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(54) **Title:** MODIFIED T CELL RECEPTORS AND RELATED MATERIALS AND METHODS

(57) **Abstract:** The invention is directed to a modified T cell receptor (TCR) comprising an amino acid sequence of a wild-type (WT) TCR with no more than three amino acid substitutions, wherein the modified TCR, as compared to the WT TCR, (i) has an enhanced ability to recognize target cells when expressed by $CD4^+$ T cells and (ii) does not exhibit a decrease in antigen specificity when expressed by $CD8^+$ T cells. Polypeptides, proteins, nucleic acids, recombinant expression vectors, host cells, populations of cells, antibodies, and pharmaceutical compositions related to the modified TCR also are part of the invention. Further, the invention is directed to methods of detecting a diseased cell in a host, methods of treating or preventing a disease in a host, and methods of identifying a candidate adoptive immunotherapy TCR.

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MODIFIED T CELL RECEPTORS AND RELATED MATERIALS AND METHODS

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This patent application claims the benefit of U.S. Provisional Patent Application No. 60/847,447 filed September 26, 2006, which is incorporated by reference.

INCORPORATION-BY-REFERENCE OF MATERIAL SUBMITTED ELECTRONICALLY

[0002] Incorporated by reference in its entirety herein is a computer-readable nucleotide/amino acid sequence listing submitted concurrently herewith and identified as follows: One 122,662 Byte ASCII (Text) file named "701866ST25.TXT," created on September 25, 2007.

BACKGROUND OF THE INVENTION

[0003] In an ongoing adoptive transfer clinical trial, cancer patients received autologous peripheral blood mononuclear cells (PBMC) that were transduced with nucleic acids encoding a T cell receptor (TCR) specific for the melanoma antigen MART-1. Thus far, two out of 17 patients have demonstrated an objective clinical response (Morgan et al., *Sciencexpress,* e-publication August 31, 2006). The results of this clinical trial demonstrate that normal autologous T lymphocytes, transduced *ex vivo* with anti-cancer antigen TCR genes and reinfused in cancer patients, can persist and express the transgene long term *in vivo* and mediate durable regression of large established tumors. However, approaches to increase the expression and function of the transgene are still needed.

[0004] There remains a need in the art for modified TCRs for use in treating patients with disease. The invention provides such T cell receptors and methods of treating cancer.

BRIEF SUMMARY OF THE INVENTION

[0005] The invention provides a modified T cell receptor (TCR) comprising an amino acid sequence of a wild-type (WT) TCR with no more than three amino acid substitutions, wherein the modified TCR, as compared to the WT TCR, (i) has an enhanced ability to recognize target cells when expressed by $CD4^+$ T cells and (ii) does not exhibit a decrease in antigen specificity when expressed by $CD8^+$ T cells.

[0006] The invention also provides related polypeptides and proteins, as well as related nucleic acids, recombinant expression vectors, host cells, and populations of cells. Further provided by the invention are antibodies, or an antigen binding portion thereof, and pharmaceutical compositions relating to the modified TCRs of the invention.

[0007] Further, the invention provides a method of detecting a diseased cell in a host, wherein the diseased cell expresses an antigen characteristic of a disease. The method comprises (a) contacting a sample comprising cells of the host with an inventive modified TCR, polypeptide, protein, nucleic acid, recombinant expression vector, host cell, or population of cells, thereby forming a complex between the modified TCR, polypeptide, protein, nucleic acid, recombinant expression vector, host cell, or population of cells and the antigen, and (b) detecting the complex, wherein detection of the complex is indicative of a diseased cell in the host.

[0008] Also provided by the invention is a method of treating or preventing a disease in a host. The method comprises administering to the host an inventive pharmaceutical composition in an amount effective to treat or prevent the disease in the host.

[0009] A method of identifying a candidate adoptive immunotherapy TCR is also provided. The method consists of (a) producing a nucleic acid encoding a modified TCR comprising a WT TCR amino acid sequence with no more than three amino acid substitutions, (b) expressing the nucleic acid in $CD4^+$ T cells and $CD8^+$ T cells, and (c) assaying the T cells for the ability to recognize target cells and for antigen specificity. A candidate adoptive immunotherapy TCR is identified when the modified TCR, as compared to the WT TCR, (i) has an enhanced ability to recognize target cells when expressed by $CD4^+$ T cells and (ii) does not exhibit a decrease in antigen specificity when expressed by $CD8^+$ T cells..

DETAILED DESCRIPTION OF THE INVENTION

[0010] The invention provides a modified T cell receptor (TCR) comprising an amino acid sequence of a wild-type (WT) TCR with no more than three amino acid substitutions, (e.g., 1, 2, or 3) wherein the modified TCR, as compared to the WT TCR, (i) has an enhanced ability to recognize target cells when expressed by $CD4^+$ T cells and (ii) does not exhibit a decrease in antigen specificity when expressed by $CD8^+$ T cells.

[0011] The term "wild-type" as used herein refers to a TCR which is naturally expressed by a T cell of a host, e.g., a TCR which is endogenous to a T cell of a host. Nucleic acids

encoding wild-type TCRs are known in the art and can be obtained from the GenBank database of the National Center for Biotechnology Information (NCBI). For example, wild-type TCR nucleic acid sequences are available as GenBank Accession Nos. NG_001333, NG_000016, NG_001337, NG_001332, NG_001336, AF043179, HSJ004872, M13863, Z81026, AF397440, AY124793, and the like. Also, nucleic acids encoding wild-type TCRs can be obtained by methods known in the art, such as the PCR-based method described herein (see Example 1). The cells used to obtain the nucleic acids encoding the wild-type TCR are not limited to those used in Example 1. Rather, the cells can be any of the T cells described herein. In addition, the wild-type TCR can be entirely synthesized using oligonucleotide primers corresponding to the known sequence.

[0012] The modified TCR of the invention is marked by one or more enhanced biological properties when expressed in T cells. Specifically, the modified TCR, when compared to the corresponding WT TCR, (i) has an enhanced ability to recognize target cells when expressed by $CD4^+$ T cells and (ii) does not exhibit a decrease in antigen specificity when expressed by $CD8^+$ T cells. The term "target cells" as used herein refers to cells which express and present, by way of an MHC molecule, the antigen which is specifically recognized by the modified TCR. The phrase "recognize target cells" as used herein refers to the ability of the modified TCR to immunologically recognize (e.g., specifically bind to) an antigen which is expressed and presented by a target cell. The term "enhanced" as used herein means that the modified TCR of the invention consistently exhibits at least twice the ability to recognize antigen expressed and presented by target cells, as compared to its WT counterpart. Preferably, the modified TCR of the invention recognizes antigen expressed and presented by target cells at least five times better than its WT counterpart. More preferably, the modified TCRs of the invention recognize antigen at least ten times better than its WT counterpart. Most preferably, the modified TCRs of the invention recognize antigen at least 2 times better than its WT counterpart.

[0013] The enhanced properties exhibited by the modified TCR consistently exhibits the properties, e.g., ability to recognize antigen expressed and presented by target cells. By "consistently" is meant that the modified TCR of the invention exhibits the enhanced properties in at least two assays. Preferably, the TCR of the invention exhibits the enhanced properties in at least three assays (e.g., in five or more assays, or in ten or more assays).

[0014] The modified TCR of the invention exhibits an enhanced ability to recognize target cells without exhibiting a decrease in antigen specificity when expressed by $CD8^+$ T

cells. In this respect, the modified TCR is said to retain the antigen specificity of the counterpart WT TCR, e.g., recognizes only the antigen(s) recognized by the WT TCR and does not recognize antigen(s) that are not recognized by the WT TCR.

[0015] Methods of testing a TCR for the ability to recognize target cells and for antigen specificity are known in the art. For instance, Clay et al., *J. Immunol.*, 163: 507-513 (1999), teaches methods of measuring the release of cytokines (e.g., interferon-γ, granulocyte/monocyte colony stimulating factor (GM-CSF), tumor necrosis factor a (TNF-α) or interleukin 2 (IL-2)). In addition, TCR function can be evaluated by measurement of cellular cytoxicity, as described in Zhao et al., *J. Immunol.*, 174: 4415-4423 (2005). Methods of testing a modified TCR for the ability to recognize target cells and for antigen specificity are described herein as Examples 2 to 4.

[0016] The modified TCR of the invention can have antigen specificity for any antigen. The phrase "have antigen specificity" as used herein means that the modified TCR can specifically bind to and immunologically recognize an antigen, such that binding of the TCR to the antigen elicits an immune response.

[0017] Preferably, the modified TCR of the invention has antigen specificity for an antigen which is characteristic of a disease. The disease can be any disease involving an antigen, as discussed herein, e.g., an infectious disease, an autoimmune disease, or a cancer. The antigen could be, for example, a viral antigen, a bacterial antigen, a cancer antigen, etc.

[0018] More preferably, the modified TCR of the invention has antigen specificity for a cancer antigen. The term "cancer antigen" as used herein refers to any molecule (e.g., protein, peptide, lipid, carbohydrate, etc.) solely or predominantly expressed or over-expressed by a tumor cell or cancer cell, such that the antigen is associated with the tumor or cancer. The cancer antigen additionally can be expressed by normal, non-tumor, or non-cancerous cells. However, in such a situation, the expression of the cancer antigen by normal, non-tumor, or non-cancerous cells is not as robust as the expression by tumor or cancer cells. In this regard, the tumor or cancer cells can over-express the antigen or express the antigen at a significantly higher level, as compared to the expression of the antigen by normal, non-tumor, or non-cancerous cells. Also, the cancer antigen additionally can be expressed by cells of a different state of development or maturation. For instance, the cancer antigen can be additionally expressed by cells of the embryonic or fetal stage, which cells are not normally found in an adult host. Alternatively, the cancer antigen additionally can be expressed by stem cells or precursor cells, which cells are not normally found in an adult

host. Another group of cancer antigens are represented by the differentiation antigens that are expressed in only a limited set of tissues in the adult, such as the melanocytes differentiation antigens, whose expression is limited to normal melanocytes. Although it is not known why these molecules elicit immune responses, the limited expression pattern of these proteins may allow these molecules to be recognized by the immune system.

[0019] The cancer antigen can be an antigen expressed by any cell of any cancer or tumor, including the cancers and tumors described herein. The cancer antigen may be a cancer antigen of only one type of cancer or tumor, such that the cancer antigen is associated with or characteristic of only one type of cancer or tumor. Alternatively, the cancer antigen may be a cancer antigen (e.g., may be characteristic) of more than one type of cancer or tumor. For example, the cancer antigen may be expressed by both breast and prostate cancer cells and not expressed at all by normal, non-tumor, or non-cancer cells. In a preferred embodiment of the invention, the cancer antigen is a melanoma cancer antigen. In a more preferred embodiment, the cancer antigen is selected from the group consisting of NY-ESO-1, MART-1, gp100, p53, TRP-1, TRP-2, and tyrosinase. In a most preferred embodiment, the cancer antigen is NY-ESO-1 or MART-1.

[0020] With respect to the inventive modified TCR, the amino acid substitution(s) can be located in any part of the amino acid sequence of the TCR. Preferably, the amino acid substitutions are located within the amino acid sequence of the complementary determining region (CDR) of the TCR, which are known in the art. These regions have been defined by elucidation of X-ray crystallographic structures, as well as sequence comparisons which have revealed the presence of regions of high diversity encoded in germline sequences, in the case of CDR1 and CDF2 regions, as well as recombinational diversity, in the case of CDR3 region (Lefranc et al., *Nucl. Acids Res.*, *27*, 209-212 (1999)). Preferably, the one, two, or three amino acid substitutions are located in the amino acid sequence of a CDR2 or CDR3 of the TCR (e.g., in the CDR2 region of the beta chain of the TCR). More preferably, the amino acid substitutions are located in the amino acid sequence of a CDR2, e.g., CDR2 of an α chain of a TCR or a β chain of a TCR. Most preferably, the amino acid substitutions are located in the CDR2 of a β chain of a TCR. For example, the modified TCR can comprise an amino acid sequence selected from the group consisting of SEQ ID NOs: 116 to 121 in which the amino acid substitutions are located at the Xaa's of these sequences.

[0021] The invention provides a modified TCR comprising two polypeptides (i.e., polypeptide chains), such as an α chain of a TCR, a β chain of a TCR, a γ chain of a TCR, a δ

chain of a TCR, or a combination thereof. The amino acid substitutions of the inventive modified TCRs can be located in the amino acid sequence of either or both polypeptide chains which constitute the TCR. In a preferred embodiment of the invention, the amino acid substitutions are located in the amino acid sequence of the β chain of the modified TCR. In a more preferred embodiment, the amino acid substitutions are located in only the amino acid sequence of the β chain of the modified TCR.

[0022] The amino acid substitutions of the inventive modified TCR are preferably conservative amino acid substitutions. Conservative amino acid substitutions are known in the art, and include amino acid substitutions in which one amino acid having certain physical and/or chemical properties is exchanged for another amino acid that has the same chemical or physical properties. For instance, the conservative amino acid substitution can be an acidic amino acid substituted for another acidic amino acid (e.g., Asp or Glu), an amino acid with a nonpolar side chain substituted for another amino acid with a nonpolar side chain (e.g., Ala, Gly, Val, Ile, Leu, Met, Phe, Pro, Trp, Val, etc.), a basic amino acid substituted for another basic amino acid (Lys, Arg, etc.), an amino acid with a polar side chain substituted for another amino acid with a polar side chain (Asn, Cys, Gln, Ser, Thr, Tyr, etc.), etc. Preferably, the conservative amino acid substitutions are selected from the group consisting of T→A, G→A, A→I, T→V, A→M, T→I, A→V, T→G, and T→S.

[0023] The polypeptide chains of the inventive modified TCR can comprise any amino acid sequence, provided that the modified TCR, as compared to the WT TCR, (i) has an enhanced ability to recognize antigen when expressed by $CD4^+$ T cells and (ii) does not exhibit a decrease in antigen specificity when expressed by $CD8^+$ T cells.

