residues in length, commonly at least 18 amino acid residues in length, commonly at least 19 amino acid residues in length, commonly at least 20 amino acid residues in length, commonly at least 21 amino acid residues in length,  
10 commonly at least 22 amino acid residues in length, commonly at least 25 amino acid residues in length, commonly at least 30 amino acid residues in length, commonly at least 35 amino acid residues in length, commonly at least 40 amino acid residues in length, commonly at least 45 amino acid residues in length, or commonly at least 50 amino acid residues in length. Some of the shortest  
15 polypeptide domains, *e.g.*, TMDs, are generally about 15-30 amino acid residues in length, commonly about 17-25 amino acid residues in length, commonly about 18-22 amino acid residues in length, or commonly about 20 amino acid residues in length.

Once degenerate nucleic acid sequences are selected, homology values may  
20 be verified for newly designed sequences in comparison(s) with the original/counterpart genes and, optionally, vector nucleic acid sequence (*e.g.*, retroviral vector RNA sequence), respectively, using relevant software (such as web-based software: [www.workbench.sdsc.edu](http://www.workbench.sdsc.edu)). In certain embodiments, overall nucleic acid homology is less than 80% and/or the length of nucleotide sequences that share  
25 over 80% homology is not longer than 50-100 nucleotides.

#### Inhibition of Homologous Recombination *via* Homology Reduction

It is generally accepted that homology (% identity) levels must be very high over a sufficiently long region for recombination event(s) to take place at a significant frequency. In particular, the data from the literature suggest that a region  
30 of perfect homology of at least equal to about 200 nucleotides in length is required for the occurrence of such events. Indeed, even though recombination events can

take place over shorter regions, their frequency is much lower and irregular. Moreover, over such a region whose homology is reduced by 19%, it appears that the frequency of recombination is reduced by a factor of 1000 (Waldman and Liskay, 1987).

5           As described herein, nucleic acid sequences can be modified in various ways. With regard to coding sequence, modifications can be introduced based on the degeneracy of the genetic code, as described in more detail above. In this way, regions of otherwise identical sequence are disrupted, thereby reducing homology yet allowing for the expression product to remain unchanged.

10           The invention resides therefore, at least in part, in a modification of the sequence of nucleic acid sequences (*e.g.*, CIRs) within a vector (*e.g.*, retroviral vector) in such a way as to prevent the pairing between the two homologous regions. The modification makes it possible to decrease the length and degree of homology between the two regions concerned.

15           Advantageously, in one method of the invention, at least one nucleic acid sequence is degenerated, within a region that would otherwise be highly homologous and/or identical at the amino acid level and, therefore, likely to be involved in homologous recombination events, in a proportion of 1 non-identical base pair at least every 50 base pairs, 1 non-identical base pair at least every 20 base  
20           pairs, or 1 non-identical base pair at least every 10 base pairs. More preferably, it is degenerated in a proportion of 1 non-identical base pair at least every 10 base pairs or 1 non-identical base pair at least every 5 base pairs.

          In certain embodiments, a sequence can be degenerated over all the possible positions. The degeneracy of a sequence according to the invention is  
25           advantageously produced as a function of the codon use of the cell or organism in which the nucleic acid should be used. In the case of a viral vector whose production is carried out in a human cell line, it is particularly advantageous to degenerate the sequences by favouring the preferred codon use in humans when this choice is possible (refer to U.S. Patent Number 6,410,298).

30           Moreover, further modifications can be introduced into the nucleic acid sequence. Thus, in, *e.g.*, noncoding regions, it is possible to reduce the size of

certain elements (regulatory sequences for expression, promoters) or to modify these elements or to substitute certain other elements with heterologous regions.

It may also be possible to introduce one or more substitutions of amino acid residues within a polypeptide sequence of the invention for purpose of reducing  
5 homology. Such modification(s) can be informed by, *e.g.*, alignments of homologous and/or orthologous sequences that identify evolutionarily non-conserved amino acids that are of greatest interest for performance of such substitutions. For example, where native polypeptide(s) and/or domains of native polypeptide(s) derived from both human and chimpanzee sequences are non-  
10 identical yet known to be functionally interchangeable, both such sequences can be used within a vector (*e.g.*, within a CIR polypeptide) of the present invention. Alternatively, individual amino acid substitutions selected from among those residues that are non-identical between compared sequences can be performed to reduce homology between nucleic acid sequences, and such approaches can be  
15 combined with the use of degenerate codon sequences as described herein, in order to achieve generation of a single vector comprising two nucleic acid sequences possessing dramatically reduced levels of homology yet encoding two identical or highly homologous polypeptides (*e.g.*, CIR polypeptides).

In certain embodiments of the present invention, when two nucleic acid  
20 sequences encoding identical and/or highly homologous polypeptide sequence(s) (*e.g.*, nucleic acid sequences encoding CIRs possessing identical CD3 $\zeta$  cytoplasmic domain polypeptides) contained within a single vector of the invention are compared, at least 2% of codons within the region of nucleic acid sequence that encodes the identical and/or highly homologous domain of polypeptide sequence are  
25 non-identical, degenerate codons. In certain additional embodiments, at least 5% of such codons are non-identical, optionally at least 10% of such codons are non-identical, optionally at least 15% of such codons are non-identical, optionally at least 20% of such codons are non-identical, optionally at least 25% of such codons are non-identical, optionally at least 30% of such codons are non-identical, optionally at  
30 least 35% of such codons are non-identical, optionally at least 40% of such codons are non-identical, optionally at least 45% of such codons are non-identical, optionally at least 50% of such codons are non-identical, optionally at least 55% of



such codons are non-identical, optionally at least 60% of such codons are non-identical, optionally at least 65% of such codons are non-identical, optionally at least 70% of such codons are non-identical, optionally at least 75% of such codons are non-identical, optionally at least 80% of such codons are non-identical, optionally at least 85% of such codons are non-identical, optionally at least 90% of such codons are non-identical, or optionally at least 95% of such codons are non-identical. Optionally, all codons other than those encoding methionine or tryptophan are non-identical between the two compared nucleic acid sequences.

In certain embodiments of the present invention, when two nucleic acid sequences encoding identical and/or highly homologous polypeptide sequence(s) (*e.g.*, nucleic acid sequences encoding CIRs possessing identical CD3 $\zeta$  cytoplasmic domain polypeptides) contained within a single vector of the invention are compared, at least 1 codon within the region of nucleic acid sequence that encodes the identical and/or highly homologous domain of polypeptide sequence is a non-identical, degenerate codon. In certain additional embodiments, at least 2 such codons are non-identical, optionally at least 3 such codons are non-identical, optionally at least 4 such codons are non-identical, optionally at least 5 such codons are non-identical, optionally at least 10 such codons are non-identical, optionally at least 15 such codons are non-identical, optionally at least 20 such codons are non-identical, optionally at least 25 such codons are non-identical, optionally at least 30 such codons are non-identical, optionally at least 35 such codons are non-identical, optionally at least 40 such codons are non-identical, optionally at least 45 such codons are non-identical, optionally at least 50 such codons are non-identical, optionally at least 55 such codons are non-identical, optionally at least 60 such codons are non-identical, optionally at least 65 such codons are non-identical, optionally at least 70 such codons are non-identical, optionally at least 75 such codons are non-identical, optionally at least 80 such codons are non-identical, optionally at least 85 such codons are non-identical, optionally at least 90 such codons are non-identical, optionally at least 95 such codons are non-identical, optionally at least 100 such codons are non-identical, optionally at least 110 such codons are non-identical, optionally at least 120 such codons are non-identical, optionally at least 130 such codons are non-identical, optionally at least 140 such

codons are non-identical, optionally at least 150 such codons are non-identical, optionally at least 160 such codons are non-identical, optionally at least 170 such codons are non-identical, optionally at least 180 such codons are non-identical, optionally at least 190 such codons are non-identical, or optionally at least 200 such  
5 codons are non-identical.

In certain embodiments, the percent identity values of two nucleic acid sequences that encode for identical and/or highly homologous polypeptides (*e.g.*, certain CIR polypeptide domain sequences, *e.g.*, the CD3 $\zeta$  cytoplasmic domain of two CIRs of the invention located upon the same vector yet wherein at least one  
10 nucleic acid sequence has been modified through use of degenerate codons to reduce nucleic acid homology) are reduced to less than 98% identity between such nucleic acid sequences, more preferably less than 95% identity between such nucleic acid sequences, more preferably less than 90% identity between such nucleic acid sequences, more preferably less than 85% identity between such nucleic acid  
15 sequences, more preferably less than 80% identity between such nucleic acid sequences, optionally less than 75% identity between such nucleic acid sequences, optionally less than 70% identity between such nucleic acid sequences, optionally less than 65% identity between such nucleic acid sequences, or optionally less than 60% identity between such nucleic acid sequences.

## 20 Therapeutic Use of Vectors Comprising Degenerate CIR Sequences

The vectors of the present invention, possessing mutated genes as described *infra*, can be used for applications including, but not limited to, gene therapy and immunotherapy. For example, immunotherapy for infectious disease may be performed *via* use of CIRs that recognize the infectious disease, or cancer may be  
25 treated using T cells that express antigen-specific CIRs.

In certain embodiments, production of a T cell that expresses such CIRs may be accomplished *via* retroviral gene therapy.

### Retroviral Gene Therapy

Gene therapy includes any one or more of: the addition, the replacement, the  
30 deletion, the supplementation, the manipulation of one or more nucleotide sequences

in, for example, one or more targeted sites, *e.g.*, targeted cells. If the targeted sites are targeted cells, then the cells may be part of a tissue or an organ. General teachings on gene therapy may be found in Molecular Biology (Ed Robert Meyers, Pub VCH, *e.g.*, refer to pages 556-558).

5           By way of further example, gene therapy also provides a means by which any one or more of: a nucleotide sequence, such as a gene, can be applied to replace or supplement a defective gene; a pathogenic gene or gene product can be eliminated; a new gene can be added in order, for example, to create a more favorable phenotype; cells can be manipulated at the molecular level to treat cancer  
10 (Schmidt-Wolf and Schmidt-Wolf, 1994, *Annals of Hematology* 69:273-279) or other conditions – such as immune, cardiovascular, neurological, inflammatory or infectious disorders; antigens can be manipulated and/or introduced to elicit an immune response – such as genetic vaccination.

          In certain embodiments of the invention, retroviral gene therapy is performed  
15 upon T cells *in vitro* to achieve T cell expression of CIR molecules. In other embodiments of the invention, retroviral gene therapy that introduces CIR molecules to T cells is performed upon such T cells *in vivo*.

#### Retroviruses and Lentiviruses

          In recent years, retroviruses have been proposed for use in gene therapy.  
20 Essentially, retroviruses are RNA viruses with a life cycle different from that of lytic viruses. In this regard, when a retrovirus infects a cell, its genome is converted to a DNA form. In other words, a retrovirus is an infectious entity that replicates through a DNA intermediate.

          Lentivirus is a genus of slow viruses within the *Retroviridae* (retrovirus)  
25 family. Lentiviruses are characterized by a long incubation period, and can deliver a significant amount of genetic information into the DNA of a host cell. Accordingly, they are one of the most efficient forms of gene delivery vector. HIV, SIV and FIV are all examples of lentiviruses. Notably, lentiviruses are capable of infecting neighboring cells in direct contact with host cells, absent the need to form  
30 extracellular particles (though virions can be produced and harvested for implementation of cell-free infection of newly-targeted cells).

Any of the following exemplary retroviruses are contemplated for use in the methods of the invention: murine leukemia virus (MLV), equine infectious anaemia virus (EIAV), mouse mammary tumour virus (MMTV), Rous sarcoma virus (RSV), Fujinami sarcoma virus (FuSV), Moloney murine leukemia virus (Mo-MLV), FBR murine osteosarcoma virus (FBR MSV), Moloney murine sarcoma virus (Mo-MSV), Abelson murine leukemia virus (A-MLV), Avian myelocytomatosis virus-29 (MC29), Avian erythroblastosis virus (AEV), AKR (endogenous) murine leukemia virus, Avian carcinoma, Mill Hill virus 2, Avian leukosis virus-RSA, Avian myeloblastosis virus, Avian myelocytomatosis virus 29, Bovine syncytial virus, Caprine arthritis encephalitis virus, Chick syncytial virus, Feline leukemia virus, Feline syncytial virus, Finkel-Biskis-Jenkins murine sarcoma virus, Friend murine leukemia virus, Fujinami sarcoma virus, Gardner-Arnstein feline sarcoma virus, Gibbon ape leukemia virus, Guinea pig type C oncovirus, Hardy-Auckerman feline sarcoma virus, Harvey murine sarcoma virus, Human foamy virus, Human spumavirus, Human T-lymphotropic virus 1, Human T-lymphotropic virus 2, Jaagsiekte virus, Kirsten murine sarcoma virus, Langur virus, Mason-Pfizer monkey virus, Moloney murine sarcoma virus, Ovine pulmonary adenocarcinoma virus, Porcine type C oncovirus, Reticuloendotheliosis virus, Simian foamy virus, Simian sarcoma virus, Simian T-lymphotropic virus, Simian type D virus 1, Snyder-Theilen feline sarcoma virus, Squirrel monkey retrovirus, Trager duck spleen necrosis virus, UR2 sarcoma virus, Viper retrovirus, Visna/maedi virus, Woolly monkey sarcoma virus, and Y73 sarcoma virus human-, simian-, feline-, and bovine immunodeficiency viruses (HIV, SIV, FIV, BIV).

A detailed list of retroviruses can be found in Coffin *et al* ("Retroviruses" 1997 Cold Spring Harbour Laboratory Press Eds: J M Coffin, S M Hughes, H E Varmus pp. 758-763). Details on the genomic structure of some retroviruses can also be found in the art. By way of example, details regarding HIV structure can be found in NCBI Genbank (*i.e.* Genome Accession No. AF033819).

#### Retroviral Transduction of CIRs into Primary Human Lymphocytes

The use of retroviral vectors to transduce chimeric immune receptors into primary human lymphocytes has been limited by low gene transfer efficiency when

viral supernatant infections have been carried out. Transfer rates into primary human T cells using amphotropic virus in such prior studies has ranged from 1 to 12% (Bunnell, 1995 *Proc Natl Acad Sci U S A.* 92(17): 7739-43). Certain strategies have been employed to increase the transduction rates to 20-50%, as described in  
5 WO 03/033670.

The methods of the instant invention allow for use of a single vector possessing two or more nucleic acid sequences encoding highly homologous polypeptide sequences for transduction into host cells, thereby overcoming problems associated with low transduction efficiencies of retroviral vectors into host cells.

## 10 Retrovirus Structure

All retroviruses contain three major coding domains, gag, pol, and env, which code for essential virion proteins. Nevertheless, retroviruses may be broadly divided into two categories: "simple" and "complex". These categories are distinguishable by the organization of their genomes. Simple retroviruses usually  
15 carry only this elementary information. In contrast, complex retroviruses also code for additional regulatory proteins derived from multiple spliced messages.

Retroviruses can be further divided into seven groups. Five of these groups represent retroviruses with oncogenic potential. The remaining two groups are the lentiviruses and the spumaviruses. A review of these retroviruses is presented in  
20 "Retroviruses" (1997 Cold Spring Harbour Laboratory Press Eds: J M Coffin, S M Hughes, H E Varmus pp 1-25).

All oncogenic members except the human T-cell leukemia virus-bovine leukemia virus (HTLV-BLV) are simple retroviruses. HTLV, BLV and the lentiviruses and spumaviruses are complex. Some of the best-studied oncogenic  
25 retroviruses are Rous sarcoma virus (RSV), mouse mammary tumour virus (MMTV) and murine leukemia virus (MLV) and the human T-cell leukemia virus (HTLV).

The lentivirus group can be split even further into "primate" and "non-primate". Examples of primate lentiviruses useful in the methods and compositions  
30 of the instant invention include the human immunodeficiency virus (HIV), the causative agent of human auto-immunodeficiency syndrome (AIDS), and the simian

immunodeficiency virus (SIV). The non-primate lentiviral group includes the prototype "slow virus" visna/maedi virus (VMV), as well as the related caprine arthritis-encephalitis virus (CAEV), equine infectious anaemia virus (EIAV) and the more recently described feline immunodeficiency virus (FIV) and bovine  
5 immunodeficiency virus (BIV).

In a typical recombinant retroviral vector for use in gene therapy, at least part of one or more of the gag, pol and env protein coding regions may be removed from the virus. This makes the retroviral vector replication-defective. The removed portions can be replaced by a nucleotide of interest (NOI; *e.g.*, a CIR sequence) in  
10 order to generate a virus capable of integrating its genome into a host genome but wherein the modified viral genome is unable to propagate itself due to a lack of structural proteins. When integrated in the host genome, expression of the NOI occurs, resulting in, for example, a therapeutic effect. Thus, the transfer of a NOI into a site of interest is typically achieved by: integrating the NOI into the  
15 recombinant viral vector; packaging the modified viral vector into a virion coat; and allowing transduction of a site of interest, such as a targeted cell or a targeted cell population (*e.g.*, human T cell population).

It is possible to propagate and isolate quantities of retroviral vectors (*e.g.*, to prepare suitable titres of the retroviral vector) for subsequent transduction of, for  
20 example, a site of interest *via* use of a combination of a packaging or helper cell line and a recombinant vector.

In some instances, propagation and isolation can entail isolation of the retroviral gag, pol and env genes and their separate introduction into a host cell to produce a "packaging cell line". The packaging cell line produces the proteins  
25 required for packaging retroviral DNA but it cannot bring about encapsidation due to the lack of a psi region. However, when a recombinant vector carrying a NOI and a psi region is introduced into the packaging cell line, the helper proteins can package the psi-positive recombinant vector to produce the recombinant virus stock. This can be used to infect cells to introduce the NOI (*e.g.*, CIR) into the genome of  
30 the cells. The recombinant virus whose genome lacks all genes required to make viral proteins can infect only once and cannot propagate. Hence, the NOI (*e.g.*, CIR) is introduced into the host cell genome without the generation of potentially harmful

retrovirus. A summary of the available packaging lines is presented in "Retroviruses" (1997 Cold Spring Harbour Laboratory Press Eds: J M Coffin, S M Hughes, H E Varmus pp 449).

5 The above technique, however, can be problematic in the sense that viral titre levels are not always at a satisfactory level. Nevertheless, the design of retroviral packaging cell lines has evolved to address the problem of *inter alia* the spontaneous production of helper virus that was frequently encountered with early designs. As recombination is greatly facilitated by homology, reducing or eliminating homology between the genomes of the vector and the helper has reduced the problem of helper  
10 virus production.

In another embodiment, a strategy sometimes referred to as the three plasmid transfection method is used in the methods of the invention (Soneoka *et al.* 1995 *Nucl. Acids Res.* 23: 628-633). In this method, packaging cells in which the gag, pol and env viral coding regions are carried on separate expression plasmids are  
15 independently transfected into a packaging cell line, such that three recombinant events are required for wild type viral production.

Transient transfection can be used to measure vector production when vectors are being developed. In this regard, transient transfection avoids the longer time required to generate stable vector-producing cell lines and is used if the vector  
20 or retroviral packaging components are toxic to cells. Components typically used to generate retroviral vectors include a plasmid encoding the Gag/Pol proteins, a plasmid encoding the Env protein and a plasmid containing a NOI (*e.g.*, CIR). Vector production involves transient transfection of one or more of these components into cells containing the other required components. If the vector  
25 encodes toxic genes or genes that interfere with the replication of the host cell, such as inhibitors of the cell cycle or genes that induce apoptosis, it may be difficult to generate stable vector-producing cell lines, but transient transfection can be used to produce the vector before the cells die. Also, cell lines have been developed using transient infection that produce vector titre levels that are comparable to the levels  
30 obtained from stable vector-producing cell lines (Pear et al 1993, *PNAS* 90:8392-8396). The compositions and methods of the present invention provide particular advantage in such transient transfection strategies, in view of their reliance upon a

single viral vector transformation event, rather than multiple viral vector transformation events.

In view of the toxicity of some HIV proteins – which can make it difficult to generate stable HIV-based packaging cells – HIV vectors are usually made by transient transfection of vector and helper virus. Some workers have even replaced the HIV Env protein with that of vesicular stomatis virus (VSV). Insertion of the Env protein of VSV facilitates vector concentration as HIV/VSV-G vectors with titres of  $5 \times 10^5$  ( $10^8$  after concentration) were generated by transient transfection (Naldini *et al* 1996 *Science* 272: 263-267). Thus, transient transfection of HIV vectors can provide a useful strategy for the generation of high titre vectors (Yee *et al* 1994 *PNAS* 91: 9564-9568). A drawback, however, with this approach is that the VSV-G protein is quite toxic to cells.

Replacement of the env gene with a heterologous env gene is an example of a technique or strategy called pseudotyping. Pseudotyping is not a new phenomenon and examples may be found in WO 98/05759, WO 98/05754, WO 97/17457, WO 96/09400, WO 91/00047 and Mebatsion *et al* 1997 *Cell* 90: 841-847. Various methods of pseudotyping are described, *e.g.*, in WO 03/066868.

