

BINDING PROTEINS RECOGNIZING HPV16 E7 ANTIGEN AND USES THEREOF

Cross-Reference to Related Applications

This application claims the benefit of U.S. Provisional Application No. 63/342,479, filed on 16 May 2022; U.S. Provisional Application No. 63/317,326, filed on 7 March 2022; and U.S. Provisional Application No. 63/277,901, filed on 10 November 2021; the entire contents of each of said applications are incorporated herein in their entirety by this reference.

Background of the Invention

Human papilloma virus (HPV) is an oncogenic virus found in many solid tumors (*e.g.*, 20,000-30,000 HPV-associated cancers are diagnosed annually in the U.S.) that is responsible for a wide variety of malignancies, including greater than 25% of head and neck cancers, greater than 70% of oropharyngeal cancers, greater than 90% of cervical and anal cancers, and greater than 60% of vaginal, vulval, and penile cancers. HPV antigens, such as the HPV E6 and HPV E7 proteins, are compelling targets for a number of reasons, including 1) HPV proteins drive tumorigenesis and are essential for cancer cell survival, 2) HPV proteins are expressed in every tumor cell, thereby resulting in homogenous target expression, and 3) HPV proteins are not expressed by vital healthy tissues, thereby avoiding healthy tissue toxicity when targeting HPV. Initial clinical data from TCR-T cell therapy targeting HPV antigens have demonstrated tumor shrinkage and objective response rates in 50% of patients (6 of 12 patients) treated in a phase 1 trial (trial NCT02858310). Twenty-five percent (3 of 12) of patients demonstrated complete regression of one or more tumors. There is a need for developing HPV-specific TCR immunotherapy, such as to treat disorders characterized by expression of an HPV antigen.

Summary of the Invention

The present invention is based, at least in part, on the discovery of binding proteins, including T cell receptors (TCRs), that recognize HPV16 E7₁₁₋₁₉ antigen.

In one aspect, a binding protein comprising: a) a T cell receptor (TCR) alpha chain CDR sequence with at least about 80% identity to a TCR alpha chain CDR sequence selected from the group consisting of TCR alpha chain CDR sequences listed in Table 1; and/or b) a TCR beta chain CDR sequence with at least about 80% identity to a TCR beta

chain CDR sequence selected from the group consisting of TCR beta chain CDR sequences listed in Table 1, wherein the binding protein is capable of binding to an HPV16 E7₁₁₋₁₉ immunogenic peptide-MHC (pMHC) complex, optionally wherein the binding affinity has a K_d less than or equal to about 5×10^{-4} M, is provided.

In another aspect, a binding protein comprising: a) a TCR alpha chain variable (V_α) domain sequence with at least about 80% identity to a TCR V_α domain sequence selected from the group consisting of TCR V_α domain sequences listed in Table 1; and/or b) a TCR beta chain variable (V_β) domain sequence with at least about 80% identity to a TCR V_β domain sequence selected from the group consisting of TCR V_β domain sequences listed in Table 1, wherein the binding protein is capable of binding to an HPV16 E7₁₁₋₁₉ immunogenic peptide-MHC (pMHC) complex, optionally wherein the binding affinity has a K_d less than or equal to about 5×10^{-4} M, is provided.

In still another aspect, a binding protein comprising: a) a TCR alpha chain sequence with at least about 80% identity to a TCR alpha chain sequence selected from the group consisting of TCR alpha chain sequences listed in Table 1; and/or b) a TCR beta chain sequence with at least about 80% identity to a TCR beta chain sequence selected from the group consisting of TCR beta chain sequences listed in Table 1, wherein the binding protein is capable of binding to an HPV16 E7₁₁₋₁₉ immunogenic peptide-MHC (pMHC) complex, optionally wherein the binding affinity has a K_d less than or equal to about 5×10^{-4} M, is provided.

In yet another aspect, a binding protein comprising: a) a TCR alpha chain CDR sequence selected from the group consisting of TCR alpha chain CDR sequences listed in Table 1; and/or b) a TCR beta chain CDR sequence selected from the group consisting of TCR beta chain CDR sequences listed in Table 1, wherein the binding protein is capable of binding to an HPV16 E7₁₁₋₁₉ immunogenic peptide-MHC (pMHC) complex, optionally wherein the binding affinity has a K_d less than or equal to about 5×10^{-4} M, is provided.

In another aspect, a binding protein comprising: a) a TCR alpha chain variable (V_α) domain sequence selected from the group consisting of TCR V_α domain sequences listed in Table 1; and/or b) a TCR beta chain variable (V_β) domain sequence selected from the group consisting of TCR V_β domain sequences listed in Table 1, wherein the binding protein is capable of binding to an HPV16 E7₁₁₋₁₉ immunogenic peptide-MHC (pMHC) complex, optionally wherein the binding affinity has a K_d less than or equal to about 5×10^{-4} M, is provided.

In still another aspect, a binding protein comprising: a) a TCR alpha chain sequence selected from the group consisting of TCR alpha chain sequences listed in Table 1; and/or b) a TCR beta chain sequence selected from the group consisting of TCR beta chain sequences listed in Table 1, wherein the binding protein is capable of binding to an HPV16 E7₁₁₋₁₉ immunogenic peptide-MHC (pMHC) complex, optionally wherein the binding affinity has a K_d less than or equal to about 5×10^{-4} M, is provided.

Numerous embodiments are further provided that may be applied to any aspect encompassed by the present invention and/or combined with any other embodiment described herein. For example, in one embodiment, 1) the TCR alpha chain CDR, TCR V_α domain, and/or TCR alpha chain is encoded by a TRAV, TRAJ, and/or TRAC gene or fragment thereof selected from the group of TRAV, TRAJ, and TRAC genes listed in Table 1, and/or 2) the TCR beta chain CDR, TCR V_β domain, and/or TCR beta chain is encoded by a TRBV, TRBJ, and/or TRBC gene or fragment thereof selected from the group of TRBV, TRBJ, and TRBC genes listed in Table 1, and/or 3) each CDR of the binding protein has up to five amino acid substitutions, insertions, deletions, or a combination thereof as compared to the cognate reference CDR sequence listed in Table 1. In another embodiment, an HPV16 E7₁₁₋₁₉ immunogenic peptide comprises the amino acid sequence YMLDLQPET. In still another embodiment, a binding protein is chimeric, humanized, or human. In yet another embodiment, a binding protein is a TCR, an antigen-binding fragment of a TCR, a single chain TCR (scTCR), a chimeric antigen receptor (CAR), or a fusion protein comprising a TCR and an effector domain, optionally wherein the binding domain comprises a transmembrane domain and an effector domain that is intracellular. In another embodiment, a TCR alpha chain and a TCR beta chain are covalently linked, optionally wherein the TCR alpha chain and the TCR beta chain are covalently linked through a linker peptide. In still another embodiment, a TCR alpha chain and/or a TCR beta chain are covalently linked to a moiety, optionally wherein the covalently linked moiety comprises an affinity tag or a label. In yet another embodiment, an affinity tag is selected from the group consisting of CD34 enrichment tag, Glutathione-S-Transferase (GST), calmodulin binding protein (CBP), protein C tag, Myc tag, HaloTag, HA tag, Flag tag, His tag, biotin tag, and V5 tag, and/or wherein the label is a fluorescent protein. In another embodiment, a covalently linked moiety is selected from the group consisting of an inflammatory agent, cytokine, toxin, cytotoxic molecule, radioactive isotope, or antibody or antigen-binding fragment thereof. In still another embodiment, a binding protein binds to

the pMHC complex on a cell surface. In yet another embodiment, an MHC is a MHC multimer, optionally wherein the MHC multimer is a tetramer. In another embodiment, an MHC is a MHC class I molecule. In still another embodiment, an MHC comprises an MHC alpha chain that is an HLA serotype HLA-A*02. In yet another embodiment, an HLA allele is selected from the group consisting of HLA-A*0201, HLA-A*0202, HLA-A*0203, HLA-A*0205, HLA-A*0206, and HLA-A*0207 allele. In another embodiment, binding of a binding protein described herein to an HPV16 E7₁₁₋₁₉ peptide-MHC (pMHC) complex elicits an immune response, optionally wherein the immune response is a T cell response. In still another embodiment, a T cell response is selected from the group consisting of T cell expansion (*e.g.*, proliferation), cytokine release, and/or cytotoxic killing. In yet another embodiment, a binding protein is capable of specifically and/or selectively binding to an HPV16 E7₁₁₋₁₉ immunogenic peptide-MHC (pMHC) complex with a K_d less than or equal to about 1×10^{-4} M, less than or equal to about 5×10^{-5} M, less than or equal to about 1×10^{-5} M, less than or equal to about 5×10^{-6} M, less than or equal to about 1×10^{-6} M, less than or equal to about 5×10^{-7} M, less than or equal to about 1×10^{-7} M, less than or equal to about 5×10^{-8} M, less than or equal to about 1×10^{-8} M, less than or equal to about 5×10^{-9} M, less than or equal to about 1×10^{-9} M, less than or equal to about 5×10^{-10} M, less than or equal to about 1×10^{-10} M, less than or equal to about 5×10^{-11} M, less than or equal to about 1×10^{-11} M, less than or equal to about 5×10^{-12} M, or less than or equal to about 1×10^{-12} M. In yet another embodiment, a binding protein has a higher binding affinity to a peptide-MHC (pMHC) than does a known T-cell receptor. In another embodiment, a binding protein has at least 1.05 fold higher binding affinity to a peptide-MHC (pMHC) than does a known T-cell receptor. In still another embodiment, a binding protein induces higher T cell expansion, cytokine release, and/or cytotoxic killing than does a known T-cell receptor. In yet another embodiment, a binding protein induces at least 1.05-fold increase in T cell expansion, cytokine release, and/or cytotoxic killing than does a known T-cell receptor. As used herein, references to fold changes, in some embodiments, may be in comparison to any reference modality of interest, such as comparison to a different binding protein; comparison to the same binding protein under different context like expression of the same binding protein in a different immune cell, at a different level, in combination with other agents described herein; and the like. In another embodiment, a target cell is a CaSki, SCC152, or SCC090 cell line. In still another embodiment, a target cell is a cancer cell, optionally wherein the cancer cell is a head & neck cancer cell, an

oropharyngeal cancer cell, a cervical cancer cell, an anal cancer cell, a vaginal cancer cell, a vulval cancer cell, or a penile cancer cell. In still another embodiment, a binding protein described herein does not bind to a peptide-MHC (pMHC) complex, wherein the peptide comprises the amino acid sequence YMLDLQPET. In yet another embodiment, a binding protein described herein does not bind to a peptide-MHC (pMHC) complex, optionally wherein the peptide is derived from SPTA1, MPL, HERC1, CPAMD8, INTS4, NUTM1, or XM_00172256. These genes are well-known and are art-recognized to be annotated according to the following NCBI Gene ID numbers, each of which is available on the World Wide Web at ncbi.nlm.nih.gov/gene: SPTA1: Gene ID 6708; MPL: Gene ID 4352; HERC1: Gene ID 8925; CPAMD8: Gene ID 27151; INTS4: Gene ID 92105; and NUTM1: Gene ID 256646. XM_00172256: maps to the heterochromatic centromere region of chromosome 20 and has been removed from the RefSeq annotation indicating a lack of evidence for its expression.

In yet another aspect, a TCR alpha chain and/or beta chain selected from the group consisting of TCR alpha chain and beta chain sequences listed in Table 1, is provided.

In another aspect, an isolated nucleic acid molecule that hybridizes, under stringent conditions, with the complement of a nucleic acid encoding a polypeptide selected from the group consisting of polypeptide sequences listed in Table 1, or a sequence with at least about 80% homology to a nucleic acid encoding a polypeptide selected from the group consisting of the polypeptide sequences listed in Table 1, optionally wherein the isolated nucleic acid molecule comprises 1) a TRAV, TRAJ, and/or TRAC gene or fragment thereof selected from the group of TRAV, TRAJ, and TRAC genes listed in Table 1 and/or 2) a TRBV, TRBJ, and/or TRBC gene or fragment thereof selected from the group of TRBV, TRBJ, and TRBC genes listed in Table 1, is provided.

Numerous embodiments are further provided that may be applied to any aspect encompassed by the present invention and/or combined with any other embodiment described herein. For example, in one embodiment, a nucleic acid is codon optimized for expression in a host cell.

In still another aspect, a vector comprising an isolated nucleic acid described herein, is provided.

Numerous embodiments are further provided that may be applied to any aspect encompassed by the present invention and/or combined with any other embodiment described herein. For example, in one embodiment, a vector is a cloning vector, expression

vector, or viral vector. In another embodiment, a vector further comprises a nucleic acid sequence encoding CD8 α , CD8 β , a dominant negative TGF β receptor II (DN-TGF β RII), selectable protein marker, optionally wherein the selectable protein marker is dihydrofolate reductase (DHFR). In still another embodiment, a nucleic acid sequence encoding CD8 α , CD8 β , the DN-TGF β RII, and/or the selectable protein marker is operably linked to a nucleic acid encoding a tag. In yet another embodiment, a nucleic acid encoding a tag is at the 5' upstream of the nucleic acid sequence encoding CD8 α , CD8 β , the DN-TGF β RII, and/or the selectable protein marker such that the tag is fused to the N-terminal of CD8 α , CD8 β , the DN-TGF β RII, and/or the selectable protein marker. In another embodiment, a tag is a CD34 enrichment tag. In still another embodiment, an isolated nucleic acid described herein, either alone (*e.g.*, encoding TCR α and/or TCR β), or in combination with a nucleic acid sequence encoding CD8 α , CD8 β , the DN-TGF β RII, and/or the selectable protein marker are interconnected with an internal ribosome entry site or a nucleic acid sequence encoding a self-cleaving peptide. In yet another embodiment, a self-cleaving peptide is P2A, E2A, F2A or T2A.