[0024] In a preferred embodiment of the invention, the modified TCR comprises the amino acid sequence of SEQ ID NO: 8 with no more than three amino acid substitutions. In a more preferred embodiment of the invention, the modified TCR comprises the amino acid sequence of SEQ ID NO: 1, SEQ ID NO: 2, or SEQ ID NO: 3, each of which is an amino acid sequence of a variable region of a beta chain of a modified TCR which recognizes the cancer antigen NY-ESO-1. In a most preferred embodiment of the invention, the modified TCR comprises the amino acid sequence of SEQ ID NO: 14, 15, or 16, each of which is the amino acid sequence of a full-length beta chain comprising a constant region and a variable region. The modified TCR can additionally comprise the amino acid sequence of SEQ ID NO: 7, which is the WT alpha chain of the 1G4 NY-ESO-1-specific TCR.

[0025] In another preferred embodiment, the modified TCR comprises the amino acid sequence of SEQ ID NO: 10 or SEQ ID NO: 12 with no more than three amino acid substitutions. In a more preferred embodiment, the modified TCR comprises an amino acid sequence selected from the group consisting of SEQ ID NO: 4 to 6, 13, and 95 to 103, each of which is an amino acid sequence of a variable region of a beta chain of a modified TCR which recognizes the cancer antigen MART-1. In a most preferred embodiment of the invention, the modified TCR comprises the amino acid sequence of any of SEQ ID NOs: 17 to 20, 37 to 39, and 104 to 109, each of which is the amino acid sequence of a full-length beta chain comprising a constant region and a variable region. The modified TCR can additionally comprise the amino acid sequence of SEQ ID NO: 9 or SEQ ID NO: 11.

[0026] Preferably, when the modified TCR comprises the amino acid sequence of SEQ ID NO: 10 with no more than three amino acid substitutions, the modified TCR comprises the amino acid sequence of any of SEQ ID NOs: 4, 13, and 95 to 103. More preferably, the modified TCR comprises the amino acid sequence of any of SEQ ID NOs: 17, 20, 37 to 39, and 104 to 109. Also, in these instances, it is preferred that the modified TCR additionally comprises the amino acid sequence of SEQ ID NO: 9, which is the WT alpha chain of the F5 MART-1-specific TCR.

[0027] Likewise, when the modified TCR comprises the amino acid sequence of SEQ ID NO: 12 with no more than three amino acid substitutions, the modified TCR preferably comprises SEQ ID NO: 5 or SEQ ID NO: 6. More preferably, the modified TCR comprises the amino acid sequence of SEQ ID NO: 18 or 19. Also, in these instances, it is preferred that the modified TCR additionally comprises the amino acid sequence of SEQ ID NO: 11, which is the WT alpha chain of the F4 MART-1-specific TCR.

[0028] In a preferred embodiment, the modified TCR comprises an amino acid sequence of (i) any one of SEQ ID NOs: 17, 20, 37 to 39, and 104 to 109 and SEQ ID NO: 9, (ii) SEQ ID NO: 18 or 19 and SEQ ID NO: 11, or (iii) SEQ ID NO: 14, 15, or 16 and SEQ ID NO: 7. Such modified TCRs comprise the amino acid sequences of a mutated β chain and a WT α chain of a TCR which recognizes either NY-ESO-1 or MART-1.

[0029] The modified TCRs of the invention can comprise one or more immature TCR chains comprising a leader sequence or one or more mature chains in which the leader sequence has been cleaved off. As one of ordinary skill in the art appreciates, the leader sequence of a TCR chain comprises the amino acids at the N-terminus which together serve as a signal to transport the TCR to the plasma membrane and which amino acids are cleaved

off to yield the mature form of the TCR. In this regard, the modified TCRs described herein can additionally comprise a leader sequence selected from the group consisting of SEQ ID NOs: 110-115. Preferably, when the modified TCR comprises SEQ ID NO: 7, the modified TCR comprises the leader sequence of SEQ ID NO: 110; when the modified TCR comprises any of SEQ ID NOs: 1-3, 8, and 14-16, the modified TCR comprises the leader sequence of SEQ ID NO: 111; when the modified TCR comprises SEQ ID NO: 11, the modified TCR comprises the leader sequence of SEQ ID NO: 112; when the modified TCR comprises any of SEQ ID NOs: 5, 6, 12, 18, and 19, the modified TCR comprises the leader sequence of SEQ ID NO: 113; when the modified TCR comprises SEQ ID NO: 9, the modified TCR comprises the leader sequence of SEQ ID NO: 114; when the modified TCR comprises any of SEQ ID NOs: 4, 10, 13, 17, 20, 37-39, and 95-109, the modified TCR comprises the leader sequence of SEQ ID NO: 115.

[0030] Also provided by the invention is an isolated or purified polypeptide comprising a functional portion of any of the modified TCRs described herein, wherein the functional portion comprises the amino acid substitutions. The term "polypeptide" as used herein includes oligopeptides and refers to a single chain of amino acids connected by one or more peptide bonds.

[0031] With respect to the inventive polypeptides, the functional portion can be any portion comprising contiguous amino acids of the modified TCR of which it is a part, provided that the functional portion comprises the amino acid substitutions. The term "functional portion" when used in reference to a modified TCR refers to any part or fragment of the modified TCR of the invention, which part or fragment retains the biological activity of the modified TCR of which it is a part (the parent modified TCR). Functional portions encompass, for example, those parts of a modified TCR that retain the ability to recognize target cells, or detect, treat, or prevent a disease, to a similar extent, the same extent, or to a higher extent, as the parent modified TCR. In reference to the parent modified TCR, the functional portion can comprise, for instance, about 10%, 25%, 30%, 50%, 68%, 80%, 90%, 95%, or more, of the parent TCR.

[0032] The functional portion can comprise additional amino acids at the amino or carboxy terminus of the portion, or at both termini, which additional amino acids are not found in the amino acid sequence of the parent modified TCR. Desirably, the additional amino acids do not interfere with the biological function of the functional portion, e.g., recognize target cells, detect cancer, treat or prevent cancer, etc. More desirably, the

additional amino acids enhance the biological activity, as compared to the biological activity of the parent modified TCR.

[0033] The polypeptide can comprise a functional portion of either or both of the α and β chains of the TCRs of the invention, such as a functional portion comprising one of more of CDR1, CDR2, and CDR3 of the variable region(s) of the α chain and/or β chain of a TCR of the invention. In this regard, the polypeptide can comprise the amino acid sequence of any of SEQ ID NOs: 1 to 6, 13, and 95 to 103. The polypeptides can additionally comprise an amino acid sequence selected from the group consisting of SEQ ID NOs: 7, 9, and 11.

[0034] Alternatively or additionally, the inventive polypeptide can comprise the entire length of an α or β chain of one of the modified TCRs described herein. In this regard, the inventive polypeptide can comprise an amino acid sequence selected from the group consisting of any of SEQ ID NOs: 14 to 20, 37 to 39, and 104 to 109. Alternatively, the polypeptide of the invention can comprise both chains of the TCRs described herein. For example, the inventive polypeptide can comprise: (i) any of SEQ ID NOs: 14 to 16 in combination with SEQ ID NO: 7; (ii) any of SEQ ID NOs: 17, 20, 37 to 39, and 104 to 109 in combination with SEQ ID NO: 9; or (iii) SEQ ID NO: 18 or 19 in combination with SEQ ID NO: 11.

[0035] The invention further provides an isolated or purified protein comprising at least one of the inventive polypeptides described herein. By "protein" is meant a molecule comprising one or more polypeptide chains.

[0036] The protein of the invention can comprise (i) a first polypeptide chain comprising the amino acid sequence of SEQ ID NO: 1, 2, or 3 and a second polypeptide chain comprising the amino acid sequence of SEQ ID NO: 7, (ii) a first polypeptide chain comprising the amino acid sequence of any of SEQ ID NOs: 4, 13, and 95 to 103 and a second polypeptide chain comprising the amino acid sequence of SEQ ID NO: 9, or (iii) a first polypeptide chain comprising the amino acid sequence of SEQ ID NO: 5 or 6 and a second polypeptide chain comprising the amino acid sequence of SEQ ID NO: 11. In this instance, the protein of the invention can be a TCR.

[0037] Alternatively, if, for example, the protein comprises a single polypeptide chain comprising SEQ ID NO: 1 and SEQ ID NO: 7, or if the first and/or second polypeptide chain(s) of the protein further comprise(s) other amino acid sequences, e.g., an amino acid sequence encoding an immunoglobulin or a portion thereof, then the inventive protein can be a fusion protein. In this regard, the invention also provides a fusion protein comprising at

least one of the inventive polypeptides described herein along with at least one other polypeptide. The other polypeptide can exist as a separate polypeptide of the fusion protein, or can exist as a polypeptide, which is expressed in frame (in tandem) with one of the inventive polypeptides described herein. The other polypeptide can encode any peptidic or proteinaceous molecule, or a portion thereof, including, but not limited to an immunoglobulin, CD3, CD4, CD8, an MHC molecule, etc.

[0038] The fusion protein can comprise one or more copies of the inventive polypeptide and/or one or more copies of the other polypeptide. For instance, the fusion protein can comprise 1, 2, 3, 4, 5, or more, copies of the inventive polypeptide and/or of the other polypeptide. Suitable methods of making fusion proteins are known in the art, and include, for example, recombinant methods. See, for instance, Choi et al., *Mol. Biotechnol.* 31: 193-202 (2005).

[0039] The protein of the invention can be a recombinant antibody comprising at least one of the inventive polypeptides described herein. As used herein, "recombinant antibody" refers to a recombinant (e.g., genetically engineered) protein comprising at least one of the polypeptides of the invention and a polypeptide chain of an antibody, or a portion thereof. The polypeptide of an antibody, or portion thereof, can be a heavy chain, a light chain, a variable or constant region of a heavy or light chain, a single chain variable fragment (scFv), or an Fc, Fab, or $F(ab)_2'$ fragment of an antibody, etc. The polypeptide chain of an antibody, or portion thereof, can exist as a separate polypeptide of the recombinant antibody. Alternatively, the polypeptide chain of an antibody, or portion thereof, can exist as a polypeptide, which is expressed in frame (in tandem) with the polypeptide of the invention. The polypeptide of an antibody, or portion thereof, can be a polypeptide of any antibody or any antibody fragment, including any of the antibodies and antibody fragments described herein.

[0040] Included in the scope of the invention are functional variants of the inventive modified TCRs, polypeptides, and proteins described herein. The term "functional variant" as used herein refers to a modified TCR, polypeptide, or protein having substantial or significant sequence identity or similarity to a parent modified TCR, polypeptide, or protein, which functional variant retains the biological activity of the modified TCR, polypeptide, or protein of which it is a variant. Functional variants encompass, for example, those variants of the TCR, polypeptide, or protein described herein (the parent modified TCR, polypeptide, or protein) that retain the ability to recognize target cells to a similar extent, the same extent, or

to a higher extent, as the parent modified TCR, polypeptide, or protein. In reference to the parent modified TCR, polypeptide, or protein, the functional variant can, for instance, be at least about 30%, 50%, 75%, 80%, 90%, 98% or more identical in amino acid sequence to the parent modified TCR, polypeptide, or protein.

[0041] The functional variant can, for example, comprise the amino acid sequence of the parent TCR, polypeptide, or protein with at least one conservative amino acid substitution. Alternatively or additionally, the functional variants can comprise the amino acid sequence of the parent modified TCR, polypeptide, or protein with at least one non-conservative amino acid substitution. In this case, it is preferable for the non-conservative amino acid substitution to not interfere with or inhibit the biological activity of the functional variant. Preferably, the non-conservative amino acid substitution enhances the biological activity of the functional variant, such that the biological activity of the functional variant is increased as compared to the parent modified TCR, polypeptide, or protein.

[0042] The modified TCR, polypeptide, or protein can consist essentially of the specified amino acid sequence or sequences described herein, such that other components of the functional variant, e.g., other amino acids, do not materially change the biological activity of the functional variant. In this regard, the inventive modified TCR, polypeptide, or protein can, for example, consist essentially of an amino acid sequence selected from the group consisting of SEQ ID NOs: 1 to 6, 13, and 95 to 103. Also, for instance, the inventive modified TCRs, polypeptides, or proteins can consist essentially of an amino acid sequence selected from the group consisting of SEQ ID NOs: 14 to 20, 37 to 39, and 104 to 109.

[0043] The modified TCRs, polypeptides, and proteins of the invention (including functional portions and functional variants) can be of any length, i.e., can comprise any number of amino acids, provided that the modified TCRs, polypeptides, or proteins (or functional portions or functional variants thereof) retain their biological activity, e.g., the ability to specifically bind to antigen, detect diseased cells in a host, or treat or prevent disease in a host, etc. For example, the polypeptide can be 50 to 5000 amino acids long, such as 50, 70, 75, 100, 125, 150, 175, 200, 300, 400, 500, 600, 700, 800, 900, 1000 or more amino acids in length. In this regard, the polypeptides of the invention also include oligopeptides.

[0044] The modified TCRs, polypeptides, and proteins of the invention (including functional portions and functional variants) of the invention can comprise synthetic amino acids in place of one or more naturally-occurring amino acids. Such synthetic amino acids

are known in the art, and include, for example, aminocyclohexane carboxylic acid, norleucine, α-amino n-decanoic acid, homoserine, S-acetylaminomethyl-cysteine, trans-3- and trans-4-hydroxyproline, 4-aminophenylalanine, 4- nitrophenylalanine, 4-chlorophenylalanine, 4-carboxyphenylalanine, β-phenylserine β-hydroxyphenylalanine, phenylglycine, α-naphthylalanine, cyclohexylalanine, cyclohexylglycine, indoline-2-carboxylic acid, 1,2,3,4-tetrahydroisoquinoline-3-carboxylic acid, aminomalonic acid, aminomalonic acid monoamide, N'-benzyl-N'-methyl-lysine, N',N'-dibenzyl-lysine, 6-hydroxylysine, ornithine, α-aminocyclopentane carboxylic acid, α-aminocyclohexane carboxylic acid, α-aminocycloheptane carboxylic acid, α-(2-amino-2-norbornane)-carboxylic acid, α,γ-diaminobutyric acid, α,β-diaminopropionic acid, homophenylalanine, and α-tert-butylglycine.