#### Retroviral Vectors

The present invention, at least in part, provides a retroviral vector that contains two or more nucleic acid sequences that encode homologous, optionally perfectly identical or highly identical, polypeptides, wherein the at least two nucleic acid sequences, by design, are insufficiently homologous to enable homologous recombination to occur between the two or more highly homologous, optionally identical, nucleic acid sequences.

Thus, in certain embodiments, the present invention provides a retroviral vector having at least two exogenous nucleic acid sequences that encode homologous polypeptides, *e.g.*, CIR polypeptides. This retroviral vector is useful in gene therapy.

The retroviral vectors of the present invention are useful for the delivery of nucleic acid sequences expressing at least two homologous polypeptide (*e.g.*, CIR polypeptide) sequences to cells (*e.g.*, T cells) *in vivo* and *in vitro*, in particular the



delivery of therapeutically active nucleic acid sequences that encode CIR polypeptides. Two or more selected nucleic acid sequences encoding homologous polypeptides (*e.g.*, CIR polypeptides) can be incorporated in the same vector genome for expression in the target cell. The homologous polypeptide-encoding  
5 (*e.g.*, CIR-encoding) nucleic acid sequences can have one or more expression control sequences of their own, or their expression can be controlled by the vector LTRs. For appropriate expression of the polypeptides, *e.g.*, CIRs, a promoter may be included in or between the LTRs which is preferentially active under certain conditions or in certain cell types. In certain embodiments of the present invention,  
10 an IRES is included between nucleotide sequences encoding highly homologous (*e.g.*, identical) polypeptides and/or polypeptide domains. In certain other embodiments, nucleotides encoding a 'self-cleaving' 2A peptide are included between nucleotide sequences encoding highly homologous (*e.g.*, identical) polypeptides and/or polypeptide domains. The plurality of nucleic acid sequences  
15 that encode homologous polypeptides (*e.g.*, CIR polypeptides) can be sense sequences, antisense sequences, or combinations thereof.

In certain embodiments of the instant invention, the two or more selected nucleic acid sequences encoding homologous polypeptides (*e.g.*, CIR polypeptides) can be incorporated in two or more distinct viral vectors for expression in a target  
20 cell. While such two vector approaches confront the potential difficulties associated with achieving co-transduction of independent viral vectors into the same host cell, the methods of the invention may be implemented to reduce the probability of homologous recombination events occurring between such co-transduced highly homologous (*e.g.*, identical) polypeptides and/or polypeptide domains. As for single  
25 viral vector embodiments, degenerate codons can be employed during synthesis of nucleic acid sequences to reduce homology levels present between nucleic acid sequences encoding homologous (*e.g.*, identical) polypeptides and/or polypeptide domains. Polypeptide-encoding (*e.g.*, CIR-encoding) nucleic acid sequences can have one or more expression control sequences of their own, or their expression can  
30 be controlled by the vector LTRs. For appropriate expression of the homologous polypeptides, *e.g.*, CIRs, a promoter may be included in or between the LTRs which is preferentially active under certain conditions or in certain cell types. In certain

embodiments of the present invention, an IRES is included in appropriate position to induce transcription and expression of nucleotide sequences encoding highly homologous (*e.g.*, identical) polypeptides and/or polypeptide domains. As for single viral vector compositions and methods of the instant invention, the plurality of  
5 nucleic acid sequences that encode homologous polypeptides (*e.g.*, CIR polypeptides) may be sense sequences, antisense sequences, or combinations thereof.

The retroviral vector genome of the present invention may generally comprise LTRs at the 5' and 3' ends, two or more NOIs (*e.g.*, CIRs) including  
10 therapeutically active genes and/or marker genes, or suitable insertion sites for inserting two or more NOIs, and a packaging signal to enable the genome to be packaged into a vector particle in a producer cell. At least one of the NOIs of the present invention is modified to incorporate at least one degenerate codon sequence (as compared to another NOI sequence contained within the same viral vector),  
15 optionally enough degenerate codons are introduced to reduce nucleic acid identity between sequences encoding highly homologous polypeptides to less than, *e.g.*, 80% identity, thereby significantly reducing the probability of a homologous recombination event between the NOI sequences. Within the retroviral vectors of the present invention, there may be suitable primer binding sites and integration sites  
20 to allow reverse transcription of the vector RNA to DNA, and integration of the proviral DNA into the target cell genome. In certain embodiments, the retroviral vector particle has a reverse transcription system (compatible reverse transcription and primer binding sites) and an integration system (compatible integrase and integration sites).

25 Thus, in accordance with the present invention, it is possible to manipulate the viral genome or the retroviral vector nucleotide sequence, so that viral genes are replaced or supplemented with two or more nucleic acid sequences encoding homologous CIR polypeptides. Such retroviral vector nucleotide sequences will also contain genes that enable identification of transformed cells. Such genes may  
30 be any one or more of selection gene(s) and marker gene(s). Many different selectable markers have been used successfully in retroviral vectors. These are reviewed in "Retroviruses" (1997 Cold Spring Harbour Laboratory Press Eds: J M

Coffin, S M Hughes, H E Varmus pp 444) and include, but are not limited to, the bacterial neomycin and hygromycin phosphotransferase genes which confer resistance to G418- and hygromycin, respectively; a mutant mouse dihydrofolate reductase gene which confers resistance to methotrexate; the bacterial gpt gene  
5 which allows cells to grow in medium containing mycophenolic acid, xanthine and aminopterin; the bacterial hisD gene which allows cells to grow in medium without histidine but containing histidinol; the multidrug resistance gene (mdr) which confers resistance to a variety of drugs; and the bacterial genes which confer resistance to puromycin or phleomycin. All of these markers are dominant  
10 selectable and allow for chemical selection of cells expressing these genes.

#### Therapeutic Use of Retroviral Vectors and Recombinant Retrovirus

In certain embodiments of the present invention, diseases which may be treated by the compositions and methods of the invention include, but are not limited to infectious diseases and cancer, though any disease or disorder for which “designer  
15 T cells” and modified NK cells can be used for treatment of the disease or disorder is within the scope of the present invention. Accordingly, within such embodiments, target cells for gene therapy using retroviral vectors include but are not limited to T cells and NK cells.

Within the retroviral vectors of the present invention, two or more nucleic  
20 acid sequences that encode highly homologous polypeptides, *e.g.*, CIR polypeptides, can be under the transcriptional control of the viral LTRs. However, in certain embodiments of the present invention, the two or more nucleic acid sequences of the retroviral vector are under the transcriptional control of an IRES element.

Alternatively, a combination of enhancer-promoter elements can be present in order  
25 to achieve higher levels of expression. The promoter-enhancer elements are preferably strongly active or capable of being strongly induced in the target cells.

An example of a strongly active promoter-enhancer combination is a human cytomegalovirus (HCMV) major intermediate early (MIE) promoter/enhancer combination. The promoter-enhancer combination may be tissue or temporally  
30 restricted in their activity. Examples of a suitable tissue restricted promoter-

enhancer combinations are those which are highly active in tumor cells such as a promoter-enhancer combination from a MUC1 gene or a CEA gene.

Hypoxia or ischemia regulatable expression is also useful in certain embodiments of the invention. Hypoxia is a powerful regulator of gene expression in a wide range of different cell types and acts by the induction of the activity of hypoxia-inducible transcription factors such as hypoxia inducible factor-1 (HIF-1) (Wang and Semenza 1993 *PNAS (USA)* 90: 430) which bind to cognate DNA recognition sites, the hypoxia responsive elements (HREs) on various gene promoters. A multimeric form of HRE from the mouse phosphoglycerate kinase-1 (PGK-1) gene has been used to control expression of both marker and therapeutic genes by human fibrosarcoma cells in response to hypoxia *in vitro* and within solid tumors *in vivo* (Firth *et al* 1994 *PNAS* 91(14): 6496-6500; Dachs *et al* 1997 *Nature Med.* 5: 515). Alternatively, the fact that glucose deprivation is also present in ischemic areas of tumours can be used to activate heterologous gene expression, especially in tumors. A truncated 632 base pair sequence of the grp 78 gene promoter, known to be activated specifically by glucose deprivation, has been shown to be capable of driving high level expression of a reporter gene in murine tumors *in vivo* (Gazit *et al* 1995 *Cancer Res.* 55: 1660).

The retroviral vector genomes of the present invention for subsequent use in gene therapy preferably contain the minimum retroviral material necessary to function efficiently as vectors. The purpose of this is to allow space for the incorporation of the homologous exogenous polypeptides, and for safety reasons. Retroviral vector genomes are preferably replication defective due to the absence of functional genes encoding one or more of the structural (or packaging) components encoded by the gag-pol and env genes. The absent components required for particle production are provided in *trans* in the producer cell. The absence of virus structural components in the genome also means that undesirable immune responses generated against virus proteins expressed in the target cell are reduced or avoided. Furthermore, possible reconstruction of infectious viral particles is preferably avoided where *in vivo* use is contemplated. Therefore, the viral structural components are preferably excluded from the genome as far as possible, in order to reduce the chance of any successful recombination.

### Retroviral Host/Producer Cells

The retroviral vector particles of the present invention are typically generated in a suitable producer cell. Producer cells are generally mammalian cells but can be, for example, insect cells. A producer cell may be a packaging cell containing the virus structural genes, normally integrated into its genome. The packaging cell is then transfected with a nucleic acid encoding the vector genome, for the production of infective, replication defective vector particles. Alternatively, the producer cell may be co-transfected with nucleic acid sequences encoding the vector genome and the structural components, and/or with the nucleic acid sequences present on one or more expression vectors such as plasmids, adenovirus vectors, herpes viral vectors or any method known to deliver functional DNA into target cells.

In one embodiment, the vector of the present invention is constructed from or is derivable from a lentivirus. This has the advantage that the vector may be capable of transducing non-dividing cells and dividing cells. Accordingly, in certain aspects of the instant invention, the retroviral vectors of the invention are lentivirus vectors such as HIV or EIAV vectors. These have the advantages noted above.

### Use of Codon Degeneracy to Reduce Homologous Recombination in Vectors Comprising IRES and Carcinoembryonic Antigen (CA) Sequences

The methods of the present invention can also be applied to reduce homologous recombination events caused by homologous natural domains found within, *e.g.*, IRES and carcinoembryonic antigen (CA) sequences. Both IRES and CA have replicated domains within their sequences that could lead to deletion of such sequences. Accordingly, the use of codon degeneracy in synthesis of vectors containing such nucleic acid sequences can prove advantageous for the same reasons described *infra* for CIR production. Highly homologous natural domains within distinct polypeptides are also a concern for vectors that comprise *e.g.*, TCR- $\alpha$  and TCR- $\beta$  in same vector with an IRES, if homology between them is significant – in such instances, one molecule can comprise multiple repeated domains, with two such genes joined by an IRES.

### Pharmaceutical Compositions

In certain embodiments, the present invention provides a pharmaceutical composition for treating an individual by gene therapy, wherein the composition comprises a therapeutically effective amount of a retroviral vector according to the present invention. The pharmaceutical composition may be for human or animal  
5 usage. Typically, a physician will determine the actual dosage which will be most suitable for an individual subject and it will vary with the age, weight and response of the particular patient.

The composition may optionally comprise a pharmaceutically acceptable  
10 carrier, diluent, excipient or adjuvant. The choice of pharmaceutical carrier, excipient or diluent can be selected with regard to the intended route of administration and standard pharmaceutical practice. The pharmaceutical compositions may comprise as--or in addition to--the carrier, excipient or diluent any suitable binder(s), lubricant(s), suspending agent(s), coating agent(s),  
15 solubilising agent(s), and other carrier agents that may aid or increase the viral entry into the target site (such as for example a lipid delivery system).

Where appropriate, the pharmaceutical compositions can be administered by any one or more of: inhalation, in the form of a suppository or pessary, topically in the form of a lotion, solution, cream, ointment or dusting powder, by use of a skin  
20 patch, orally in the form of tablets containing excipients such as starch or lactose, or in capsules or ovules either alone or in admixture with excipients, or in the form of elixirs, solutions or suspensions containing flavouring or colouring agents, or they can be injected parenterally, for example intracavernosally, intravenously, intramuscularly or subcutaneously. For parenteral administration, the compositions  
25 may be best used in the form of a sterile aqueous solution which may contain other substances, for example enough salts or monosaccharides to make the solution isotonic with blood. For buccal or sublingual administration the compositions may be administered in the form of tablets or lozenges which can be formulated in a conventional manner.

## Kits

In certain embodiments, the invention provides kits which contain, *e.g.*, compositions of the invention as described herein and/or components specifically useful in the methods described herein. In other embodiments, the invention provides kits useful in the generation of vectors of the invention. For example, the pharmaceutical compositions of the invention can be included in a container, pack, or dispenser together with instructions for use.

## EXAMPLES

The present invention is further detailed in the following examples, which are offered by way of illustration and are not intended to limit the invention in any manner. Standard techniques well known in the art or the techniques specifically described below are utilized.

### General Methods

In general, the practice of the present invention employs, unless otherwise indicated, conventional techniques of chemistry, molecular biology, recombinant DNA technology, PCR technology, immunology (especially, *e.g.*, antibody technology), expression systems (*e.g.*, cell-free expression, phage display, ribosome display, and Profusion<sup>TM</sup>), and any necessary cell culture that are within the skill of the art and are explained in the literature. *See, e.g.* Sambrook, Fritsch and Maniatis, Molecular Cloning. Cold Spring Harbor Laboratory Press (1989); DNA Cloning, Vols. 1 and 2, (D.N. Glover, Ed. 1985); Oligonucleotide Synthesis (M.J. Gait, Ed. 1984); PCR Handbook Current Protocols in Nucleic Acid Chemistry, Beaucage, Ed. John Wiley & Sons (1999) (Editor), Oxford Handbook of Nucleic Acid Structure, Neidle, Ed., Oxford Univ Press (1999); PCR Protocols: A Guide to Methods and Applications, Innis et al., Academic Press (1990); PCI2 Essential Techniques: Essential Techniques, Burke, Ed., John Wiley & Son Ltd (1996); The PCR Technique. RT-PCR, Siebert, Ed., Eaton Pub. Although certain aspects of the present invention relate to compositions and uses of recombinant RNA retrovirus

(e.g., lentiviral HIV-2, SIV, etc.), the molecular cloning may be done using proviral DNA clones, thus allowing the use of standard cloning techniques.

Site-directed mutagenesis in vitro by synthetic oligodeoxynucleotides can be carried out according to the method developed by Taylor *et al.* (*Nucleic Acids Res.* 13 (1985): 8749-8764) using the kit distributed by Amersham. Genetic fusions, especially of use in the synthesis of fusion proteins, *e.g.*, CIRs, of the present invention can be made by art-recognized methods, *e.g.*, gene SOE (splicing by overlap extension) methods that commonly rely upon the use of fusion primers (which are optionally mutagenic) during PCR amplification. (Horton *et al.* 1989 *Gene* 77: 61-68; U.S. Patent No. 5,023,171).

Enzymatic amplification of DNA fragments by the so-called PCR technique (polymerase-catalysed Chain Reaction, Saiki R. K. *et al.*, *Science* 230 (1985) 1350-1354; Mullis K. B. and Faloona F. A., *Meth. Enzym.* 155 (1987) 335-350) can be carried out using a DNA thermal cycler (Perkin Elmer Cetus) according to the manufacturer's specifications.

Verification of the nucleotide sequences can be carried out by the method developed by Sanger *et al.*, (*Proc. Natl. Acad. Sci. USA*, 74 (1977): 5463-5467) using the kit distributed by Amersham. Verification of whether a homologous recombination event has occurred between two homologous polypeptides that were and likely still are contained within a single vector of the present invention may be performed by any art-recognized method, including but not limited to, Northern blot and/or RT-PCR methods (*e.g.*, if assessed directly within isolated retroviral genomes), Southern blot and/or PCR methods (*e.g.*, if assessed upon host cell genomic DNAs comprising integrated retroviral vectors), and SDS-PAGE followed by Western blot and/or immunoprecipitation followed by SDS-PAGE and detection of labeled polypeptides (*e.g.*, if homologous polypeptides are of discernible sizes and/or contain distinguishable domains, features and/or epitopes).

#### Example 1

Use of the present invention to develop "designer T cells" initially involved the use of two nine-mer immunodominant CTL epitopes derived from JCV VP1 proteins (termed p36 and p100) in HLA-A0201<sup>+</sup> subjects to expand JCV-specific T



cells from an HLA-A0201<sup>+</sup> PML survivor. Following this expansion of JCV-specific T cells, cell sorting was performed to identify and isolate p36 or p100/HLA-A0201 tetramer-positive cells. Two cell populations, one specific to p36 and another specific to p100, were subjected to TCR cloning. Two distinct dominant alpha ( $\alpha$ ) chains (Va6 and Va12) and a unique beta ( $\beta$ ) chain (Vb5.1) were cloned from the p36-specific cell line, while only one alpha (Va8.6) and one beta (Vb2) chain were dominant in the p100-specific line. DNA constructs encoding chimeric immune receptors (CIRs) were created comprising the extracellular domains of TCR alpha and beta chains fused to the transmembrane and cytoplasmic portions of CD3zeta (these CIRs were designated VaCaCD3z or VbCbCD3z, respectively). Recombinant retroviruses encoding each of the CIRs were then constructed. Each pair of alpha and beta chains in CIR format (two pairs for p36 due to two alpha chains and one pair for p100) were subjected to cellular expression and screened for specific binding of the peptide-HLA-A0201 tetramer. This screening confirmed the reactivity of the p100 TCRAb and of one of the two pairs of p36 TCRAb(Va12 and Vb5.1). Having established the successful isolation and expression of JCV-specific TCRs, functional tests of the CIRs in human T cells were performed, including assessment of T cell activation, cytokine expression and cytotoxic potency on contact with JCV antigen positive target cells. (Yang *et al.* 2005 *J. Neuro Virology* 11(Suppl. 2): 124).

Retroviral vectors encoding these anti-JCV CIRs (see Figure 25, diagrams 1-3 (Tctv-anti-JCV p36Z CIR, Tcsv-anti-JCV p36Z CIR and Tcsv-anti JCV p3628Z CIR)), were then also constructed for purpose of testing two chain two vector (Tctv) and two chain single vector (Tcsv) approaches. Such retroviral vectors were constructed using art-recognized methods for synthesis of nucleic acid sequences encoding fusion proteins. However, in the Tcsv approach, one or both nucleic acid sequences encoding the cytoplasmic CD3 $\zeta$  domain common to and encoding an identical polypeptide within both anti-JCV p36Z CIR and anti JCV p3628Z CIR nucleic acid sequences were subjected to mutagenesis using degenerate codon usage, for purpose of reducing the nucleic acid sequence identity of this domain between the two CIRs of the single vector. Human T cells containing the Tctv CIRs and Tcsv CIRs were then tested for expression of such CIRs in mammalian cells.

## Example 2

It was demonstrated that CIR-T cells can mediate antiviral activity against HIV-1 in cells that are resistant to class I-restricted CTL-mediated activity.

- 5 Furthermore, CIR-T cells can suppress virus in multiple cell types, including monocytes, dendritic cells, and lymphocyte-dendritic cell clusters. These results showed that T cells can be redirected against novel targets, and that independence from the class I pathway can have distinct advantages. (See Ma *et al*, 2002, for review.)

10

## Example 3

- Construction of vectors containing CIR nucleic acid sequences involved the mutation of a number of genes, with such mutations performed in order to exploit the degeneracy of the genetic code, thereby reducing homologous recombination in
- 15 vectors that contain two or more CIR molecules encoding for highly homologous polypeptide sequences (*e.g.*, highly homologous proteins and/or polypeptide domains within CIR polypeptide sequences). Genes that were altered at the nucleotide level include: CD3 $\zeta$  (refer to the exemplary mutated CD3 $\zeta$  nucleic acid sequence shown in Figure 1, which comprises a partial extracellular domain-TMD-
- 20 intracellular domain sequence of mutated CD3 $\zeta$ ); CD28 (refer to the exemplary mutated CD28CD3 $\zeta$  nucleic acid sequence shown in Figure 3, which comprises a partial extracellular domain-TMD-intracellular domain sequence of mutated CD28 and an intracellular (cytoplasmic) domain of mutated CD3 $\zeta$ ); and Fc $\epsilon$ RI $\gamma$  (refer to the exemplary mutated hFc $\epsilon$ RI $\gamma$  nucleic acid sequence shown in Figure 5, which
- 25 comprises a partial extracellular domain-TMD-intracellular domain sequence of mutated human Fc $\epsilon$ RI $\gamma$ ). The preceding mutated sequences were used to produce the retroviral vector constructs shown in Figures 7-10. Construction of these vectors was performed by art-recognized methods of vector and/or fusion protein construction.

30

## Example 4

Vectors containing CIR nucleic acid sequences are also constructed to include human CD4, anti-CEA sFv and anti-PSMA sFv sequences. Mutated nucleic acid sequences that encode the signal peptide and extracellular domain polypeptides of human CD4 were generated (refer to Figure 21). Mutated forms of anti-CEA sFv and anti-PSMA sFv sequences are readily constructed by applying the methods of degenerate codon usage described *infra* to the sequences of anti-CEA sFv (Nolan *et al.* 1999 *Clin Cancer Res.* 5: 3928-41) and anti-PSMA sFv (Ma *et al.* 2004 *Prostate* 6: 12-25). Mutated sequences of human CD4, anti-CEA sFv, and anti-PSMA sFv are used in combination with non-mutated forms of such sequences to synthesize retroviral vectors containing both mutated and non-mutated forms of such sequences (*e.g.*, one such viral vector construct is schematically depicted in Figure 11). Construction of such vectors is performed using art-recognized methods of vector and/or fusion protein construction.