In yet another aspect, a host cell which comprises an isolated nucleic acid described herein, comprises a vector described herein, and/or expresses a binding protein described herein, optionally wherein the cell is genetically engineered, is provided.

Numerous embodiments are further provided that may be applied to any aspect encompassed by the present invention and/or combined with any other embodiment described herein. For example, in one embodiment, a host cell comprises a chromosomal gene knockout of a TCR gene, an HLA gene, or both. In another embodiment, a host cell comprises a knockout of an HLA gene selected from an α 1 macroglobulin gene, α 2 macroglobulin gene, α 3 macroglobulin gene, β 1 microglobulin gene, β 2 microglobulin gene, and combinations thereof. In still another embodiment, a host cell comprises a knockout of a TCR gene selected from a TCR α variable region gene, TCR β variable region gene, TCR constant region gene, and combinations thereof. In yet another embodiment, a host cell expresses CD8 α , CD8 β , a DN-TGF β RII, and/or a selectable protein marker, optionally wherein the selectable protein marker is DHFR. In another embodiment, CD8 α , CD8 β , the DN-TGF β RII, and/or the selectable protein marker is fused to a CD34 enrichment tag. In still another embodiment, host cells are enriched using a CD34 enrichment tag. In yet another embodiment, a host cell is an immune cell. In another

embodiment, an immune cell is a cytotoxic lymphocyte, cytotoxic lymphocyte precursor cell, cytotoxic lymphocyte progenitor cell, cytotoxic lymphocyte stem cell, CD4⁺ T cell, CD8⁺ T cell, CD4/CD8 double negative T cell, gamma delta ($\gamma\delta$) T cell, natural killer (NK) cell, NK-T cell, dendritic cell, or combination thereof. In another embodiment, a T cell is a naive T cell, central memory T cell, effector memory T cell, or a combination thereof. In still another embodiment, a T cell is a primary T cell or a cell of a T cell line. In yet another embodiment, a T cell does not express or has a lower surface expression of an endogenous TCR. In another embodiment, a host cell is capable of producing a cytokine or a cytotoxic molecule when contacted with a target cell that comprises a peptide-MHC (pMHC) complex comprising the HPV16 E7₁₁₋₁₉ peptide epitope in the context of an MHC molecule. In still another embodiment, a host cell is contacted with a target cell *in vitro*, *ex vivo*, or *in vivo*. In yet another embodiment, a cytokine is TNF- α , IL-2, and/or IFN- γ . In another embodiment, a cytotoxic molecule is perforins and/or granzymes, optionally wherein the cytotoxic molecule is granzyme B. In still another embodiment, a host cell is capable of producing a higher level of cytokine or a cytotoxic molecule when contacted with a target cell expressing HPV16 E7₁₁₋₁₉ peptide epitope. In yet another embodiment, a host cell is capable of producing an at least 1.05-fold higher level of cytokine or a cytotoxic molecule. In another embodiment, a host cell is capable of killing a target cell that comprises a peptide-MHC (pMHC) complex comprising an HPV16 E7₁₁₋₁₉ peptide epitope in the context of an MHC molecule. In still another embodiment, killing is determined by a killing assay. In yet another embodiment, a ratio of a host cell and a target cell in a killing assay is from 20:1 to 0.625:1. In another embodiment, a target cell is a T2 cell pulsed with 1 μ g/mL to 50 pg/mL of HPV16 E7₁₁₋₁₉ peptide. In still another embodiment, a host cell is capable of killing a higher number of target cells when contacted with target cells expressing HPV16 E7₁₁₋₁₉ peptide epitope. In yet another embodiment, a host cell is capable of killing an at least 1.05-fold higher number of target cells. In another embodiment, a target cell is a CaSki, SCC152, or SCC090 cell line. In still another embodiment, an HPV16 E7₁₁₋₁₉ immunogenic peptide comprises the amino acid sequence YMLDLQPET. In yet another embodiment, an MHC molecule is a MHC class I molecule. In another embodiment, an MHC molecule comprises an MHC alpha chain that is an HLA serotype HLA-A*02. In still another embodiment, an HLA allele is selected from the group consisting of HLA-A*02:01, HLA-A*02:02, HLA-A*02:03, HLA-A*02:05, HLA-A*02:06, and HLA-A*02:07 allele. In yet another embodiment, a target cell is a cell line

selected from the group consisting of CaSki, SCC152 and SCC090 cell lines, is a cancer cell expressing HPV16 E7₁₁₋₁₉ immunogenic peptide, or is not siHa cell line and/or is not NCI-H1792 cell line. In another embodiment, a cancer cell is selected from the group consisting of head & neck cancer cell, an oropharyngeal cancer cell, a cervical cancer cell, an anal cancer cell, a vaginal cancer cell, a vulval cancer cell, and a penile cancer cell. In still another embodiment, a) a host cell does not induce T cell expansion, cytokine release, or cytotoxic killing when contacted with a target cell that comprises a peptide-MHC (pMHC) complex comprising a SPTA1, MPL, HERC1, CPAMD8, INTS4, NUTM1, and/or XM_00172256 peptide epitope in the context of an MHC molecule and/or b) a host cell does not express HPV16 E7₁₁₋₁₉ antigen, is not recognized by a binding protein described herein, is not of serotype HLA-A*02, and/or does not express an HLA-A*02 allele, such as HLA-A*02:01 and/or HLA-A*02:06.

In another aspect, a population of host cells described herein, is provided.

In still another aspect, a composition comprising: a) a binding protein described herein, b) an isolated nucleic acid described herein, c) a vector described herein, d) a host cell described herein, and/or e) a population of host cells described herein, and a carrier, is provided.

In yet another aspect, a device or kit comprising: a) a binding protein described herein, b) an isolated nucleic acid described herein, c) a vector described herein, d) a host cell described herein, and/or e) a population of host cells described herein, said device or kit optionally comprising a reagent to detect binding of a), d) and/or e) to a pMHC complex, is provided.

In another aspect, a method of producing a binding protein described herein, wherein the method comprises the steps of: (i) culturing a transformed host cell which has been transformed by a nucleic acid comprising a sequence encoding a binding protein described herein under conditions suitable to allow expression of said binding protein; and (ii) recovering the expressed binding protein, is provided.

In still another aspect, a method of producing a host cell expressing a binding protein described herein, wherein the method comprises the steps of: (i) introducing a nucleic acid comprising a sequence encoding a binding protein described herein into the host cell; (ii) culturing the transformed host cell under conditions suitable to allow expression of said binding protein, is provided.

In yet another aspect, a method of detecting the presence or absence of an HPV16 E7₁₁₋₁₉ antigen and/or a cell expressing HPV16 E7₁₁₋₁₉, optionally wherein the cell is a hyperproliferative cell, comprising detecting the presence or absence of said HPV16 E7₁₁₋₁₉ antigen in a sample by use of at least one binding protein described herein, or at least one host cell described herein, wherein detection of the HPV16 E7₁₁₋₁₉ antigen is indicative of the presence of an HPV16 E7₁₁₋₁₉ antigen and/or cell expressing HPV16 E7₁₁₋₁₉, is provided.

Numerous embodiments are further provided that may be applied to any aspect encompassed by the present invention and/or combined with any other embodiment described herein. For example, in one embodiment, at least one binding protein, or at least one host cell, forms a complex with an HPV16 E7₁₁₋₁₉ peptide in the context of an MHC molecule, and the complex is detected in the form of fluorescence activated cell sorting (FACS), enzyme linked immunosorbent assay (ELISA), radioimmune assay (RIA), immunochemically, Western blot, or intracellular flow assay. In another embodiment, a method further comprises obtaining a sample from a subject. In still another embodiment, a method further comprises confirming cells expressing HPV16 E7₁₁₋₁₉ by bone marrow biopsy.

In another aspect, a method of detecting the level of a non-malignant disorder, a hyperproliferative disorder, or a relapse of a hyperproliferative disorder characterized by expression of an HPV16 E7₁₁₋₁₉ antigen in a subject, comprising: a) contacting a sample obtained from the subject with at least one binding protein described herein, at least one host cell described herein, or a population of host cells described herein; and b) detecting the level of reactivity, wherein a higher level of reactivity compared to a control level indicates the level of a non-malignant disorder, a hyperproliferative disorder, or a relapse of a hyperproliferative disorder characterized by expression of an HPV16 E7₁₁₋₁₉ antigen in the subject, is provided.

Numerous embodiments are further provided that may be applied to any aspect encompassed by the present invention and/or combined with any other embodiment described herein. For example, in one embodiment, a control level is a reference number. In another embodiment, a control level is a level of a subject without the non-malignant disorder, a hyperproliferative disorder, or a relapse of a hyperproliferative disorder characterized by expression of an HPV16 E7₁₁₋₁₉ antigen.

In still another aspect, a method for monitoring the progression of a non-malignant disorder, a hyperproliferative disorder, or a relapse of a hyperproliferative disorder characterized by expression of an HPV16 E7₁₁₋₁₉ antigen in a subject, the method comprising: a) detecting in a subject sample at a first point in time the level of an HPV16 E7₁₁₋₁₉ antigen or a cell of interest expressing HPV16 E7₁₁₋₁₉, as described herein; b) repeating step a) at a subsequent point in time; and c) comparing the level of the HPV16 E7₁₁₋₁₉ antigen or the cell of interest expressing HPV16 E7₁₁₋₁₉ detected in steps a) and b) to monitor the progression of a non-malignant disorder, a hyperproliferative disorder, or a relapse of a hyperproliferative disorder characterized by expression of an HPV16 E7₁₁₋₁₉ antigen in the subject, wherein an absent or reduced level of the HPV16 E7₁₁₋₁₉ antigen or the cell of interest expressing HPV16 E7₁₁₋₁₉ detected in step b) compared to step a) indicates an inhibited progression of the non-malignant disorder, the hyperproliferative disorder, or the relapse of a hyperproliferative disorder characterized by expression of an HPV16 E7₁₁₋₁₉ antigen in the subject.

Numerous embodiments are further provided that may be applied to any aspect encompassed by the present invention and/or combined with any other embodiment described herein. For example, in one embodiment, a subject has undergone treatment to treat the non-malignant disorder, the hyperproliferative disorder, or the relapse of a hyperproliferative disorder characterized by expression of an HPV16 E7₁₁₋₁₉ antigen between the first point in time and the subsequent point in time.

In yet another aspect, a method of assessing the efficacy of a therapy for a non-malignant disorder, a hyperproliferative disorder, or a relapse of a hyperproliferative disorder characterized by expression of an HPV16 E7₁₁₋₁₉ antigen comprising: a) determining the presence or level of reactivity between a sample obtained from a subject and at least one binding protein described herein, at least one host cell described herein, or a population of host cells described herein, in a first sample obtained from the subject prior to providing at least a portion of the therapy for the non-malignant disorder, the hyperproliferative disorder, or the relapse of a hyperproliferative disorder characterized by expression of an HPV16 E7₁₁₋₁₉ antigen to the subject, and b) determining the presence or level of reactivity between a sample obtained from the subject and at least one binding protein described herein, at least one host cell described herein, or a population of host cells described herein, in a second sample obtained from the subject following provision of the portion of the therapy for the non-malignant disorder, the hyperproliferative disorder, or the

relapse of a hyperproliferative disorder characterized by expression of an HPV16 E7₁₁₋₁₉ antigen, wherein the absence or a reduced level of reactivity in the second sample, relative to the first sample, is an indication that the therapy is efficacious for treating the non-malignant disorder, the hyperproliferative disorder, or the relapse of a hyperproliferative disorder characterized by expression of an HPV16 E7₁₁₋₁₉ antigen in the subject, is provided.

Numerous embodiments are further provided that may be applied to any aspect encompassed by the present invention and/or combined with any other embodiment described herein. For example, in one embodiment, a level of reactivity is indicated by a) the presence of binding and/or b) T cell activation and/or effector function. In another embodiment, T cell activation or effector function is T cell proliferation, killing, or cytokine release. In still another embodiment, T cell binding, activation, and/or effector function is detected using fluorescence activated cell sorting (FACS), enzyme linked immunosorbent assay (ELISA), radioimmune assay (RIA), immunochemically, Western blot, or intracellular flow assay.

In another aspect, a method of preventing and/or treating a non-malignant disorder, a hyperproliferative disorder or a relapse of a hyperproliferative disorder characterized by expression of an HPV16 E7₁₁₋₁₉ antigen in a subject comprising administering to the subject a therapeutically effective amount of a composition comprising cells expressing at least one binding protein described herein.