[0045] The modified TCRs, polypeptides, and proteins of the invention (including functional portions and functional variants) can be glycosylated, amidated, carboxylated, phosphorylated, esterified, N-acylated, cyclized via, e.g., a disulfide bridge, or converted into an acid addition salt and/or optionally dimerized or polymerized, or conjugated.

[0046] When the modified TCRs, polypeptides, and proteins of the invention (including functional portions and functional variants) are in the form of a salt, preferably, the polypeptides are in the form of a pharmaceutically acceptable salt. Suitable pharmaceutically acceptable acid addition salts include those derived from mineral acids, such as hydrochloric, hydrobromic, phosphoric, metaphosphoric, nitric, and sulphuric acids, and organic acids, such as tartaric, acetic, citric, malic, lactic, fumaric, benzoic, glycolic, gluconic, succinic, and arylsulphonic acids, for example, *p*-toluenesulphonic acid.

[0047] The modified TCR, polypeptide, and/or protein of the invention (including functional portions and functional variants thereof) can be obtained by methods known in the art. Suitable methods of *de novo* synthesizing polypeptides and proteins are described in references, such as Chan et al., Fmoc Solid Phase Peptide Synthesis, Oxford University Press, Oxford, United Kingdom, 2005; Peptide and Protein Drug Analysis, ed. Reid, R., Marcel Dekker, Inc., 2000; Epitope Mapping, ed. Westwoood et al., Oxford University Press, Oxford, United Kingdom, 2000; and U.S. Patent No. 5,449,752. Also, polypeptides and proteins can be recombinantly produced using the nucleic acids described herein using standard recombinant methods. See, for instance, Sambrook et al., Molecular Cloning: A Laboratory Manual, 3rd ed., Cold Spring Harbor Press, Cold Spring Harbor, NY 2001; and

Ausubel et al., Current Protocols in Molecular Biology, Greene Publishing Associates and John Wiley & Sons, NY, 1994. Further, some of the TCRs, polypeptides, and proteins of the invention (including functional portions and functional variants thereof) can be isolated and/or purified from a source, such as a plant, a bacterium, an insect, a mammal, e.g., a rat, a human, etc. Methods of isolation and purification are well-known in the art. Alternatively, the TCRs, polypeptides, and/or proteins described herein (including functional portions and functional variants thereof) can be commercially synthesized by companies, such as Synpep (Dublin, CA), Peptide Technologies Corp. (Gaithersburg, MD), and Multiple Peptide Systems (San Diego, CA). In this respect, the inventive TCRs, polypeptides, and proteins can be synthetic, recombinant, isolated, and/or purified.

[0048] Included in the scope of the invention are conjugates, e.g., bioconjugates, comprising any of the inventive modified TCRs, polypeptides, or proteins (including any of the functional portions or variants thereof), nucleic acids, recombinant expression vectors, host cells, populations of host cells, or antibodies, or antigen binding portions thereof. Conjugates, as well as methods of synthesizing conjugates in general, are known in the art (See, for instance, Hudecz, F., *Methods Mol. Biol.* 298: 209-223 (2005) and Kirin et al., *Inorg Chem.* 44(15): 5405-5415 (2005)).

[0049] Further provided by the invention is a nucleic acid comprising a nucleotide sequence encoding any of the modified TCRs, polypeptides, or proteins described herein (including functional portions and functional variants thereof).

[0050] By "nucleic acid" as used herein includes "polynucleotide," "oligonucleotide," and "nucleic acid molecule," and generally means a polymer of DNA or RNA, which can be single-stranded or double-stranded, synthesized or obtained (e.g., isolated and/or purified) from natural sources, which can contain natural, non-natural or altered nucleotides, and which can contain a natural, non-natural or altered internucleotide linkage, such as a phosphoroamidate linkage or a phosphorothioate linkage, instead of the phosphodiester found between the nucleotides of an unmodified oligonucleotide. It is generally preferred that the nucleic acid does not comprise any insertions, deletions, inversions, and/or substitutions. However, it may be suitable in some instances, as discussed herein, for the nucleic acid to comprise one or more insertions, deletions, inversions, and/or substitutions.

[0051] Preferably, the nucleic acids of the invention are recombinant. As used herein, the term "recombinant" refers to (i) molecules that are constructed outside living cells by joining natural or synthetic nucleic acid segments to nucleic acid molecules that can replicate in a

living cell, or (ii) molecules that result from the replication of those described in (i) above. For purposes herein, the replication can be *in vitro* replication or *in vivo* replication.

[0052] The nucleic acids can be constructed based on chemical synthesis and/or enzymatic ligation reactions using procedures known in the art. See, for example, Sambrook et al., *supra*, and Ausubel et al., *supra*. For example, a nucleic acid can be chemically synthesized using naturally occurring nucleotides or variously modified nucleotides designed to increase the biological stability of the molecules or to increase the physical stability of the duplex formed upon hybridization (e.g., phosphorothioate derivatives and acridine substituted nucleotides). Examples of modified nucleotides that can be used to generate the nucleic acids include, but are not limited to, 5-fluorouracil, 5-bromouracil, 5-chlorouracil, 5-iodouracil, hypoxanthine, xanthine, 4-acetylcytosine, 5-(carboxyhydroxymethyl) uracil, 5-carboxymethylaminomethyl-2-thiouridine, 5-carboxymethylaminomethyluracil, dihydrouracil, beta-D-galactosylqueosine, inosine, N^6-isopentenyladenine, 1-methylguanine, 1-methylinosine, 2,2-dimethylguanine, 2-methyladenine, 2-methylguanine, 3-methylcytosine, 5-methylcytosine, N^6-substituted adenine, 7-methylguanine, 5-methylaminomethyluracil, 5-methoxyaminomethyl-2-thiouracil, beta-D-mannosylqueosine, 5'-methoxycarboxymethyluracil, 5-methoxyuracil, 2-methylthio-N^6-isopentenyladenine, uracil-5-oxyacetic acid (v), wybutoxosine, pseudouracil, queosine, 2-thiocytosine, 5-methyl-2-thiouracil, 2-thiouracil, 4-thiouracil, 5-methyluracil, uracil-5-oxyacetic acid methylester, 3-(3-amino-3-N-2-carboxypropyl) uracil, and 2,6-diaminopurine. Alternatively, one or more of the nucleic acids of the invention can be purchased from companies, such as Macromolecular Resources (Fort Collins, CO) and Synthegen (Houston, TX).

[0053] The nucleic acid can comprise any nucleotide sequence which encodes any of the modified TCRs, polypeptides, or proteins, or functional portions or functional variants thereof. For example, the nucleic acid can comprise a nucleotide sequence comprising SEQ ID NO: 22 to 24, 28, 29, 32, or 33. The nucleotide sequence alternatively can comprise a nucleotide sequence which is degenerate to any of these sequences or a combination of degenerate sequences. For example, the nucleotide sequence can comprise a nucleotide sequence comprising a nucleotide sequence degenerate to SEQ ID NO: 22 and a nucleotide sequence degenerate to SEQ ID NO: 23 or comprising a nucleotide sequence degenerate to SEQ ID NO: 23 and a nucleotide sequence degenerate to SEQ ID NO: 25.

[0054] The invention also provides an isolated or purified nucleic acid comprising a nucleotide sequence which is complementary to the nucleotide sequence of any of the nucleic

acids described herein or a nucleotide sequence which hybridizes under stringent conditions to the nucleotide sequence of any of the nucleic acids described herein.

[0055] The nucleotide sequence which hybridizes under stringent conditions preferably hybridizes under high stringency conditions. By "high stringency conditions" is meant that the nucleotide sequence specifically hybridizes to a target sequence (the nucleotide sequence of any of the nucleic acids described herein) in an amount that is detectably stronger than non-specific hybridization. High stringency conditions include conditions which would distinguish a polynucleotide with an exact complementary sequence, or one containing only a few scattered mismatches from a random sequence that happened to have a few small regions (e.g., 3-10 bases) that matched the nucleotide sequence. Such small regions of complementarity are more easily melted than a full-length complement of 14-17 or more bases, and high stringency hybridization makes them easily distinguishable. Relatively high stringency conditions would include, for example, low salt and/or high temperature conditions, such as provided by about 0.02-0.1 M NaCl or the equivalent, at temperatures of about 50-70 °C. Such high stringency conditions tolerate little, if any, mismatch between the nucleotide sequence and the template or target strand, and are particularly suitable for detecting expression of any of the inventive TCRs. It is generally appreciated that conditions can be rendered more stringent by the addition of increasing amounts of formamide.

[0056] The nucleic acids of the invention can be incorporated into a recombinant expression vector. In this regard, the invention provides recombinant expression vectors comprising any of the nucleic acids of the invention. For purposes herein, the term "recombinant expression vector" means a genetically-modified oligonucleotide or polynucleotide construct that permits the expression of an mRNA, protein, polypeptide, or peptide by a host cell, when the construct comprises a nucleotide sequence encoding the mRNA, protein, polypeptide, or peptide, and the vector is contacted with the cell under conditions sufficient to have the mRNA, protein, polypeptide, or peptide expressed within the cell. The vectors of the invention are not naturally-occurring as a whole. However, parts of the vectors can be naturally-occurring. The inventive recombinant expression vectors can comprise any type of nucleotides, including, but not limited to DNA and RNA, which can be single-stranded or double-stranded, synthesized or obtained in part from natural sources, and which can contain natural, non-natural or altered nucleotides. The recombinant expression vectors can comprise naturally-occurring, non-naturally-occuring internucleotide linkages, or

both types of linkages. Preferably, the non-naturally occurring or altered nucleotides or internucleotide linkages does not hinder the transcription or replication of the vector.

[0057] The recombinant expression vector of the invention can be any suitable recombinant expression vector, and can be used to transform or transfect any suitable host. Suitable vectors include those designed for propagation and expansion or for expression or both, such as plasmids and viruses. The vector can be selected from the group consisting of the pUC series (Fermentas Life Sciences), the pBluescript series (Stratagene, LaJolla, CA), the pET series (Novagen, Madison, WI), the pGEX series (Pharmacia Biotech, Uppsala, Sweden), and the pEX series (Clontech, Palo Alto, CA). Bacteriophage vectors, such as λGT10, λGT11, λZapII (Stratagene), λEMBL4, and λNM1149, also can be used. Examples of plant expression vectors include pBI01, pBI101.2, pBI101.3, pBI121 and pBIN19 (Clontech). Examples of animal expression vectors include pEUK-Cl, pMAM and pMAMneo (Clontech). Preferably, the recombinant expression vector is a viral vector, e.g., a retroviral vector.

[0058] The recombinant expression vectors of the invention can be prepared using standard recombinant DNA techniques described in, for example, Sambrook et al., *supra*, and Ausubel et al., *supra*. Constructs of expression vectors, which are circular or linear, can be prepared to contain a replication system functional in a prokaryotic or eukaryotic host cell. Replication systems can be derived, e.g., from ColEl, 2 μ plasmid, λ, SV40, bovine papilloma virus, and the like.

[0059] Desirably, the recombinant expression vector comprises regulatory sequences, such as transcription and translation initiation and termination codons, which are specific to the type of host (e.g., bacterium, fungus, plant, or animal) into which the vector is to be introduced, as appropriate and taking into consideration whether the vector is DNA- or RNA-based.

[0060] The recombinant expression vector can include one or more marker genes, which allow for selection of transformed or transfected hosts. Marker genes include biocide resistance, e.g., resistance to antibiotics, heavy metals, etc., complementation in an auxotrophic host to provide prototrophy, and the like. Suitable marker genes for the inventive expression vectors include, for instance, neomycin/G418 resistance genes, hygromycin resistance genes, histidinol resistance genes, tetracycline resistance genes, and ampicillin resistance genes.

[0061] The recombinant expression vector can comprise a native or nonnative promoter operably linked to the nucleotide sequence encoding the modified TCR, polypeptide, or protein (including functional portions and functional variants thereof), or to the nucleotide sequence which is complementary to or which hybridizes to the nucleotide sequence encoding the modified TCR, polypeptide, or protein. The selection of promoters, e.g., strong, weak, inducible, tissue-specific and developmental-specific, is within the ordinary skill of the artisan. Similarly, the combining of a nucleotide sequence with a promoter is also within the skill of the artisan. The promoter can be a non-viral promoter or a viral promoter, e.g., a cytomegalovirus (CMV) promoter, an SV40 promoter, an RSV promoter, and a promoter found in the long-terminal repeat of the murine stem cell virus.

[0062] The inventive recombinant expression vectors can be designed for either transient expression, for stable expression, or for both. Also, the recombinant expression vectors can be made for constitutive expression or for inducible expression.

[0063] Further, the recombinant expression vectors can be made to include a suicide gene. As used herein, the term "suicide gene" refers to a gene that causes the cell expressing the suicide gene to die. The suicide gene can be a gene that confers sensitivity to an agent, e.g., a drug, upon the cell in which the gene is expressed, and causes the cell to die when the cell is contacted with or exposed to the agent. Suicide genes are known in the art (see, for example, Suicide Gene Therapy: Methods and Reviews, Springer, Caroline J. (Cancer Research UK Centre for Cancer Therapeutics at the Institute of Cancer Research, Sutton, Surrey, UK), Humana Press, 2004) and include, for example, the Herpes Simplex Virus (HSV) thymidine kinase (TK) gene, cytosine daminase, purine nucleoside phosphorylase, and nitroreductase.

[0064] The invention further provides a host cell comprising any of the recombinant expression vectors described herein. As used herein, the term "host cell" refers to any type of cell that can contain the inventive recombinant expression vector. The host cell can be a eukaryotic cell, e.g., plant, animal, fungi, or algae, or can be a prokaryotic cell, e.g., bacteria or protozoa. The host cell can be a cultured cell or a primary cell, i.e., isolated directly from an organism, e.g., a human. The host cell can be an adherent cell or a suspended cell, i.e., a cell that grows in suspension. Suitable host cells are known in the art and include, for instance, DH5α *E. coli* cells, Chinese hamster ovarian cells, monkey VERO cells, COS cells, HEK293 cells, and the like. For purposes of amplifying or replicating the recombinant expression vector, the host cell is preferably a prokaryotic cell, e.g., a DH5α cell. For

purposes of producing a recombinant modified TCR, polypeptide, or protein, the host cell is preferably a mammalian cell. Most preferably, the host cell is a human cell. While the host cell can be of any cell type, can originate from any type of tissue, and can be of any developmental stage, the host cell preferably is a peripheral blood lymphocyte (PBL). More preferably, the host cell is a T cell.