## 15 Example 5

To perform immunotherapy using designer T cells that contain anti-JCV p36 and anti-JCV p100 CIR molecules, the following procedures can be implemented. First, mutated CD28Z-MFG based anti-JCV TCRCIR vectors are created that contain either alpha and beta chains of an anti-JCV p36 antibody or alpha and beta chains of an anti-JCV p100 antibody. For anti-JCV p36, the vector VaCaCD28Z-IRES-VbCbmuCD28Z-MFG (henceforth referred to as "tcp36muCD28Z") is generated, while for anti-JCV p100, the vector VaCaCD28Z-IRES-VbCbmuCD28Z-MFG (henceforth referred to as "tcp100muCD28Z") is made. Both vectors are constructed using art-recognized methods of vector and/or fusion protein construction. Second, Phoenix cells (a 293 cell derivative line with high calcium phosphate transfection efficiency; mix of amphi and ecto) are transfected with either the tcp36muCD28Z or tcp100muCD28Z vector. Third, PG13 cells (viral producing cells; VPCs) are infected with viral supernatants (containing viral virions) of the transfected Phoenix cells. Fourth, Jurkat T cells are transduced with viral supernatants of the cultured PG13 cells that have been infected with virus encoding either the tcp36muCD28Z or the tcp100muCD28Z CIR polypeptide. Fifth,

transduced Jurkat T cells are subjected to FACS-based sorting to identify TCRVb5<sup>+</sup> (for tcp36muCD28Z) or TCRVb2<sup>+</sup> (for tcp100muCD28Z) cells that also bind specific PE-labeled anti-human TCRVb antibodies (native Jurkat cells are negative for both TCRVb2 and Vb5). Sixth, possible viral recombination events are evaluated by generating (from sorted cells) and then selecting 15-20 Jurkat T cell clones that are TCRVb5.1<sup>+</sup> (for tcp36muCD28Z-transduced) or TCRVb2<sup>+</sup> (for tcp100muCD28Z-transduced), isolating genomic DNAs from such T cell clones, and subjecting these genomic DNAs to amplification as PCR templates using specific primers designed to match sequences immediately upstream of the VaCaCD28Z and immediately downstream of VbCbmuCD28Z, respectively. Changes in amplification product sizes derived from individual clones will reflect the occurrence of any recombination events, while the absence of such alterations will verify that no such events have occurred.

Once Jurkat T cell clones that are TCRVb5.1<sup>+</sup> (for tcp36muCD28Z-transduced) or TCRVb2<sup>+</sup> (for tcp100muCD28Z-transduced) are generated, isolated and verified in the above manner, such cells are optionally subjected to tests for binding function and/or activity in inducing cytokine secretion. An exemplary binding assay for such Jurkat T cells is a tetramer binding assay in which the Jurkat cells are stained with PE-p36/HLA-A0201 tetramer or PE-p100/HLA-A0201 tetramer, then subjected to FACS analysis to determine whether the labeled p36 or p100 antigen-containing tetramer has bound. Additionally and/or alternatively, such Jurkat cells can be subjected to an exemplary cytokine secretion assay to identify those cells expressing functionally active CIRs, with such assays involving co-culture of the TCRVb5.1<sup>+</sup> (for tcp36muCD28Z-transduced) or TCRVb2<sup>+</sup> (for tcp100muCD28Z-transduced) Jurkat cells with HLA-A0201<sup>+</sup> B cells in the presence of peptide (antigen) p36 or p100. Jurkat cells expressing functional CIR molecules can then be identified by assessing the cultured supernatant for IL-2 or IFN $\gamma$  cytokines.

Finally, once CIR-positive cells are identified that have not undergone recombination events between the nucleic acid sequences encoding highly homologous CIR polypeptides, human PBMC cells are transduced with viral supernatant from PG13 cells that contain either tcp36muCD28Z or

tcp100muCD28Z. Transduced human (PBMC) T cells are then tested for their *in vivo* function as an effective immunotherapy capable of, *e.g.*, killing target cells, inducing cytokine secretion and proliferation upon antigen stimulation, reducing JCV titer in a subject, reducing morbidity and/or mortality in a JCV-infected subject,  
 5 etc.

#### Example 6

The approach described in Example 5 is readily applied to achieve gene therapy and/or immunotherapy of a number of diseases and/or disorders. For  
 10 example, immunotherapy for infectious disease or cancer that uses retrovirally-transduced T cells that express antigen-specific CIRs can be employed with the following exemplary CIR-containing vector constructs:

anti-JCV TCRVaCaCD28CD3Z–IRES–anti-JCV  
 TCRVbCbmuCD28muCD3Z (refer to Figure 7);  
 15 anti-JCV TCRVaCaCD3Z–IRES–anti-JCV TCRVbCbmuCD3Z (refer to Figure 8);  
 anti-JCV TCRVaCaFC(e)RI $\gamma$  –IRES–anti-JCV TCRVbCbmuFC(e)RI $\gamma$   
 (refer to Figure 9);  
 anti-CEA sFV-CD28CD3Z –IRES–anti-PSMA sFV-muCD28muCD3Z  
 20 (refer to Figure 10); and  
 anti-CEA sFV-CD3Z–IRES–mu anti-CEA sFV-CD28 (refer to Figure 11).

#### Example 7 Retroviral Vectors Encoding Anti-JC Virus Chimeric T Cell Receptors with Degenerate Codons

25 Progressive multifocal leukoencephalopathy (PML), is a rare and usually fatal viral disease that is characterized by progressive damage or inflammation of the white matter of the brain at multiple locations. It occurs almost exclusively in people with severe immune deficiency, *e.g.* transplant patients on immunosuppressive medications, or AIDS patients.

30 The cause of PML is a type of polyomavirus called the JC virus (JCV), after the initials of the patient in whom it was first discovered. The virus is widespread,

with 86% of the general population presenting antibodies, but it usually remains latent, causing disease only when the immune system has been severely weakened.

The immune response to JCV could be humoral. 90% adults have anti-JCV IgG but the humoral immune response is unable to prevent PML.

5 The cellular immune response is mediated by CD8+ T cells. The presence of JCV-specific CTL is associated with long-term survival in HIV+/PML patients.

Two JCV VP1 derived nonamer peptides (P36 and P100) have been shown to be immunodominant.

Described herein is the creation of anti-JC virus (JCV) chimeric T cell  
10 receptors (cTCRs) to redirect autologous T cells to recognize and lyse JCV infected cells for therapy in progressive multifocal leukoencephalopathy (PML), a demyelinating AIDS-associated brain disease. These cTCRs are engineered with JCV specific TCRA and TCRb chains, each fused to the transmembrane (TM) and cytoplasmic (cyt) domains of CD3zeta. Both chains are co-expressed in recipient T  
15 cells to create a functional TCR. As shown herein, co-expression of two partially homologous chimeric immune receptors (CIRs) in a retroviral vector (two chain single vector, tcsv) led to recombination-deletion between repeated sequences, excising the equivalent of one of the CIRs. Also shown herein is that cells could be transduced with separate chains in two vectors (called two chain two vector (tctv).  
20 This arrangement displayed poor cell co-expression due to low probability of co-transduction from two separate retroviral vectors. In an effort to improve co-transduction, a novel type of tcsv anti-JCV cTCR that would resist this deletion process was designed. To suppress the potential for homologous recombination in the tcsv format, mutagenesis was applied to create codon degeneracy to minimize  
25 sequence homology between the repeated CD3zeta domains while preserving the final protein sequence. This strategy showed co-expression of chains as expected. A redesign of the tcsv configuration is underway to allow a definitive measurement of the actual efficiency of the deletion suppression.

### 30 Conclusion

TcTv format results in low cell co-expression due to low probability of same cell transduction.

TcSv format enables same cell transduction and co-expression but requires engineering of degenerate nucleotides in repeated sequence to prevent homologous recombination and deletion.

Degenerate nucleotide TcSV format enables high-level coexpression.

5 Thus, provided herein is a new approach for T cell Therapy for PML, that is and anti-JCV “designer T cell” therapy, using ex vivo expansion of T cells transduced with anti-JCV TCRs.

The teachings of all patents, published applications and references cited herein are incorporated by reference in their entirety.

10 While this invention has been particularly shown and described with references to example embodiments thereof, it will be understood by those skilled in the art that various changes in form and details may be made therein without departing from the scope of the invention encompassed by the appended claims.

## CLAIMS

What is claimed is:

1. A retroviral vector comprising:
  - a first nucleic acid sequence that encodes a first polypeptide sequence
  - 5 and a second nucleic acid sequence that encodes a second polypeptide sequence, wherein:
    - (a) the first polypeptide sequence and the second polypeptide sequence comprise an identical polypeptide sequence of greater than 15 amino acids in length; and
    - 10 (b) the first nucleic acid sequence and the second nucleic acid sequence contain at least one non-identical codon within the codons that encode the identical polypeptide sequence of the first and second nucleic acid sequences.
  
- 15 2. A retroviral vector comprising:
  - a first nucleic acid sequence that encodes a first polypeptide sequence
  - and a second nucleic acid sequence that encodes a second polypeptide sequence, wherein:
    - (c) the first polypeptide sequence comprises a polypeptide sequence
    - 20 of greater than 15 amino acids in length that is greater than 90% identical to the second polypeptide sequence; and
    - (d) the first nucleic acid sequence and the second nucleic acid sequence contain at least one non-identical codon that encodes an
    - 25 identical amino acid residue, wherein the greater than 90% identical polypeptide sequence of the first and second nucleic acid sequences comprises the identical amino acid residue.
  
3. The retroviral vector of either of claims 1 or 2, wherein at least one of the first and second nucleic acid sequences is a synthetic sequence.



4. The retroviral vector of either of claims 1 or 2, wherein the homology between the first and the second nucleic acid sequences is insufficient to cause homologous recombination between the first and the second nucleic acid sequences in a cell.
- 5
5. The retroviral vector of claim 4, wherein the cell is a bacterial cell.
6. The retroviral vector of claim 4, wherein the cell is a host cell.
- 10 7. The retroviral vector of either of claims 1 or 2, wherein the first and second nucleic acid sequences encode non-viral polypeptide sequences.
8. The retroviral vector of either of claims 1 or 2, wherein the first and second nucleic acid sequences encode mammalian polypeptide sequences.
- 15
9. The retroviral vector of either of claims 1 or 2, wherein the first and second nucleic acid sequences encode human polypeptide sequences.
10. The retroviral vector of claim 1, wherein the retroviral vector is selected
- 20 from the group consisting of avian sarcoma-leukosis virus (ASLV), murine leukemia virus (MLV), human-, simian-, feline-, and bovine immunodeficiency viruses (HIV, SIV, FIV, BIV), equine infectious anaemia virus (EIAV), mouse mammary tumour virus (MMTV), Rous sarcoma virus (RSV), Fujinami sarcoma virus (FuSV), Moloney murine leukemia virus (Mo-MLV), MFG, FBR murine osteosarcoma virus
- 25 (FBR MSV), Moloney murine sarcoma virus (Mo-MSV), Abelson murine leukemia virus (A-MLV), Avian myelocytomatosis virus-29 (MC29), Avian erythroblastosis virus (AEV), AKR (endogenous) murine leukemia virus, Avian carcinoma, Mill Hill virus 2, Avian leukosis virus--RSA, Avian myeloblastosis virus, Avian
- myelocytomatosis virus 29, Bovine syncytial virus, Caprine arthritis encephalitis
- 30 virus, Chick syncytial virus, Equine infectious anemia virus, Feline leukemia virus, Feline syncytial virus, Finkel-Biskis-Jinkins murine sarcoma virus, Friend murine leukemia virus, Fujinami sarcoma virus, Gardner-Arnstein feline sarcoma virus,

Gibbon ape leukemia virus, Guinea pig type C oncovirus, Hardy-Auckerman feline sarcoma virus, Harvey murine sarcoma virus, Human foamy virus, Human spumavirus, Human T-lymphotropic virus 1, Human T-lymphotropic virus 2, Jaagsiekte virus, Kirsten murine sarcoma virus, Langur virus, Mason-Pfizer monkey virus, Mouse mammary tumor virus, Ovine pulmonary adenocarcinoma virus, Porcine type C oncovirus, Reticuloendotheliosis virus, Rous sarcoma virus, Simian foamy virus, Simian sarcoma virus, Simian T-lymphotropic virus, Simian type D virus 1, Snyder-Theilen feline sarcoma virus, Squirrel monkey retrovirus, Trager duck spleen necrosis virus, UR2 sarcoma virus, Viper retrovirus, Visna/maedi virus, Woolly monkey sarcoma virus, and Y73 sarcoma virus.

11. The retroviral vector of either of claims 1 or 2, wherein at least 20% of the codons that encode the at least one identical polypeptide domain of the first and second nucleic acid sequences are non-identical.

15

12. The retroviral vector of either of claims 1 or 2, wherein the first nucleic acid sequence and the second nucleic acid sequence are less than 80% identical within the codons that encode the at least one identical polypeptide domain of the first and second nucleic acid sequences.

20

13. The retroviral vector of either of claims 1 or 2, wherein at least one of the first and second polypeptide sequences is a chimeric immune receptor polypeptide sequence.

25 14. The retroviral vector of claim 13, wherein at least one of the first and second polypeptide sequences is a chimeric immune receptor polypeptide sequence comprising a signal sequence that directs the polypeptide to the cell surface.

30 15. The retroviral vector of claim 14, wherein the signal sequence that directs the polypeptide to the cell surface is selected from the group consisting of TCR- $\alpha$ , TCR- $\beta$ , TCR- $\gamma$ , TCR- $\delta$ , IgG, IgA, IgM, IgE, IgD, CD2, CD4, CD8, CD28, CD3 $\zeta$ , Fc $\epsilon$ RI $\gamma$ , and LFA-1.

16. The retroviral vector of claim 13, wherein at least one of the first and second polypeptide sequences is a chimeric immune receptor polypeptide sequence comprising an extracellular binding domain selected from the group consisting of a surface membrane polypeptide that binds specifically to at least one ligand and a secreted polypeptide that binds specifically to at least one ligand.

17. The retroviral vector of claim 13, wherein at least one of the first and second polypeptide sequences is a chimeric immune receptor polypeptide sequence comprising a transmembrane domain selected from the group consisting of TCR- $\alpha$ , TCR- $\beta$ , TCR- $\gamma$ , TCR- $\delta$ , IgG, IgA, IgM, IgE, IgD, CD2, CD4, CD8, CD28, CD3 $\zeta$ , Fc $\epsilon$ R1 $\gamma$ , and LFA-1.

18. The retroviral vector of claim 13, wherein at least one of the first and second polypeptide sequences is a chimeric immune receptor polypeptide sequence comprising an intracellular cytoplasmic domain selected from the group consisting of a CD3 $\zeta$  cytoplasmic domain or a functional fragment thereof, a CD28 cytoplasmic domain or a functional fragment thereof, a polypeptide that combines CD28 and CD3 $\zeta$  polypeptide sequences or a functional fragment thereof, and an Fc $\epsilon$ R1 $\gamma$  cytoplasmic domain or a functional fragment thereof.

19. The retroviral vector of claim 14, wherein at least one of the first and second polypeptide sequences is a chimeric immune receptor polypeptide sequence comprising:

- 25 (a) a signal sequence which directs the polypeptide to the cell surface;
- (b) an extracellular binding domain selected from the group consisting of a surface membrane polypeptide that binds specifically to at least one ligand and a secreted polypeptide that binds specifically to at least one ligand;
- 30 (c) a transmembrane domain; and

- (d) an intracellular cytoplasmic domain selected from the group consisting of a CD3 $\zeta$  cytoplasmic domain or a functional fragment thereof, a CD28 cytoplasmic domain or a functional fragment thereof, a polypeptide that combines CD28 and CD3 $\zeta$  polypeptide sequences or a functional fragment thereof, a CD2 cytoplasmic domain or a functional fragment thereof, a LFA-1 polypeptide sequence or a functional fragment thereof, and an Fc $\epsilon$ RI $\gamma$  cytoplasmic domain or a functional fragment thereof.
- 5
- 10 20. The retroviral vector of either of claims 1 or 2 comprising a mutant nucleic acid sequence selected from the group consisting of the mutant sequence shown in Figure 2, the mutant sequence shown in Figure 4, the mutant sequence shown in Figure 6, the mutant sequence shown in Figure 16, the mutant sequence shown in Figure 19, the mutant sequence shown in Figure 21, and the mutant sequence shown in Figure 22.
- 15
21. The retroviral vector of either of claims 1 or 2, wherein one of the first and second nucleic acid sequences is selected from the group consisting of the mutant sequence shown in Figure 2, the mutant sequence shown in Figure 4, the mutant sequence shown in Figure 6, the mutant sequence shown in Figure 16, the mutant sequence shown in Figure 19, the mutant sequence shown in Figure 21, and the mutant sequence shown in Figure 22, or a functional fragment thereof.
- 20
22. A recombinant virus comprising the retroviral vector of either of claims 1 or 2.
- 25
23. A cell comprising the retroviral vector of either of claims 1 or 2.
24. The retroviral vector of Claim 1 wherein:

- 5
- (a) the first polypeptide sequence and the second polypeptide sequence each comprises an identical single chain antibody polypeptide sequence or functional fragment thereof; and
  - (b) the first nucleic acid sequence and the second nucleic acid sequence contain at least one non-identical codon within the codons that encode the identical single chain antibody polypeptide sequence or functional fragment thereof of the first and second nucleic acid sequences.

10 25. The retroviral vector of Claim 1 wherein:

- (a) the first polypeptide sequence and the second polypeptide sequence each comprises an identical polypeptide sequence comprising a target-binding domain or functional fragment thereof; and
- 15 (b) the first nucleic acid sequence and the second nucleic acid sequence contain at least one non-identical codon within the codons that encode the identical target-binding domain or functional fragment thereof of the first and second nucleic acid sequences.

20

26. A method for inhibiting growth of a tumor in a subject comprising administering a virus comprising the retroviral vector of either of claims 1 or 2 to the subject, thereby inhibiting the growth of the tumor.

25 27. A method for reducing the size of a tumor in a subject comprising administering a virus comprising the retroviral vector of either of claims 1 or 2 to the subject, thereby reducing the size of the tumor.

28. A method for inhibiting the proliferation of an infectious agent in a subject  
30 comprising administering a virus comprising the retroviral vector of claim 1 to the subject, thereby inhibiting proliferation of the infectious agent.

29. The method of claim 28, wherein the infectious agent is selected from the group consisting of polyomavirus JC (JCV), HIV, HBV, HCV, CMV, and EBV.

30. A method for killing a virus-infected cell of a subject comprising  
5 administering a virus comprising the retroviral vector of either of claims 1 or 2 to the subject, thereby killing the virus-infected cell of the subject.

31. The method of claim 30, wherein the infectious agent is selected from the group consisting of polyomavirus JC (JCV), HIV, HBV, HCV, CMV, and EBV.

10

32. A method for treatment of a tumor or infectious disease in a subject comprising transforming lymphocyte cells with the retroviral vector of claim 1, wherein the extracellular binding domain is a scFv domain of an antibody directed against the tumor or infectious disease, and administering the transformed cells to  
15 the subject, wherein the transformed lymphocyte cells are targeted to the tumor cells or infectious disease, thereby treating the subject.

33. A method for generating a host cell that contains a viral vector comprising at least two non-viral nucleic acid sequences that encode at least one identical  
20 polypeptide sequence of greater than 15 amino acids in length comprising introducing the retroviral vector of claim 7 into a host cell, thereby generating the host cell.

34. A method for expressing in a subject at least two polypeptides that encode at  
25 least one identical polypeptide sequence of greater than 15 amino acids in length and are contained on a single viral vector comprising:

(a) introducing the retroviral vector of claim 7 into a host cell; and

(b) exposing the subject to virions of the host cell media,

thereby expressing the polypeptides in the subject.

30

35. A pharmaceutical composition comprising a recombinant retrovirus that contains a first nucleic acid sequence that encodes a first CIR polypeptide and a

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second nucleic acid sequence that encodes a second CIR polypeptide, wherein the first CIR polypeptide and second CIR polypeptide comprise at least one identical polypeptide sequence of greater than 15 amino acids in length and wherein the first nucleic acid sequence and the second nucleic acid sequence contain at least one non-  
5 identical codon within the codons that encode the at least one identical polypeptide sequence of the first and second nucleic acid sequences, and a pharmaceutically acceptable carrier.