Numerous embodiments are further provided that may be applied to any aspect encompassed by the present invention and/or combined with any other embodiment described herein. For example, in one embodiment, a cell is an allogeneic cell, syngeneic cell, or autologous cell. In another embodiment, a cell is genetically modified. In still another embodiment, a cell comprises a chromosomal gene knockout of a TCR gene, an HLA gene, or both a TCR gene and an HLA gene. In yet another embodiment, a cell comprises a knockout of an HLA gene selected from an $\alpha 1$ macroglobulin gene, $\alpha 2$ macroglobulin gene, $\alpha 3$ macroglobulin gene, $\beta 1$ microglobulin gene, $\beta 2$ microglobulin gene, and a combination thereof. In another embodiment, a cell comprises a knockout of a TCR gene selected from a TCR α variable region gene, TCR β variable region gene, TCR constant region gene, and combinations thereof. In still another embodiment, a cell expresses CD8 α , CD8 β , a DN-TGF β R2, and/or a selectable protein marker, optionally wherein the selectable protein marker is DHFR, and further optionally wherein the CD8 α ,

CD8 β , the DN-TGF β RII, and/or the selectable protein marker is fused to a CD34 enrichment tag. In yet another embodiment, cells are enriched using the CD34 enrichment tag. In another embodiment, an immune cell. In still another embodiment, an immune cell is a cytotoxic lymphocyte, cytotoxic lymphocyte precursor cell, cytotoxic lymphocyte progenitor cell, cytotoxic lymphocyte stem cell, CD4⁺ T cell, CD8⁺ T cell, CD4/CD8 double negative T cell, gamma delta ($\gamma\delta$) T cell, natural killer (NK) cell, NK-T cell, dendritic cell, or combination thereof. In yet another embodiment, a T cell is a naive T cell, central memory T cell, effector memory T cell, or combination thereof. In another embodiment, a T cell is a primary T cell or a cell of a T cell line. In still another embodiment, a T cell does not express or has a lower surface expression of an endogenous TCR. In yet another embodiment, a cell is capable of producing a cytokine or a cytotoxic molecule when contacted with a target cell that comprises a peptide-MHC (pMHC) complex comprising an HPV16 E7₁₁₋₁₉ peptide epitope in the context of an MHC molecule. In another embodiment, a cytokine is TNF- α , IL-2, and/or IFN- γ . In still another embodiment, a cytotoxic molecule is perforins and/or granzymes, optionally wherein the cytotoxic molecule is granzyme B. In yet another embodiment, a cell is capable of producing a higher level of cytokine or a cytotoxic molecule when contacted with a target cell expressing HPV16 E7₁₁₋₁₉ peptide epitope. In another embodiment, a cell is capable of producing an at least 1.05-fold higher level of cytokine or a cytotoxic molecule. In still another embodiment, a host cell is capable of killing a target cell that comprises a peptide-MHC (pMHC) complex comprising an HPV16 E7₁₁₋₁₉ peptide epitope in the context of an MHC molecule. In yet another embodiment, a host cell is capable of killing a higher number of target cells when contacted with target cells expressing HPV16 E7₁₁₋₁₉ peptide epitope. In another embodiment, a host cell is capable of killing an at least 1.05-fold higher number of target cells. In still another embodiment, an HPV16 E7₁₁₋₁₉ immunogenic peptide comprises the amino acid sequence YMLDLQPET. In yet another embodiment, an MHC molecule is an MHC class I molecule. In another embodiment, an MHC molecule comprises an MHC alpha chain that is an HLA serotype HLA-A*02. In still another embodiment, an HLA allele is selected from the group consisting of HLA-A*02:01, HLA-A*02:02, HLA-A*02:03, HLA-A*02:05, HLA-A*02:06, and HLA-A*02:07 allele. In yet another embodiment, a target cell is a non-malignant cell or a hyperproliferating cell expressing HPV16 E7₁₁₋₁₉ antigen in a subject. In another embodiment, a composition further comprises a pharmaceutically acceptable carrier. In still another embodiment, a

composition induces an immune response against non-malignant cells or hyperproliferating cells expressing an HPV16 E7₁₁₋₁₉ antigen in a subject. In yet another embodiment, a composition induces an antigen-specific T cell immune response against non-malignant cells or hyperproliferating cells expressing HPV16 E7₁₁₋₁₉ antigen in a subject. In another embodiment, an antigen-specific T cell immune response comprises at least one of a CD4⁺ helper T lymphocyte (Th) response and a CD8⁺ cytotoxic T lymphocyte (CTL) response. In still another embodiment, the disorder is associated with HPV infection, such as HPV16 infection. In another embodiment, the cancer is a head & neck cancer (e.g., head & neck squamous cell carcinoma (HNSCC)), an oropharyngeal cancer, a cervical cancer, an anal cancer, a vaginal cancer, a vulvar cancer, and/or a penile cancer. In yet another embodiment, a subject is receiving or previously received a hematopoietic cell transplant (HCT), optionally wherein the HCT comprises cells that do not express HPV16 E7₁₁₋₁₉ antigen, are not recognized by a binding protein described herein, are not of serotype HLA-A*02, and/or do not express an HLA-A*02:01 allele. In another embodiment, HCT comprises a donor hematopoietic cell comprising a chromosomal knockout of a gene that encodes an HLA component, a chromosomal knockout of a gene that encodes a TCR component, or both. In still another embodiment, a subject had previously received lymphodepleting chemotherapy. In another embodiment, a lymphodepleting chemotherapy comprised cyclophosphamide, fludarabine, anti-thymocyte globulin, or a combination thereof. In still another embodiment, a method further comprising administering at least one additional treatment for the non-malignant disorder, the hyperproliferative disorder or the relapse of a hyperproliferative disorder to a subject. In yet another embodiment, at least one additional treatment for the non-malignant disorder, the hyperproliferative disorder or the relapse of a hyperproliferative disorder is administered concurrently or sequentially with the composition. In another embodiment, a subject is an animal model of a disorder characterized by HPV16 E7₁₁₋₁₉ expression and/or the subject is a mammal, optionally wherein the mammal is a human, a primate, or a rodent.

In still another aspect, an expression vector comprising a promoter operably linked to a nucleic acid sequence encoding CD8 α , CD8 β , a DN-TGF β R2, and/or a selectable protein marker, optionally wherein the selectable protein marker is DHFR, is provided.

Numerous embodiments are further provided that may be applied to any aspect encompassed by the present invention and/or combined with any other embodiment described herein. For example, in one embodiment, a nucleic acid sequence encoding

CD8 α , CD8 β , the DN-TGF β R2, and/or the selectable protein marker is operably linked to a nucleic acid encoding a tag such that the tag is fused to the CD8 α , CD8 β , the DN-TGF β R2, and/or the selectable protein marker. In another embodiment, a nucleic acid encoding a tag is at the 5' upstream of the nucleic acid sequence encoding CD8 α , CD8 β , the DN-TGF β R2, and/or the selectable protein marker such that the tag is fused to the N-terminal of CD8 α , CD8 β , the DN-TGF β R2, and/or the selectable protein marker. In still another embodiment, a tag is a CD34 enrichment tag. In yet another embodiment, a vector further comprises a nucleic sequence encoding a TCR α and/or TCR β . In another embodiment, the TCR α , TCR β , and/or DN-TGF β R2 comprises a mutated transmembrane domain and/or a mutated constant domain. In still another embodiment, a mutated transmembrane domain and/or mutated constant domain enhance cellular surface expression of TCR α , TCR β , and/or DN-TGF β R2, while decreasing expression of endogenous TCR α , TCR β , and/or TGF β R2. In yet another embodiment, a nucleic acid sequence encoding CD8 α , CD8 β , the DN-TGF β R2, the selectable protein marker, TCR α , and/or the TCR β , are interconnected with an internal ribosome entry site or a nucleic acid sequence encoding a self-cleaving peptide. In another embodiment, a self-cleaving peptide is P2A, E2A, F2A or T2A. In still another embodiment, a vector further comprises a nucleic sequence encoding a polypeptide selected from the group consisting of polypeptide sequences listed in Table 1, or a sequence with at least about 80% homology to a nucleic acid encoding a polypeptide selected from the group consisting of the polypeptide sequences listed in Table 1, optionally wherein the isolated nucleic acid molecule comprises 1) a TRAV, TRAJ, and/or TRAC gene or fragment thereof selected from the group of TRAV, TRAJ, and TRAC genes listed in Table 1 and/or 2) a TRBV, TRBJ, and/or TRBC gene or fragment thereof selected from the group of TRBV, TRBJ, and TRBC genes listed in Table 1. In still another embodiment, a vector has or comprises a nucleic sequence set forth in Table 3, or fragment thereof, optionally wherein the fragment encodes DN-TGF β R2.

Brief Description of the Drawings

Unless otherwise described below, MGTM-modified versions of TCRs (*e.g.*, E7-11-28 MGTM) were used to generate data shown in the figures and exemplified in the working examples.

FIG. 1 shows an HPV16 E7₁₁₋₁₉ peptide sequence.

FIG. 2 shows selection of a variety of TCRs that recognize HPV16 E7₁₁₋₁₉. Four hundred and fifty nine (459) HPV16 E7₁₁₋₁₉ (YMLDLQPET)-specific TCRs were identified using a proprietary ReceptorScan platform. Briefly, CD14⁺ monocytes were isolated from PBMCs of HLA-A*02:01 healthy donors on day -4 and differentiated to mature DCs. On day -1, naïve CD8 T cells were isolated from autologous PBMCs and rested overnight. Co-culture of naïve CD8 T cells and DCs was performed following 3 h pulsing of DCs with 1 µg/mL HPV16 E7₁₁₋₁₉ peptide as part of multiplexed ReceptorScan screens, followed by an 11-day cell expansion phase. Dextramer staining was performed with HLA-A*02:01-specific HPV16 E7₁₁₋₁₉ (YMLDLQPET) dextramer to identify clones. DNA barcoded dextramers were used to isolate HPV16 E7₁₁₋₁₉-specific cells. TCR alpha beta pairs were identified by 10X genomics platform.

Pan-T cells were transduced to individually express 293 HPV-specific TCRs. Surface expression of the TCRs were assessed by HPV16 E7₁₁₋₁₉ dextramer staining. Engineered T cells were co-cultured with Incucyte® NucLight Red-labeled target cells, such as T2 cells loaded with 1 ng/mL HPV16 E7₁₁₋₁₉ peptide and CaSki cells. Survival of the target cells was quantified by time-dependent imaging as a readout of T cell cytotoxicity. Non-transduced cells (NTD) served as control. Fifty-nine (59) out of 293 TCRs listed in Figure 2 were selected for further evaluation for surface expression and cytotoxic potential against HPV16 and HLA-A*02:01 positive and negative cell lines.

FIG. 3A - FIG. 3D show results of selecting HPV16 E7₁₁₋₁₉ TCRs based on expression and cytotoxic function. Pan-T cells from an HLA-A*02:01-positive healthy donor were transduced to express 59 HPV16 E7₁₁₋₁₉ TCRs that were selected from the VAYG screen described in FIG. 2 above. Twenty-four (24) out of 59 TCRs were selected based on high surface binding of HPV16 E7₁₁₋₁₉ (YMLDLQPET) dextramer and were evaluated further in an *in vitro* cytotoxicity assay where they were compared to the ‘comparator TCR’. FIG. 3A shows dot plots of surface expression of the 24 TCRs as assessed by A*02:01-specific HPV16 E7₁₁₋₁₉ (YMLDLQPET) dextramer staining. Cytotoxic responses of these TCRs to HLA-A*02:01⁺ HPV16⁺ target cell lines, CaSki (FIG. 3B), SCC152 (FIG. 3C), and SCC090 (FIG. 3D) are shown. Engineered T cells were co-cultured with Incucyte®NucLight Red labeled target cell lines at indicated effector cell to target cell (E:T) ratios, and their survival was quantified on an IncuCyte® as a readout of cytotoxicity of the T cells.

FIG. 4A - FIG. 4K show functional evaluation results of HPV16 E7₁₁₋₁₉ TCRs. Pan T cells isolated from three HLA-A*02:01-positive healthy donor PBMCs were transduced to express HPV16 E7₁₁₋₁₉-specific TCRs, E7-11-194, E7-11-176 and E7-11-28, and the ‘comparator TCR’ and assessed for functional responses to target cells positive and negative for HPV16 and HLA-A*02:01. FIG. 4A shows dot plot results displaying expression of the E7₁₁₋₁₉ specific TCRs as assessed by A*02:01-specific HPV16 E7₁₁₋₁₉ (YMLDLQPET) dextramer staining. Functional responses of the E7₁₁₋₁₉-specific TCRs to HLA-A*02:01⁺ HPV16⁺ target cell lines, CaSki (FIG. 4B and FIG. 4C), SCC152 (FIG. 4D and FIG. 4E), SCC090 (FIG. 4F and FIG. 4G), the HLA-A*02:01⁺ HPV16⁺ negative control cell line SiHa (FIG. 4H and FIG. 4I), and the HLA-A*02:01⁺ HPV16⁻ cell line NCI-H1792 (FIG. 4J and FIG. 4K) are shown. Engineered T cells were co-cultured with IncuCyte® NucLight Red-labeled target cell lines at indicated E:T ratios, and their survival was quantified on an IncuCyte® as a readout of cytotoxicity of the T cells. Production of IFN- γ , IL-2, TNF- α and granzyme B in co-culture supernatants at 24 h (E:T 1:1) were analyzed and are shown. A T cell-only condition was used to determine background level of cytokine production. Dotted lines represent highest levels of cytokine in T cell-only condition (*i.e.*, background levels of cytokine production or proliferation by T cells). For the cytotoxicity assays, means were compared using one-way ANOVA followed by Dunnett’s multiple comparisons test where the TCRs were compared with the ‘comparator TCR’. For CaSki, SCC152 and SCC090 cell lines, only differences that were non-significant are shown. Remainder of the differences are significant with $P < 0.05$. None of the differences are significant for SiHa and NCI-H1792 cell lines.