[0065] For purposes herein, the T cell can be any T cell, such as a cultured T cell, e.g., a primary T cell, or a T cell from a cultured T cell line, e.g., Jurkat, SupT1, etc., or a T cell obtained from a mammal. If obtained from a mammal, the T cell can be obtained from numerous sources, including but not limited to blood, bone marrow, lymph node, the thymus, or other tissues or fluids. T cells can also be enriched for or purified. Preferably, the T cell is a human T cell. More preferably, the T cell is a T cell isolated from a human. The T cell can be any type of T cell and can be of any developmental stage, including but not limited to, $CD4^+/CD8^+$ double positive T cells, $CD4^+$ helper T cells, e.g., Th_1 and Th_2 cells, $CD8^+$ T cells (e.g., cytotoxic T cells), peripheral blood mononuclear cells (PBMCs), peripheral blood leukocytes (PBLs), tumor infiltrating cells (TILs), memory T cells, naïve T cells, and the like. Preferably, the T cell is a $CD8^+$ T cell or a $CD4^+$ T cell.

[0066] Also provided by the invention is a population of cells comprising at least one host cell described herein. The population of cells can be a heterogeneous population comprising the host cell comprising any of the recombinant expression vectors described, in addition to at least one other cell, e.g., a host cell (e.g., a T cell), which does not comprise any of the recombinant expression vectors, or a cell other than a T cell, e.g., a B cell, a macrophage, a neutrophil, an erythrocyte, a hepatocyte, an endothelial cell, an epithelial cells, a muscle cell, a brain cell, etc. Alternatively, the population of cells can be a substantially homogeneous population, in which the population comprises mainly of host cells (e.g., consisting essentially of) comprising the recombinant expression vector. The population also can be a clonal population of cells, in which all cells of the population are clones of a single host cell comprising a recombinant expression vector, such that all cells of the population comprise the recombinant expression vector. In one embodiment of the invention, the population of cells is a clonal population comprising host cells comprising a recombinant expression vector as described herein.

[0067] The invention further provides an antibody, or antigen binding portion thereof, which specifically binds to an epitope of the modified TCR of the invention, wherein the epitope comprises the amino acid substitutions. The antibody can be any type of

immunoglobulin that is known in the art. For instance, the antibody can be of any isotype, e.g., IgA, IgD, IgE, IgG, IgM, etc. The antibody can be monoclonal or polyclonal. The antibody can be a naturally-occurring antibody, e.g., an antibody isolated and/or purified from a mammal, e.g., mouse, rabbit, goat, horse, chicken, hamster, human, etc. Alternatively, the antibody can be a genetically-engineered antibody, e.g., a humanized antibody or a chimeric antibody. The antibody can be in monomeric or polymeric form. Also, the antibody can have any level of affinity or avidity for the functional portion of the inventive modified TCR. Desirably, the antibody is specific for the epitope of the inventive modified TCR comprising the amino acid substitutions, such that there is minimal cross-reaction with other peptides or proteins.

[0068] Methods of testing antibodies for the ability to bind to any functional portion of the inventive modified TCR are known in the art and include any antibody-antigen binding assay, such as, for example, radioimmunoassay (RIA), ELISA, Western blot, immunoprecipitation, and competitive inhibition assays (see, e.g., Janeway et al., *infra*, and U.S. Patent Application Publication No. 2002/0197266 A1).

[0069] Suitable methods of making antibodies are known in the art. For instance, standard hybridoma methods are described in, e.g., Köhler and Milstein, *Eur. J.* Immunol., *5*, 511-519 (1976), Harlow and Lane (eds.), *Antibodies: A Laboratory Manual*, CSH Press (1988), and C.A. Janeway et al. (eds.), *Immunobiology*, 5th Ed., Garland Publishing, New York, NY (2001)). Alternatively, other methods, such as EBV-hybridoma methods (Haskard and Archer, *J. Immunol. Methods*, *74*(2), 361-67 (1984), and Roder et al., *Methods Enzymol.*, *121*, 140-67 (1986)), and bacteriophage vector expression systems (see, e.g., Huse et al., *Science*, *246*, 1275-81 (1989)) are known in the art. Further, methods of producing antibodies in non-human animals are described in, e.g., U.S. Patents 5,545,806, 5,569,825, and 5,714,352, and U.S. Patent Application Publication No. 2002/0197266 A1).

[0070] Phage display furthermore can be used to generate the antibody of the invention. In this regard, phage libraries encoding antigen-binding variable (V) domains of antibodies can be generated using standard molecular biology and recombinant DNA techniques (see, e.g., Sambrook et al. (eds.), *Molecular Cloning, A Laboratory Manual*, 3rd Edition, Cold Spring Harbor Laboratory Press, New York (2001)). Phage encoding a variable region with the desired specificity are selected for specific binding to the desired antigen, and a complete or partial antibody is reconstituted comprising the selected variable domain. Nucleic acid sequences encoding the reconstituted antibody are introduced into a suitable cell line, such as

a myeloma cell used for hybridoma production, such that antibodies having the characteristics of monoclonal antibodies are secreted by the cell (see, e.g., Janeway et al., *supra*, Huse et al., *supra*, and U.S. Patent 6,265,150).

[0071] Antibodies can be produced by transgenic mice that are transgenic for specific heavy and light chain immunoglobulin genes. Such methods are known in the art and described in, for example U.S. Patents 5,545,806 and 5,569,825, and Janeway et al., *supra*.

[0072] Methods for generating humanized antibodies are well known in the art and are described in detail in, for example, Janeway et al., *supra*, U.S. Patents 5,225,539, 5,585,089 and 5,693,761, European Patent No. 0239400 B1, and United Kingdom Patent No. 2188638. Humanized antibodies can also be generated using the antibody resurfacing technology described in U.S. Patent 5,639,641 and Pedersen et al., *J. Mol. Biol.*, *235*, 959-973 (1994).

[0073] The invention also provides antigen binding portions of any of the antibodies described herein. The antigen binding portion can be any portion that has at least one antigen binding site, such as Fab, $F(ab')_2$, dsFv, sFv, diabodies, and triabodies.

[0074] A single-chain variable region fragment (sFv) antibody fragment, which consists of a truncated Fab fragment comprising the variable (V) domain of an antibody heavy chain linked to a V domain of a light antibody chain via a synthetic peptide, can be generated using routine recombinant DNA technology techniques (see, e.g., Janeway et al., *supra*). Similarly, disulfide-stabilized variable region fragments (dsFv) can be prepared by recombinant DNA technology (see, e.g., Reiter et al., *Protein Engineering*, *7*, 697-704 (1994)). Antibody fragments of the invention, however, are not limited to these exemplary types of antibody fragments.

[0075] Also, the antibody, or antigen binding portion thereof, can be modified to comprise a detectable label, such as, for instance, a radioisotope, a fluorophore (e.g., fluorescein isothiocyanate (FITC), phycoerythrin (PE)), an enzyme (e.g., alkaline phosphatase, horseradish peroxidase), and element particles (e.g., gold particles).

[0076] The inventive modified TCRs, polypeptides, proteins, (including functional portions and functional variants thereof), nucleic acids, recombinant expression vectors, host cells (including populations thereof), and antibodies (including antigen binding portions thereof), can be isolated and/or purified. The term "isolated" as used herein means having been removed from its natural environment. The term "purified" as used herein means having been increased in purity, wherein "purity" is a relative term, and not to be necessarily

construed as absolute purity. For example, the purity can be at least about 50%, can be greater than 60%, 70% or 80%, or can be 100%.

[0077] The inventive modified TCRs, polypeptides, proteins (including functional portions and variants thereof), nucleic acids, recombinant expression vectors, host cells (including populations thereof), and antibodies (including antigen binding portions thereof), all of which are collectively referred to as "inventive TCR materials" hereinafter, can be formulated into a composition, such as a pharmaceutical composition. In this regard, the invention provides a pharmaceutical composition comprising any of the modified TCRs, polypeptides, proteins, functional portions, functional variants, nucleic acids, expression vectors, host cells (including populations thereof), and antibodies (including antigen binding portions thereof), and a pharmaceutically acceptable carrier. The inventive pharmaceutical compositions containing any of the inventive TCR materials can comprise more than one inventive TCR material, e.g., a polypeptide and a nucleic acid, or two or more different modified TCRs. Alternatively, the pharmaceutical composition can comprise an inventive TCR material in combination with another pharmaceutically active agents or drugs, such as a chemotherapeutic agents, e.g., asparaginase, busulfan, carboplatin, cisplatin, daunorubicin, doxorubicin, fluorouracil, gemcitabine, hydroxyurea, methotrexate, paclitaxel, rituximab, vinblastine, vincristine, etc.

[0078] With respect to pharmaceutical compositions, the pharamaceutically acceptable carrier can be any of those conventionally used and is limited only by chemico-physical considerations, such as solubility and lack of reactivity with the active compound(s), and by the route of administration. The pharmaceutically acceptable carriers described herein, for example, vehicles, adjuvants, excipients, and diluents, are well-known to those skilled in the art and are readily available to the public. It is preferred that the pharmaceutically acceptable carrier be one which is chemically inert to the active agent(s) and one which has no detrimental side effects or toxicity under the conditions of use.

[0079] The choice of carrier will be determined in part by the particular inventive TCR material, as well as by the particular method used to administer the inventive TCR material. Accordingly, there are a variety of suitable formulations of the pharmaceutical composition of the invention. The following formulations for oral, aerosol, parenteral, subcutaneous, intravenous, intramuscular, intraarterial, intrathecal, interperitoneal, rectal, and vaginal administration are exemplary and are in no way limiting. More than one route can be used to

administer the inventive TCR materials, and in certain instances, a particular route can provide a more immediate and more effective response than another route.

[0080] Topical formulations are well-known to those of skill in the art. Such formulations are particularly suitable in the context of the invention for application to the skin.

[0081] Formulations suitable for oral administration can consist of (a) liquid solutions, such as an effective amount of the inventive TCR material dissolved in diluents, such as water, saline, or orange juice; (b) capsules, sachets, tablets, lozenges, and troches, each containing a predetermined amount of the active ingredient, as solids or granules; (c) powders; (d) suspensions in an appropriate liquid; and (e) suitable emulsions. Liquid formulations may include diluents, such as water and alcohols, for example, ethanol, benzyl alcohol, and the polyethylene alcohols, either with or without the addition of a pharmaceutically acceptable surfactant. Capsule forms can be of the ordinary hard- or soft-shelled gelatin type containing, for example, surfactants, lubricants, and inert fillers, such as lactose, sucrose, calcium phosphate, and corn starch. Tablet forms can include one or more of lactose, sucrose, mannitol, corn starch, potato starch, alginic acid, microcrystalline cellulose, acacia, gelatin, guar gum, colloidal silicon dioxide, croscarmellose sodium, talc, magnesium stearate, calcium stearate, zinc stearate, stearic acid, and other excipients, colorants, diluents, buffering agents, disintegrating agents, moistening agents, preservatives, flavoring agents, and other pharmacologically compatible excipients. Lozenge forms can comprise the inventive TCR material in a flavor, usually sucrose and acacia or tragacanth, as well as pastilles comprising the inventive TCR material in an inert base, such as gelatin and glycerin, or sucrose and acacia, emulsions, gels, and the like containing, in addition to, such excipients as are known in the art.

[0082] The inventive TCR material, alone or in combination with other suitable components, can be made into aerosol formulations to be administered via inhalation. These aerosol formulations can be placed into pressurized acceptable propellants, such as dichlorodifluoromethane, propane, nitrogen, and the like. They also may be formulated as pharmaceuticals for non-pressured preparations, such as in a nebulizer or an atomizer. Such spray formulations also may be used to spray mucosa.

[0083] Formulations suitable for parenteral administration include aqueous and non-aqueous, isotonic sterile injection solutions, which can contain anti-oxidants, buffers, bacteriostats, and solutes that render the formulation isotonic with the blood of the intended

recipient, and aqueous and non-aqueous sterile suspensions that can include suspending agents, solubilizers, thickening agents, stabilizers, and preservatives. The inventive TCR material can be administered in a physiologically acceptable diluent in a pharmaceutical carrier, such as a sterile liquid or mixture of liquids, including water, saline, aqueous dextrose and related sugar solutions, an alcohol, such as ethanol or hexadecyl alcohol, a glycol, such as propylene glycol or polyethylene glycol, dimethylsulfoxide, glycerol, ketals such as 2,2-dimethyl-1,3-dioxolane-4-methanol, ethers, poly(ethyleneglycol) 400, oils, fatty acids, fatty acid esters or glycerides, or acetylated fatty acid glycerides with or without the addition of a pharmaceutically acceptable surfactant, such as a soap or a detergent, suspending agent, such as pectin, carbomers, methylcellulose, hydroxypropylmethylcellulose, or carboxymethylcellulose, or emulsifying agents and other pharmaceutical adjuvants.

[0084] Oils, which can be used in parenteral formulations include petroleum, animal, vegetable, or synthetic oils. Specific examples of oils include peanut, soybean, sesame, cottonseed, corn, olive, petrolatum, and mineral. Suitable fatty acids for use in parenteral formulations include oleic acid, stearic acid, and isostearic acid. Ethyl oleate and isopropyl myristate are examples of suitable fatty acid esters.

[0085] Suitable soaps for use in parenteral formulations include fatty alkali metal, ammonium, and triethanolamine salts, and suitable detergents include (a) cationic detergents such as, for example, dimethyl dialkyl ammonium halides, and alkyl pyridinium halides, (b) anionic detergents such as, for example, alkyl, aryl, and olefin sulfonates, alkyl, olefin, ether, and monoglyceride sulfates, and sulfosuccinates, (c) nonionic detergents such as, for example, fatty amine oxides, fatty acid alkanolamides, and polyoxyethylenepolypropylene copolymers, (d) amphoteric detergents such as, for example, alkyl-β-aminopropionates, and 2-alkyl-imidazoline quaternary ammonium salts, and (e) mixtures thereof.