36. A kit comprising a virus comprising the retroviral vector of either of claims 1  
10 or 2, and instructions for use.

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## FIG. 1

```

1   ttggatcctaagttatgttatttagacgggattttattatatatacgaggatgatat 60
    L D P K L C Y L L D G I L F I Y G V I L

61  acagcgctattttacgtgtcaaatttcacgctccgctgatgcccggcctatcaaaa 120
    T A L F L R V K F S R S A D A P A Y Q Q

121 gggcaaatcaattgtacaatgaattgaacttgggtcgtagagaagaatatgacgtactc 180
    G Q N Q L Y N E L N L G R R E E Y D V L

181 gataaacggggggcgatccagaaatgggcccgaaccacgggaaaaaatccacaaa 240
    D K R R G R D P E M G G K P R R K N P Q

241 gaggattataacgagttacaaaaggcaaaatgggcagaagcatattcagaaataggt 300
    E G L Y N E L Q K D K M A E A Y S E I G

301 atgaaaggggaaaggagacgagggaaagggtcatgacggattgtatcaaggattatcgacc 360
    M K G E R R R G K G H D G L Y Q G L S T

361 gcgactaaagatacgtatgatgcgttacacatgcaagcattaccgcccagaataa 414 (SEQ ID
NO:1)
    A T K D T Y D A L H M Q A L P P R * (SEQ ID
NO:2)

```



FIG. 2

Mutated partial CD3ζ	TTGGATCCTAAGTTATGTTATTATTAGACGGGATTTTATTATATACGG
Partial CD3ζ	CTGGATCCCAAACTCTGCTACCTGCTGGATGGAATCCCTTTCATCTATGG *****
Mutated partial CD3ζ	AGTGATATTACAGCGCTATTTTACGGTGTCAAATTTTCACGCTCCGCTG
Partial CD3ζ	TGTCATTTCTCACTGCCCTTGTTCCCTGAGAGTGAAGTTCAGCAGGAGCGCAG ** ** *
Mutated partial CD3ζ	ATCGCGCGCCTATCAACAAGGCAAAATCAATTGTACAAITGAATTGAAC
Partial CD3ζ	ACGCCCCCGCGTACCAGCAGGCGCCAGAACCAGCTCTATAACGAGCTCAAT * ** *
Mutated partial CD3ζ	TTGGGTCGTAGAGAAGAATATGACGTACTCGATAAACGGAGGGCGCGGA
Partial CD3ζ	CTAGGACGAAGAGAGGAGTACGATGTTTGGACAAGAGACCGTGGCCGGGA * ** *
Mutated partial CD3ζ	TCCAGAAATGGGCGGCAAAACCACGGCGGAAAAATCCACAAGAGGGATTAT
Partial CD3ζ	CCCTGAGATGGGGGAAAGCCGAGAAAGAAACCCTCAGGAAGGCCCTGT ** ** *
Mutated partial CD3ζ	ATAACGAGTTACAAAAGGACAAAATGCCAGAAGCATAATTCAGAAATAGGT
Partial CD3ζ	ACAATGAACTGCAGAAAGATAAGATGGCGGAGGCCCTACAGTGAGATTGGG * ** *

FIG. 2 (continued)

```

Mutated partial CD3ζ      ATGAAGGGGAAAGGAGACGAGGAAAGGTCATGACGGATTGTATCAAGG
Partial CD3ζ              ATGAAAGGGCGAGCCCGGAGGGCAAGGGCACGATGGCCTTTACCAGGG
***** ** ** * * * * * ** ** ** ** ** ** ** ** ** ** ** ** **
Mutated partial CD3ζ      ATTATCGACCGGACTAAAGATACGTATGATGCCGTTACACATGCAAGCAT
Partial CD3ζ              TCTCAGTACAGCCACCAAGGACACCTACGACGCCCTTCACATGCAGGCC
* ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** **
Mutated partial CD3ζ      TACCGCCAAGATAA (SEQ ID NO:1)
Partial CD3ζ              TGCCCCCTCGCTAA (SEQ ID NO:3)
* ** ** * * **
    
```

FIG. 3

```

1  cctaggaagatcgaggtaatgtacccaccgcccctatctcgataaacgaaaaagtaacggt 60
   P R K I E V M Y P P P Y L D N E K S N G
61  acaataattcacggttaaggaaagcatttatgcccttccccggttgttccccggaagc 120
   T I I H V K G K H L C P S P L F P G P S
    
```

FIG. 3 (continued)

121	aaaccgttctggggttctcgtagttgtaggcgggtggttagcatggttactctctccttggt	180
	K P F W V L V V V G G V L A C Y S L L V	
181	acagtagctttcataaatcttttgggtccgatcaaaaacgctctcgattgttacattccgat	240
	T V A F I I F W V R S K R S R L L H S D	
241	tatatgaatatgacaccgaggagacctggcccgcgaggaacactatcaaacggtacgca	300
	Y M N M T P R R P G P T R K H Y Q P Y A	
301	cctccgagagattttgctgctgctacaggagtcgtgtcaaattttcacgctccgctgatgcg	360
	P P R D F A A Y R S R V K F S R S A D A	
361	ccggcctatcaacaaggcacaatcaattgtacaatgaattgaacttgggtcgtagagaa	420
	P A Y Q Q G Q N Q L Y N E L N L G R R E	
421	gaatatgactctcgataaaacggaggggcgatccagaaatgggaggcaaacccacgg	480
	E Y D V L D K R R G R D P E M G G K P R	
481	cgaaaaatccacaaggaggattatataacgaggttacaagaagcaaaatggcagaagca	540
	R K N P Q E G L Y N E L Q K D K M A E A	
541	tattcagaaataggtatgaaggggaaaggagacgggaaagggtcatgacggattgtat	600
	Y S E I G M K G E R R R G K G H D G L Y	
601	caaggattatcgaccgcgactaaagatacgtatgatgcgttacacatgcaagcattaccg	660
	Q G L S T A T K D T Y D A L H M Q A L P	
661	ccaagataa (SEQ ID NO:4)	669
	P R * (SEQ ID NO:5)	

FIG. 4

Mutated CD28CD3ζ	CCTAGGAAGATCGAGGTAATGTACCCACCGCCCTATCTCGATAACGAAAA	50
CD28CD3ζ	CCTAGGAAAATTGAAGTTATGTATCCTCCTCCTACCTAGACAATGAGAA ***** ** ** ** **	
Mutated CD28CD3ζ	AAGTAACGGTACAATAATTACGTTAAGGAAAGCATTTATGCCCTTCCC	100
CD28CD3ζ	GAGCAATGGAACCATTTATCCATGTGAAAGGAAACACCTTTGTCCAAAGTC ** ** ** **	
Mutated CD28CD3ζ	CGTTGTTCCGGGCCAAGCAAACCGTTCGGTTCCTCGTAGTTGTAGGC	150
CD28CD3ζ	CCCTATTTCCCGGACCTTCTAAGCCCTTTTGGTGTGGTGGTGGTGGT * * * * *	
Mutated CD28CD3ζ	GGTGTGTAGCATGTTACTCTCTCCTTGTACAGTAGCTTTCATAATCTT	200
CD28CD3ζ	GGAGTCCITGGCTTGCTATAGCTTGTCTAGTAACAGTGGCCTTATATATTT ** ** * * * * *	
Mutated CD28CD3ζ	TTGGGTCGGATCAAAACGCTCTCGATTGTTACATTCGGATTATATGAATA	250
CD28CD3ζ	CTGGGTGAGGAGTAAGAGGAGCAGGCTCTGCACAGTGACTACATGAACA ***** * * * *	
Mutated CD28CD3ζ	TGACACCGAGGAGACCTGGCCCGACGAGGAAACACTATCAACCGTACGCA	300
CD28CD3ζ	TGACTCCCCCGCCCGCCCGCCACCCGCAAGCATTACCAGCCCTATGCC ***** * * * *	
Mutated CD28CD3ζ	CCTCCGAGAGATTTTGCTGCGGTACAGGAGTCGTCAAAATTTTCACCGCTC	350
CD28CD3ζ	CCACCACGCGACTTCGACGCCCTATCGCTCCAGAGTGAAGTTCAGCAGGAG ** ** * * * * *	

FIG. 4 (continued)

Mutated CD28CD3ζ 400  
CGCTGATGCCGCCCTATCAACAAGGGCAAAATCAATTGTACAATGAAT  
CD28CD3ζ CGCAGACGCCCCCGGTACCAGCAGGCCAGAACCCAGCTCTATAACGAGC  
\*\*\* \*\*

Mutated CD28CD3ζ 450  
CD28CD3ζ TGAAC TTGGGTCGTAGAGAAGAATATGACGTA CTGATAAACGGAGGGGG  
TCAATCTAGGACGAAGAGAGAGGAGTACGATGTTTGGACAAAGAGACGTTGGC  
\* \* \* \* \* \*\*

Mutated CD28CD3ζ 500  
CD28CD3ζ CGCGATCCAGAAATGGGCGGCAAAACCACGGCGAAATAATCCACAAGAGGG  
CGGACCCCTGAGATGGGGGAAAGCCGAGAAAGAAACCCCTCAGGAAGG  
\* \* \* \* \* \*\*

Mutated CD28CD3ζ 550  
CD28CD3ζ ATTATATAACGAGTTACAATAAGGACAAAATGCGCAGAGCATATTCAGAAA  
CCTGTACAATGAACTGCAGAAAGATAAGATGGCGGAGGCCCTACAGTGAGA  
\* \* \* \* \* \*\*

Mutated CD28CD3ζ 600  
CD28CD3ζ TAGGTATGAAAGGGGAAAGGAGACGAGGAAAGTCA TGACGGATTGTAT  
TTGGGATGAAAGGCGAGCGCCGGAGGGCAAGGGCCAGATGGCCTTTAC  
\* \* \* \* \* \*\* \*\* \*\* \*\* \*\* \* \* \* \* \* \*\* \*\* \*\* \* \* \* \* \* \*\* \*\* \* \* \* \* \*

Mutated CD28CD3ζ 650  
CD28CD3ζ CAAGGATTATCGACCGGACTAAGATA CGTATGATCGGTACACATGCA  
CAGGGTCTCAGTACAGCCACC AAGGACACCCTACGACGCCCTTCACATGCA  
\*\* \*\* \* \* \* \* \* \* \*\* \*\* \* \* \* \* \* \*\* \*\* \* \* \* \* \*

Mutated CD28CD3ζ 669  
CD28CD3ζ AGCAATTACCGCCAAGATAA (SEQ ID NO: 4)  
GGCCCTGCCCCCTCGCTAA (SEQ ID NO: 6)  
\*\* \* \* \* \* \* \*\*

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## FIG. 5

```

1   cctcaattatggttacatatattagacgcgattttattctttatacgggacggttttaacatta   60
   P Q L C Y I L D A I L F L Y G I V L T L
61  ttatatgcccgtttaaaaaattcaggttcggaaagccgcatcacttcatacgaaaaagagc   120
   L Y C R L K I Q V R K A A I T S Y E K S
121 gacggcgtgtatcacaggtttatcaaacacgaaatcaagaaacgtatgaaacctttaaaccac   180
   D G V Y T G L S T R N Q E T Y E T L K H
181 gaaaagccccctcaatag (SEQ ID NO:7)
   E K P P Q * (SEQ ID NO:8)

```

FIG. 6

```

Mutated hFcεRIγ
hFcεRIγ M33195.1
-----
CAGAACGGCCGATCTCCAGCCCAAGATGATTCAGCAGTGGTCTTGCTCTTACTCCTTTT
-----
Mutated hFcεRIγ
hFcεRIγ M33195.1
-----CCTCAATATGTTACATATTAGACGGGATTTT
***** * * * * * * * * * * * * * * * *
Mutated hFcεRIγ
hFcεRIγ M33195.1
ATTCTTATACGGGATCGTTTAAACATTATATATTGCCGTTTAAAAAATTCAGGTTCCGGAA
GTTTCTGTATGGAATTGTCTCACCCCTCCTCTACTGTCTGACTGAAGATCCAAGTGCCGAAA
** * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
Mutated hFcεRIγ
hFcεRIγ M33195.1
AGCCCGGATCACTTCATACGAAAAGAGCGGCGGTGTATACAGGTTTATCAACACGAAA
GGCAGCTATAACCAGCTATGAGAAATCAGATGGTGTTTACACGGGCTGAGCACCCAGGAA
** * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
Mutated hFcεRIγ
(SEQ ID NO: 7)
TCAAGAAACGTATGAAACCTTAAACACGAAAAGCCCCCTCAATAG-----
hFcεRIγ M33195.1
CCAGGAGACTTACGAGACTCTGAAGCATGAGAAAACCCACACAGTAGCTTTAGAAATAGATG
** * * * * * * * * * * * * * * * * * * * * * * * * * * * * *

```

FIG. 7

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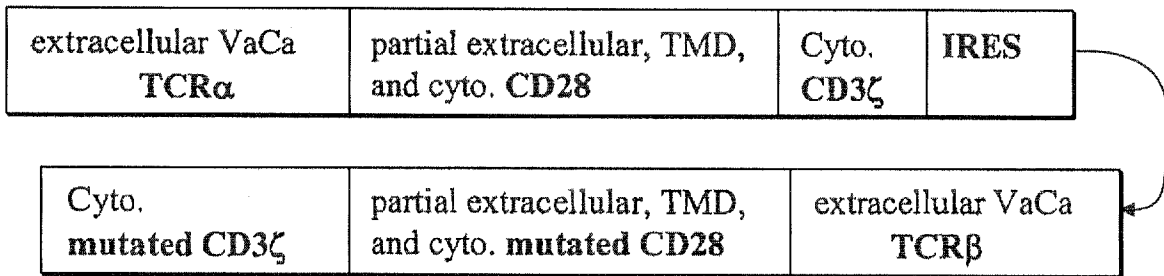


FIG. 8

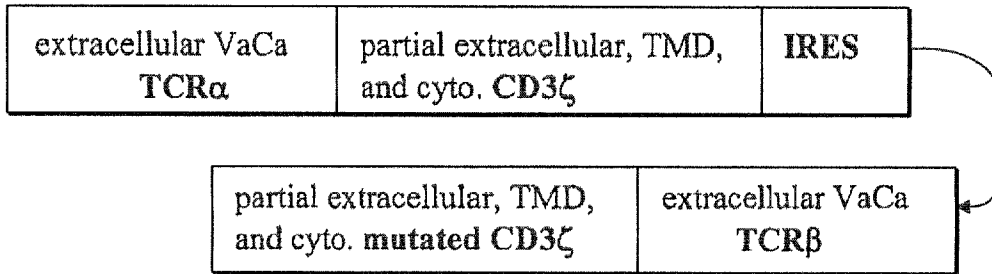


FIG. 9

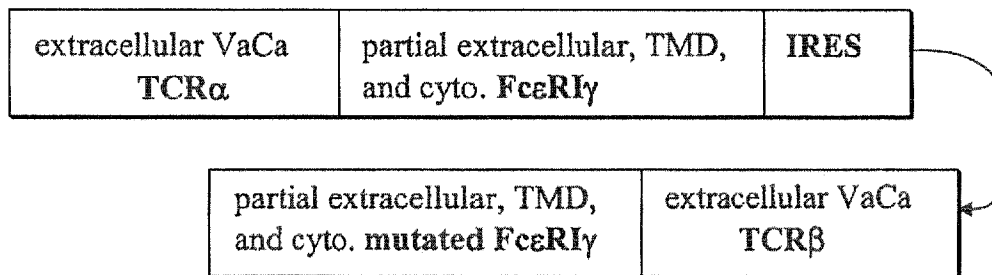


FIG. 10

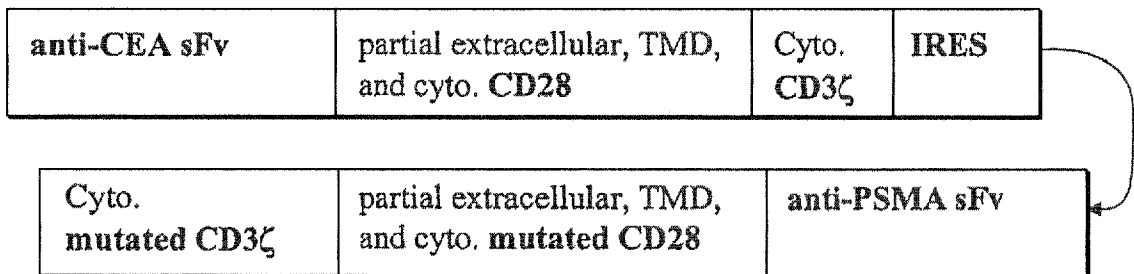


FIG. 11

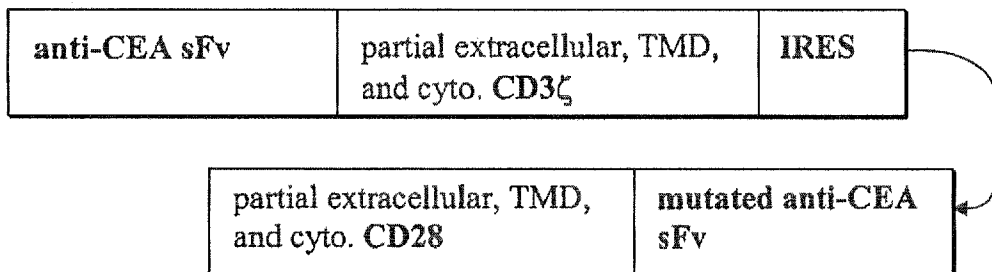




FIG. 12

Anti-p36 TCR $\alpha$  sequence -GGGATCTGGATCCCAAACCTGCTACCTGCTGGATGGATCCCTCTTC  
ATCTATGGTGTCAATCTCACTGCCCTTGTCTCCTGAGAGTGAAGTTCAGCAGGAGCGCAGACGCCCCCGGTACCAG  
CAGGCCAGAACCAGCTCTATAACGAGCTCAATCTAGGACGAAGAGAGGATCGATGTTTGGACAAGAGACGCT  
GGCCGGACCCCTGAGATGGGGGAAGCCGGAGAAGAAACCTCAGGAAGCCCTGTACAATGAATGCAAGAAA  
GATAAGATGGCGGAGCCCTACAGTGAGATTGGGATGAAAGGCCGAGCCGGAGGGCAAGGGCCACGATGGCCCTT  
TACCAGGGTCTCAGTACAGCCACCAAGGACACCTACGACGCCCTTCACATGCAGGCCCTGCCCCCTCGCTAA  
 (SEQ ID NO:10)

FIG. 14

Anti-p36 TCR $\beta$  sequence -GGGATCTGGATCCCAAACCTGCTACCTGCTGGATGGATCCCTCTTCATCTAT  
 GGTGTCAATCTCACTGCCCTTGTCTCCTGAGAGTGAAGTTCAGCAGGAGCGCAGACGCCCCCGGTACCAGCGGCCAGAAC  
 CAGCTCTATAACGAGCTCAATCTAGGACGAAGAGAGGATACGATGTTTGGACAAGAGACGTTGGCCGGGACCCCTGAGATG  
 GGGGAAAGCCGAGAAAGGAACCCCTCAGGAAGCCCTGTACAATGAATGCAGAAAGATTAAGATGGCGGAGGCCCTACAGT  
 GAGATTGGGATGAAAGCCGAGCCCGGAGGGCAAGGGCCACGATGGCCCTTACCAGGGTCTCAGTACAGCCACCAAGGAC  
 ACCTACGACGCCCTTCACATGCAGGCCCTGCCCCCTCGCTAA  
 (SEQ ID NO:13)

FIG. 13

-----Anti-p36 TCRα sequence-----  
-----amino acids encoded by anti-p36 TCRα sequence-----

ggggatctggatccc[aaactctgctacctgctggatgggaatcctctcatctatggt](#)  
G D L D P K L C Y L L D G I L F I Y G *TM of CD3ζ*

gtcattctactgccttgttcctgagagtgaaagttcagcaggagcgcagacgccccccgcg  
V I L T A L F L R V K F S R S A D A P A

taccaggggcccagaaccagctctataacgagctcaatctaggacgaagagaggtac  
Y Q Q G Q N Q L Y N E L N L G R R E E Y

gatgtttggacaagagacgtggccggaccctgagatgggggaaagccgagaaggaag  
D V L D K R R G R D P E M G G K P R R K

aaccctcaggaaggcctgtacaatgaactgcagaagataagatggcggagccctacagt  
N P Q E G L Y N E L Q K D K M A E A Y S

gagattgggatgaaaggcgagcggagggggcaaggggcacgatggcctttaccagggt  
E I G M K G E R R R G K G H D G L Y Q G

ctcagtacagccaaaggacacctacgacgccccttcacatgcaggccctgccccctcgc  
L S T A T K D T Y D A L H M Q A L P P R

taa (SEQ ID NO:11)  
\* (SEQ ID NO:12)