FIG. 5 shows that TCR E7-11-28 shows no alloreactivity to 108 of 110 HLA types. TCR E7-11-28-expressing pan T cells or untransduced control T cells were co-cultured with MHC-null HEK293T cells re-expressing one of the 110 most frequently encountered Class I MHCs in the U.S. population for 48 h. A positive control consisting of HEK293T cells expressing both a fragment of HPV16-E7 which contains the E7₁₁₋₁₉ epitope (YMLDLQPET) and HLA-A*02:01 was included in the screen. The inhibition on target cell growth by the TCR E7-11-28-expressing pan T cells relative to that by the untransduced control T cells was measured after 48 h of co-culture as a readout of the reactivity of the TCR E7-11-28 to allogeneic MHC molecules. The positive control and the alloreactive alleles (target cell inhibition > 20%) are indicated.

FIG. 6A and **FIG. 6B** show additional selection of a variety of TCRs that recognize HPV16 E7₁₁₋₁₉. Pan T cells isolated from an HLA-A*02:01 positive healthy donor PBMCs were transduced to express 161 HPV16 E7₁₁₋₁₉-specific TCRs individually and the 'comparator TCR'. FIG. 6A shows representative data for surface expression of the TCRs as assessed by HPV16 E7₁₁₋₁₉ dextramer staining and cytotoxic responses to T2 cells pulsed with 200 pg/ml of HPV16 E7₁₁₋₁₉ peptide and HLA-A*02:01⁺ HPV16⁺ target cell line SCC152. FIG. 6B shows that 15 out of 161 TCRs were selected for further evaluation for surface expression and cytotoxic potential against HPV16 and HLA-A*02:01 positive and negative cell lines.

FIG. 7 show results of selecting HPV16 E7₁₁₋₁₉ TCRs based on expression and cytotoxic function. Pan T cells isolated from an HLA-A*02:01 positive healthy donor PBMCs were transduced to express HPV16 E7₁₁₋₁₉ specific TCRs E7-11-28 and E7-11-455 and the 'comparator TCR' and assessed for cytotoxic responses to target cells positive and negative for HPV16 and HLA-A*02:01. Functional responses of the E7₁₁₋₁₉-specific TCRs to HLA-A*02:01⁺ HPV16⁺ target cell lines CaSki, SCC152, SCC090, the HLA-A*02:01⁻ HPV16⁺ negative control cell line SiHa, and the HLA-A*02:01⁺ HPV16⁻ cell line, NCI-H1792, are shown. Engineered T cells were co-cultured with IncuCyte® NucLight™ Red-labeled target cell lines at indicated E:T ratios, and their survival was quantified on an IncuCyte® as a readout of cytotoxicity of the T cells. For the cytotoxicity assays, means were compared using one-way ANOVA followed by Dunnett's multiple comparisons test where the TCRs were compared with the 'comparator TCR'. * indicates p<0.05.

FIG. 8 provides summary results demonstrating that TCR-28 shows comparable cytotoxicity and superior effector function relative to the comparator TCR.

FIG. 9A - FIG. 9E show T cell proliferation responses produced by HPV16 E7₁₁₋₁₉ TCRs. Pan T cells isolated from three HLA-A*02:01-positive healthy donor PBMCs were transduced to express HPV16 E7₁₁₋₁₉ specific TCRs E7-11-194, E7-11-176 and E7-11-28 and the 'comparator TCR' and assessed for functional responses to target cells positive and negative for HPV16 and HLA-A*02:01. To determine proliferation of the HPV16 E7₁₁₋₁₉-specific TCR-expressing T cells, engineered T cells were labeled with a proliferation dye and co-cultured with target cell lines (CaSki, FIG. 9A; SCC152, FIG. 9B; SCC090, FIG. 9C; SiHa, FIG. 9D; and NCI-H1792, FIG. 9E for 96 h (E:T 1:1). These cell lines have the following properties: CaSki, SCC152 and SCC090 are HLA-A*02:01+HPV16+; SiHa is HLA-A*02:01-HPV16+; and NCI-H1792 is HLA-A*02:01+HPV16-. Dye dilution was

used to assess proliferation of CD8+ and CD4+ T cells. Counting beads were added to the samples prior to analysis by flow cytometry and absolute numbers of divided CD8+ and CD4+ T cells were enumerated. A T cell-only condition was used to determine background level of proliferation; dotted line represents highest levels of proliferation in T cell only condition. Means were compared using one-way ANOVA followed by Dunnett's multiple comparisons test where the TCRs were compared with the 'comparator TCR'. For CaSki (FIG. 9A), SCC152 (FIG. 9B), and SCC090 (FIG. 9C) cell lines, only differences that were non-significant (ns) are shown. Remainder of the differences are significant with $P < 0.05$.

FIG. 10A and FIG. 10B show results of a genome-wide *SafetyScan* screen to identify putative off-targets for TCR E7-11-28. FIG. 10A provides an overview of a representative, non-limiting, genome-wide *SafetyScan* screen. FIG. 10B shows *SafetyScan* screen data of TCR E7-11-28 identifying seven potential off-targets in a screen of >600,000 protein fragments spanning every wild-type (w.t.) human protein. The screen is designed to overpredict off-targets by overexpressing 90-aa protein fragments, which are more efficiently processed than full-length proteins. Putative off-targets are identified by gene names. XM_0017722256 maps to the heterochromatic centromere region of chromosome 20 and has been removed from the RefSeq annotation indicating a lack of evidence for its expression. No expression of this gene was detected using RNA-seq analysis of 51 samples, including normal tissue samples, cancer cell lines and tumor samples.

FIG. 11A - FIG. 11J show that TCR E7-11-28 shows no reactivity to cancer cell lines expressing putative off-targets. TCR E7-11-28-expressing pan T cells or NTD cells were tested for their reactivity to HLA-A*02:01+ cancer cell lines naturally expressing off-targets identified in the genome wide safety screen. FIG. 11A, 11C, 11E, 11G, and 11I show results of target cells that were pulsed with the E7₁₁₋₁₉ peptide or non-pulsed, and co-cultured with TCR E7-11-28 or NTD cells. IFN γ secretion in culture supernatants was used as a read out of TCR E7-11-28's reactivity to target cells. Peptide-pulsed T2 cells were used as a positive control. HLA-A*02:01+HPV16+ SCC152 cells were used as an additional positive control where indicated. For cell lines expressing multiple off-targets, cocultures were performed only once, but are shown in multiple figures. FIG. 11B, 11D, 11F, 11H, and 11J show expression of *HERC1*, *INTS4*, *CPAMD8*, *MPL* and *SPTA1*, respectively, as determined in the target cells relative to a control gene, TBP.

FIG. 12A - FIG. 12I show that TCR E7-11-28 shows no reactivity to healthy human primary cells. TCR E7-11-28-expressing pan T cells or NTD cells were tested for

their reactivity to a panel of primary cells or iPS-derived cells from healthy HLA-A*02:01+ human donors including cells that naturally express the putative off-targets identified in the genome-wide safety screen. FIG. 12A to FIG. 12O show results of target cells that were pulsed with the E7₁₁₋₁₉ peptide or non-pulsed, and co-cultured with TCR E7-11-28 or NTD cells. IFN γ secretion in culture supernatants was used as a readout of TCR E7-11-28's reactivity to target cells. HLA-A*02:01+HPV16+ SCC152 cells were used as a positive control and HLA-A*02:01+ HPV16- NCI-H1792 cells or unpulsed T2 or OVCAR-3 were used as negative controls. FIG. 12P and FIG. 12Q show expression of *HERC1* and *INTS4*, respectively, as determined in the target cells relative to a control gene, TBP. RT = reverse transcriptase.

FIG. 13A - FIG. 13D show that TCR E7-11-28 efficiently controls tumor growth *in vivo*. NCG mice were subcutaneously injected with either 1x10⁶ Caski or 1x10⁶ SCC152 cells per mouse (n=8 mice per group). When tumors reached 95 $\pm$ 15 mm³ on Day 10, the mice were randomized and were treated on Day 11 with 20x10⁶ cells of TCR E7-11-28, NTD, or vehicle. FIG. 13A and FIG. 13C show results of treatment with 20x10⁶ cells of TCR E7-11-28, which demonstrate strong inhibition of tumor growth *in vivo*. FIG. 13B and FIG. 13D show results of individual mouse tumor growth per group over time. *p<0.05, One-way ANOVA, Holms-Šidák correction for multiple comparisons test *in vivo*. Data line labels shown in FIGS. 13A and 13C.

FIG. 14 shows that dominant negative TGF β Receptor II (DN-TGF β RII) provides resistance of DN-TGF β RII-expressing cells to the suppressive effect of TGF β signaling (*e.g.*, DN-TGF β RII renders TCR E7-11-28 resistant to TGF β -mediated suppression). T cells were co-transduced with lentivirus encoding TCR E7-11-28 and DN-TGF β RII, respectively, and were FACS sorted into DN-TGF β RII-positive and DN-TGF β RII-negative fractions. Intracellular IFN γ within the TCR-expressing T cells was quantified after 24 hrs of co-culture with peptide-pulsed T2 cells +/- 5 ng/mL TGF β .

FIG. 15A - FIG. 15C show results of expression and functional evaluation of TCR E7-11-28 and DN-TGF β RII in representative pNVVD154 and pNVVD160 vectors. PBMCs from an HLA-A*02:01-positive healthy donor were transfected to express HPV16 TCR E7-11-28 using pNVVD154 and pNVVD160 vectors. Untransfected (UTF) PBMCs from the same donor was used as control. FIG. 15A shows dot plots of surface expression of TGF β RII, CD34, and TCR E7-11-28 as assessed by A*02:01-specific HPV16 E7₁₁₋₁₉ (YMLDLQPET) dextramer staining. FIG. 15B shows cytotoxic responses of TCR E7-11-

28-engineered T cells to HLA-A*02:01⁺ HPV16⁺ target cell lines CaSki and SCC152, and HLA-A*02:01⁺ HPV16⁻ target cell line NCI-H1792. The top panel of FIG. 15A shows results of engineered T cells co-cultured with IncuCyte® NucLight™ Red-labeled target cell lines CaSki and NCI-H1792 (E:T ratio of 10:1) and SCC-152 (E:T ratio of 5:1), and their survival was quantified on IncuCyte® as a readout of cytotoxicity of the T cells. The bottom panel of FIG. 15B shows target cell survival at 96 hours for CaSki, SCC-152, and NCI-H1792 cell lines. FIG. 15C shows results of assays testing T-cell avidity. For example, HPV16 TCR E7-11-28-expressing T cells were co-cultured with E7₁₁₋₁₉ peptide pulsed (0-1,000 pg/ml E7-peptide) IncuCyte® NucLight™-expressing T2 cells at an E:T ratio of 5:1. The graph shows the area under the curve (AUC) of T2 cells growth between 0 and 96 hours of co-culture. The experiments was done in duplicate. A Mann-Whitney t-test was performed.

For any figure showing a bar histogram, curve, or other data associated with a legend, the bars, curve, or other data presented from left to right for each indication correspond directly and in order to the boxes from top to bottom, or from left to right, of the legend unless indicated othrewise.

Detailed Description of the Invention

The present invention is based, at least in part, on the discovery of binding proteins, including T cell receptors (TCRs), that recognize HPV16 E7₁₁₋₁₉ antigen (*e.g.*, immunogenic peptide comprising the amino acid sequence, YMLDLQPET).

Accordingly, the present invention relates, in part, to the identified binding proteins (*e.g.*, TCRs), host cells expressing binding proteins (*e.g.*, TCRs), compositions comprising binding proteins (*e.g.*, TCRs) and host cells expressing binding proteins (*e.g.*, TCRs), methods of diagnosing, prognosing, and monitoring T cell response to cells expressing the HPV16 E7₁₁₋₁₉ antigen, and methods for preventing and/or treating a non-malignant disorder, a hyperproliferative disorder, or a relapse of a hyperproliferative disorder characterized by expression of the HPV16 E7₁₁₋₁₉ antigen by administering host cells expressing binding proteins (*e.g.*, TCRs).

I. Definitions

For convenience, certain terms employed in the specification, examples, and appended claims are collected here.

The articles “a” and “an” are used herein to refer to one or to more than one (*i.e.*, to at least one) of the grammatical object of the article. By way of example, “an element” means one element or more than one element.

The term “administering” means providing a pharmaceutical agent or composition to a subject, and includes, but is not limited to, administering by a medical professional and self-administering. This involves the physical introduction of a composition comprising a therapeutic agent to a subject, using any of the various methods and delivery systems known to those skilled in the art. In some embodiments, routes of administration for binding proteins described herein include intravenous, intraperitoneal, intramuscular, subcutaneous, spinal or other parenteral routes of administration, for example by injection or infusion. The phrase “parenteral administration” as used herein means modes of administration other than enteral and topical administration, usually by injection, and includes, without limitation, intravenous, intraperitoneal, intramuscular, intraarterial, intrathecal, intralymphatic, intralesional, intracapsular, intraorbital, intracardiac, intradermal, transtracheal, subcutaneous, subcuticular, intraarticular, subcapsular, subarachnoid, intraspinal, epidural and intrasternal injection and infusion, as well as *in vivo* electroporation. Alternatively, a binding protein described herein may be administered via a non-parenteral route, such as a topical, epidermal or mucosal route of administration, for example, intranasally, orally, vaginally, rectally, sublingually or topically. Administering may also be performed, for example, once, a plurality of times, and/or over one or more extended periods.