[0086] The parenteral formulations will typically contain from about 0.5% to about 25% by weight of the inventive TCR material in solution. Preservatives and buffers may be used. In order to minimize or eliminate irritation at the site of injection, such compositions may contain one or more nonionic surfactants having a hydrophile-lipophile balance (HLB) of from about 12 to about 17. The quantity of surfactant in such formulations will typically range from about 5% to about 15% by weight. Suitable surfactants include polyethylene glycol sorbitan fatty acid esters, such as sorbitan monooleate and the high molecular weight adducts of ethylene oxide with a hydrophobic base, formed by the condensation of propylene oxide with propylene glycol. The parenteral formulations can be presented in unit-dose or

multi-dose sealed containers, such as ampoules and vials, and can be stored in a freeze-dried (lyophilized) condition requiring only the addition of the sterile liquid excipient, for example, water, for injections, immediately prior to use. Extemporaneous injection solutions and suspensions can be prepared from sterile powders, granules, and tablets of the kind previously described.

[0087] Injectable formulations are in accordance with the invention. The requirements for effective pharmaceutical carriers for injectable compositions are well-known to those of ordinary skill in the art (see, e.g., *Pharmaceutics and Pharmacy Practice*, J.B. Lippincott Company, Philadelphia, PA, Banker and Chalmers, eds., pages 238-250 (1982), and *ASHP Handbook on Injectable Drugs*, Toissel, 4th ed., pages 622-630 (1986)). Preferably, when administering cells, e.g., dendritic cells, the cells are administered via injection.

[0088] Additionally, the inventive TCR materials, or compositions comprising such inventive TCR materials, can be made into suppositories by mixing with a variety of bases, such as emulsifying bases or water-soluble bases. Formulations suitable for vaginal administration can be presented as pessaries, tampons, creams, gels, pastes, foams, or spray formulas containing, in addition to the active ingredient, such carriers as are known in the art to be appropriate.

[0089] It will be appreciated by one of skill in the art that, in addition to the above-described pharmaceutical compositions, the inventive TCR materials of the invention can be formulated as inclusion complexes, such as cyclodextrin inclusion complexes, or liposomes.

[0090] For purposes of the invention, the amount or dose of the inventive TCR material administered should be sufficient to effect, e.g., a therapeutic or prophylactic response, in the subject or animal over a reasonable time frame. For example, the dose of the inventive TCR material should be sufficient to bind to antigen, or detect, treat or prevent disease in a period of from about 2 hours or longer, e.g., 12 to 24 or more hours, from the time of administration. In certain embodiments, the time period could be even longer. The dose will be determined by the efficacy of the particular inventive TCR material and the condition of the animal (e.g., human), as well as the body weight of the animal (e.g., human) to be treated.

[0091] Many assays for determining an administered dose are known in the art. For purposes of the invention, an assay, which comprises comparing the extent to which target cells are lysed or IFN-γ is secreted by T cells expressing the inventive modified TCR, polypeptide, or protein upon administration of a given dose of such T cells to a mammal among a set of mammals of which is each given a different dose of the T cells, could be used

to determine a starting dose to be administered to a mammal. The extent to which target cells are lysed or IFN-γ is secreted upon administration of a certain dose can be assayed by methods known in the art, including, for instance, the methods described herein as Example 2.

[0092] The dose of the inventive TCR material also will be determined by the existence, nature and extent of any adverse side effects that might accompany the administration of a particular inventive TCR material. Typically, the attending physician will decide the dosage of the inventive TCR material with which to treat each individual patient, taking into consideration a variety of factors, such as age, body weight, general health, diet, sex, inventive TCR material to be administered, route of administration, and the severity of the condition being treated. By way of example and not intending to limit the invention, the dose of the inventive TCR material can be about 0.001 to about 1000 mg/kg body weight of the subject being treated/day, from about 0.01 to about 10 mg/kg body weight/day, about 0.01 mg to about 1 mg/kg body weight/day.

[0093] One of ordinary skill in the art will readily appreciate that the inventive TCR materials of the invention can be modified in any number of ways, such that the therapeutic or prophylactic efficacy of the inventive TCR materials is increased through the modification. For instance, the inventive TCR materials can be conjugated either directly or indirectly through a linker to a targeting moiety. The practice of conjugating compounds, e.g., inventive TCR materials, to targeting moieties is known in the art. See, for instance, Wadwa et al., *J. Drug Targeting* 3: 111 (1995) and U.S. Patent No. 5,087,616. The term "targeting moiety" as used herein, refers to any molecule or agent that specifically recognizes and binds to a cell-surface receptor, such that the targeting moiety directs the delivery of the inventive TCR materials to a population of cells on which surface the receptor is expressed. Targeting moieties include, but are not limited to, antibodies, or fragments thereof, peptides, hormones, growth factors, cytokines, and any other natural or non-natural ligands, which bind to cell surface receptors (e.g., Epithelial Growth Factor Receptor (EGFR), T-cell receptor (TCR), B-cell receptor (BCR), CD28, Platelet-derived Growth Factor Receptor (PDGF), nicotinic acetylcholine receptor (nAChR), etc.). The term "linker" as used herein, refers to any agent or molecule that bridges the inventive TCR materials to the targeting moiety. One of ordinary skill in the art recognizes that sites on the inventive TCR materials, which are not necessary for the function of the inventive TCR materials, are ideal sites for attaching a linker and/or a targeting moiety, provided that the linker and/or targeting moiety, once attached to

the inventive TCR materials, do(es) not interfere with the function of the inventive TCR materials, i.e., the ability to bind to antigen, or to detect, treat, or prevent disease.

[0094] Alternatively, the inventive TCR materials can be modified into a depot form, such that the manner in which the inventive TCR materials is released into the body to which it is administered is controlled with respect to time and location within the body (see, for example, U.S. Patent No. 4,450,150). Depot forms of inventive TCR materials can be, for example, an implantable composition comprising the inventive TCR materials and a porous or non-porous material, such as a polymer, wherein the inventive TCR materials is encapsulated by or diffused throughout the material and/or degradation of the non-porous material. The depot is then implanted into the desired location within the body and the inventive TCR materials are released from the implant at a predetermined rate.

[0095] It is contemplated that the inventive pharmaceutical compositions, modified TCRs, polypeptides, proteins, nucleic acids, recombinant expression vectors, host cells, or populations of cells can be used in methods of treating or preventing a disease in a host. Without being bound to a particular theory, the inventive modified TCRs are believed to have enhanced biological activity, e.g., ability to recognize antigen, such that the modified TCR (or related inventive polypeptide or protein) when expressed by a cell is able to mediate a stronger immune response against the cell expressing the antigen for which the modified TCR is specific. In this regard, the invention provides a method of treating or preventing a disease in a host, comprising administering to the host any of the pharmaceutical compositions in an amount effective to treat or prevent the disease in the host.

[0096] The disease can be any disease involving an antigen, e.g., an infectious disease, an autoimmune disease, a cancer.

[0097] For purposes herein, "infectious disease" means a disease that can be transmitted from person to person or from organism to organism, and is caused by a microbial agent (e.g., common cold). Infectious diseases are known in the art and include, for example, hepatitis, sexually transmitted diseases (e.g., Chlamydia, gonorrhea), tuberculosis, HIV/AIDS, diphtheria, hepatitis B, hepatitis C, cholera, and influenza.

[0098] For purposes herein, "autoimmune disease" refers to a disease in which the body produces an immunogenic (i.e., immune system) response to some constituent of its own tissue. In other words the immune system loses its ability to recognize some tissue or system within the body as "self" and targets and attacks it as if it were foreign. Autoimmune diseases can be classified into those in which predominantly one organ is affected (e.g.,

hemolytic anemia and anti-immune thyroiditis), and those in which the autoimmune disease process is diffused through many tissues (e.g., systemic lupus erythematosus). For example, multiple sclerosis is thought to be caused by T cells attacking the sheaths that surround the nerve fibers of the brain and spinal cord. This results in loss of coordination, weakness, and blurred vision. Autoimmune diseases are known in the art and include, for instance, Hashimoto's thyroiditis, Grave's disease, lupus, multiple sclerosis, rheumatic arthritis, hemolytic anemia, anti-immune thyroiditis, systemic lupus erythematosus, celiac disease, Crohn's disease, colitis, diabetes, scleroderma, psoriasis, and the like.

[0099] With respect to the inventive methods, the cancer can be any cancer, including any of acute lymphocytic cancer, acute myeloid leukemia, alveolar rhabdomyosarcoma, bone cancer, brain cancer, breast cancer, cancer of the anus, anal canal, or anorectum, cancer of the eye, cancer of the intrahepatic bile duct, cancer of the joints, cancer of the neck, gallbladder, or pleura, cancer of the nose, nasal cavity, or middle ear, cancer of the oral cavity, cancer of the vulva, chronic lymphocytic leukemia, chronic myeloid cancer, colon cancer, esophageal cancer, cervical cancer, gastrointestinal carcinoid tumor. Hodgkin lymphoma, hypopharynx cancer, kidney cancer, larynx cancer, liver cancer, lung cancer, malignant mesothelioma, melanoma, multiple myeloma, nasopharynx cancer, non-Hodgkin lymphoma, ovarian cancer, pancreatic cancer, peritoneum, omentum, and mesentery cancer, pharynx cancer, prostate cancer, rectal cancer, renal cancer (e.g., renal cell carcinoma (RCC)), small intestine cancer, soft tissue cancer, stomach cancer, testicular cancer, thyroid cancer, ureter cancer, and urinary bladder cancer. Preferably, the cancer is melanoma.

[0100] The terms "treat," and "prevent" as well as words stemming therefrom, as used herein, do not necessarily imply 100% or complete treatment or prevention. Rather, there are varying degrees of treatment or prevention of which one of ordinary skill in the art recognizes as having a potential benefit or therapeutic effect. In this respect, the inventive methods can provide any amount of any level of treatment or prevention of cancer in a mammal. Furthermore, the treatment or prevention provided by the inventive method can include treatment or prevention of one or more conditions or symptoms of the disease, e.g., cancer, being treated or prevented. Also, for purposes herein, "prevention" can encompass delaying the onset of the disease, or a symptom or condition thereof.

[0101] Also provided is a method of detecting a diseased cell in a host, wherein the diseased cell expresses an antigen characteristic of a disease. The method comprises (i) contacting a sample comprising cells of the host with any of the inventive modified TCRs,

polypeptides, proteins, nucleic acids, recombinant expression vectors, host cells, and populations of host cells described herein, thereby forming a complex between the antigen which is characteristic of the disease and the inventive modified TCR, polypeptide, protein, nucleic acid, recombinant expression vector, host cell, or population of cells, and (ii) detecting the complex, wherein detection of the complex is indicative of a diseased cell in the host.

[0102] The diseased cell can be any cell of any disease, which cell expresses an antigen that is characteristic of the disease. The diseased cell can be a cancer cell or an infected cell, for example. Preferably, the diseased cell is a melanoma cell

[0103] In the method of treating or preventing a disease or of detecting a diseased cell, the inventive modified TCR has antigenic specificity for an antigen that is characteristic of the disease to be treated, prevented, or detected. For instance, if the disease to be treated, prevented or detected is melanoma, the inventive modified TCR has antigenic specificity for a melanoma antigen, e.g., MART-1, NY-ESO-1, gp100, etc. If a host cell or a population comprising at least one host cell is used in the method, the host cell desirably expresses a TCR having antigenic specificity for the antigen of the disease. If an inventive nucleic acid or recombinant expression vector is used in the method, the nucleic acid or recombinant expression vector desirably encodes the modified TCR which has antigenic specificity for an antigen of the disease to be treated, prevented, or detected, such that expression of the nucleic acid or recombinant expression vector is achieved in a cell and the TCR expressed by the cell is capable of binding to the antigen of the disease.

[0104] With respect to the inventive method of detecting a diseased cell in a host, the sample comprising cells of the host can be a sample comprising whole cells, lysates thereof, or a fraction of the whole cell lysates, e.g., a nuclear or cytoplasmic fraction, a whole protein fraction, or a nucleic acid fraction. If the sample comprises whole cells, the cells can be any cells of the host, e.g., the cells of any organ or tissue, including blood cells.

[0105] For purposes of the inventive detecting method, the contacting step can take place *in vitro* or *in vivo* with respect to the host. Preferably, the contacting is an *in vitro* step.

[0106] Also, detection of the complex can occur through any number of ways known in the art. For instance, the inventive modified TCRs, polypeptides, proteins, nucleic acids, recombinant expression vectors, host cells, populations of cells, or antibodies, or antigen binding portions thereof, described herein, can be labeled with a detectable label such as, for instance, a radioisotope, a fluorophore (e.g., fluorescein isothiocyanate (FITC), phycoerythrin

(PE)), an enzyme (e.g., alkaline phosphatase, horseradish peroxidase), and element particles (e.g., gold particles).

[0107] For purposes of the inventive methods, wherein host cells or populations of cells are administered to the host, the cells can be cells that are allogeneic or autologous to the host. Preferably, the cells are autologous to the host.

[0108] The host referred to herein can be any host. Preferably, the host is a mammal. As used herein, the term "mammal" refers to any mammal, including, but not limited to, mammals of the order Rodentia, such as mice and hamsters, and mammals of the order Logomorpha, such as rabbits. It is preferred that the mammals are from the order Carnivora, including Felines (cats) and Canines (dogs). It is more preferred that the mammals are from the order Artiodactyla, including Bovines (cows) and Swines (pigs) or of the order Perssodactyla, including Equines (horses). It is most preferred that the mammals are of the order Primates, Ceboids, or Simoids (monkeys) or of the order Anthropoids (humans and apes). An especially preferred mammal is the human.