FIG. 15

-----Anti-p36 TCRβ sequence-ggggatctggatcccaaaactctgctac  
 -Anti-p36 TCRβ encoded amino acids--G D L D P K L C Y  
 ctgctggatggaatcctcttcatctatggtgtcattctcactgccttcttctcctgagagtg  
 L L D G I L F I Y G V I L T A L F L R V  
 aagttcagcaggagcagacgccccgcgtaccagcaggccagaaaccagctctataac  
 K F S R S A E P P A Y Q Q G Q N Q L Y N  
 gagctcaatctaggacgaagagaggtagtactgatgttttgacaagagacgtggccgggac  
 E L N L G R R E E Y D V L D K R R G R D  
 cctgagatgggggaaagccgagaaagaaaccctcaggaaggcctgtacaatgaactg  
 P E M G G K P R R K N P Q E G L Y N E L  
 cagaagataagatggcggaggccctacagtgagattgggatgaaaggcggcgggagg  
 Q K D K M A E A Y S E I G M K G E R R R  
 ggcaagggcagatggcctttaccagggtctcagttacagccaccaaggacacctacgac  
 G K G H D G L Y Q G L S T A T K D T Y D  
 cccttcacatgcaggccctgccccctcgctaa (SEQ ID NO:14)  
 A L H M Q A L P P R \* (SEQ ID NO:15)

FIG. 16

Anti-p36 TCRβ sequence-GGGGATCTGGATCCTAAGTTATGTTATTTATTATAGACGGGATTTTATT  
 TATATACGGAGTGATATTAACAGCGCTATTTTACGGTGTCAAAATTTTCACGCTCCGCTGATGCGCCGCCCTATCAACAAGGGCAAAA  
 TCAATTGTACAATGAATTGAACTTGGTCTGTAGAGAAGAATATGACGTACTCGATAAACGGAGGGGGCCGATCCAGAAATGGGCGG  
 CAACCACGGCGAAATAATCCACAAGAGGGATATATAACGAGTTACAATAAGGACAAAATGGCAGAAGCATATTCAGAAATAGGTAT  
 GAAGGGGAAAGGACGAGCGGAAAGGTCATGACGGGATTTGTATCAAGGATTAATCGACCCGGACTAAAGATACGTTATGATGCGGTTACA  
 CATGCAAGCATTACCGCCCAAGATAA (SEQ ID NO:16)

FIG. 17

Anti-p36 TCR $\alpha$  sequence - CCTAGGAAATTTGAAGTTATGTAATCCTCCTCCTTAGACAATGAGAAAGAGC  
 AATGGAAACCATTTATCCATGTGAAAGGAAACAACCTTTGTCCAAAGTCCCTATAFTTCCCGGACCTTCTAAGCCCTTTTGGGTG  
 CTGGTGGTGGTGGAGTCCCTGGCTTGCCTATAGCTTGGCTAGTAACAGTGGCCTTTATATTATTTCTGGGTGAGGAGTAAAG  
 AGGAGCAGGCTCCTGTCACAGTGAATACATGAACATGACTCCCGCCCGGGCCCAACCCGCAAGCATTACCAGCCCTAT  
 GCCCCACCAACCGGACTTTCGCAGCCCTATCGCTCCAGAGTGAAGTTACAGCAGGAGCCAGACGCCCCCGGCTACCAGCAGGGC  
 CAGAACCAGCTCTATAACGAGCTCAATCTAGGACGAAGAGAGGAGTACGATGTTTGGACAAGAGACGCTGGCCGGGACCCCT  
 GAGATGGGGGAAAGCCGAGAGGAAGAACCTTCAGGAAGCCCTGTACAAATGAACCTGCAGAAAGATAAGATGGCGGAGGCC  
 TACAGTGAGATTGGGATGAAGGGGAGCCCGGAGGGCAAGGGCCATGGCCCTTACCAGGGTCTCAGTACAGCCACC  
 AAGGACACCTACGACGCCCTTCACATGCGAGGCCCTGCCCTCGCTAA (SEQ ID NO:17)

FIG. 19

Anti-p36 TCR $\beta$  sequence - CCTAGGAAAGATCGAGGTAATGTACCCACCCGCCCTATCTCGATAAACGA  
 AAAAAGTAACGGTACAATAATTCACGTTAAGGAAAGCATTTATGCCCTTCCCGTGTTCCTCCGGGCCCA  
 AGCAAACCGTGTTCGTAGTTGTAGGCGGTGTGTAGCATGTACTCTCTCCTTGTACAGTAG  
 CTTTCAATACTTTGGTCCGATCAAAACCGCTCTCGATTGTTACATTCGGATTATATGAATATGACACC  
 GAGGACCTGGCCCGACGAGGAAACACTATCAACCCTACGCCACCTCCGAGAGATTTGCTGCGTACAGG  
 AGTCGTGTCAAATTTTCAACGCTCCGCTGATGCCCGCCCTATCAACAAGGGCAAATACTAATGTACAATG  
 AATTGAACTTGGTCTGTAGAGAAATAATGACGTACTCCGATAAACGGAGGGCGCGATCCAGAAATGGG  
 CGGCAAACCAACGGGAAATAATCCACAAGAGGGAATTATAACGAGTTACAAAAGGACAAAATGGCAGAA  
 GCATATTCAGAAATAGGATGAAGGGGAAAGGAGACGAGGAAAGGTGATGACGGATTGTAATCAAGGAT  
 TATCGACCGGACTAAAGATACGTTATGATGCGTTACACATGCAAGCATTACCGCCAAGATAA (SEQ ID NO:20)

FIG. 18

-----Anti-p36 TCRα sequence-----  
 -----amino acids encoded by anti-p36 TCRα sequence-----  
 cctaggaattgaagttatgtatcctcctcctacatgacaatgagaagagcaatgga  
 P R K I E V M Y P P P Y L D N E K S N G  
 accattatccatgtgaaagggaaacaccttgtccaagtccccatttccccggacctct  
 T I I H V K G K H L C P S P L F P G P S CD/TM/CY of CD28  
 aagccctttgggtgctgggtgggtgggtgagtcctggcttgctatagcttgctagta  
 K P F W V L V V V G G V L A C Y S L L V  
 acagtggcctttattttctgggtgaggagtaagaggagcaggctcctgcacagtgac  
T V A F I I F W V R S K R S R L L H S D  
 tacatgaacatgactccccgccccggccccaccgcaagcattaccagccctatgcc  
 Y M N M T P R R P G P T R K H Y Q P Y A  
 ccaccagcgacttgcagcctatcgctccagagtgaaagtccagcaggagcagcagcc  
 P P R D F A A Y R S R V K F S R S A D A

FIG. 18 (continued)

```

cccgcgtaccagcaggccagaaccagcctctataacgagctcaatctaggacgaagagag
P A Y Q Q G Q N Q L Y N E L N L G R R E
gagtacgatgttttggacaagagacgtggccgggaccctgagatgggggaaagccgaga
E Y D V L D K R R G R D P E M G G K P R
aggaagaaccctcaggaaggcctgtacaatgaaactgcagaaagataagatggcggaggcc
R K N P Q E G L Y N E L Q K D K M A E A
tacagtgagattgggatgaaaggcgagcggcgggcaaggggcacgatggccctttac
Y S E I G M K G E R R R G K G H D G L Y
cagggcttcagtacagccaccaaggacacctacgacgcccttcacatgcaggccctgccc
Q G L S T A T K D T Y D A L H M Q A L P
cctcgctaa (SEQ ID NO:18)
P R * (SEQ ID NO:19)
    
```

Cy of CD3ζ

FIG. 20

ATGAACCCGGGAGTCCCTTTTAGGCACTTGCTGCTGCAACTGGCGCTCCTCCAGCAGCCACTC  
 AGGGAAGAAAGTGGTCTGGGCAAAAAGGGATACAGTGGAACTGACCTGTACAGCTTCCAGAGAA  
 GAGCATACAATTCCACTGGAAAACCTCAACAGATAAAGATTCTGGAAATCAGGGCTCCTTCTTAAC  
 AAAGTCCATCCAAGCTGAATGATCGCGCTGACTCAAGAAGAAGCCTTTGGACCAAGGAAACTTTCCTCC  
 TGATCATCAAGAATCTTAAGATAGAAGACTCAGATACTTACATCTGTGAAGTGGAGGACCAAGAAGGAGGA  
 GGTGCAATTGCTAGTGTTCGGATTGACTGCCAACTCTGACACCCACCTGCTTCAGGGCCAGAGCCTGACC  
 CTGACCTTGGAGAGCCCCCTGGTAGCCCCCTCAGTGCAATGTAGGAGTCCAAGGGTAAAACATAC  
 AGGGGGGAAGACCTCTCCGTGCTCAGCTGGAGCTCCAGGATAGTGGCACCTGGACATGCACCTGTCTT  
 GCAGAACCCAGAAGAGTGGAGTTCAAAATAGACATCGTGTGCTAGCTTCCAGAAGGCCCTCCAGCATA  
 GTCTATAAGAAAGAGGGGGAACAGTGGAGTCTCCCTTCCACTCGCCCTTACAGTTGAAAAGCTGACCG  
 GCAGTGGCAGCTGTGGTGGCAGCGGAGAGGGCTTCCCTCCAAGTCTTGGATCACCTTTGACCTGAA  
 GAACAAGGAAGTGTGTAAACGGGTACCAGGACCTAAGCTCCAGATGGGCAAGAAAGCTCCCGCTC  
 CACCTCACCTGCCCCAGGCTTGCCTCAGTATGCTGGCTCTGGAAACCTCACCTGGCCCTTGAAGCGA  
 AAACAGGAAAGTTGCATCAGGAAGTGAACCTGGTGTGATGAGACCACCTCAGCTCCAGAAAATTTGAC  
 CTGTGAGGTGTGGGACCCACCTCCCTAAGCTGATGCTGAGCTTGAACCTGGAGAACAAGGAGGCAAG  
 GTCTCGAAGCGGGAGAGCGGTGTGGTGTGTAACCTGAGCGGGGATGTGGCAGTGTCTGTGAGTG  
 ACTCGGACAGGTCTGCTGGAATCCAACATCAAGGTTCTGCCCCACATGGTCCACCCCGGTGCAGCCAATG  
 (SEQ ID NO:21)

FIG. 21

ATGAACCGAGGGTGCCATTTCAGACATTTGCTGCTTGTCCCTCCAGCTTGTCCCTGCTTCCCTGCCGCAACTC  
 AAGGAAAAAAGGTCCCTCGGGAAGAAGGAGACACTGTTGAGCTAACATGCATGCATCGCATCGCAAAAAGAGATA  
 TTCAGTTTCAATTGGAAGAATTCAAATCAAATACTCGGTAACCAAGGGTCTGTTTTCGACAAAAGGG  
 ACCTTCCGAAACTCAACGACCCGGCAGATTCTAGGAGAAGTCTATGGATCAGGGTAATTTCCCGCTCATATA  
 ATAAAAACCTAAAAATTGAGGATTCTGACACATATATTGCCAGGTCGAAGATCAAAAAGAAGAAGTCC  
 AGTTACTTGTCTTTGGTTTAAACAGCGAATTTCAGATACGCATCTCCACAAGGCCAAAAGTCTCACGCTCAC  
 GTTAGAAAAGTCCGCCAGGAAGCAGTCCGTCGTCCAGTGCAGAACCCCTAGAGGAAAGAATAATTCAAGGC  
 GGCAAAACCGTGTCCGCTTCACACAACTCGAACTCGAAGACAGCGGGACCTGGACTTGTACAGTGTACAAA  
 ATCAAAAAGGTCGAATTTAAGATTTAGATATAGTCCGTCCTTGCATTTCAAAAAGCCGTCGAGTATTTGTGTA  
 CAAAAGGAAGCGAGCAAGTCGAAATTTTCGTTTCCCTCTGGCGTTCACTGTAGAGAAACTCACCCGGGAGC  
 GGGAACTCTGGTGGCAAGCGGTAACGCAAGATCCAAAACCTGCAAAATGGGGAATAAACTGCCCTGCATCT  
 AAGAGGTCCTCAGTTAAGCGGTTACCAATAACGCAGGTCAGGGAATCTGACGCTCGGCTAGAGGCCAAGACT  
 GACGCTCCCGCAAGCGTTACCAATAACGCAGGTCAGGGAATCTGACGCTCGGCTAGAGGCCAAGACT  
 GGTAATTTACACCAGAGGTTCAATCTCGTCTCATGAGGGCCACAACTGCAAAAAGAACTTAACGTTGCC  
 AAGTCTGGGTCCGACGTCGCCAAAACCTCATGCTCAGTTTAAAGCTCGAAAATAAAGAAGCTAAAGTGTCTC  
 CAAACCGGAAAAGCCGTCTGGTCTCAATCCAGAAGCCGGCATGTGGCAATGCCCTCCCTCAGCGGATTC  
 GGGCAAGTGTCTCCGAGTCGAATATTAAGTACTCCCGACTTGGTCTGACGCCCGTACAACCTATG  
 (SEQ ID NO:22)



FIG. 22

CD4_signalpepECD	ATGAACGGGAGTCCCTTTTAGGCACCTTGTGGTCTGCAACTGGGGCTCCTCCCA
Mu_CD4_signalECD	ATGAACCGAGGGTGCCATTCAGACATTTGCTGCTTGTCCCTCCAGCTTGCCCTGCTTCCT
	***** ** ** ** **
CD4_signalpepECD	GCAGCCACTCAGGGAAGAAAGTGGTCTGGGCAAAAAGGGGATACAGTGGAACTGACC
Mu_CD4_signalECD	GCCGCAACTCAAGGAAAAGGTCGTCCTCGGGAAGAAAGGAGACACTGTTGAGGCTAACA
	** ** ***** ** ** ** **
CD4_signalpepECD	TGTACAGCTTCCAGAAGAAGAGCATACAATCCACTGGAAAACTCCAACCAGATAAAG
Mu_CD4_signalECD	TGCACTGCATCGCAAAAGAAGAGTATTCAGTTTCATTTGGAAGAATTCAAAATCAAA
	** ** ** ***** ** ** **
CD4_signalpepECD	ATTCTGGGAAATCAGGGCTCCTTCTTAACTAAAGTCCATCCAAGCTGAATGATCGGGCT
Mu_CD4_signalECD	ATACTCGGTAAACCAAGGTCGTTTGTGACAAAGGACCTTCGAAACTCAACGCCGGGCA
	** ** ** ** ** ** ** ** ** ** ** ** **
CD4_signalpepECD	GACTCAAGAAGAAGCCTTTGGGACCAGGAAACTTCCCTGATCATCAAGAATCTTAAG
Mu_CD4_signalECD	GATCTAGGAGAAGTCTATGGGATCAGGGTAAATTTCCCGCTCATAATAAAAACCTAAA
	** ** ** ***** ** ** **
CD4_signalpepECD	ATAGAAGACTCAGATACATCTGTGAAGTGGAGACCAGAAGGAGGAGGTCAATTG
Mu_CD4_signalECD	ATTGAGGATCTGACACATATATTTGCGAGGTCGAAAGATCAAAAAGAAGATCCAGTTA
	** ** ** ** ** ** ** ** ** ** **
CD4_signalpepECD	CTAGTGTTCGGATTGACTGCCAACTGTGACACCCACCCTGCTTCAGGGCAGAGCCTGACC
Mu_CD4_signalECD	CTTGTCTTTTGGTTAACAGCGAATTCAGATACGCATCTCCTACAAGGCCAAAAGTCTCACG
	** ** ** ** ** ** **^ ^ ^ ^ ^
CD4_signalpepECD	CTGACCTTGGAGAGCCCCCTGGTAGCCCTCAGTGCATGTAGGAGTCCAAGGGGT
Mu_CD4_signalECD	CTCACGTTAGAAAAGTCCGCCAGGAAGCAGTCCGTCGTCCAGTGCAGAAGCCCTAGAGGA
	** ** ** **^ ^ ^ ^ ^

FIG. 22 (continued)

CD4\_signalpepECD      AAAAACATACAGGGGGGGAAGACCCTCTCCGTGTCTCAGCTGGAGCTCCAGGATAGTGGC  
Mu\_CD4\_signalECD      AAGAATATTCAAGCGGCAAAACGCTGTCCGTCTCACTCACTCGAACTCGAACTGCAAGACAGCGGG  
\*\* \*\*

CD4\_signalpepECD      ACCTGGACATGCACTGTCTTGCAGAACCCAGAGAAGGTTGAGTTCAAAATAGACATCGTG  
Mu\_CD4\_signalECD      ACGTGGACTTGTACAGTGTACAAAATCAAAAAGGTCGAAATTTAAGATTGATATAGTGC  
\*\* \*\*

CD4\_signalpepECD      GTGCTAGCTTTCAGAGGCCCTCCAGCATAGTCTATAAGAAAGAGGGGGAACAGGTGGAG  
Mu\_CD4\_signalECD      GTCCTTGCATTTCAAAAAGCGTCCGAGTATTGTGTACAAAAGAAAGCGGAGCAAGTCCGAA  
\*\* \*\*

CD4\_signalpepECD      TTCTCCCTCCACTCGCCCTTACAGTTGAAAAGCTGACGGGCAGTGGCGAGCTGTGGTGG  
Mu\_CD4\_signalECD      TTTTTCGTTTCTCTGGCGTTCACCTGTAGAGAACTCACCGGGAGCGGGAACCTCTGGTGG  
\*\* \*\*

CD4\_signalpepECD      CAGCGGAGAGGGCTTCCCTCCAAAGTCTTGGATCACCTTTGACCTGAAGAACAAGGAA  
Mu\_CD4\_signalECD      CAAGCGGAAAGAGCATCGTCGTCGAAATCATGGATTACGTTCCGATCTCAAAAATAAAGAG  
\*\* \*\*^\*\* \*\* \*\*

CD4\_signalpepECD      GTGTCTGTAAAACGGGTTACCCAGGACCCCTAAGCTCCAGATGGGGCAAGAAGCTCCCCTC  
Mu\_CD4\_signalECD      GTCTCAGTTAAGCGCGTAACGCAAGATCCAAAACCTGCAAAATGGGAAAACCTGCCCTG  
\*\* \*\* \*\*^\*\* \*\* \*\* \*\* \*\* \*\*^\*\* \*\* \*\*^\*\* \*\* \*\*^\*\* \*\* \*\*^\*\* \*\* \*\*^\*\* \*\* \*\*^\*\* \*\* \*\*^\*\* \*\* \*\*

CD4\_signalpepECD      CACCTCACCCCTGCCCCAGGCCCTTGCCTCAGTATGCTGGCTGTGGAAACCTCACCCCTGGCC  
Mu\_CD4\_signalECD      CATCTGACGCTCCCGCAAGCGTTACCACAATAACGCAGGGTCAAGGAAATCTGACGCTCGCG  
\*\* \*\* \*\*^\*\* \*\* \*\*^\*\* \*\* \*\*^\*\* \*\* \*\*^\*\* \*\* \*\*^\*\* \*\* \*\*^\*\* \*\* \*\*^\*\* \*\* \*\*^\*\* \*\* \*\*

CD4\_signalpepECD      CTTGAACCGAAAACAGGAAAGTTGCATCAGGAAGTGAACCTGGTGGTATGAGAGCCACT  
Mu\_CD4\_signalECD      CTAGAGGCCAAGACTGGTAAATTACACCAAGAGGTCAATCTCGTCTCATGAGGGCGACA  
\*\* \*\* \*\*^\*\* \*\* \*\*^\*\* \*\* \*\*^\*\* \*\* \*\*^\*\* \*\* \*\*^\*\* \*\* \*\*^\*\* \*\* \*\*^\*\* \*\* \*\*^\*\* \*\* \*\*