As used herein, the term “antigen” refers to any natural or synthetic immunogenic substance, such as a protein, peptide, or hapten. An antigen may be an HPV16 E7₁₁₋₁₉ antigen, or a fragment thereof, against which protective or therapeutic immune responses are desired.

The term “adjuvant” as used herein refers to substances, which when administered prior, together or after administration of an antigen accelerates, prolong and/or enhances the quality and/or strength of an immune response to the antigen in comparison to the administration of the antigen alone. Adjuvants can increase the magnitude and duration of the immune response induced by vaccination.

The term “antibody” as used to herein includes whole antibodies and any antigen binding fragments (*i.e.*, “antigen-binding portions”) or single chains thereof. An “antibody” refers, in one embodiment, to a glycoprotein comprising at least two heavy (H)

chains and two light (L) chains inter-connected by disulfide bonds, or an antigen binding portion thereof. Each heavy chain is comprised of a heavy chain variable region (abbreviated herein as V_H) and a heavy chain constant region. In certain naturally occurring antibodies, the heavy chain constant region is comprised of three domains, CH1, CH2 and CH3. In certain naturally occurring antibodies, each light chain is comprised of a light chain variable region (abbreviated herein as V_L) and a light chain constant region. The light chain constant region is comprised of one domain, CL. The V_H and V_L regions may be further subdivided into regions of hypervariability, termed complementarity determining regions (CDR), interspersed with regions that are more conserved, termed framework regions (FR). Each V_H and V_L is composed of three CDRs and four FRs, arranged from amino-terminus to carboxy-terminus in the following order: FR1, CDR1, FR2, CDR2, FR3, CDR3, FR4. The variable regions of the heavy and light chains contain a binding domain that interacts with an antigen. The constant regions of the antibodies may mediate the binding of the immunoglobulin to host tissues or factors, including various cells of the immune system (*e.g.*, effector cells) and the first component (C1q) of the classical complement system.

The term “antigen presenting cell” or “APC” includes professional antigen presenting cells (*e.g.*, B lymphocytes, monocytes, dendritic cells, Langerhans cells), as well as other antigen presenting cells (*e.g.*, keratinocytes, endothelial cells, astrocytes, fibroblasts, and oligodendrocytes).

The term “antigen-binding portion” of a binding protein, such as a TCR, as used herein, refers to one or more portions of a TCR that retain the ability to bind (*e.g.*, specifically and/or selectively) to an antigen (*e.g.*, an HPV16 E7₁₁₋₁₉ antigen and cognate MHC/HLA). Such portions are, for example, between about 8 and about 1500 amino acids in length, suitably between about 8 and about 745 amino acids in length, suitably about 8 to about 300, for example about 8 to about 200 amino acids, or about 10 to about 50 or 100 amino acids in length. It has been shown that the antigen-binding function of a TCR can be performed by fragments of a full-length TCR. Examples of binding portions encompassed within the term “antigen-binding portion” of a TCR, include (i) a Fv fragment consisting of the V_α and V_β domains of a TCR, (ii) an isolated complementarity determining region (CDR) or (iii) a combination of two or more isolated CDRs which may optionally be joined by a synthetic linker. Furthermore, although V_α and V_β , are coded by separate genes, they may be joined, using recombinant methods, by a synthetic linker that enables them to be

made as a single protein chain in which the V_{α} and V_{β} regions pair to form monovalent molecules (known as single chain TCR (scTCR)). Such single chain TCRs are also intended to be encompassed within the term "antigen-binding portion" of a TCR. These TCR fragments can be obtained using conventional techniques known to those with skill in the art, and the fragments are screened for utility in the same manner as are complete binding proteins. Antigen-binding portions may be produced by recombinant DNA techniques, or by enzymatic or chemical cleavage of intact immunoglobulins.

The terms "complementarity determining region" and "CDR" are synonymous with "hypervariable region" or "HVR" and are known in the art to refer to non-contiguous sequences of amino acids within certain binding proteins, such as TCR variable regions, which confer antigen specificity and/or binding affinity. For TCRs, in general, there are three CDRs in each α -chain variable region (α CDR1, α CDR2, and α CDR3) and three CDRs in each β -chain variable region (β CDR1, β CDR2, and β CDR3). CDR3 is believed to be the main CDR responsible for recognizing processed antigen. CDR1 and CDR2 mainly interact with the MHC.

The term "body fluid" refers to fluids that are excreted or secreted from the body as well as fluids that are normally not excreted or secreted from the body (*e.g.*, amniotic fluid, aqueous humor, bile, blood and blood plasma, cerebrospinal fluid, cerumen and earwax, cowper's fluid or pre-ejaculatory fluid, chyle, chyme, stool, female ejaculate, interstitial fluid, intracellular fluid, lymph, menses, breast milk, mucus, pleural fluid, pus, saliva, sebum, semen, serum, sweat, synovial fluid, tears, urine, vaginal lubrication, vitreous humor, vomit). In some embodiments, the body fluid comprises immune cells, optionally wherein the immune cells are cytotoxic lymphocytes such as cytotoxic T cells and/or NK cells, CD4+ T cells, and the like.

The term "coding region" refers to regions of a nucleotide sequence comprising codons that are translated into amino acid residues, whereas the term "non-coding region" refers to regions of a nucleotide sequence that are not translated into amino acids (*e.g.*, 5' and 3' untranslated regions).

The term "complementary" refers to the broad concept of sequence complementarity between regions of two nucleic acid strands or between two regions of the same nucleic acid strand. It is known that an adenine residue of a first nucleic acid region is capable of forming specific hydrogen bonds ("base pairing") with a residue of a second nucleic acid region which is anti-parallel to the first region if the residue is thymine or

uracil. Similarly, it is known that a cytosine residue of a first nucleic acid strand is capable of base pairing with a residue of a second nucleic acid strand which is anti-parallel to the first strand if the residue is guanine. A first region of a nucleic acid is complementary to a second region of the same or a different nucleic acid if, when the two regions are arranged in an antiparallel fashion, at least one nucleotide residue of the first region is capable of base pairing with a residue of the second region. In some embodiments, the first region comprises a first portion and the second region comprises a second portion, whereby, when the first and second portions are arranged in an antiparallel fashion, at least about 50%, and, in other embodiments, at least about 75%, 76%, 77%, 78%, 79%, 80%, 81%, 82%, 83%, 84%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or more, or any range in between, inclusive, such as at least about 80%-100%, of the nucleotide residues of the first portion are capable of base pairing with nucleotide residues in the second portion. In some embodiments, all nucleotide residues of the first portion are capable of base pairing with nucleotide residues in the second portion.

As used herein, the term “costimulate” with reference to activated immune cells includes the ability of a costimulatory molecule to provide a second, non-activating receptor mediated signal (a “costimulatory signal”) that induces proliferation or effector function. For example, a costimulatory signal may result in cytokine secretion, *e.g.*, in a T cell that has received a T cell-receptor-mediated signal. Immune cells that have received a cell-receptor mediated signal, *e.g.*, via an activating receptor are referred to herein as “activated immune cells.”

“CD3” is known in the art as a multi-protein complex of six chains (see, Abbas and Lichtman, *Cellular and Molecular Immunology* (9th Edition) (2018); Janeway *et al.* (Immunobiology) (9th Edition) (2016)). In mammals, the complex comprises a CD3 γ chain, a CD3 δ chain, two CD3 ϵ chains, and a homodimer of CD3 ζ chains. The CD3 γ , CD3 δ , and CD3 ϵ chains are related cell surface proteins of the immunoglobulin superfamily containing a single immunoglobulin domain. The transmembrane regions of the CD3 γ , CD3 δ , and CD3 ϵ chains are negatively charged, which is a characteristic that is believed to allow these chains to associate with positively charged regions or residues of T cell receptor chains. The intracellular tails of the CD3 γ , CD3 δ , and CD3 ϵ chains each contain a single conserved motif known as an immunoreceptor tyrosine-based activation motif or ITAM, whereas each CD3 ζ chain has three ITAMs. Without wishing to be bound by theory, it is believed that the ITAMs are important for the signaling capacity of a TCR complex. CD3 used in

accordance with the present invention may be from various animal species, including human, mouse, rat, or other mammals.

A "component of a TCR complex," as used herein, refers to a TCR chain (*i.e.*, TCR α , TCR β , TCR γ or TCR δ), a CD3 chain (*i.e.*, CD3 γ , CD3 δ , CD3 ϵ or CD3 ζ), or a complex formed by two or more TCR chains or CD3 chains (*e.g.*, a complex of TCR α and TCR β , a complex of TCR γ and TCR δ , a complex of CD3 ϵ and CD3 δ , a complex of CD3 γ and CD3 ϵ , or a sub-TCR complex of TCR α , TCR β , CD3 γ , CD3 δ , and two CD3 ϵ chains).

"Chimeric antigen receptor" or "CAR" refers to a fusion protein that is engineered to contain two or more amino acid sequences linked together in a way that does not occur naturally or does not occur naturally in a host cell, which fusion protein can function as a receptor when present on a surface of a cell. CARs encompassed by the present invention include an extracellular portion comprising an antigen-binding domain (*i.e.*, obtained or derived from an immunoglobulin or immunoglobulin-like molecule, such as a TCR specific for an HPV16 E7₁₁₋₁₉ antigen, a single chain TCR-derived binding protein, an scFv derived from an antibody, an antigen binding domain derived or obtained from a killer immunoreceptor from an NK cell, and the like) linked to a transmembrane domain and one or more intracellular signaling domains (such as an effector domain, optionally containing co-stimulatory domain(s)) (see, *e.g.*, Sadelain *et al.* (2013) *Cancer Discov.* 3:388; see also Harris and Kranz (2016) *Trends Pharmacol. Sci.* 37: 220; Stone *et al.* (2014) *Cancer Immunol. Immunother.* 63:1163).

As used herein, the term "cytotoxic T lymphocyte (CTL) response" refers to an immune response induced by cytotoxic T cells. CTL responses are mediated primarily by CD8⁺ T cells.

The term "consisting essentially of" is not equivalent to "comprising" and refers to the specified materials or steps of a claim, or to those that do not materially affect the basic characteristics of a claimed subject matter. For example, a protein domain, region, or module (*e.g.*, a binding domain, hinge region, linker module) or a protein (which may have one or more domains, regions, or modules) "consists essentially of a particular amino acid sequence when the amino acid sequence of a domain, region, module, or protein includes extensions, deletions, mutations, or a combination thereof (*e.g.*, amino acids at the amino- or carboxy -terminus or between domains) that, in combination, contribute to at most 20% (*e.g.*, at most 15%, 10%, 8%, 6%, 5%, 4%, 3%, 2% or 1%) of the length of a domain, region, module, or protein and do not

substantially affect (*i.e.*, do not reduce the activity by more than 50%, such as no more than 40%, 30%, 25%, 20%, 15%, 10%, 5%, or 1%) the activity of the domain(s), region(s), module(s), or protein (*e.g.*, the target binding affinity of a binding protein).

The term “determining a suitable treatment regimen for the subject” is taken to mean the determination of a treatment regimen (*i.e.*, a single therapy or a combination of different therapies that are used for the prevention and/or treatment of the viral infection in the subject) for a subject that is started, modified and/or ended based or essentially based or at least partially based on the results of the analysis according to the present invention. One example is starting an adjuvant therapy after surgery whose purpose is to decrease the risk of recurrence, another would be to modify the dosage of a particular chemotherapy. The determination can, in addition to the results of the analysis according to the present invention, be based on personal characteristics of the subject to be treated. In most cases, the actual determination of the suitable treatment regimen for the subject will be performed by the attending physician or doctor.

The term “dominant negative TGF β receptor” or “DN-TGF β R” refers to a transforming growth factor (TGF) beta receptor variant or mutant that provides resistance to TGF β signaling.

There are five type II receptors (activation receptors) and seven type I receptors (signaling propagation receptors). The active TGF β receptor is a heterotetramer consisting of two TGF β receptors I (TGF β RI) and two TGF β receptors II (TGF β RII). In some embodiments, the DN-TGF β R is a DN-TGF β RII (*i.e.*, a TGF beta receptor II variant or mutant). In some embodiments, resistance is to the suppressive effect of TGF β signaling on an immune cell, such as a T cell, which TGF β may be produced by cancer cells or by other immune cells within a cellular environment, such as by stromal cells, macrophages, myeloid cells, epithelial cells, natural killer cells, and the like. TGF β signaling inhibitors are well-known in the art and include, without limitation, mutant TGF β that sequesters receptors and thereby inhibits signaling, antibodies that bind to TGF β and/or TGF β receptors (*e.g.*, lerdelimumab, metlimumab, fressolimumab, and the like), soluble TGF β -binding proteins such as portions of TGF β receptors that sequester TGF β (*e.g.*, TGF β RII-Fc fusion proteins) or other binders, such as beta-glycans. Any and all known TGF β signaling inhibitors may be used instead of or in addition to DN-TGF β R (*e.g.*, DN-TGF β RII) described herein. In some embodiments, a DN-TGF β R lacks an intracellular portion required for TGF β -mediated signaling, such as the entire intracellular domain, a

kinase signaling domain, etc. DN-TGF β R constructs are well-known in the art (see representative, non-limiting embodiments at Brand *et al.* (1993) *J. Biol. Chem.* 268:11500-11503; Weiser *et al.* (1993) *Mol. Cell Biol.* 13:7239-7247; Bollard *et al.* (2002) *Blood* 99:3179-3187; PCT Publ. WO 2009/152610; PCT Publ. WO 2017/156484; Kloss *et al.* (2018) *Mol. Ther.* 26:1855-1866; PCT Publ. WO. 2019/089884; PCT Publ. WO 2020/042647; and PCT Publ. WO 2020/042648).