[0109] A method of identifying a candidate adoptive immunotherapy TCR is also provided. The method consists of (a) producing a nucleic acid encoding a modified TCR comprising a WT TCR amino acid sequence with no more than three amino acid substitutions, (b) expressing the nucleic acid in CD4+ T cells and CD8+ T cells, and (c) assaying the T cells for the ability to recognize target cells and for antigen specificity. A candidate adoptive immunotherapy TCR is identified when the modified TCR, as compared to the WT TCR, (i) has an enhanced ability to recognize target cells when expressed in CD4+ T cells and (ii) does not exhibit a decrease in antigen specificity when expressed by CD8+ T cells.

[0110] The term "candidate adoptive immunotherapy TCR" as used herein refers to a modified TCR which comprises an amino acid sequence of a WT TCR with no more than three amino acid substitutions and, as compared to the WT TCR (i) has an enhanced ability recognize target cells when expressed in CD4+ T cells and (ii) does not exhibit a decrease in antigen specificity when expressed by CD8+ T cells. Such candidate cells are predicted to work well in the context of adoptive immunotherapy, such that the TCR, when expressed in T cells of a patient, will be able to treat or prevent a disease of the patient.

[0111] Producing a nucleic acid encoding a modified TCR can be carried out by any means known in the art. For instance, Examples 2 to 4 describe methods of making such a nucleic acid in which a WT TCR sequence is used as a template for a PCR reaction which

utilizes primers which encode the amino acid substitutions. The resulting PCR product, which encodes the amino acid mutations is then in vitro transcribed, thereby producing an RNA encoding the modified TCR. Alternatively, the nucleic acid can be produced by other means, e.g., site directed mutagenesis.

[0112] With respect to the method of identifying a candidate adoptive immunotherapy TCR, the amino acid substitutions preferably are conservative amino acid substitutions. More preferably, the amino acid substitutions are located within a CDR of the TCR, e.g., CDR1, CDR2, CDR3. Most preferably, the amino acid substitutions are located within the CDR2 of a β chain of the TCR. Also, with regard to this method, the modified TCR has at least twice the ability to recognize target cells as the WT TCR and exhibits this enhanced ability in at least two assays.

[0113] Methods of expressing nucleic acids in cells (including CD4+ T cells and CD8+ T cells) are known in the art, as discussed herein. Preferably, the nucleic acid is an RNA and the RNA is expressed in T cells by methods described in Example 2.

[0114] The T cells can be assayed for the ability to recognize target cells and for antigen specificity employing methods known in the art. Preferably, the T cells are assayed as described herein as Example 2.

EXAMPLES

[0115] The following examples further illustrate the invention but, of course, should not be construed as in any way limiting its scope.

[0116] The following examples describe the amino acid substitutions of the modified TCRs with respect to the immature TCR sequence (i.e., the TCR sequence with the leader sequence).

EXAMPLE 1

[0117] This example demonstrates a method of making a modified TCR of the invention.

[0118] The WT 1G4 alpha and beta chains were isolated using RT-PCR. The RT reaction was carried out as described in Huang et al., *J. Immunol.*, 172: 6057-6064 (2004), and the fragments were amplified using a high fidelity DNA polymerase, Fusion (New

England Biolabs) according to the manufacturer's instructions. Specifically, the WT 1G4 β chain was isolated by RT-PCR from an *in vitro* cultured tumor infiltrating lymphocytes (TIL) sample isolated from a melanoma patient using two primer pairs: the first pair (Primers A and B) was used to isolate the variable region sequence but also contained sequences corresponding to the appropriate J region, while the second primer pair (Primers C and D) was used to isolate the full length constant region but also encoded the J region to allow an overlap with the sequence amplified using the first primer pair. The full length construct encoding the β chain was generated by isolation of the two PCR products on an agarose gel, which products were then mixed and used to carry out a second round of amplification using Primers E and F.

[0119] The 1G4 TR α chain was constructed by RT-PCR from an *in vitro* cultured TIL sample of using two primer pairs: the first pair (Primers G and H) was used to isolate the 1G4 α chain variable region sequence including part of the J region, while the second pair (Primers I and J) was used to isolate the 1G4 α chain constant region but also encoded the J region. The full length construct encoding the α chain was generated by isolation of the two PCR products on an agarose gel, which were then mixed and used to carry out a second round of amplification using Primers K and L. The sequences of the primers used to obtain the WT 1G4 nucleic acid are set forth in Table 1.

TABLE 1

Name	Primer	Sequence	SEQ ID NO
β chain 5' fragment	A	GACTAATTAACCCTCACTAAAGGGACACCATGAGCATCGGCCTCCTGTG	40
	B	CTCCCCGGTGTTCCCGACGTAACTGCTGGCACAGAAGTAC	41
β chain 3' fragment	C	CAGCAGTTACGTCGGGAACACCGGGGAGCTGTTTTTGGAGAAG	42
	D	TTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTT TCAGCCTCTGGAATCCTTTCTCTTGA	43
β chain full length Primers	E	GACTAATTAACCCTCACTAAAGGGACACCATGAGCATCGGCCTCCTGTG	44
	F	TTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTT TCAGCCTCTGGAATCCTTTCTCT	45
α chain 5' fragment	G	CTGGTTCCTCTTCCAAATGTAGGTATGTAGCTTCCTCCTGATGTGGGCCTCACAGCAC AGAGGTAGG	46
	H	GACTAATTAACCCTCACTAAAGGGACACCATGGAGACCCTCTTGGGC	47
α chain 3' fragment	I	CTACATACCTACATTTGGAAGAGGAACCAGCCTTATTGTTCATCCGTATATCCAGAA CCCTGACCC	48
	J	TTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTT TCAGCTGGACCACAGCCGCAGCGTC	49
α chain full length Primers	K	GACTAATTAACCCTCACTAAAGGGACACCATGGAGACCCTCTTGGGC	50
	L	TTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTT TCAGCTGGACCACAGCCGCAGCG	51

[0120] The nucleotide sequence of the 1G4 TCR obtained is set forth as SEQ ID NO: 25 (alpha chain) and SEQ ID NO: 21 (beta chain). For generation of each mutant 1G4 TCR, a 5' fragment and a 3' fragment, which encoded the amino acid substitution, were produced by PCR amplification of SEQ ID NO: 21. Primers M and N were used to produce the 5' fragment for each mutant. Primers O and P were used to produce the 3' fragment of 1G4 mut1, Primers Q and R were used to produce the 3' fragment of 1G4 mut2, and Primers S and T were used to produce the 3' fragment of 1G4 mut3. The 1G4 PCR products were isolated on agarose gels and the final PCR product generated by amplification of the 5' fragment with the 3' fragments using the full length primer pair (Primers U and V). The sequences of the primers used to generate the mutant beta chains of are set forth in Table 2.

TABLE 2

Name		Primer	Sequence	SEQ ID NO:
1G4 β	5'	M	GACTAATTAACCCTCACTAAAGGGACACCATGAGCATCGGCCTCCTGTG	52
	fragment	N	TGAGTAATGAATCAGCCTCAGC	53
1G4 mut1	3'	O	GCTGAGGCTGATTCATTACTCAGTTGCCGCTGGTATCACTGACCAAGGAGAAGTC	54
(G70A)	fragment	P	TTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTT TTTTTTTTTTTTCAGCCTCTGGAATCCTTTCTCT	55
1G4 mut2	3'	Q	GCTGAGGCTGATTCATTACTCAGTTGGTATCGGTATCACTGACCAAGGAGAAGTC	56
(A71I)	fragment	R	TTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTT CAGCCTCTGGAATCCTTTCTCT	57
1G4 mut3	3'	S	GCTGAGGCTGATTCATTACTCAGTTGCCATCGGTATCACTGACCAAGGAGAAGTC	58
(G70A/A71I)	fragment	T	TTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTT CAGCCTCTGGAATCCTTTCTCT	59
Full length Primer Pair		U	GACTAATTAACCCTCACTAAAGGGACACCATGAGCATCGGCCTCCTGTG	60
		V	TTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTT CAGCCTCTGGAATCCTTTCTCT	61

***mutated nucleotides noted by shading

[0121] The resulting PCR products were *in vitro* transcribed into RNA as described in Zhao et al., *Mol. Ther.* 13: 151-159 (2006).

[0122] This example demonstrates that the modified TCRs of the invention can be made.

EXAMPLE 2

[0123] This example demonstrates the biological activity of the modified TCRs of the invention as compared to their wild-type counterparts.

[0124] The modified TCRs produced in Example 1 were tested for their ability recognize antigen when separately expressed in $CD8^+$ T cells and $CD4^+$ T cells. PBMC from Patient KS were transfected as described in Zhao et al. (2006), *supra* with (i) RNA encoding the WT alpha chain of the 1G4 NY-ESO-1-specific TCR and (ii) RNA encoding the WT beta chain of the 1G4 TCR, RNA encoding one of the following mutant beta chains of 1G4: 1G4 mut1 (G70A; SEQ ID NO: 1), 1G4 mut2 (A71I, SEQ ID NO: 2), or 1G4 mut3 (G70A/A71I, SEQ ID NO: 3), or DNA encoding Green Fluorescence Protein (GFP).

[0125] Transfected cells were washed and stimulated with or without (T alone) one of the following cells: T2+ pulsed with either 1 μM NY-ESO-1 peptide SLLMWITQC (ESO; SEQ ID NO: 92) or g9-154 peptide KTWGQYWQV (g9-154; SEQ ID NO: 93) or melanoma cells: A375 (HLA-$A2^+$/NY-ESO-1^+), 624.38 (HLA-$A2^+$/NY-ESO-1^+), 1363 (HLA-$A2^+$/NY-ESO-1^+), 526 (HLA-$A2^+$/NY-ESO-1^-), and SK (HLA-$A2^+$/NY-ESO-1^-).

[0126] Responder cells ($1x10^5$ electroporated PBLs) and $1x10^5$ stimulator cells (pulsed T2 cells or melanoma cells) were incubated in a 0.2-ml culture volume in individual wells of 96-well plates. Stimulator cells and responder cells were co-cultured for 16 to 24 h. Cytokine secretion of culture supernatants diluted to the linear range of the assay was measured using commercially available ELISA kits (IFN-γ Endogen, Cambridge, MA).

[0127] The amount of IFN-γ (pg/ml) produced by transfected $CD8^+$ T cells are shown in Table 3, while the amount of IFN-γ (pg/ml) produced by transfected $CD4^+$ T cells are shown in Table 4.

TABLE 3

α chain	WT	WT	WT	WT	GFP
β chain	WT	G70A	G70A/A71I	A71I	
g9-154	<30	<30	<30	<30	<30
ESO	11250	10150	8860	10080	<30
A375	145	579	766	1058	<30
624.38	3030	6270	5280	7530	<30
1363	175	517	535	911	46
526	<30	<30	<30	<30	<30
SK	<30	<30	38	<30	<30
T alone	<30	<30	<30	<30	<30

TABLE 4

α chain	WT	WT	WT	WT	GFP
β chain	WT	G70A	G70A/A71I	A71I	
g9-154	<30	<30	<30	<30	<30
ESO	3540	6380	10690	8970	<30
A375	30	58	872	157	40
624.38	<30	88	1374	418	<30
1363	49	75	611	269	50
526	<30	<30	<30	<30	<30
SK	<30	<30	<30	<30	<30
T alone	<30	<30	<30	<30	<30

[0128] This example demonstrated that the modified TCRs of the invention have enhanced antigen specificity when expressed in $CD4^+$ T cells and $CD8^+$ T cells.

EXAMPLE 3

[0129] This example demonstrates a method of making modified TCRs specific for the MART-1 cancer antigen.

[0130] The DMF5 (F5) TCR which is specific for the cancer antigen MART-1 was isolated and the nucleotide sequence of the F5 TCR obtained is set forth as SEQ ID NO: 30 (alpha chain) and SEQ ID NO: 31 (beta chain).

[0131] The F5 α chain was amplified from the cloned gene product (SEQ ID NO: 30) to generate RNA using Primers W and X. The F5 beta chain was amplified from the cloned gene product (SEQ ID NO: 31) to generate RNA using Primers Y and Z.

[0132] For generation of each mutant F5 TCR, a 5' fragment and a 3' fragment, which encoded the amino acid substitution, were produced by PCR amplification of SEQ ID NO: 31. Primers AA and AB were used to produce the 5' fragment for each mutant. Primers AC and AD were used to produce the 3' fragment of F5 mut1, Primers AE and AF were used to produce the 3' fragment of F5mut2, Primers AG and AH were used to produce the 3' fragment of F5mut3, Primers AI and AJ were used to produce the 3' fragment of F5mut 4, and Primers AK and AL were used to produce the 3' fragment of F5mut5. The PCR products were isolated on agarose gels and the final PCR product generated by amplification of the 5' fragment with the 3' fragments using the full length primer pair (Primers AM and AN). The sequences of the primers used to generate the mutant beta chains of are set forth in Table 5.