FIG. 23

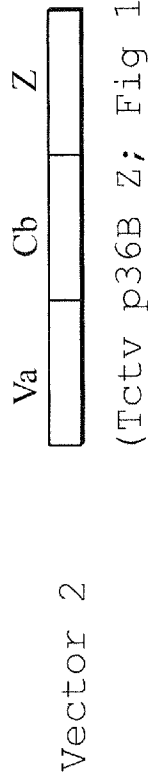
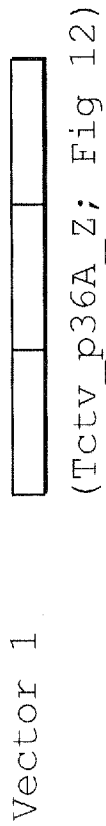
ATGAACCGGGAGTCCCTTTTAGGCAC<sup>1</sup>TTGCTTCTGGTGTGCAACTGGCGCTCCTCCAGCAGCCACTC  
AGGGAAGAAAGTGGTGTGGCAAAAAGGGGATACAGTGGAACTGACCTGTACAGCTTCCAGAGAA  
GAGCATACAATTCCACTGGAAAAC<sup>2</sup>TCCACCAGATAAAGATCTGGGAAATCAGGGCTCCTTCTTAACT  
AAAGGTCATCCAAAGCTGAATGATCGCGTGA<sup>3</sup>CTCAAGAAGAAGCC<sup>4</sup>TTTGGACCAAGGAAACTTTTCCCC  
TGATCATCAAGAATCTTAAGATAGAAGACTCAGATACTTACATCTGTGAAGTGGAGGACCAGAAGGAGGA  
GGTGCAATTGCTAGTGTTCGGATTGACTGCCAACTCTGACACCCACCTGCTTCAGGGGCAGAGCCTGACC  
CTGACCTTGGAGAGCCCCCTGGTAGTAGCCCCCTCAGTGCAATG<sup>5</sup>FAGGAGTCCAAGGGGFAAAAACATAC  
AGGGGGGAAGACCCCTCCTCCGTGTCTCAGCTGGAGCTCCAGGATAGTGGCACCTGGACATGCAC<sup>6</sup>TGTCTT  
GCAGAACCAAGAAGGTGGAGTTCAAAATAGACATCGTGGTCTAGCTTTCCAGAAGGCCCTCCAGCATA  
GTCTATAAGAAAAGAGGGGAACAGGTGGAGTCTCTCCCTTCCCACTCGCC<sup>7</sup>TTTACAGTTGAAAAGCTGACCGG  
CCAGTGGCGAGCTGTGGTGGCAGGGGAGGGCTTCCCTCCCAAGTCTTTGGATCACCTTTTGACCTGAA  
GAACAAGGAAGTGTCTGTAAAACGGGTTACCCAGGACCC<sup>8</sup>TAAGCTCCAGATGGGCAAGAAGCTCCCGCTC  
CACCTCACCCCTGCCAGGCC<sup>9</sup>TTGCCCTCAGTATGCTGGCTCTGGAAACCTCACCCCTGGCCCTTGAAGCGA  
AAACAGGAAAGTTGCATCAGGAAGTGAACCTGGTGGTGTGATGAGAGCCACTCAGCTCCAGAAAATTTGAC  
CTGTGAGGTGTGGGACCCACCCTCCCTAAGCTGATGCTGAGCTTGAAACTGGAGAACAAAGGAGGCAAG  
GTCTCGAAGCGGGAGAAAGCCGGTGTGGTGTGCTGAACCTGAGGGGGGATGTGGCAGTGTCTGTGAGTG  
ACTCGGGACAGGTCCTGCTGGAA<sup>10</sup>TCCAACATCAAGGTTCTGCCCCACATGGTCCACCCCGGTGCAGCCAAT  
GGATCCCAA<sup>11</sup>ACTCTGCTACCTGCTGGATGGAA<sup>12</sup>TCCCTTTCATCTATGGTGTCA<sup>13</sup>TTCTCACTGCC<sup>14</sup>TTGTTCTCCTGAGAGTGAAGTTCAG  
CAGGAGCGCAGACGCC<sup>15</sup>CCCCGGTACCAGCAGGGCCAGAACCCAGCTCTATAACGAGCTCAATCTAGGACGAAGAGGAGTACCGATGT  
TTTGGACAAGAGACGTGGCCGGGACCCTGAGATGGGGGAAAGCCGAGAAAGAAACCCCTCAGGAAGCCCTGTACAATGA<sup>16</sup>ACTGCA  
GAAAGATAAGATGGCGGAGGCC<sup>17</sup>TACAGT<sup>18</sup>GAGAT<sup>19</sup>TGGGAT<sup>20</sup>GAAAGCCGAGCGCCGGAGGGGCAAGGGCC<sup>21</sup>TGATGGCC<sup>22</sup>TTTACCAGGG  
TCTCAGTACAGCCCAAGGACACCTTACGACGCCCTTCA<sup>23</sup>CATGCAGGCCCTGCCCCCTCGCTAA (SEQ ID NO: 23)

FIG. 24

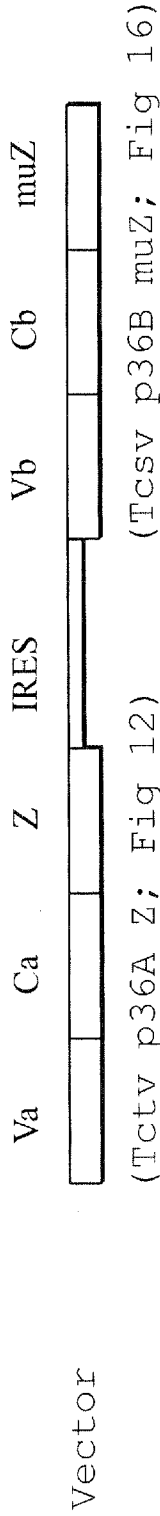
ATGAACCGAGGGTGCCAATTCAGACAAATTTGCTGCTTGTCTCCAGCTTGGCCCTGCTTCCCTGCCGCAACTC  
 AAGGA  
 AAAAAGGTCTCTCGGGAAGAAGGAGACACTGTTGAGCTAACATGCACCTGCATCGCAAAAAGAAAGAGTA  
 TTCAGTTTCATTGGAAGAATTCAAATCAAATACTCGGTAACCAAGGGTCTGTTTGTGACAAAAGGG  
 ACCTTCGAAACTCAACGACCGGGCAGATTTCTAGGAGAAAGTCTATGGGATCAGGGTAATTTCCCGCTCATA  
 ATAAAACCCTAAAATTTGAGGATTTGACACATATATTTGCCGAGGTCGAAGATCAAAAAGAAAGAAAGTCC  
 AGTTACTTTGCTTTTGGTTTAAACAGCGGAATTCAGATACTCCATCTCTACAAGGCCAAAAGTCTCACCGCTCAC  
 GTTAGAAAAGTCCCGCCAGGAAGCAGTCCGTCTGTCCAGTGCAGAAAGCCCTAGAGGAAAGAAATATTCAGGC  
 GGCAAAAACGCTGTCCGTCTCACAACTCGAACTGCAAGACAGCGGGACGTGGACTTTGTACAGTGTGTACAAA  
 ATCAAAAATAAGGTCGAATTTAAGATTTGATATAGTCTCCTTTGCATTTCAAAAAGCGTCCGAGTATTGTGTA  
 CAAAAAGGAAAGCGGAGCAAGTCGAATTTTTCGTTTCCCTTGGCGTTCACCTGTAGAGAAAACCTCACCGGGAGC  
 GGGAACTCTGGTGGCAAGCGGAAAGAGCATCGTCTCGTAAATCATGGATTACGTTCCGATCTCAAAAATA  
 AAGAGGTCACAGTTAAGCGCGTAAACGCAAGATCCAAAACCTGCAAAATGGGGAAAAAACTGCCCTCCATCT  
 GACGCTCCCGCAAGCGTTACCACAATACGCAGGGTCAGGGAATCTGACGCTCCGCTTAGAGGCCAAAGACT  
 GGTAATTTACACCAAGAGGTCAATCTCGTCTCATGAGGGCGCACACAACCTGCAAAAAGAACTTAACCGTGGC  
 AAGTCTGGGGTCCGACGTCGCCAAAACCTCATGCTCAGTTTAAAGCTCGAAAATAAAGAAAGCTAAAGTGT  
 CAACGCGAAAAGCCGTCCTGGTCCCTCAATCCAGAACCGGCAATGTGGCAATGCCCTCCTCAGCGGATCC  
 GGGCAAGTCTCCTCGAGTCGAAATATTAAGTACTCCCGACTTTGGTTCGACGCCCTGACAACTATG  
CCTAGGAAAATTGAAGTTATGTATCCTCCTTACCCTAGACAAATGAGAAGAGCAATGGAACTTATCCATGTGAAGGG  
 AAACACCTTTGTCCAAAGTCCCTTATTTCCCGGACCTTCTAAGCCCTTTTGGGTGCTGTGTGGTGGAGTCCCTGGCT  
 TGCTATAGCTTGGCTAGTAACAGTGGCTTTTATTATTCTGGGTGAGGAGTAAGAGGAGCAGGCTCCTGCACAGTGACTAC  
 ATGAACATGACTCCCGCCGCCCCCGGCCCAAGCATTACCAGCCCTATGCCCCACCACCGGACTTTCGCAGCCCTAT  
 CGCTCCTAA (SEQ ID NO:24)

**FIG. 25**

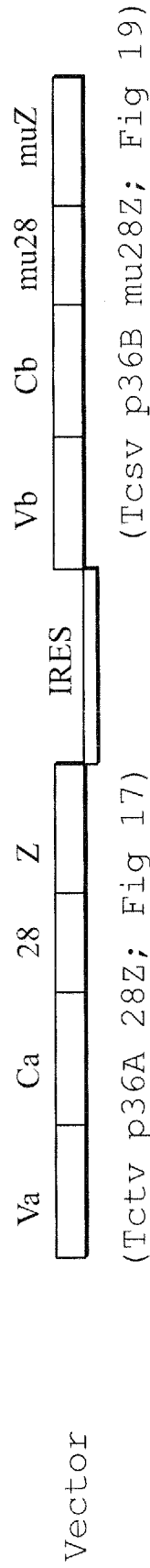
1. Tctv-anti-JCV p36Z CIR



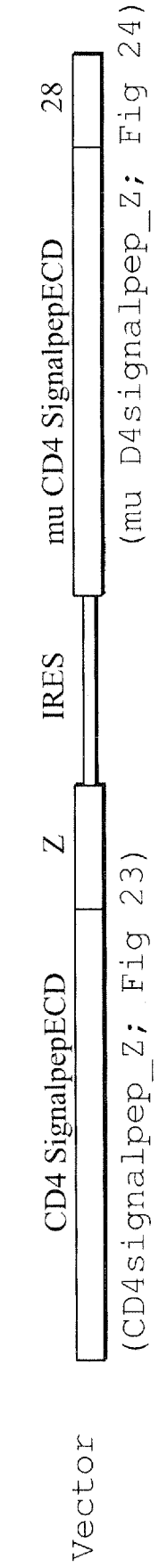
2. Tcsv-anti-JCV p36Z CIR



3. Tcsv-anti-JCV p3628Z CIR



4. Tcsv-anti HIV CD4 CIR



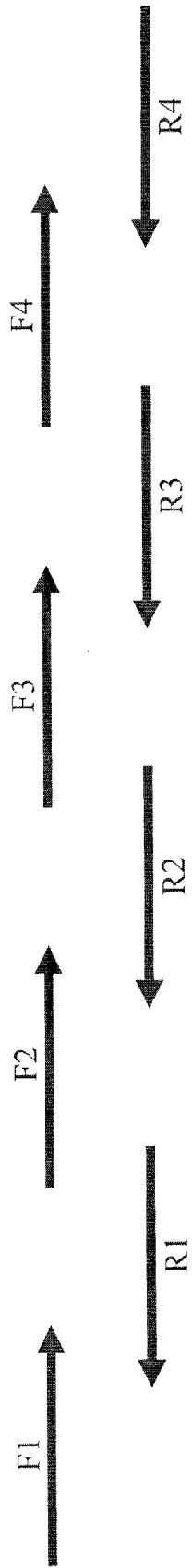


FIG. 27

## FIG. 26

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1. MuCD3Z\_F1\_primer (42 bp)

&gt;MuCD3Z\_F1\_primer

TGCGGAGACTTGGATCCTAAGTTATGTTATTTATTAGACGGG (SEQ ID NO:25)

2. MuCD3Z\_R1\_primer (61 bp)

&gt;MuCD3Z\_R1\_primer

AAATAGCGCTGTTAATATCACTCCGTATATAAAATAAAATCCCGTCTAATAAATAACATAAC (SEQ ID NO:26)

3. MuCD3Z\_F2\_primer (49 bp)

&gt;MuCD3Z\_F2\_primer

GTGATATTAACAGCGCTATTTTACGTGTCAAATTTTCACGCTCCGCTG (SEQ ID NO:27)

4. MuCD3Z\_R2\_primer (93 bp)

&gt;MuCD3Z\_R2\_primer

TTCTTCTCTACGACCCAAGTCAATTCATTGTACAATTGATTTTGCCCTTGTTGATAGCCGGCGCATCA  
GCGGAGCGTGAAAATTTGACACG (SEQ ID NO:28)

5. MuCD3Z\_F3\_primer (92 bp)

&gt;MuCD3Z\_F3\_primer

CTTGGGTCGTAGAGAAGAATATGACGTACTCGATAAACGGAGGGGGCGCGATCCAGAAATGGCCGGCAAA  
CCACGGCGAAAAAATCCACAAG (SEQ ID NO:29)

6. MuCD3Z\_R3\_primer (94 bp)

&gt;MuCD3Z\_R3\_primer

CCCCTTCATACCTATTTCTGAATATGCTTCTGCCATTTTGTCTTTTGTAACTCGTTATATAATCCCTCT  
TGTGGATTTTTTCGCCGTGGTTG (SEQ ID NO:30)

7. MuCD3Z\_F4\_primer (97 bp)

&gt;MuCD3Z\_F4\_primer

TTCAGAAATAGGTATGAAGGGGAAAGGAGACGAGGGAAAGGTCATGACGGATTGTATCAAGGATTATCG  
ACCGCGACTAAAGATACGTATGATGCG (SEQ ID NO:31)

8. MuCD3Z\_R4\_StopBsepI\_primer (64 bp)

&gt;MuCD3Z\_R4\_StopBsepI\_primer

ACGATCCGGACTTATCTTGGCGGTAATGCTTGCATGTGTAACGCATCATACGTATCTTTAGTCC  
(SEQ ID NO:32)



FIG. 28

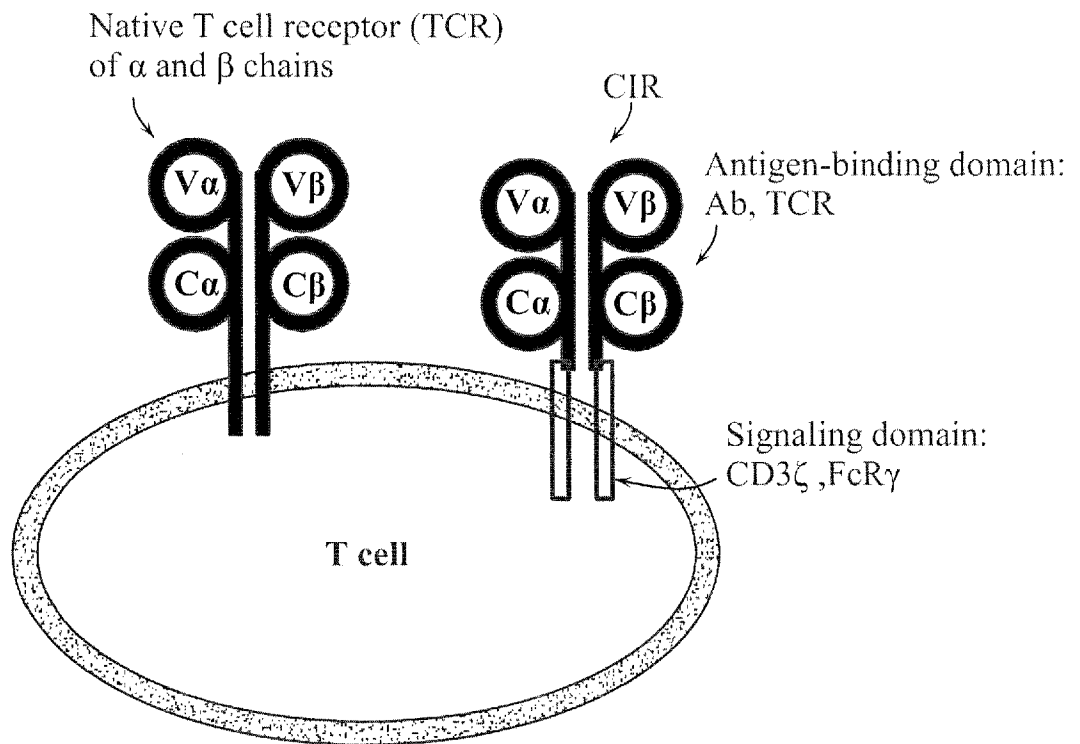


FIG. 29

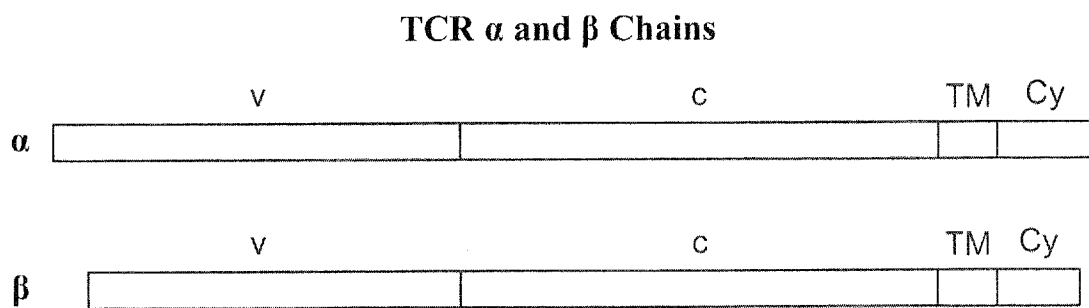
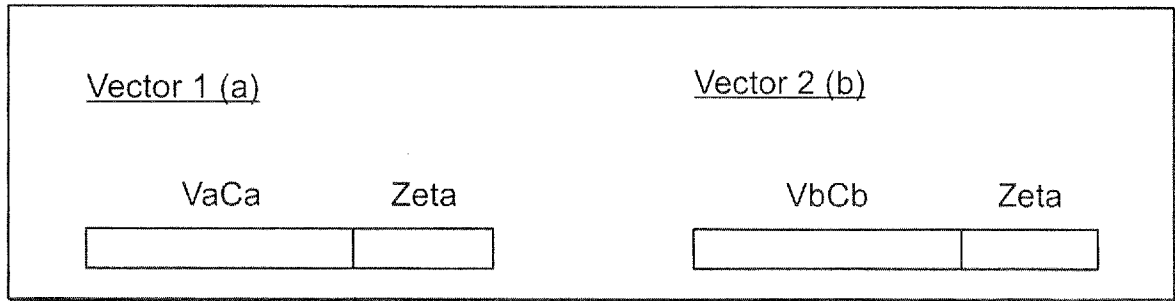


FIG. 30

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Potential problem:

- due to low rates of co-transductions

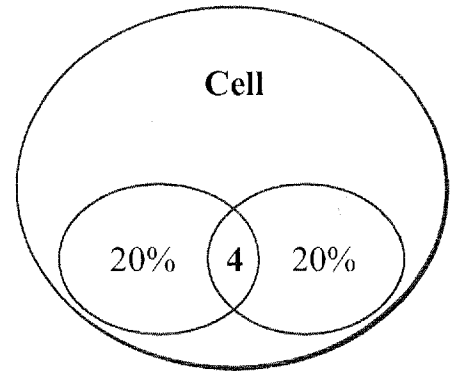


FIG. 31

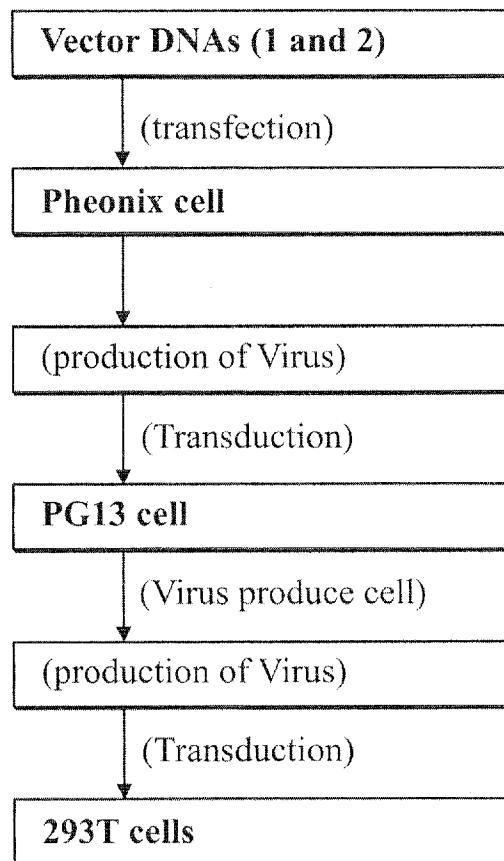


FIG. 32

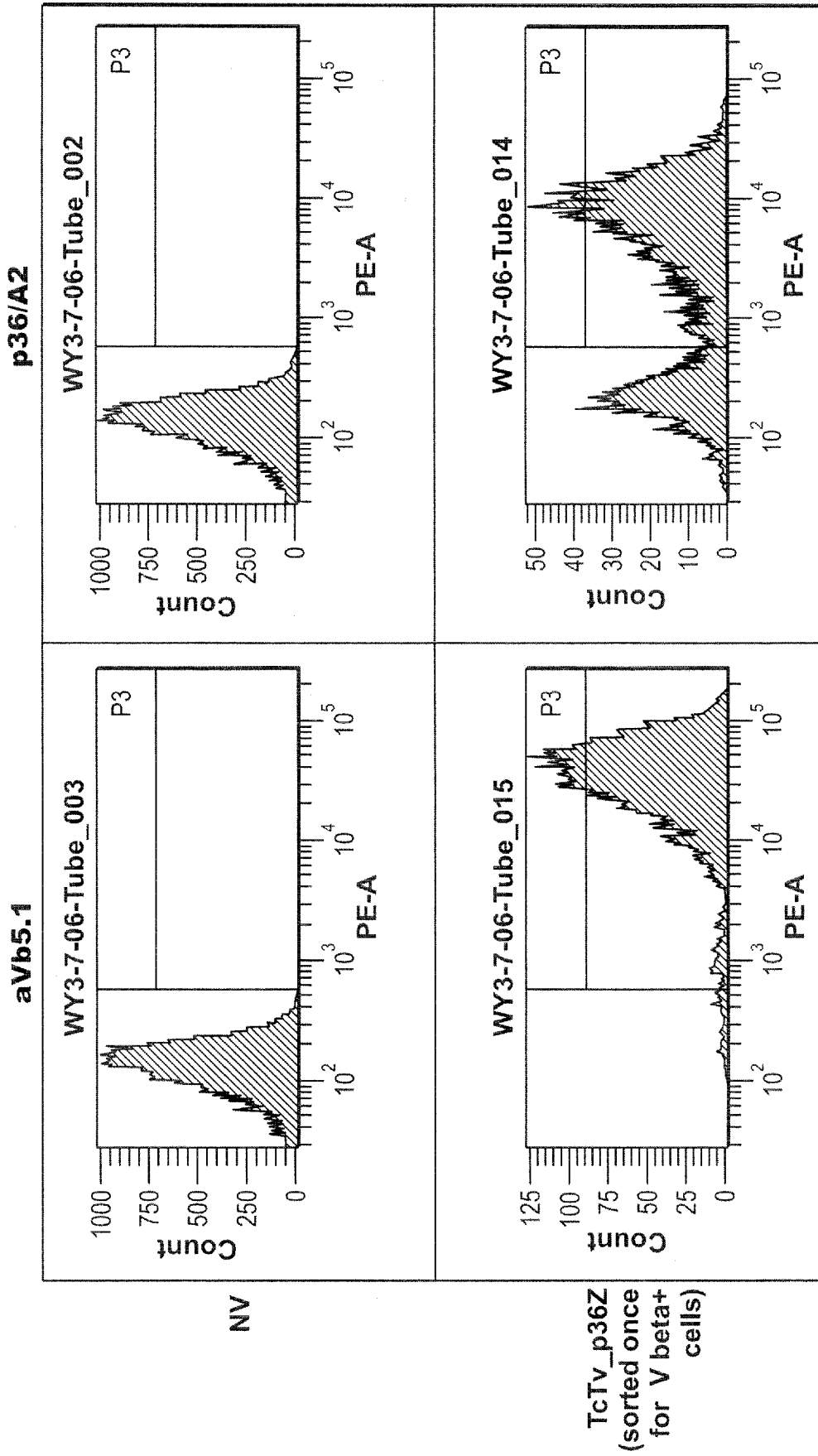


FIG. 33

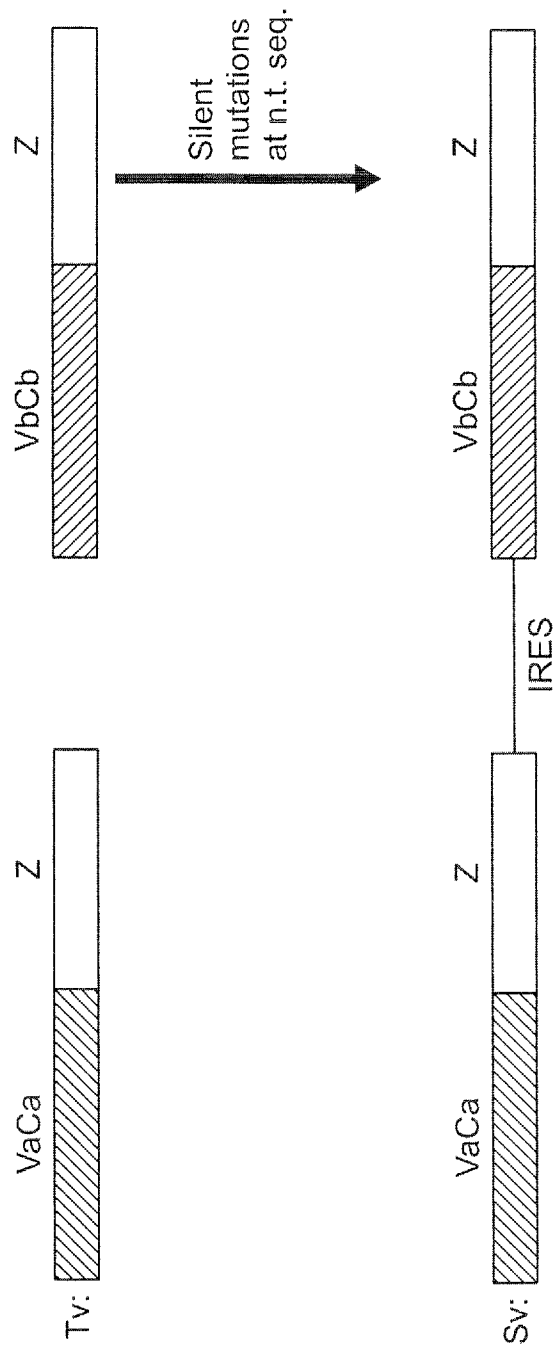


FIG. 34

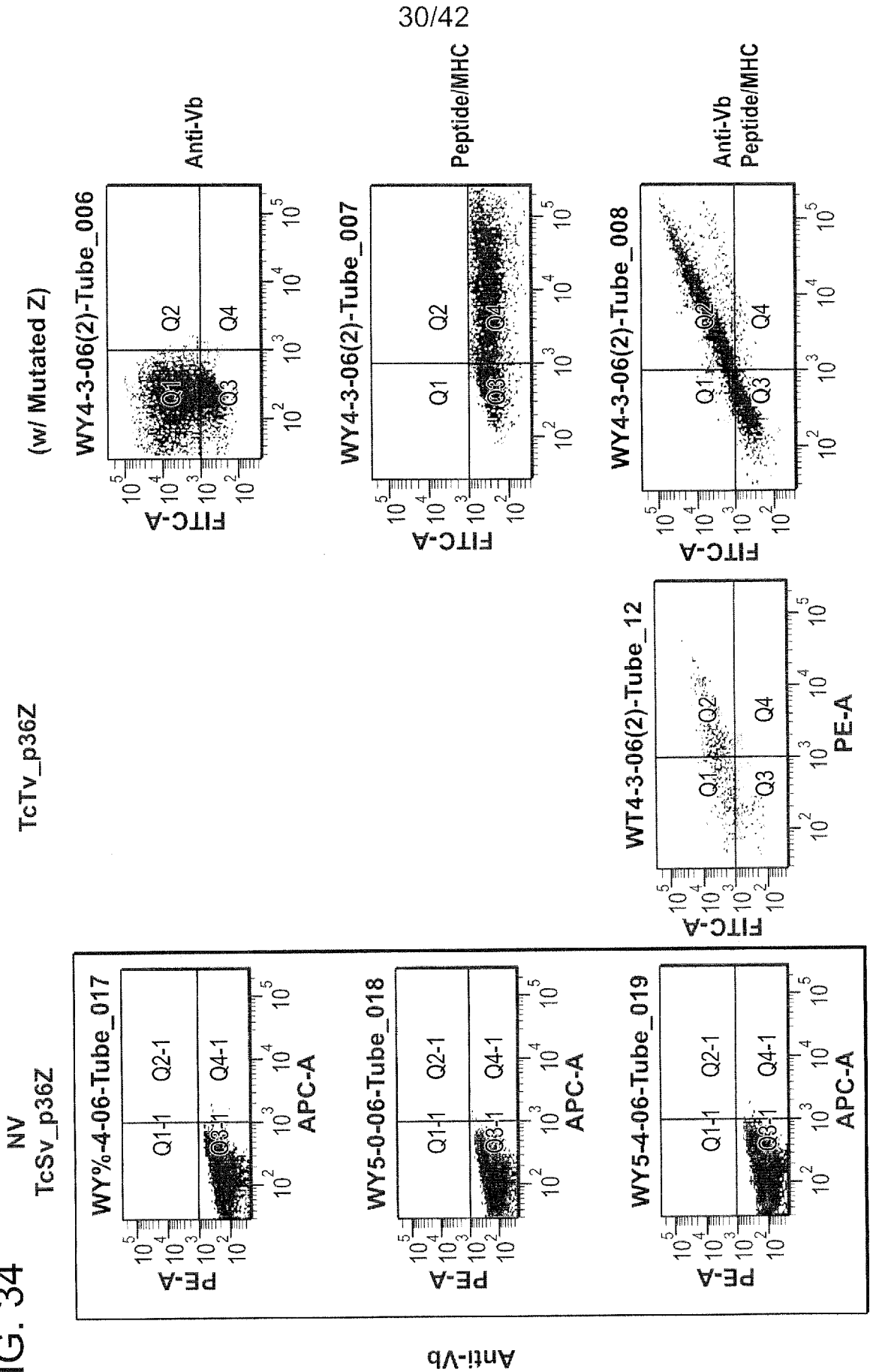
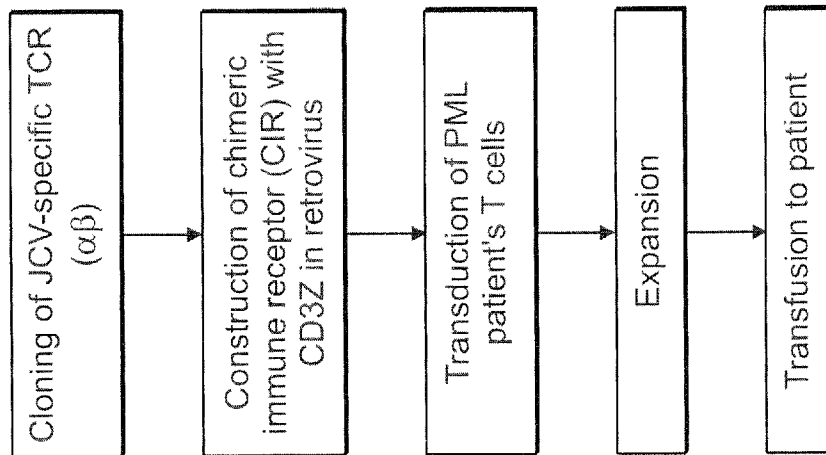


FIG. 35

Strategies for generation of anti-JCV "Designer T cells"



Tetramer staining to test for heterodimer

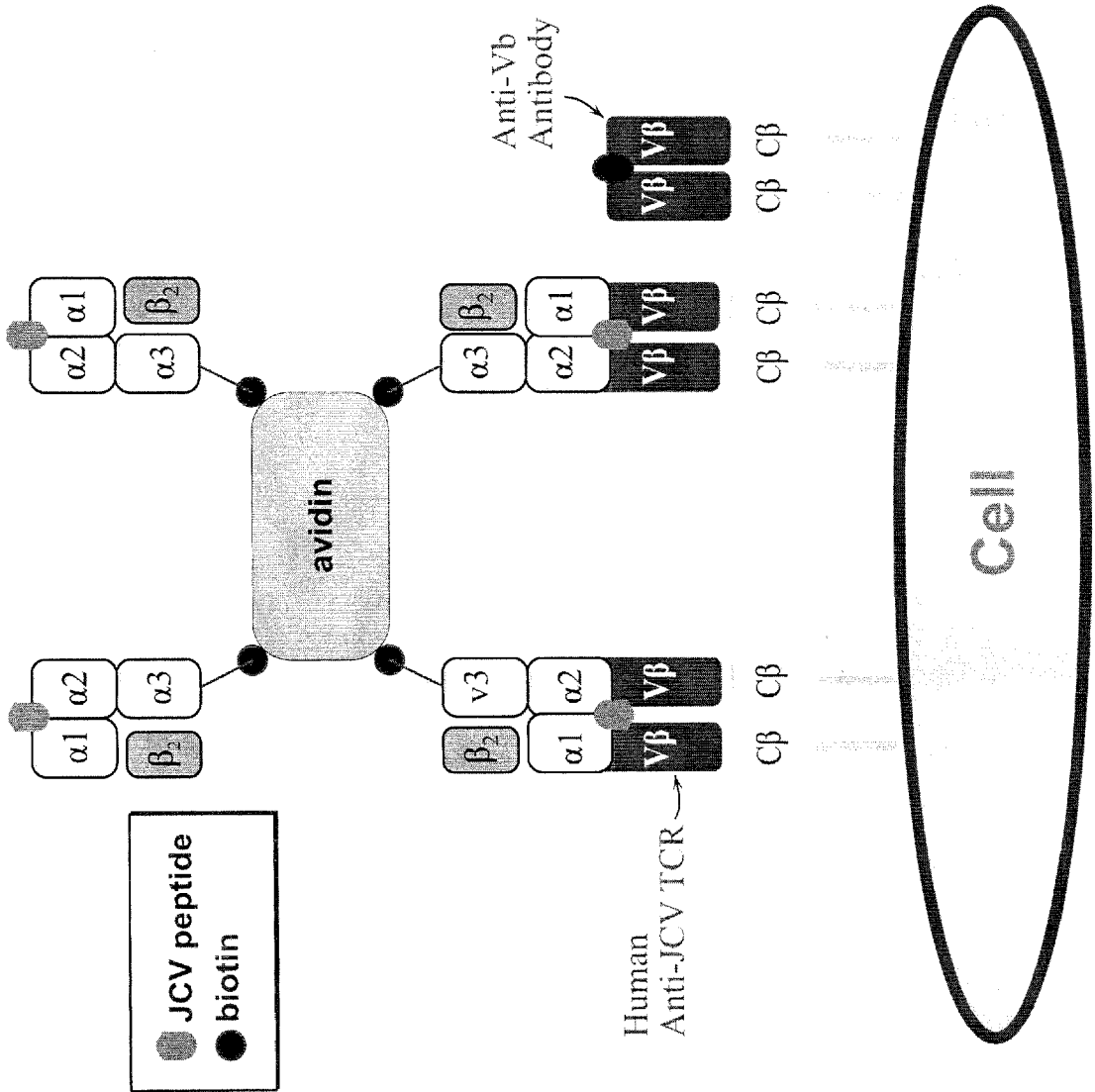


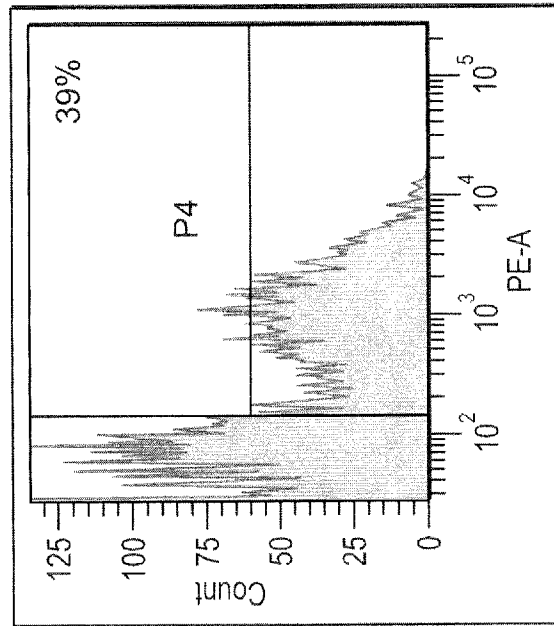
FIG. 36

T cells can be transduced by separate chains in two vectors:  
**Two-Chain Two-Vector CIR (TcTv)**

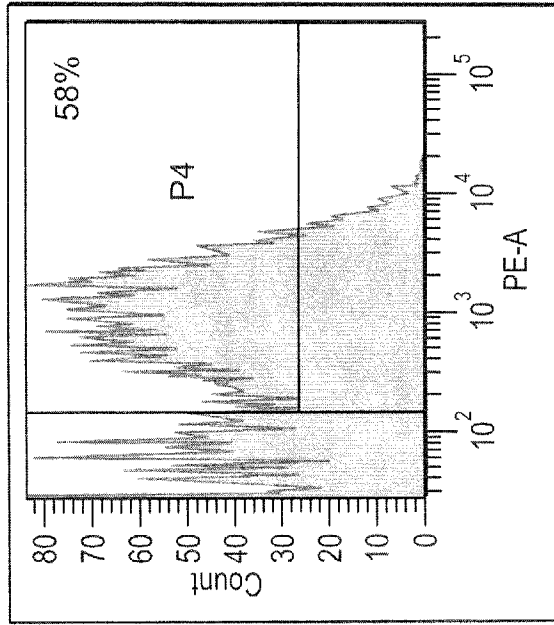


but

This arrangement displays low cell co-expression due to low probability of co-transduction from two separate retroviral vectors



TcTV\_p36Z



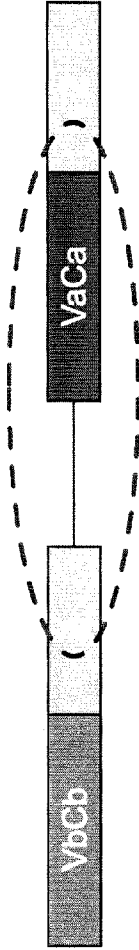
**Tetramer-PE** **Vb5.1-PE**

To increase the co-transduction we link chains using IRES  
**Two-Chain Single-Vector CIRs (TcSv)**

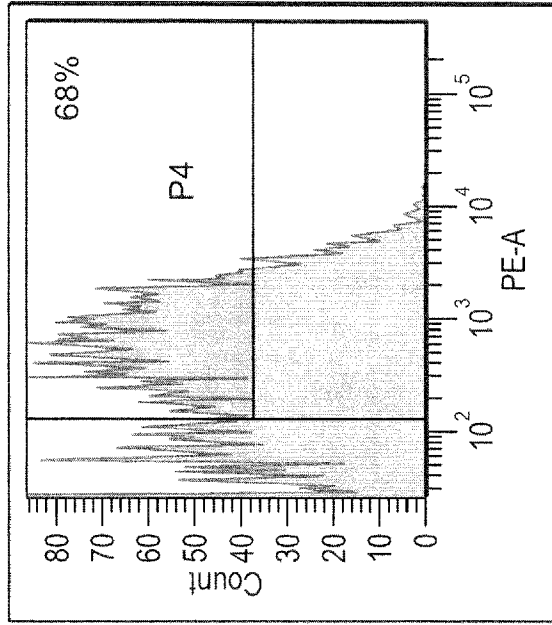
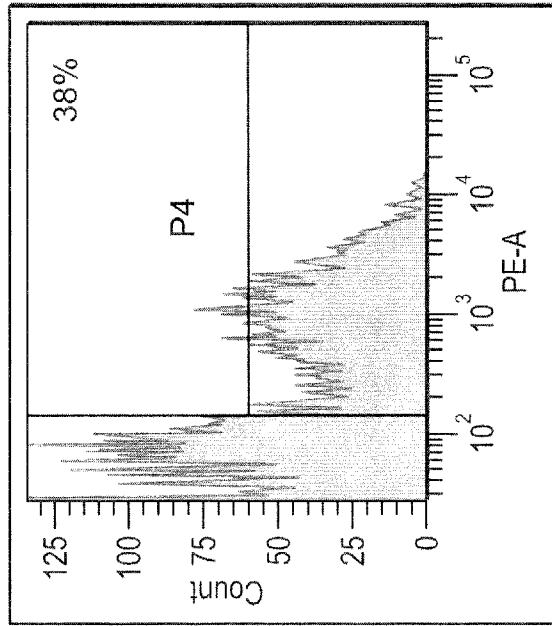


FIG. 37

HOWEVER: CIR DELETION OCCURS!!