In some embodiments, immune cell products (*e.g.*, engineered T cells) comprising one or more binding proteins (*e.g.*, TCRs) described herein are resistant to β -mediated immunosuppression. As described above and further herein, TGF β is an immunosuppressive cytokine produced by tumor cells and cells in the tumor microenvironment. TGF β inhibits the function and expansion of cytotoxic and Th1 helper T cells resulting in suppression of the tumor-specific T cell responses (Dahmani and Delisle (2018) *Cancers* 10:194). TGF β signaling in T cells can be abrogated by expression of a dominant negative TGF β type II receptor (DN-TGF β RII) (Wieser *et al.* (1993) *Mol. Cell Biol.* 13:7239-7247; Bollard *et al.* (2002) *Blood* 99:3179-3187). Upon binding to TGF β , wild-type TGF β RII phosphorylates and thereby activates the TGF β RI and initiating intracellular signal transmission. This signaling cascade is interrupted in cells that express truncated TGF β RII lacking the intracellular kinase domain (DN-TGF β RII), thereby rendering the cells resistant to inhibition by TGF β . DN-TGF β RII blocks TGF β signaling in engineered T cells (both CAR-T and TCR-T cells) (Bollard *et al.* (2002) *Blood* 99:3179-3187; Foster *et al.* (2008) *J. Immunother.* 31:500-505; Kloss *et al.* (2018) *Mol. Ther.* 26:1855-1866; Alabanza *et al.* (2022) *Front. Immunol.* 13:832645; Silk *et al.* (2022) *J. Immunol.* 208:169-180; Li *et al.* (2020) *Front. Oncol.* 10:1117). In a representative study, evaluation of EBV-specific T cells equipped with DN-TGF β RII for the treatment of Hodgkin lymphoma showed that T cells engineered with DN-TGF β RII are both safe and efficacious (Bollard *et al.* (2018) *J. Clin. Oncol.* 36:1128-1139).

“Kite T-cell receptor” or “comparator T-cell receptor” refers to at least one benchmark T-cell receptor (*e.g.*, “Kite-439”) that has been reported in U.S. Pat. No. 10,174,098 and U.S. Pat. Appl. Nos. 62/004,335; 61/846,167; and 61/846,161. In some embodiments, the “Kite or “Comparator” T-cell receptor has sequences set forth in Table 2.

“Homologous” as used herein, refers to nucleotide sequence similarity between two regions of the same nucleic acid strand or between regions of two different nucleic acid strands. When a nucleotide residue position in both regions is occupied by the same

nucleotide residue, then the regions are homologous at that position. A first region is homologous to a second region if at least one nucleotide residue position of each region is occupied by the same residue. Homology between two regions is expressed in terms of the proportion of nucleotide residue positions of the two regions that are occupied by the same nucleotide residue. By way of example, a region having the nucleotide sequence 5'-ATTGCC-3' and a region having the nucleotide sequence 5'-TATGGC-3' share 50% homology. In some embodiments, the first region comprises a first portion and the second region comprises a second portion, whereby, at least about 50%, and, in other embodiments, at least about 75%, 76%, 77%, 78%, 79%, 80%, 81%, 82%, 83%, 84%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or more, or any range in between, inclusive, such as at least about 80%-100%, of the nucleotide residue positions of each of the portions are occupied by the same nucleotide residue. In some embodiments, all nucleotide residue positions of each of the portions are occupied by the same nucleotide residue.

The term "human papilloma virus" or "HPV" refers to a family of viruses, infection of some subtypes of which, such as HPV16 (NCBI Ref. Seq. NC_001526.4), are associated with a number of disorders, including cancers. In some cases, such disorders are associated with expression of the HPV oncoprotein, E7 (*e.g.*, which is believed to target tumor suppressor signaling pathways regulating cellular growth control).

As used herein, the term "HPV16 E7₁₁₋₁₉ antigen" or "HPV16 E7₁₁₋₁₉ peptide antigen" or "HPV16 E7₁₁₋₁₉-containing peptide antigen" or "HPV16 E7₁₁₋₁₉ epitope" or "HPV16 E7₁₁₋₁₉ peptide epitope" or "HPV16 E7₁₁₋₁₉ bpeptide" refers to a naturally or synthetically produced peptide portion of an HPV16 E7 oncoprotein comprising, consisting of, or consisting essentially of the sequence, YMLDLQPET.

The term "hyperproliferative disorder characterized by expression of an HPV16 E7₁₁₋₁₉ antigen" can be any hyperproliferative disorder where the HPV16 E7₁₁₋₁₉ antigen is present in a MHC (*e.g.*, HLA) complex expressed by at least some hyperproliferating cells in the subject. Examples of hyperproliferative disorders characterized by HPV16 E7₁₁₋₁₉:HLA complexes include solid malignancies, such as those described in detail *infra*.

The term "immune response" includes T cell mediated and/or B cell mediated immune responses. Exemplary immune responses include T cell responses, *e.g.*, cytokine production and cellular cytotoxicity. In addition, the term immune response includes

immune responses that are indirectly effected by T cell activation, *e.g.*, antibody production (humoral responses) and activation of cytokine responsive cells, *e.g.*, macrophages.

An increased ability to stimulate an immune response or the immune system, can result from an enhanced agonist activity of T cell costimulatory receptors and/or an enhanced antagonist activity of inhibitory receptors. An increased ability to stimulate an immune response or the immune system may be reflected by a fold increase of the EC₅₀ or maximal level of activity in an assay that measures an immune response, *e.g.*, an assay that measures changes in cytokine or chemokine release, cytolytic activity (determined directly on target cells or indirectly via detecting CD107a or granzymes) and proliferation. The ability to stimulate an immune response or the immune system activity may be enhanced by at least 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90%, 100%, 110%, 120%, 130%, 140%, 150%, 160%, 170%, 180%, 190%, 200%, 250%, 300%, 350%, 400%, 500%, or more.

The term “immunotherapeutic agent” may include any molecule, peptide, antibody or other agent which can stimulate a host immune system to generate an immune response to a viral infection in the subject. Various immunotherapeutic agents are useful in the compositions and methods described herein.

The term “immune cell” refers to any cell of the immune system that originates from a hematopoietic stem cell in the bone marrow, which gives rise to two major lineages: a myeloid progenitor cell (which give rise to myeloid cells such as monocytes, macrophages, dendritic cells, megakaryocytes and granulocytes); and a lymphoid progenitor cell (which give rise to lymphoid cells such as T cells, B cells and natural killer (NK) cells). Exemplary immune system cells include a CD4⁺ T cell, a CD8⁺ T cell, a CD4 CD8 double negative T cell, a gd T cell, a regulatory T cell, a natural killer cell, and a dendritic cell. Macrophages and dendritic cells may be referred to as “antigen presenting cells” or “APCs,” which are specialized cells that can activate T cells when a major histocompatibility complex (MHC) receptor on the surface of the APC complexed with a peptide interacts with a TCR on the surface of a T cell.

An “isolated protein” refers to a protein that is substantially free of other proteins, cellular material, separation medium, and culture medium when isolated from cells or produced by recombinant DNA techniques, or chemical precursors or other chemicals when chemically synthesized. An “isolated” or “purified” protein or biologically active portion thereof is substantially free of cellular material or other contaminating proteins from the

cell or tissue source from which the binding protein, antibody, polypeptide, peptide or fusion protein is derived, or substantially free from chemical precursors or other chemicals when chemically synthesized. The language “substantially free of cellular material” includes preparations of a biomarker polypeptide or fragment thereof, in which the protein is separated from cellular components of the cells from which it is isolated or recombinantly produced. In one embodiment, the language “substantially free of cellular material” includes preparations of a biomarker protein or fragment thereof, having less than about 30% (by dry weight) of non-biomarker protein (also referred to herein as a “contaminating protein”), or, in some embodiments, less than about 25%, 20%, 15%, 10%, 5%, 1%, or less, or any range in between inclusive, such as less than about 1% to 5%, of non-biomarker protein. When binding protein, antibody, polypeptide, peptide or fusion protein or fragment thereof, *e.g.*, a biologically active fragment thereof, is recombinantly produced, it may be substantially free of culture medium, *i.e.*, culture medium represents less than about 20%, 15%, 10%, 5%, 1%, or less, or any range in between inclusive, such as less than about 1% to 5%, of the volume of the protein preparation.

As used herein, the term “isotype” refers to the antibody class (*e.g.*, IgM, IgG1, IgG2C, and the like) that is encoded by heavy chain constant region genes.

As used herein, the term “ K_D ” is intended to refer to the dissociation equilibrium constant of a particular binding protein-antigen interaction. The binding affinity of binding proteins encompassed by the present invention may be measured or determined by standard binding protein-target binding assays, for example, competitive assays, saturation assays, or standard immunoassays, such as ELISA or RIA. A relatively lower K_D value indicates a relatively higher binding affinity (*e.g.*, K_D values of less than or equal to about 5×10^{-4} M (500 μ M) include a K_D value of 1×10^{-4} M (100 μ M) and a 100 μ M K_D indicates a relatively higher binding affinity as compared to a 500 μ M K_D).

A “kit” is any manufacture (*e.g.*, a package or container) comprising at least one reagent, *e.g.*, a probe or small molecule, for specifically detecting and/or affecting the expression of a marker encompassed by the present invention. The kit may be promoted, distributed, or sold as a unit for performing the methods encompassed by the present invention. The kit may comprise one or more reagents necessary to express a composition useful in the methods encompassed by the present invention. In some embodiments, the kit may further comprise a reference standard, *e.g.*, a nucleic acid encoding a protein that does not affect or regulate signaling pathways controlling cell growth, division, migration,

survival or apoptosis. One skilled in the art can envision many such control proteins, including, but not limited to, common molecular tags (*e.g.*, green fluorescent protein and beta-galactosidase), proteins not classified in any of pathway encompassing cell growth, division, migration, survival or apoptosis by GeneOntology reference, or ubiquitous housekeeping proteins. Reagents in the kit may be provided in individual containers or as mixtures of two or more reagents in a single container. In addition, instructional materials which describe the use of the compositions within the kit may be included.

As used herein, the term “linked” refers to the association of two or more molecules. The linkage may be covalent or non-covalent. The linkage also may be genetic (*i.e.*, recombinantly fused). Such linkages may be achieved using a wide variety of art recognized techniques, such as chemical conjugation and recombinant protein production.

A “linker,” in some embodiments, may refer to an amino acid sequence that connects two proteins, polypeptides, peptides, domains, regions, or motifs and may provide a spacer function compatible with interaction of the two sub-binding domains so that the resulting polypeptide retains a specific binding affinity (*e.g.*, scTCR) to a target molecule or retains signaling activity (*e.g.*, TCR complex). In some embodiments, a linker is comprised of about two to about 35 amino acids, for instance, or about four to about 20 amino acids or about eight to about 15 amino acids or about 15 to about 25 amino acids.

“Major histocompatibility complex” (MHC) refers to glycoproteins that deliver peptide antigens to a cell surface. MHC class I molecules are heterodimers having a membrane spanning α chain (with three α domains) and a non-covalently associated β_2 microglobulin. MHC class II molecules are composed of two transmembrane glycoproteins, α and β , both of which span the membrane. Each chain has two domains. MHC class I molecules deliver peptides originating in the cytosol to the cell surface, where a peptide antigen-MHC (pMHC) complex is recognized by CD8⁺ T cells. MHC class II molecules deliver peptides originating in the vesicular system to the cell surface, where they are recognized by CD4⁺ T cells. Human MHC is referred to as human leukocyte antigen (HLA).

The terms “prevent,” “preventing,” “prevention,” “prophylactic treatment,” and the like refer to reducing the probability of developing a disease, disorder, or condition in a subject, who does not have, but is at risk of or susceptible to developing a disease, disorder, or condition.

The term “prognosis” includes a prediction of the probable course and outcome of a viral infection or the likelihood of recovery from the disease. In some embodiments, the use of statistical algorithms provides a prognosis of a viral infection in an individual. For example, the prognosis may be surgery, development of a clinical subtype of a viral infection, development of one or more clinical factors, or recovery from the disease.