TABLE 5

	Primer	Sequence	SEQ ID NO:
α chain RNA	W	GACTAATTAACCCTCACTAAAGGGACACCATGATGAAATCCTTGAGAGTTTTACTAG	62
	X	TTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTT CAGCTGGACCACAGCCGCAGCGTC	63
β chain RNA	Y	TCAGAATTAACCCTCACTAAAGGGACTAGTCCTGCAGGTTTAAACGAATTCGCCCTTCAC CAT GAGAATCAGGCTCCTGTGCT	64
	Z	TTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTT TCAGAAATCCTTTCTCTTGACCAT	65
β chain 5' fragment	AA	TCAGAATTAACCCTCACTAAAGGGACTAGTCCTGCAGGTTTAAACGAATTCGCCCTTCAC CAT GAGAATCAGGCTCCTGTGCT	66
	AB	TGAATAATGGATGAGCCTTAGC	67
F5 mut1 (T73A)	AC	GCTAAGGCTCATCCATTATTCAAATACTGCAGGTGCCACTGGCAAAGGAGAAGTCC	68
	AD	TTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTT TCAGAAATCCTTTCTCTTGACCAT	69
F5 mut 2	AE	GCTAAGGCTCATCCATTATTCAAATGTGGCAGGTGCCACTGGCAAAGGAGAAGTCC	70

	Primer	Sequence	SEQ ID NO:
(T70V/T73A)	AF	TTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTT TCAGAAATCCTTTCTCTTGACCAT	71
F5 mut 3 (T70V/A71M)	AG	GCTAAGGCTCATCCATTATTCAAATGTGATGGGTACCACTGGCAAAGGAGAAGTCC	72
	AH	TTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTT TCAGAAATCCTTTCTCTTGACCAT	73
F5 mut 4 (A71M/T73A)	AI	GCTAAGGCTCATCCATTATTCAAATACTATGGGTGCCACTGGCAAAGGAGAAGTCC	74
	AJ	TTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTT TCAGAAATCCTTTCTCTTGACCAT	75
F5 mut 5 (T70V/A71M/T73A)	AK	GCTAAGGCTCATCCATTATTCAAATGTGATGGGTGCCACTGGCAAAGGAGAAGTCC	76
	AL	TTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTT TCAGAAATCCTTTCTCTTGACCAT	77
Full length Primer Pair	AM	GACTAATTAACCCTCACTAAAGGGACACCATGGGCACAAGGTTGTTCTTC	78
	AN	TTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTT TCAGAAATCCTTTCTCTTGACCAT	79

*** mutated nucleotides are shaded

[0133] PBMC from Patients RS, KS, and HS were transfected and assayed as described in Example 2, except that RNA encoding either the WT or mutant F5 beta chains along with the WT alpha chains were used in transfections. Also, T2+ cells were pulsed with either 1 μg g9-154 peptide or MART-1 peptide AAGIGILTV (MART; SEQ ID NO: 94). Also, the following melanoma cells were used: 526 ($A2^+$/$MART\text{-}1^+$), 624 ($A2^+$/$MART\text{-}1^+$), 1359 ($A2^+$/$MART\text{-}1^+$), 1363 ($A2^+$/$MART\text{-}1^+$), A375 ($A2^+$/$MART\text{-}1^-$), 888, 888A2, 397A2 ($A2^+$/$MART\text{-}1^+$), 624.38 ($A2^+$/$MART\text{-}1^+$), 1300 ($A2^+$/$MART\text{-}1^+$), 397A24 ($A2^+$/$MART\text{-}1^-$), 624.28 ($A2^+$/$MART\text{-}1^+$), 526 ($A2^+$/NY-ESO-1^-), SK23 ($A2^+$/$MART\text{-}1^+$), and SK ($A2^+$/NY-ESO-1^-).

[0134] The amounts of IFN-γ (pg/ml) produced by transfected $CD8^+$ T cells of Patient RS are shown in Table 6, while the amounts of IFN-γ (pg/ml) produced by transfected $CD4^+$ T cells of Patient RS are shown in Table 7. The amounts of IFN-γ (pg/ml) produced by transfected $CD8^+$ T cells of Patient KS are shown in Table 8, while the amounts of IFN-γ (pg/ml) produced by transfected $CD4^+$ T cells of Patient KS are shown in Table 9. The amounts of IFN-γ (pg/ml) produced by transfected $CD8^+$ T cells of Patient HS are shown in Table 10, while the amounts of IFN-γ (pg/ml) produced by transfected $CD4^+$ T cells of Patient HS are shown in Table 11. The amounts of IFN-γ (pg/ml) produced by transfected $CD8^+$ T cells of Patient KG and MB expressing the modified TCR containing the triple mutant are shown in Tables 12 and 14, while the amounts of IFN-γ (pg/ml) produced by transfected $CD4^+$ T cells of Patient KG and MB expressing the triple mutant are shown in Tables 13 and 15.

TABLE 6

α chain	WT	WT	WT	WT	WT	WT	WT	WT	GFP
β chain	WT	T70A	T70I	A71I	A71V	T73A	T73I	G72A	
g9-154	<31	<31	<31	<31	<31	222	<31	<31	<31
MART	17920	12770	12150	14800	12880	16010	6710	128	136
526	2030	960	1210	1710	1050	1690	120	124	110
624	7130	5130	4160	7120	4580	7360	710	163	128
1359A2	1610	700	940	1200	680	1180	280	174	196
1363	1430	440	420	1310	820	1260	155	79	167
A375	179	259	43	203	211	250	241	279	250
T alone	<31	<31	<31	<31	<31	<31	<31	<31	<31

TABLE 7

α chain	WT	WT	WT	WT	WT	WT	WT	WT	GFP
β chain	WT	T70A	T70I	A71I	A71V	T73A	T73I	G72A	
g9-154	119	114	114	79	44	39	36	42	41
MART-1	129	8440	30770	34280	30770	38190	273	14450	114
526	82	148	1630	1210	550	4650	83	205	111
624	98	260	8400	5130	2500	24250	74	732	106
1359A2	109	12360	305	219	302	1800	87	131	109
1363	132	160	248	438	352	2320	151	145	188
A375	291	359	266	306	254	306	290	295	304
T alone	<31	<31	<31	<31	<31	<31	<31	<31	<31

TABLE 8

α chain	WT	WT	WT	WT	WT	WT	WT	WT	GFP
β chain	WT	T70A	T70I	A71I	A71V	T73A	T73I	G72A	
g9-154	<30	<30	<30	<30	31	<30	<30	<30	<30
MART-1	17110	15530	<30	16450	15880	17860	4190	15060	<30
526	1265	726	<30	1016	1292	1089	19	672	<30
624	6110	3030	<30	3770	4770	4110	192	1754	<30
1359A2	1531	92	1113	1226	1315	82	727	125	109
1363	746	99	648	644	514	72	149	87	188
A375	50	37	64	<30	46	48	31	48	50
1359	<30	685	<30	<30	<30	<30	<30	<30	<30
T alone	<30	<30	<30	<30	<30	<30	<30	<30	<30

TABLE 9

α chain	WT	WT	WT	WT	WT	WT	WT	WT	GFP
β chain	WT	T70A	T70I	A71I	A71V	T73A	T73I	G72A	
g9-154	<30	<30	<30	<30	<30	<30	<30	<30	<30
MART-1	5390	316	7190	524	7120	12600	<30	1580	<30
526	30	<30	63	<30	50	207	<30	<30	<30
624	99	<30	256	13	148	767	<30	<30	<30
1359A2	94	981	94	91	85	240	51	59	29
1363	97	114	74	104	72	97	75	46	57
A375	67	52	71	59	54	67	45	38	52
1359	80	3810	94	150	66	90	120	61	59
T alone	<30	<30	<30	<30	<30	<30	<30	<30	<30

TABLE 10

α chain	WT	WT	WT	WT	WT	WT	WT	WT	GFP
β chain	WT	T70A	T70I	A71I	A71V	T73A	T73I	G72A	
G9-154	50	64	61	54	67	38	36	23	24
MART-1	20210	19280	18730	4630	20910	19890	6120	14970	24
526	1984	1114	1342	44	1598	1352	38	606	<30
624	7030	4520	7040	210	6432	7340	283	3500	9
1359A2	2140	1340	1500	118	1940	2320	83	551	37
1363	791	292	237	78	565	761	53	214	46
A375	57	83	64	105	87	95	65	30	61
1359	27	1917	57	66	50	27	66	44	34
T alone	<30	<30	<30	<30	<30	<30	<30	<30	<30

TABLE 11

α chain	WT	WT	WT	WT	WT	WT	WT	WT	GFP
β chain	WT	T70A	T70I	A71I	A71V	T73A	T73I	G72A	
g9-154	<30	<30	<30	<30	<30	<30	36	<30	<30
MART-1	22000	4553	21700	7470	36440	25820	242	<30	<30
526	294	<30	1045	<30	711	2379	<30	<30	<30
624	1626	104	3849	115	2908	9236	<30	<30	<30
1359A2	471	9240	826	93	646	2192	57	65	56
1363	453	486	474	435	545	886	484	334	550
A375	279	316	335	212	262	246	369	217	228
1359	179	2328	207	213	196	237	204	205	267
T alone	<30	<30	<30	<30	<30	<30	<30	<30	<30

TABLE 12

α chain	WT	WT	WT	WT	WT	WT	WT	WT
β chain	WT	T73A	T73G	T73S	T70V/A71M	T70V/T73A	A71M/T73A	T70V/A71M/T73A
MART (1 μM)	25100	29280	21600	24240	26240	20900	26000	18440
ESO (10 nM)	<30	<30	<30	<30	<30	<30	<30	<30
888	<30	<30	<30	<30	<30	<30	<30	<30
888A2	7600	10340	8380	10080	7360	5260	6960	4860
397 A2	3600	4440	4200	4040	3330	1780	3460	2500
624.38	6840	8140	6800	7460	5520	4080	6940	5360
1300	6400	7360	6880	5940	5840	4140	5060	5880
T Alone	<30	<30	<30	<30	<30	<30	<30	<30

TABLE 13

α chain	WT	WT	WT	WT	WT	WT	WT	WT	WT
β chain	WT	T73A	T73G	T73S	T70V/A71M	T70V/T73A	A71M/T73A	T70V/A71M/T73A	
MART (1 μM)	6980	18060	7020	17830	>20000	25180	40660	>20000	
ESO (10 nM)	<30	<30	<30	<30	<30	<30	<30	<30	
888	<30	<30	<30	<30	<30	<30	<30	<30	
888A2	2420	4600	3780	4200	5620	5170	5640	6540	
397 A2	330	1600	537	1250	2240	2100	2310	3470	
624.38	482	2410	1140	1460	2690	2300	3190	4250	
1300	851	2020	1870	640	3200	2560	3090	3420	
T alone	<30	<30	<30	<30	<30	<30	<30	<30	

TABLE 14

α chain	WT	WT	WT	WT	WT	WT	WT	WT	WT	GFP
β chain	WT	T70A/A71M	T70V/A71M/T73A	A71M/T73A	T73A	T73G	T73I	T73L	T73S	
gp100	260	250	494	144	139	125	36	40	157	<30
MART (1 uM)	52900	41250	38500	28400	36250	30050	11500	2300	16350	<30
A375	43	37	38	33	<30	31	<30	<30	<30	<30
397 A24	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30
624.28	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30
397 A2	45000	31550	27650	26850	30750	30150	5650	146	45100	<30
526	16700	15800	10750	12550	12300	13500	321	32	16200	<30
624.38	48900	47650	32500	29850	28100	35150	8000	179	49100	<30
1300	96600	43100	39100	48150	37250	49000	16450	2550	53050	32
SK 23	22250	29450	22800	24850	18600	18950	4500	144	29800	<30
T Alone	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30

TABLE 15

α chain	WT	WT	WT	WT	WT	WT	WT	WT	WT	GFP
β chain	WT	T70A/A71M	T70V/A71M/T73A	A71M/T73A	T73A	T73G	T73I	T73L	T73S	
gp100	131	<30	<30	<30	<30	<30	<30	<30	<30	<30
MART (1 uM)	32300	54000	33800	34500	25000	25300	1300 /2350	>2000/ <50,000	12100 /39800	<30
A375	40	69	37	50	59	60	128	54	37	36
397 A24	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30
624.28	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30
397 A2	39900	58800	145300	46100	31400	32800	190	51	33000	<30
526	4100	24000	26600	19000	14700	16900	<30	<30	13200	<30
624.38	60400	102200	93800	46500	49800	32600	198	<30	44500	<30
1300	53100	96400	>200,000	73600	53000	34600	555	79	51000	<30
SK	30000	86100	82000	43700	34700	32700	209	<30	44800	<30

T Alone	<30	<30	<30	<30	<30	<30	<30	<30	<30

[0135] This example demonstrated that the modified F5 receptors F5 mut1 (T52A) and F5 mut5 (T49V/A50M/T52A) have enhanced capability to recognize target cells in $CD4^+$ T cells without having a decreased antigen specificity in $CD8^+$ T cells.

EXAMPLE 4

[0136] This example demonstrates a method of making another set of modified TCRs specific for the MART-1 cancer antigen.

[0137] The DMF4 (F4) TCR which is specific for the cancer antigen MART-1 was isolated as described in Hughes et al., *Hum. Gene Ther.* 16: 457-472 (2005). The nucleotide sequence of the F4 TCR obtained is set forth as SEQ ID NO: 26 (alpha chain) and SEQ ID NO: 27 (beta chain).

[0138] The DMF4 β chain was amplified using Primers AO and AP to generate RNA. For the generation of each mutant F4 TCR, a 5' fragment and a 3' fragment, which encoded the amino acid substitution, were produce by PCR amplification of SEQ ID NO: 27. Primers AQ and AR were used to generate the 5' fragment for each mutant. Primers AS and AT were used to produce the 3' fragment of F4 mut1 and Primers AU and AV were used to produce the 3' fragment of F4 mut2. The 5' and 3' fragments were then gel purified, mixed, and amplified using the Primers AW and AX to generate the full length construct. The α chain of the F4 TCR was amplified from the cloned gene product (SEQ ID NO: 26) to generate RNA using Primers AY and AZ. The sequences of the primers used to generate mutant F4 TCRs are set forth in Table 16.