TcSv format enables same cell transduction and co-expression but results in recombination-deletion between repeated CD3z sequences excising the equivalent of one of the CIRs



TcSV\_p36Z



FIG. 38

NT_Mutated_CD28CD3zeta CD28CD3Z	50	CCTAGGAAAGATCGAGGTAATGTATCCACCGCCCTATCTCGATAACGAAA CCTAGGAAAATTGAAGTTATGTATCCCTCCTCCTACCTAGACAAATGAGAA ***** ** ** ** **
NT_Mutated_CD28CD3zeta CD28CD3Z	100	AAGTAACGGTACAATAAATCACGTTAAGGAAAGCATTTATGCCCTTCCC GAGCAAATGGAACCAATATCCATGTGAAAGGAAACACCTTTGTCCAAAGTC ** ** ** ** **
NT_Mutated_CD28CD3zeta CD28CD3Z	150	CGTTGTTCCCGGCCCAAGCAAACCGTTCTGGGTTCTCGTAGTTGAGGC CCCTATTTCCCGGACCTTCTAAGCCCTTTGGGTTCTGGTGGTGGTGGT * * * * * ** ** ** **
NT_Mutated_CD28CD3zeta CD28CD3Z	200	GGTGTGTAGCATGTTACTCTCTCCTTGTACAGTAGCTTTCATAATCTT GGAGTCCCTGGCTTGCATATAGCTTGCTAGTAAACAGTGGCCTTATATTT ** ** * * * * * ** ** ** * * * * * ** ** ** * * * * *
NT_Mutated_CD28CD3zeta CD28CD3Z	250	TTGGGTCCGATCAAACCGCTCTCGATTGTTACATTCGGATTATATGAATA CTGGGTGAGGAGTAAGAGGAGCAGGCTCCTGCACAGTGACTACATGAACA ***** * * * * * ** ** * * * * * ** ** * * * * *
NT_Mutated_CD28CD3zeta CD28CD3Z	300	TGACACCGAGGACCTGGCCCGACGAGGAAACAATAACCGTACGCA TGACTCCCCGCCCGCCACCCGAAAGCAATACCCAGCCCTATGCC *** ** * * * * * ** ** * * * * * ** ** * * * * *
NT_Mutated_CD28CD3zeta CD28CD3Z	350	CCTCCGAGAGATTTGCTGCGTACAGGAGTCGTTCAAATTTTCACGCTC CCACCAGCGACTTCGCAGCCCTATCGCTCCAGAGTGAAGTTTCAGCAGGAG ** ** * * * * * ** ** * * * * * ** ** * * * * *

FIG. 38 (continued)

NT\_Mutated\_CD28CD3zeta 400  
 CD28CD3Z  
 CGCTGATGCCCGGCCCTATCAACAAGGGCAAAAATCAATTGTAACAATGAAT  
 CGCAGACGCCCCCGGTACCAGCAGGGCCAGAACCCAGCTCTATAACGAGC  
 \*\*\* \*\* \*\* \*\* \*\*

NT\_Mutated\_CD28CD3zeta 450  
 CD28CD3Z  
 TGAACCTGGGTCGTAGAGAAGAAATATGACCGTACTCGATAAACGGAGGGGG  
 TCAATCTAGGACGAAGAGAGGAGTACGATGTTTTGGACAAAGAGACGTGGC  
 \* \*\* \* \*\* \*\* \*\*

NT\_Mutated\_CD28CD3zeta 500  
 CD28CD3Z  
 CGCGATCCAGAAATGGCGGCAACCCAGCGGAAAAAATCCACAAGAGGG  
 CGGACCCCTGAGATGGGGGAAAGCCGAGAAAGAAACCCCTCAGGAAGG  
 \*\* \*\* \*\* \*\*

NT\_Mutated\_CD28CD3zeta 550  
 CD28CD3Z  
 ATTATAACGAGTACAAAAGGACAAAATGGCAGAAGCATATTCAGAAA  
 CCTGTACAAATGAACCTGCAGAAAGATAAGATGGCGGAGGCCCTACAGTGAGA  
 \* \*\* \*\* \*\* \*\*

NT\_Mutated\_CD28CD3zeta 600  
 CD28CD3Z  
 TAGGTATGAAGGGGAAAGGAGACCGAGGGAAAGGTCATGACGGATTGTAT  
 TTGGGATGAAAGCGGAGCGCCGGAGGGCCAAAGGGCCACCGATGGCCCTTTAC  
 \* \*\* \*\* \*\* \*\*

NT\_Mutated\_CD28CD3zeta 650  
 CD28CD3Z  
 CAAGGATTATCGACCGCGACTAAAGATACGATGATGCGGTACACATGCA  
 CAGGGTCTCAGTACAGCCACCAAGGACACCTACGACGCCCTTCACATGCA  
 \*\* \*\* \* \*\* \*\* \*\*

NT\_Mutated\_CD28CD3zeta 669  
 CD28CD3Z  
 AGCATTACCGCCAAGATAA  
 GGCCCTGCCCCCTCGCTAA  
 \*\* \* \*\* \* \*\*

# FIG. 38 (continued)

Alignment of nucleotide sequences of chimeric CD28CD3Zeta with mutated chimeric CD28CD3Zeta. The corresponding n.t. sequences encoding partial CD28 and CD3Zeta are from native human CD28

Same problem in anti-JCV TcSv

Solution engineer degenerate nucleotides in repeated sequence to prevent homologous recombination and deletion

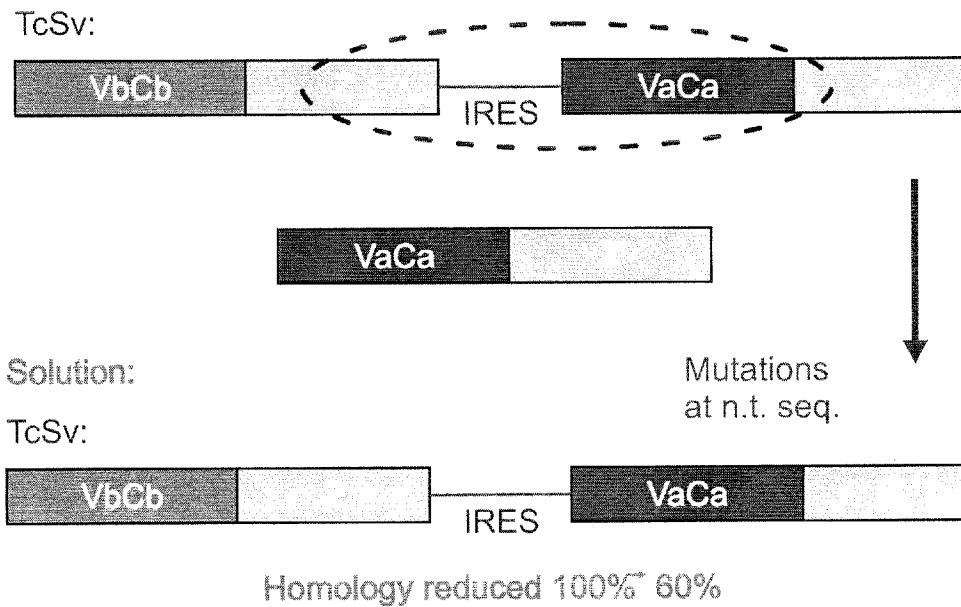


FIG. 39

**TcSv\_p36 CIR Is Functionally Expressed  
IT WORKS!**

TcSv format results in 2-fold increase in tetramer staining compared to TcTv

Transfection and transduction of TcTv and TcSv run in parallel with equal ratio of TCR chains used for transfection

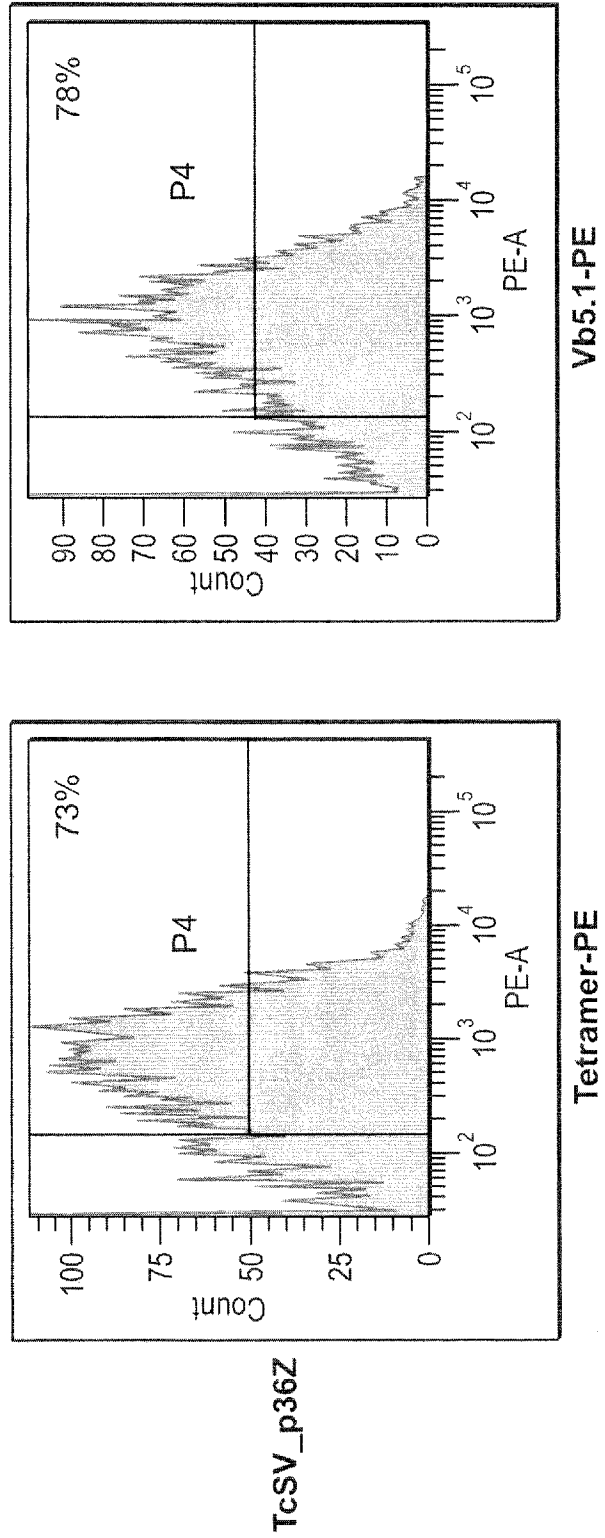


FIG. 40

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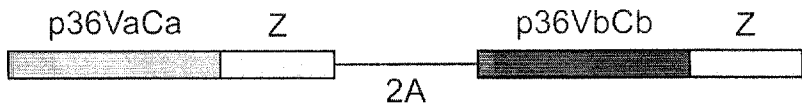
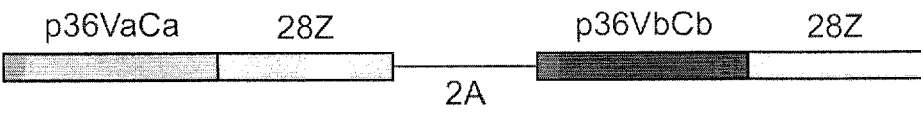
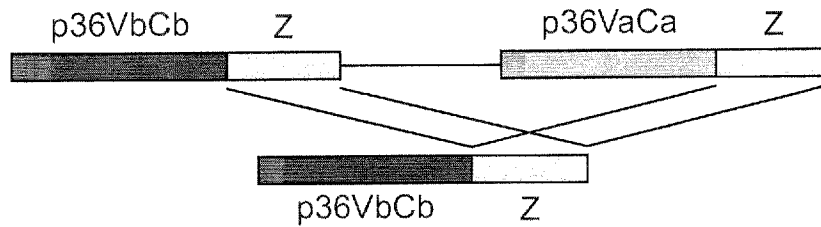
- improve design two-chain single vector (tcsv)
- expression from same vector for same cell transduction
- 1<sup>st</sup> gen: 
- 2<sup>nd</sup> gen: 
- linked using IRES or 2A
- constructs expressed in MFG retroviral expression vector

FIG. 41

- Potential for homologous sequence recombination and deletion between repeat z or 28z



- e.g. deletion of internal VaCa chain between repeat zeta reduces heterodimer expression

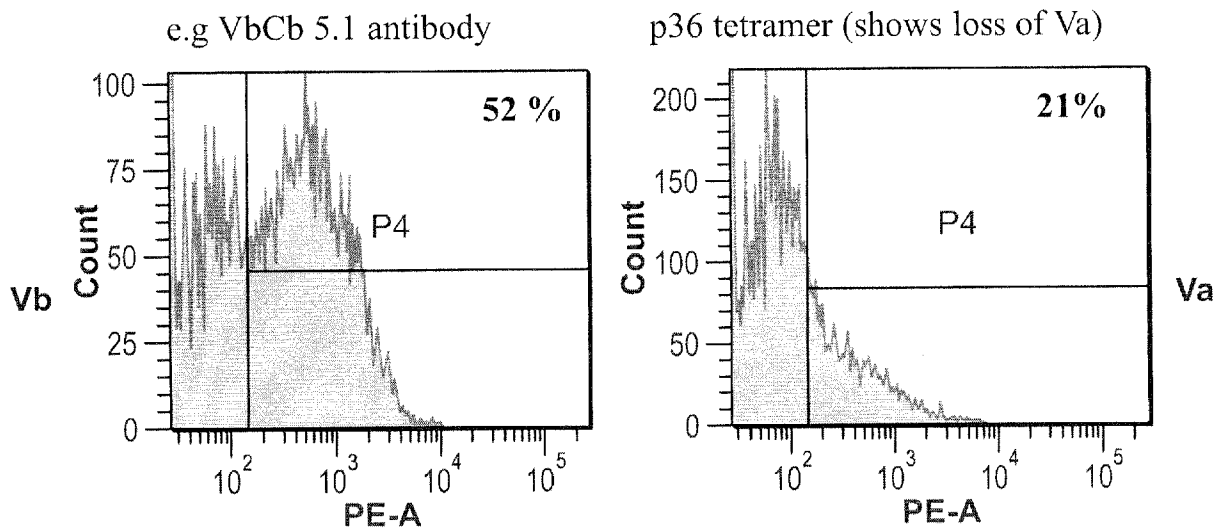


FIG. 42

- suppress recombination and deletion
- engineer codon degenerate nucleotides in repeated zeta chains to reduced homology
- tm/cyt CD3 zeta chain nucleotide homology reduced to 60%

	L D P K L C Y L L D G I L F I Y G V I L T A L F L R V K F S R S A D A
wtCD3z	CTGGATCCCAACTCTGCTACCTGCTGGATGGAAATCCTTTCATCTATGGTCAATCTCACTGCTTGTTCCTGAGAGTGAAGTTACAGCAGGAGCGCCAGACGCC
dCD3z	CTGGATCCCAAAATTGTGTTAATTTGGACGGGATTTATTTATATACGGAGTGATTAACAGCGCTATTTTACCGTGTCAAATTTTCACCGCTCCCGCTGATGCG
	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 M
wtCD3z	CCCGCTACCAGCGGCCAGAACCCAGCTCTATAACGAGCTCAATCTAGGACCAAGAGAGACTCGATGTTTGGACAAGAGACGTGGCCGGGACCTCTGAGATG
dCD3z	CCGGCTATCAACAGGGCAAAATCAATTTGTACAATGAATTTGACTGGTTCGTAGAGAGAAATATGACGTACTCGATAAACGGAGGGGGCCGATCCAGAATG
	G G K P R R K N P Q E G L Y N E L Q K D K M A E A Y S E I G M K G E R
wtCD3z	GGGGAAAGCCGAGAGGAAGAACCCCTCAGGAAGGCCCTGTACAATGAACCTGCAGAAAGATAAGATGGCCGAGGCCCTACAGTGAATGGGATGAAGGGCGGCGC
dCD3z	GGGGCAAAACCACGGCGCAAAAATCCACAAGAGGGATTATATAACGAGTTACAAAAGGACAAAATGGCAGAGCATATTCAGAAATAGGTATGAAGGGGAAGG
	R R G K G H D G L Y Q G L S T A T K D T Y D A L H M Q A L P P R *
wtCD3z	CGGAGGGCAAGGGCCACGATGGCCCTTACCAGGTTCTCAGTACAGCCCAAGGACACCTACGAGCCCTTCACATGCAGGCCCTGCCCTCCCTCGCTAA
dCD3z	AGACGAGGAAAGGTCATGACGGATTGTATCAAGGATTTATCGACCCGGACTAAGATACGTATGATGCGTTACACATGCAAGCATTACCGCAAGATAA

FIG. 43

- constructs with wild-type and degenerate CD3 zeta

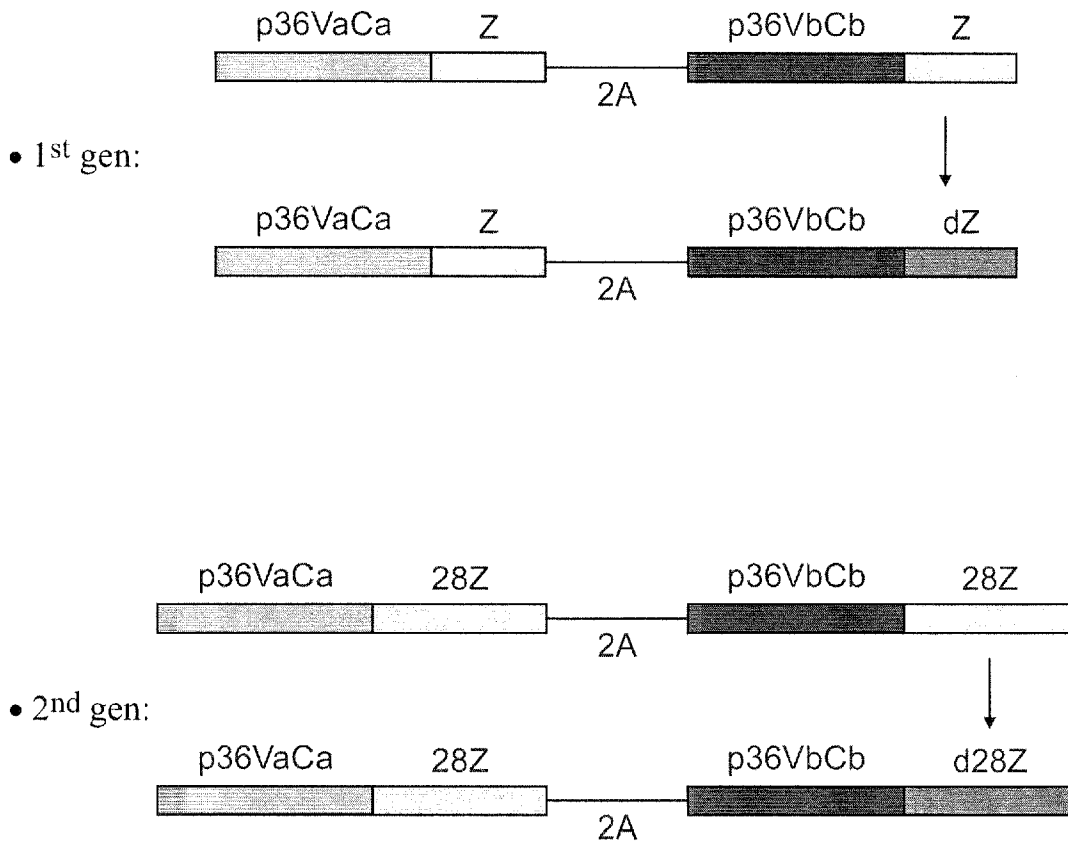


FIG. 44

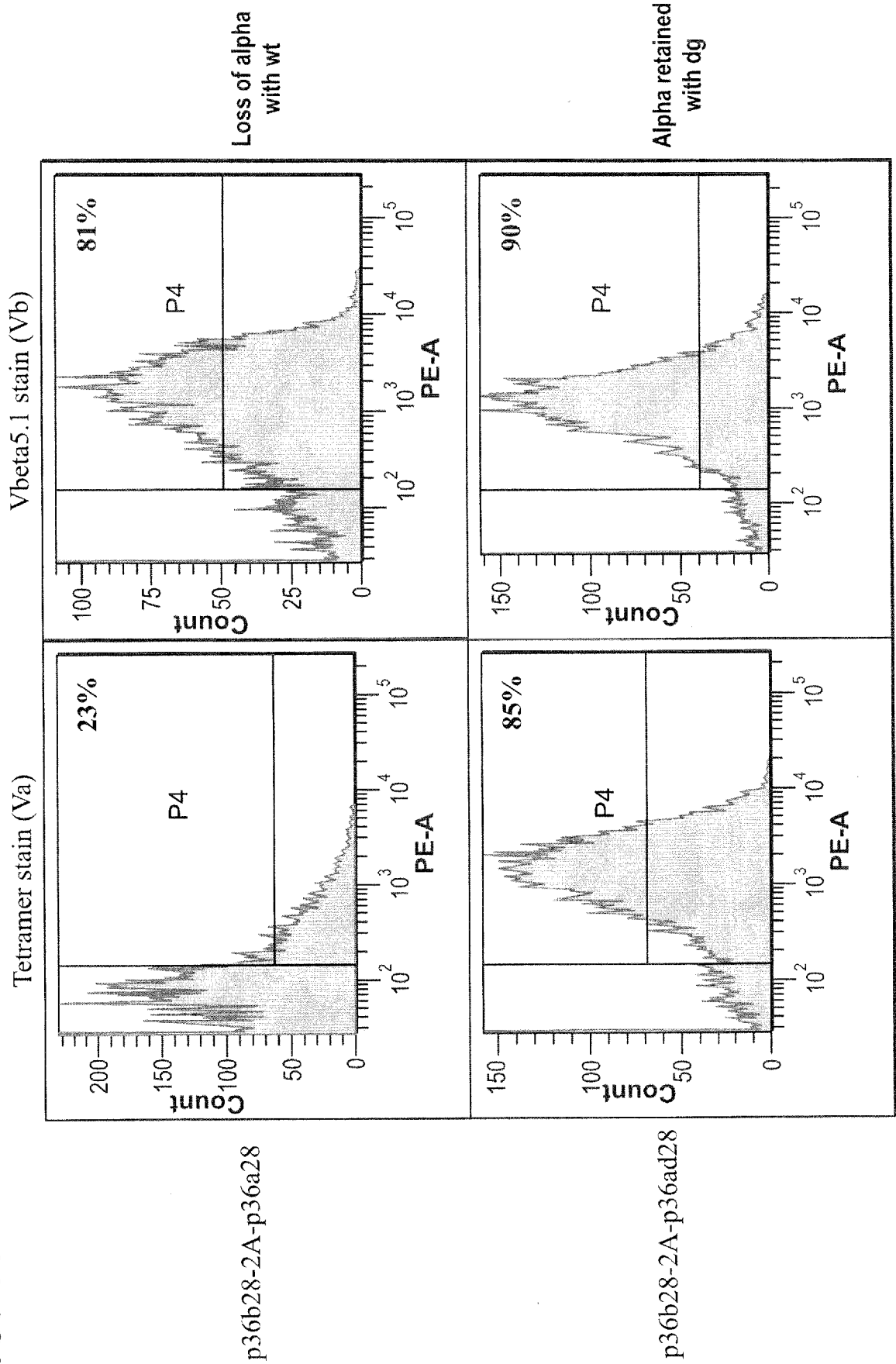




FIG. 44 (continued)