As used herein, “percent identity” between amino acid sequences is synonymous with “percent homology,” which can be determined using the algorithm of Karlin and Altschul (1990) *Proc. Natl. Acad. Sci. USA* 87:2264-2268, modified by Karlin and Altschul (1993) *Proc. Natl. Acad. Sci. USA* 90:5873-5877. The noted algorithm is incorporated into the NBLAST and XBLAST programs of Altschul *et al.* (1990) *J. Mol. Biol.* 215:403-410. BLAST nucleotide searches are performed with the NBLAST program, score=100, wordlength=12, to obtain nucleotide sequences homologous to a polynucleotide described herein. BLAST protein searches are performed with the XBLAST program, score=50, wordlength=3, to obtain amino acid sequences homologous to a reference polypeptide. To obtain gapped alignments for comparison purposes, Gapped BLAST is utilized as described in Altschul *et al.* (1997) *Nuc. Acids Res.* 25:3389-3402. When utilizing BLAST and Gapped BLAST programs, the default parameters of the respective programs (*e.g.*, XBLAST and NBLAST) may be used.

The phrase “pharmaceutically-acceptable carrier” means a pharmaceutically-acceptable material, composition or vehicle, such as a liquid or solid filler, diluent, excipient, or solvent encapsulating material, involved in carrying or transporting the subject compound from one organ, or portion of the body, to another organ, or portion of the body.

The term “recombinant host cell” (or simply “host cell”) refers to a cell that comprises a nucleic acid that is not naturally present in the cell, such as a cell into which a recombinant expression vector has been introduced. It should be understood that cells according to the present invention is intended to refer not only to the particular subject cell, but also encompasses progeny of such a cell. Because certain modifications may occur in succeeding generations due to either mutation or environmental influences, such progeny may not, in fact, be identical to the parent cell, but are still included within the scope of the term cell according to the present invention.

The term “cancer response,” “response to immunotherapy,” or “response to modulators of T-cell mediated cytotoxicity/immunotherapy combination therapy” relates to any response of the hyperproliferative disorder (*e.g.*, cancer) to a cancer agent, such as a

modulator of T-cell mediated cytotoxicity, and an immunotherapy, preferably to a change in tumor mass and/or volume after initiation of neoadjuvant or adjuvant therapy. The term “neoadjuvant therapy” refers to a treatment given before the primary treatment. Examples of neoadjuvant therapy may include chemotherapy, radiation therapy, and hormone therapy. Hyperproliferative disorder response may be assessed, for example for efficacy or in a neoadjuvant or adjuvant situation, where the size of a tumor after systemic intervention may be compared to the initial size and dimensions as measured by CT, PET, mammogram, ultrasound or palpation. Responses may also be assessed by caliper measurement or pathological examination of the tumor after biopsy or surgical resection. Response may be recorded in a quantitative fashion like percentage change in tumor volume or in a qualitative fashion like “pathological complete response” (pCR), “clinical complete remission” (cCR), “clinical partial remission” (cPR), “clinical stable disease” (cSD), “clinical progressive disease” (cPD) or other qualitative criteria. Assessment of hyperproliferative disorder response may be done early after the onset of neoadjuvant or adjuvant therapy, *e.g.*, after a few hours, days, weeks or preferably after a few months. A typical endpoint for response assessment is upon termination of neoadjuvant chemotherapy or upon surgical removal of residual tumor cells and/or the tumor bed. This is typically three months after initiation of neoadjuvant therapy. In some embodiments, clinical efficacy of the therapeutic treatments described herein may be determined by measuring the clinical benefit rate (CBR). The clinical benefit rate is measured by determining the sum of the percentage of patients who are in complete remission (CR), the number of patients who are in partial remission (PR) and the number of patients having stable disease (SD) at a time point at least 6 months out from the end of therapy. The shorthand for this formula is $CBR = CR + PR + SD$ over 6 months. In some embodiments, the CBR for a particular cancer therapeutic regimen is at least 25%, 30%, 35%, 40%, 45%, 50%, 55%, 60%, 65%, 70%, 75%, 80%, 85%, or more. Additional criteria for evaluating the response to cancer therapies are related to “survival,” which includes all of the following: survival until mortality, also known as overall survival (wherein said mortality may be either irrespective of cause or tumor related); “recurrence-free survival” (wherein the term recurrence shall include both localized and distant recurrence); metastasis free survival; disease free survival (wherein the term disease shall include cancer and diseases associated therewith). The length of said survival may be calculated by reference to a defined start point (*e.g.*, time of diagnosis or start of treatment) and end point (*e.g.*, death, recurrence or metastasis). In

addition, criteria for efficacy of treatment may be expanded to include response to chemotherapy, probability of survival, probability of metastasis within a given time period, and probability of tumor recurrence. For example, in order to determine appropriate threshold values, a particular cancer therapeutic regimen may be administered to a population of subjects and the outcome may be correlated to biomarker measurements that were determined prior to administration of any cancer therapy. The outcome measurement may be pathologic response to therapy given in the neoadjuvant setting. Alternatively, outcome measures, such as overall survival and disease-free survival may be monitored over a period of time for subjects following cancer therapy for which biomarker measurement values are known. In certain embodiments, the doses administered are standard doses known in the art for cancer therapeutic agents. The period of time for which subjects are monitored may vary. For example, subjects may be monitored for at least 2, 4, 6, 8, 10, 12, 14, 16, 18, 20, 25, 30, 35, 40, 45, 50, 55, or 60 months. Biomarker measurement threshold values that correlate to outcome of a cancer therapy may be determined using well-known methods in the art, such as those described in the Examples section.

As indicated, the terms may also refer to an improved prognosis, for example, as reflected by an increased time to recurrence, which is the period to first recurrence censoring for second primary cancer as a first event or death without evidence of recurrence, or an increased overall survival, which is the period from treatment to death from any cause. To respond or to have a response means there is a beneficial endpoint attained when exposed to a stimulus. Alternatively, a negative or detrimental symptom is minimized, mitigated or attenuated on exposure to a stimulus. It will be appreciated that evaluating the likelihood that a tumor or subject will exhibit a favorable response is equivalent to evaluating the likelihood that the tumor or subject will not exhibit favorable response (*i.e.*, will exhibit a lack of response or be non-responsive).

The term “resistance” refers to an acquired or natural resistance of a cancer sample or a mammal to a cancer therapy (*i.e.*, being nonresponsive to or having reduced or limited response to the therapeutic treatment), such as having a reduced response to a therapeutic treatment by 5%, 10%, 15%, 20%, 25%, 30%, 35%, 40%, 45%, 50%, 55%, 60%, 65%, 70%, 75%, 80%, 85%, 90%, 95%, 100%, or more, such 2-fold, 3-fold, 4-fold, 5-fold, 10-fold, 15-fold, 20-fold or more, or any range in between, inclusive. The reduction in response may be measured by comparing with the same cancer sample or mammal before

the resistance is acquired, or by comparing with a different cancer sample or a mammal that is known to have no resistance to the therapeutic treatment. A typical acquired resistance to chemotherapy is called “multidrug resistance.” The multidrug resistance may be mediated by P-glycoprotein or may be mediated by other mechanisms, or it may occur when a mammal is infected with a multi-drug-resistant microorganism or a combination of microorganisms. The determination of resistance to a therapeutic treatment is routine in the art and within the skill of an ordinarily skilled clinician, for example, may be measured by cell proliferative assays and cell death assays as described herein as “sensitizing.” In some embodiments, the term “reverses resistance” means that the use of a second agent in combination with a primary cancer therapy (*e.g.*, chemotherapeutic or radiation therapy) is able to produce a significant decrease in tumor volume at a level of statistical significance (*e.g.*, $p < 0.05$) when compared to tumor volume of untreated tumor in the circumstance where the primary cancer therapy (*e.g.*, chemotherapeutic or radiation therapy) alone is unable to produce a statistically significant decrease in tumor volume compared to tumor volume of untreated tumor. This generally applies to tumor volume measurements made at a time when the untreated tumor is growing logarithmically.

The term “sample” used for detecting or determining the absence, presence, or level of at least one biomarker is typically brain tissue, cerebrospinal fluid, whole blood, plasma, serum, saliva, urine, stool (*e.g.*, feces), tears, and any other bodily fluid (*e.g.*, as described above under the definition of “body fluids”), or a tissue sample (*e.g.*, biopsy) such as a small intestine, colon sample, or surgical resection tissue. In some embodiments, methods encompassed by the present invention further comprises obtaining the sample from the individual prior to detecting or determining the absence, presence, or level of at least one marker in the sample.

The term “sensitize” means to alter cancer cells or tumor cells in a way that allows for more effective treatment of the associated cancer with a cancer therapy (*e.g.*, anti-immune checkpoint, chemotherapeutic, and/or radiation therapy). In some embodiments, normal cells are not affected to an extent that causes the normal cells to be unduly injured by the therapies. An increased sensitivity or a reduced sensitivity to a therapeutic treatment is measured according to a known method in the art for the particular treatment and methods described herein below, including, but not limited to, cell proliferative assays (Tanigawa *et al.* (1982) *Cancer Res.* 42:2159-2164) and cell death assays (Weisenthal *et al.* (1984) *Cancer Res.* 94:161-173; Weisenthal *et al.* (1985) *Cancer Treat Rep.* 69:615-632;

Weisenthal *et al.*, In: Kaspers G J L, Pieters R, Twentyman P R, Weisenthal L M, Veerman A J P, eds. Drug Resistance in Leukemia and Lymphoma. Langhorne, P A: Harwood Academic Publishers, 1993:415-432; Weisenthal (1994) *Contrib. Gynecol. Obstet.* 19:82-90). The sensitivity or resistance may also be measured in animal by measuring the tumor size reduction over a period of time, for example, 6 month for human and 4-6 weeks for mouse. A composition or a method sensitizes response to a therapeutic treatment if the increase in treatment sensitivity or the reduction in resistance is 5%, 10%, 15%, 20%, 25%, 30%, 35%, 40%, 45%, 50%, 55%, 60%, 65%, 70%, 75%, 80%, 85%, 90%, 95%, 100%, or more, such 2-fold, 3-fold, 4-fold, 5-fold, 10-fold, 15-fold, 20-fold or more, or any range in between, inclusive, compared to treatment sensitivity or resistance in the absence of such composition or method. The determination of sensitivity or resistance to a therapeutic treatment is routine in the art and within the skill of an ordinarily skilled clinician. It is to be understood that any method described herein for enhancing the efficacy of a cancer therapy may be equally applied to methods for sensitizing hyperproliferative or otherwise cancerous cells (*e.g.*, resistant cells) to the cancer therapy.

The term "small molecule" is a term of the art and includes molecules that are less than about 1000 molecular weight or less than about 500 molecular weight. In one embodiment, small molecules do not exclusively comprise peptide bonds. In another embodiment, small molecules are not oligomeric. Exemplary small molecule compounds which may be screened for activity include, but are not limited to, peptides, peptidomimetics, nucleic acids, carbohydrates, small organic molecules (*e.g.*, polyketides) (Cane *et al.* (1998) *Science* 282:63-68), and natural product extract libraries. In another embodiment, the compounds are small, organic non-peptidic compounds. In a further embodiment, a small molecule is not biosynthetic.

The term "specific binding" refers to binding protein binding to a predetermined antigen. Typically, the binding protein binds with an affinity (K_D) of approximately less than or equal to about 5×10^{-4} M, less than or equal to about 1×10^{-4} M, less than or equal to about 5×10^{-5} M, less than or equal to about 1×10^{-5} M, less than or equal to about 5×10^{-6} M, less than or equal to about 1×10^{-6} M, less than or equal to about 5×10^{-7} M, less than or equal to about 1×10^{-7} M, less than or equal to about 5×10^{-8} M, less than or equal to about 1×10^{-8} M, less than or equal to about 5×10^{-9} M, less than or equal to about 1×10^{-9} M, less than or equal to about 5×10^{-10} M, less than or equal to about 1×10^{-10} M, less than or equal to about 5×10^{-11} M, less than or equal to about 1×10^{-11} M, less than or equal to about 5×10^{-12} M, less

than or equal to about 1×10^{-12} M, or even lower, or any range in between, inclusive, such as between about 1-50 micromolar, 1-100 micromolar, 0.1-500 micromolar, and the like, when determined by a binding assay, such as surface plasmon resonance (SPR) technology in a BIAcore™ assay instrument using an antigen of interest as the analyte and the binding protein as the ligand. In some embodiments, the binding protein binds to the predetermined antigen with an affinity that is at least 1.1-, 1.2-, 1.3-, 1.4-, 1.5-, 1.6-, 1.7-, 1.8-, 1.9-, 2.0-, 2.5-, 3.0-, 3.5-, 4.0-, 4.5-, 5.0-, 6.0-, 7.0-, 8.0-, 9.0-, or 10.0-fold or greater than its affinity for binding to a non-specific antigen (*e.g.*, BSA, casein) other than the predetermined antigen or a closely-related antigen. The phrases “a binding protein recognizing an antigen” and “a binding protein specific for an antigen” are used interchangeably herein with the term “a binding protein which binds specifically to an antigen.” Selective binding is a relative term referring to the ability of a binding protein to discriminate the binding of one antigen over another, such as a particular family member or antigen target over a related family member or antigen target. For example, analytical data provided in the Examples section demonstrate that binding proteins described herein specifically bind HPV16 E7₁₁₋₁₉ immunogenic epitopes and/or selectively bind a number of related epitopes (*e.g.*, HPV16 E7₁₁₋₁₉ immunogenic epitopes and closely related sequences) discriminating such targets from the vast majority of other possible epitopes available in the human genome.