TABLE 16

	Primer		Sequence	SEQ ID NO:
β chain RNA	AO	Forward	GACTAATTAACCCTCACTAAAGGGACACCATGGGCACAAGGTTGTTCTTC	80
	AP	Reverse	TTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTT TTTTT TCAGAAATCCTTTCTCTTGACCAT	81
β chain 5' fragment	AQ	Forward	GACTAATTAACCCTCACTAAAGGGACACCATGGGCACAAGGTTGTTCTTC	82
	AR	Reverse	GTAATGGATCAGCCTCAGCC	83
F4 mut1 (G70A)	AS	Forward	GCTGAGGCTGATCCATTACTCATATGCCGTTAAAGATACTGACAAAGGAGAAG TC	84
	AT	Reverse	TTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTT TTTTT TCAGAAATCCTTTCTCTTGACCAT	85
F4 mut 2 (G70A/V71A)	AU	Forward	GCTGAGGCTGATCCATTACTCATATGCCGCCAAAGATACTGACAAAGGAGAAG TC	86
	AV	Reverse	TTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTT TTTTT TCAGAAATCCTTTCTCTTGACCAT	87

	Primer		Sequence	SEQ ID NO:
Full length Primers	AW	Forward	GACTAATTAACCCTCACTAAAGGGACACCATGGGCACAAGGTTGTTCTTC	88
	AX	Reverse	TTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTT TTTTT TCAGAAATCCTTTCTCTTGACCAT	89
α chain RNA	AY		GACTAATTAACCCTCACTAAAGGGACACCATGCTCCTTGAACATTTATTAATAA TC	90
	AZ		TTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTT TTTTTCAGC GGACCACAGCCGCAGCGTC	91

***Mutated nucleotides noted by shading.

[0139] PBMC from Patient HS were obtained as described in Example 1. Cells were transfected and assayed as described in Example 1, except that nucleic acids encoding the WT F4 alpha chain and the mutant MART-1 beta chains (F4 mut) were used and T2+ cells were pulsed with either 1 μM gp100 peptide KTWGQYWQV (gp100; SEQ ID NO: 93) or MART-1 peptide AAGIGILTV (MART; SEQ ID NO: 94). Also, the following melanoma cells (with phenotypes in ()) were used: 397-A2 ($A2^+$/$MART\text{-}1^+$), 624.38 ($A2^+$/$MART\text{-}1^+$), 1300 ($A2^+$/$MART\text{-}1^+$), SK23 ($A2^+$/$MART\text{-}1^+$), 397-A24 ($A2^+$/$MART\text{-}1^-$), 624.28 ($A2^+$/$MART\text{-}1^+$), and A375 ($A2^+$/$MART\text{-}1^+$).

[0140] The amounts of IFN-γ (pg/ml) produced by transfected $CD8^+$ T cells of Patient HS are shown in Table 17, while the amounts of IFN-γ (pg/ml) produced by transfected $CD4^+$ T cells of Patient HS are shown in Table 18.

TABLE 17

α chain	WT	WT	WT	WT	WT	WT	GFP
β chain	WT	G70A	G70A/ V71A	V71A	K72A	D73A	
gp100	55	58	35	<30	31	<30	<30
MART	8650	9000	6860	3910	5650	690	14
397-A2	6910	8710	1550	4036	4970	110	<30
624.38	5020	4820	3206	1772	3260	184	<30
1300	12850	10010	7800	6540	11300	1576	<30
SK23	12850	10010	7800	6540	1130	206	<30
397-A24	<30	<30	<30	<30	<30	<30	<30
624.28	<30	<30	<30	<30	<30	<30	<30
A375	<30	<30	<30	<30	<30	<30	<30
T alone	5400	3930	4000	2320	3600	<30	<30

TABLE 18

α chain	WT	WT	WT	WT	WT	WT	GFP
β chain	WT	G70A	G70A/ V71A	V71A	K72A	D73A	
gp100	<30	<30	<30	<30	<30	<30	<30
MART	83	558	344	<30	57	<30	<30
397-A2	70	1618	1473	<30	<30	<30	<30
624.38	77	1060	1203	<30	42	<30	<30
1300	435	14760	16220	82	369	<30	<30
SK	88	1150	1251	<30	68	<30	<30
397-A24	<30	<30	<30	<30	<30	<30	<30
624.28	<30	<30	<30	<30	<30	<30	<30
A375	<30	<30	<30	<30	<30	<30	<30
T alone	<30	<30	<30	<30	<30	<30	<30

[0141] This example demonstrated that the F4 mutants F4 mut 1 (G70A) and F4 mut 2 (G70A/V71A) were TCRs that have enhanced ability to recognize tumor target cells without having a decrease in antigen specificity.

EXAMPLE 5

[0142] This example demonstrates a method of treating a disease in a host using the inventive TCRs.

[0143] Adoptive cell transfer is carried out as described in Morgan et al. (2006), *supra*. Briefly, PBLs are obtained by leukopheresis from a metastatic melanoma patient who is HLA-A*0201 positive. The PBLs are transduced with nucleic acids encoding a WT alpha chain and a modified beta chain of a TCR specific for either NY-ESO-1 or MART-1 as described in Example 1. The patient receives the transduced cells at the time of maximum lymphodepletion. One month post-adoptive cell transfer, quantitative RT-PCR assays are carried out to reveal whether the presence of the modified TCRs are expressed by cells of the patient. Tumor regression also is analyzed by the methods described in Morgan et al. (2006), *supra*.

[0144] All references, including publications, patent applications, and patents, cited herein are hereby incorporated by reference to the same extent as if each reference were individually and specifically indicated to be incorporated by reference and were set forth in its entirety herein.

[0145] The use of the terms "a" and "an" and "the" and similar referents in the context of describing the invention (especially in the context of the following claims) are to be construed to cover both the singular and the plural, unless otherwise indicated herein or clearly contradicted by context. The terms "comprising," "having," "including," and "containing" are to be construed as open-ended terms (i.e., meaning "including, but not limited to,") unless otherwise noted. Recitation of ranges of values herein are merely intended to serve as a shorthand method of referring individually to each separate value falling within the range, unless otherwise indicated herein, and each separate value is incorporated into the specification as if it were individually recited herein. All methods described herein can be performed in any suitable order unless otherwise indicated herein or otherwise clearly contradicted by context. The use of any and all examples, or exemplary language (e.g., "such as") provided herein, is intended merely to better illuminate the

invention and does not pose a limitation on the scope of the invention unless otherwise claimed. No language in the specification should be construed as indicating any non-claimed element as essential to the practice of the invention.

[0146] Preferred embodiments of this invention are described herein, including the best mode known to the inventors for carrying out the invention. Variations of those preferred embodiments may become apparent to those of ordinary skill in the art upon reading the foregoing description. The inventors expect skilled artisans to employ such variations as appropriate, and the inventors intend for the invention to be practiced otherwise than as specifically described herein. Accordingly, this invention includes all modifications and equivalents of the subject matter recited in the claims appended hereto as permitted by applicable law. Moreover, any combination of the above-described elements in all possible variations thereof is encompassed by the invention unless otherwise indicated herein or otherwise clearly contradicted by context.

CLAIM:

1. A modified T cell receptor (TCR) comprising an amino acid sequence of a wild-type (WT) TCR with no more than three amino acid substitutions, wherein the modified TCR, as compared to the WT TCR, (i) has an enhanced ability to recognize target cells when expressed by $CD4^+$ T cells and (ii) does not exhibit a decrease in antigen specificity when expressed by $CD8^+$ T cells.

2. The modified TCR of claim 1, wherein the amino acid substitutions are located in a complementary determining region (CDR) of the TCR.

3. The modified TCR of claim 2, wherein the CDR is a CDR2.

4. The modified TCR of any of claims 1 to 3, wherein the amino acid substitutions are located on a beta chain of the TCR.

5. The modified TCR of any of claims 1 to 4, wherein the amino acid substitutions are conservative amino acid substitutions.

6. The modified TCR of claim 5, wherein the conservative amino acid substitutions are selected from the group consisting of T→A, G→A, A→I, T→V, A→M, T→I, A→V, T→G, and T→S.

7. The modified TCR of any of claims 1 to 6, wherein the modified TCR has antigen specificity for a cancer antigen.

8. The modified TCR claim 7, wherein the cancer antigen is selected from a group consisting of NY-ESO-1, MART-1, gp100, p53, TRP-1, TRP-2, and tyrosinase.

9. The modified TCR of claim 8, wherein the WT TCR comprises the amino acid sequence of SEQ ID NO: 8.

10. The modified TCR of claim 9, wherein the modified TCR comprises the amino acid sequence of SEQ ID NO: 1, SEQ ID NO: 2, or SEQ ID NO: 3.

11. The modified TCR of claim 10, wherein the modified TCR comprises the amino acid sequence of SEQ ID NO. 14, SEQ ID NO. 15, or SEQ ID NO. 16.

12. The modified TCR of claim 10 or 11, wherein the modified TCR additionally comprises the amino acid sequence of SEQ ID NO: 7.

13. The modified TCR of claim 8, wherein the cancer antigen is MART-1.

14. The modified TCR of claim 13, wherein the WT TCR comprises the amino acid sequence of SEQ ID NO: 10 or SEQ ID NO: 12.

15. The modified TCR of claim 14, wherein the modified TCR comprises an amino acid sequence selected from the group consisting of SEQ ID NOs: 4 to 6, 13, and 95 to 103.

16. The modified TCR of claim 15, wherein the modified TCR comprises an amino acid sequence selected from the group consisting of SEQ ID NOs. 17 to 20, 37 to 39, and 104 to 109.

17. The modified TCR of claim 15 or 16, wherein the modified TCR additionally comprises an amino acid sequence of SEQ ID NO. 9 or SEQ ID NO. 11.

18. The modified TCR of claim 17, wherein the modified TCR comprises the amino acid sequence of:

(i) any of SEQ ID NOs: 17, 20, 37 to 30, and 104 to 109 in combination with SEQ ID NO. 9; or

(ii) SEQ ID NO: 18 or 19 in combination with SEQ ID NO: 11.

19. The modified TCR of any of claims 1 to 18 comprising a leader sequence selected from the group consisting of SEQ ID NOs: 110 to 115.

20. An isolated polypeptide comprising a functional portion of the modified TCR of any of claims 1 to 19, wherein the functional portion comprises the amino acid substitutions.

21. The isolated polypeptide of claim 20 comprising an amino acid sequence selected from the group consisting of SEQ ID NOs. 1 to 6, 13, and 95 to 103.

22. The isolated polypeptide of claim 21 comprising an amino acid sequence selected from the group consisting of SEQ NOs. 14 to 20, 37 to 39, and 104 to 109.

23. The isolated polypeptide of any of claims 20 to 22, wherein the polypeptide additionally comprises an amino acid sequence selected from the group consisting of SEQ ID NOs: 7, 9, and 11.

24. An isolated protein comprising the polypeptide of any of claims 20 to 23.

25. The isolated protein of claim 24, comprising (i) a first polypeptide chain comprising the amino acid sequence of SEQ ID NO. 1, 2, or 3 and a second polypeptide chain comprising the amino acid sequence of SEQ ID NO: 7, (ii) a first polypeptide chain comprising the amino acid sequence of any of SEQ ID NOs: 4, 13, and 95 to 103 and a second polypeptide chain comprising the amino acid sequence of SEQ ID NO: 9, or (iii) a first polypeptide chain comprising the amino acid sequence of SEQ ID NO: 5 or 6 and a second polypeptide chain comprising the amino acid sequence of SEQ ID NO: 11.

26. An isolated nucleic acid comprising a nucleotide sequence encoding the modified TCR of any of claims 1 to 19, the polypeptide of any of claims 20 to 23, or the protein of claim 24 or 25.

27. The isolated nucleic acid of claim 26 comprising a nucleotide sequence selected from the group consisting of SEQ ID NOs.: 22 to 24, 28, 29, 32 and 33.

28. A recombinant expression vector comprising the nucleic acid of claim 26 or 27.

29. An isolated host cell comprising the recombinant expression vector of claim 28.

30. The isolated host cell of claim 29, wherein the cell is a peripheral blood lymphocyte (PBL).

31. The isolated host cell of claim 30, wherein the PBL is a $CD8^+$ T cell or a $CD4^+$ T cell.

32. A population of cells comprising at least one host cell of any of claims 29 to 31.

33. An antibody, or antigen binding portion thereof, which specifically binds an epitope of the modified TCR of any of claims 1 to 19, wherein the epitope comprises the amino acid substitutions.

34. A pharmaceutical composition comprising the modified TCR of any of claims 1 to 19, the polypeptide of any of claims 20 to 23, the protein of claim 24 or 25, the nucleic acid of claim 26 or 27, the recombinant expression vector of claim 28, the host cell of any of claims 29 to 31, or the population of cells of claim 32.

35. A method of detecting a diseased cell in a host, wherein the diseased cell expresses an antigen characteristic of a disease, comprising

(a) contacting a sample comprising cells of the host with the modified TCR of any of claims 1 to 19, the polypeptide of any of claims 20 to 23, the protein of claim 24 or 25, the nucleic acid of claim 26 or 27, the recombinant expression vector of claim 28, the host cell of any of claims 29 to 31, or the population of cells of claim 32, thereby forming a complex between the modified TCR, polypeptide, protein, nucleic acid, recombinant expression vector, host cell, or cells and the antigen, and

(b) detecting the complex,

wherein detection of the complex is indicative of a diseased cell in the host.

36. The method of claim 35, wherein the diseased cell is a cancer cell or an infected cell.

37. The method of claim 36, wherein the cancer cell is a melanoma cell.

38. The method of any of claims 35 to 37, wherein the host is a human.

39. The method of any of claims 35 to 38, wherein the method is an *in vitro* method.

40. A method of treating or preventing a disease in a host, comprising administering to the host the pharmaceutical composition of claim 34 in an amount effective to treat or prevent the disease in the host.

41. The method of claim 40, wherein the disease is a cancer or an infectious disease.

42. The method of claim 41, wherein the cancer is melanoma.

43. The method of any of claims 40 to 42, wherein the host is a human.

44. The method of any of claims 40 to 43, wherein the host cells are cells that are autologous to the host.

45. The method of any of claims 40 to 44, wherein the cells of the population are cells that are autologous to the host.

46. A method of identifying a candidate adoptive immunotherapy T cell receptor (TCR), consisting of:

(a) producing a nucleic acid encoding a modified TCR comprising a WT TCR amino acid sequence with no more than three amino acid substitutions,

(b) expressing the nucleic acid in $CD4^+$ T cells and $CD8^+$ T cells, and

(c) assaying the T cells for the ability to recognize target cells and for antigen specificity,

wherein a candidate adoptive immunotherapy TCR is identified when the modified TCR, as compared to the WT TCR, (i) has an enhanced ability to recognize target cells when expressed by $CD4^+$ T cells and (ii) does not exhibit a decrease in antigen specificity when expressed by $CD8^+$ T cells.

47. The method of claim 46, wherein the amino acid substitutions are conservative amino acid substitutions.

48. The method of claim 46 or 47, wherein the amino acid substitutions are located within a CDR of the WT TCR.

49. The method of claim 48, wherein the CDR is a CDR2 of the beta chain of the modified TCR.

50. The method of any of claims 46 to 49, wherein the modified TCR has at least twice the ability to recognize target cells as the WT TCR.