The term “subject” refers to any healthy animal, mammal or human, or any animal, mammal or human afflicted with a non-malignant disorder, a hyperproliferative disorder, or a relapse of a hyperproliferative disorder characterized by expression of an HPV16 E7₁₁₋₁₉ antigen. The term “subject” is interchangeable with “patient.”

The term “survival” includes all of the following: survival until mortality, also known as overall survival (wherein said mortality may be either irrespective of cause or tumor related); “recurrence-free survival” (wherein the term recurrence shall include both localized and distant recurrence); metastasis free survival; disease free survival (wherein the term disease shall include cancer and diseases associated therewith). The length of said survival may be calculated by reference to a defined start point (*e.g.*, time of diagnosis or start of treatment) and end point (*e.g.*, death, recurrence or metastasis). In addition, criteria for efficacy of treatment may be expanded to include response to chemotherapy, probability of survival, probability of metastasis within a given time period, and probability of tumor recurrence.

The term “synergistic effect” refers to the combined effect of two or more agents (*e.g.*, an HPV16 E7₁₁₋₁₉-related agent described herein and another therapy for treating a disorder characterized by HPV16 E7₁₁₋₁₉ expression) that is greater than the sum of the separate effects of the cancer agents/therapies alone.

As used herein, the term “T cell-mediated response” refers to a response mediated by T cells, including effector T cells (*e.g.*, CD8⁺ cells) and helper T cells (*e.g.*, CD4⁺ cells). T cell mediated responses include, for example, T cell cytotoxicity and proliferation.

A “transcribed polynucleotide” or “nucleotide transcript” is a polynucleotide (*e.g.*, an mRNA, hnRNA, a cDNA, or an analog of such RNA or cDNA) which is complementary to or homologous with all or a portion of a mature mRNA made by transcription of a biomarker nucleic acid and normal post-transcriptional processing (*e.g.*, splicing), if any, of the RNA transcript, and reverse transcription of the RNA transcript.

A “T cell” is an immune system cell that matures in the thymus and produces T cell receptors (TCRs). T cells may be naïve (not exposed to antigen; increased expression of CD62L, CCR7, CD28, CD3, CD 127, and CD45RA, and decreased expression of CD45RO as compared to T_{CM}), memory T cells (T_M) (antigen-experienced and long-lived), and effector cells (antigen-experienced, cytotoxic). T_M may be further divided into subsets of central memory T cells (T_{CM}, increased expression of CD62L, CCR7, CD28, CD127, CD45RO, and CD95, and decreased expression of CD54RA as compared to naïve T cells) and effector memory T cells (T_{EM}, decreased expression of CD62L, CCR7, CD28, CD45RA, and increased expression of CD127 as compared to naïve T cells or T_{CM}). Effector T cells (T_E) refers to antigen-experienced CD8⁺ cytotoxic T lymphocytes that have decreased expression of CD62L, CCR7, CD28, and are positive for granzyme and perforin as compared to T_{CM}. Other exemplary T cells include regulatory T cells, such as CD4⁺ CD25⁺ (Foxp3⁺) regulatory T cells and Treg17 cells, as well as Tr1, Th3, CD8⁺CD28⁻, and Qa-1 restricted T cells.

Conventional T cells, also known as T_{conv} or T_{effs}, have effector functions (*e.g.*, cytokine secretion, cytotoxic activity, anti-self-recognition, and the like) to increase immune responses by virtue of their expression of one or more T cell receptors. T_{cons} or T_{effs} are generally defined as any T cell population that is not a Treg and include, for example, naïve T cells, activated T cells, memory T cells, resting T_{cons}, or T_{cons} that have differentiated toward, for example, the Th1 or Th2 lineages. In some embodiments, T_{effs} are a subset of non-Treg T cells. In some embodiments, T_{effs} are CD4⁺ T_{effs} or CD8⁺

Teffs, such as CD4+ helper T lymphocytes (*e.g.*, Th0, Th1, Tfh, or Th17) and CD8+ cytotoxic T lymphocytes. As described further herein, cytotoxic T cells are CD8+ T lymphocytes. "Naïve Tcons" are CD4+ T cells that have differentiated in bone marrow, and successfully underwent a positive and negative processes of central selection in a thymus, but have not yet been activated by exposure to an antigen. Naïve Tcons are commonly characterized by surface expression of L-selectin (CD62L), absence of activation markers such as CD25, CD44 or CD69, and absence of memory markers such as CD45RO. Naïve Tcons are therefore believed to be quiescent and non-dividing, requiring interleukin-7 (IL-7) and interleukin-15 (IL-15) for homeostatic survival (see, at least WO 2010/101870). The presence and activity of such cells are undesired in the context of suppressing immune responses. Unlike Tregs, Tcons are not anergic and can proliferate in response to antigen-based T cell receptor activation (Lechler *et al.* (2001) *Philos. Trans. R. Soc. Lond. Biol. Sci.* 356:625-637).

"T effector" ("T_{eff}" or "T_E") cells refers to T cells (*e.g.*, CD4+ and CD8+ T cells) with cytolytic activities as well as T helper (Th) cells, which secrete cytokines and activate and direct other immune cells, but does not include regulatory T cells (Treg cells).

"T cell receptor" or "TCR" refers to an immunoglobulin superfamily member (having a variable binding domain, a constant domain, a transmembrane region, and a short cytoplasmic tail; see, *e.g.*, Janeway *et al.* (1997) *Curr. Biol. Publ.* 4:33) that is capable of binding (*e.g.*, specifically and/or selectively) to an antigen peptide bound to a MHC receptor. A TCR can be found on the surface of a cell or in soluble form and generally is comprised of a heterodimer having alpha and beta chains (also known as TCR α and TCR β , respectively), or γ and δ chains (also known as TCR γ and TCR δ , respectively). Like immunoglobulins (*e.g.*, antibodies), the extracellular portion of TCR chains (*e.g.*, α -chain and β -chain) contain two immunoglobulin domains: a variable domain (*e.g.*, α -chain variable domain or V α and β -chain variable domain or V β ; typically amino acids 1 to 116 based on Kabat numbering (Kabat *et al.* (1991) "Sequences of Proteins of Immunological Interest, US Dept. Health and Human Services, Public Health Service National Institutes of Health, 5th ed.) at the N-terminal end, and one constant domain (*e.g.*, α -chain constant domain or C α , typically amino acids 117 to 259 based on Kabat, β -chain constant domain or C β , typically amino acids 117 to 295 based on Kabat) at the C-terminal end and adjacent to the cell membrane. Also like immunoglobulins, the variable domains contain complementary determining regions ("CDRs", also called hypervariable regions or

“HVRs”) separated by framework regions (“FRs”) (*see, e.g.,* Fores *et al.* (1990) *Proc. Natl. Acad. Sci. U.S.A.* 87:9138; Chothia *et al.* (1988) *EMBO J.* 7:3745; Lefranc *et al.* (2003) *Dev. Comp. Immunol.* 27:55). In some embodiments, a TCR is found on the surface of a T cell (or T lymphocyte) and associates with the CD3 complex. The source of a TCR encompassed by the present invention may be from various animal species, such as a human, mouse, rat, rabbit or other mammal.

The term “T cell receptor” or “TCR” should be understood to encompass full TCRs as well as antigen-binding portions or antigen-binding fragments thereof. In some embodiments, the TCR is an intact or full-length TCR, including TCRs in the $\alpha\beta$ form or $\gamma\delta$ form. In some embodiments, the TCR is an antigen-binding portion that is less than a full-length TCR but that binds to a specific peptide bound in an MHC molecule, such as binds to an MHC-peptide complex. In some cases, an antigen-binding portion or fragment of a TCR may contain only a portion of the structural domains of a full-length or intact TCR, but yet is able to bind the peptide epitope, such as MHC-peptide complex, to which the full TCR binds. In some cases, an antigen-binding portion contains the variable domains of a TCR, such as variable α chain and variable β chain of a TCR, sufficient to form a binding site for binding to a specific MHC-peptide complex. Generally, the variable chains of a TCR contain complementarity determining regions (CDRs) involved in recognition of the peptide, MHC and/or MHC-peptide complex.

Nomenclature established by the International Immunogenetics Information System (IMGT) (*see also* Scaviner and Lefranc (2000) *Exp. Clin. Immunogenet.* 17:83-96 and 97-106; Folch and Lefranc (2000) *Exp. Clin. Immunogenet.* 17:107-114; T Cell Receptor Factsbook", (2001) LeFranc and LeFranc, Academic Press, ISBN 0-12-441352-8). The IMGT provides unique sequences used to describe a TCR, and sequences described herein may be identified by reference to such unique sequences provided herein. TCR sequences are publicly available at the IMGT database at imgt.org.

As described above, native alpha/beta heterodimeric TCRs have an alpha chain and a beta chain. Broadly, each chain comprises variable, joining and constant regions, and the beta chain also usually contains a short diversity region between the variable and joining regions, but this diversity region is often considered as part of the joining region. Each variable region comprises three hypervariable CDRs (Complementarity Determining Regions) embedded in a framework sequence. CDR3 is well-known to be the main mediator of antigen recognition. There are several types of alpha chain variable ($V\alpha$)

regions and several types of beta chain variable ($V\beta$) regions distinguished by their framework, CDR1 and CDR2 sequences, and by a partly defined CDR3 sequence. The $V\alpha$ types are referred to in IMGT nomenclature by a unique TRAV number. For example, "TRAV4" defines a TCR $V\alpha$ region having unique framework and CDR1 and CDR2 sequences, and a CDR3 sequence which is partly defined by an amino acid sequence which is preserved from TCR to TCR but which also includes an amino acid sequence which varies from TCR to TCR. Similarly, "TRBV2" defines a TCR $V\beta$ region having unique framework and CDR1 and CDR2 sequences, but with only a partly defined CDR3 sequence. It is known that there are 54 alpha variable genes, of which 44 are functional, and 67 beta variable genes, of which 42 are functional, within the alpha and beta loci, respectively.

The joining regions of the TCR are similarly defined by the unique IMGT TRAJ and TRBJ nomenclature, and the constant regions by the IMGT TRAC and TRBC nomenclature. The beta chain diversity region is referred to in IMGT nomenclature by the abbreviation TRBD, and, as mentioned, the concatenated TRBD/TRBJ regions are often considered together as the joining region.

The gene pools that encode the TCR alpha and beta chains are located on different chromosomes and contain separate V, (D), J and C gene segments, which are brought together by rearrangement during T cell development. This leads to a very high diversity of T cell alpha and beta chains due to the large number of potential recombination events that occur between the 54 TCR alpha variable genes and 61 alpha J genes or between the 67 beta variable genes, two beta D genes and 13 beta J genes. The recombination process is not precise and introduces further diversity within the CDR3 region. Each alpha and beta variable gene may also comprise allelic variants, designated in IMGT nomenclature as TRAV_{xx}*01 and *02, or TRBV_{x-x}*01 and *02 respectively, thus further increasing the amount of variation. In the same way, some of the TRBJ sequences have two known variations. (Note that the absence of a "*" qualifier means that only one allele is known for the relevant sequence). The natural repertoire of human TCRs resulting from recombination and thymic selection has been estimated to comprise approximately 10^6 unique beta chain sequences, determined from CDR3 diversity (Arstila *et al.* (1999) *Science* 286:958-961) and could be even higher (Robins *et al.* (2009) *Blood* 114:4099-4107). Each beta chain is estimated to pair with at least 25 different alpha chains, thus generating further diversity (Arstila *et al.* (1999) *Science* 286:958-961).

The term "TCR alpha variable domain" therefore refers to the concatenation of TRAV and TRAJ regions; a TRAV region only; or TRAV and a partial TRAJ region, and the term TCR alpha constant domain refers to the extracellular TRAC region, or to a C-terminal truncated or full length TRAC sequence. Likewise the term "TCR beta variable domain" refers to the concatenation of TRBV and TRBD/TRBJ regions; to the TRBV and TRBD regions only; to the TRBV and TRBJ regions only; or to the TRBV and partial TRBD and/or TRBJ regions, and the term TCR beta constant domain refers to the extracellular TRBC region, or to a C-terminal truncated or full length TRBC sequence. These TCR alpha variable domain and TCR beta variable domain nomenclature similarly applies to the variable domains of TCR gamma and TCR delta chains, respectively, for gamma/delta TCRs. An ordinarily skilled artisan can obtain TRAV, TRAJ, TRAC, TRBV, TRBJ, and TRBC gene sequences, such as through the publicly available IMGT database.

The term "TCR complex" refers to a complex formed by the association of CD3 with TCR. For example, a TCR complex may be composed of a CD3 γ chain, a CD3 δ chain, two CD3 ϵ chains, a homodimer of CD3 ζ chains, a TCR α chain, and a TCR β chain. Alternatively, a TCR complex may be composed of a CD3 γ chain, a CD3 δ chain, two CD3 ϵ chains, a homodimer of CD3 ζ chains, a TCR γ chain, and a TCR δ chain.

The term "therapeutic effect" refers to a local or systemic effect in animals, particularly mammals, and more particularly humans, caused by a pharmacologically active substance. The term thus means any substance intended for use in the diagnosis, cure, mitigation, treatment or prevention of disease or in the enhancement of desirable physical or mental development and conditions in an animal or human.

The terms "therapeutically effective amount" and "effective amount" means that amount of a substance that produces some desired effect, such as a desired local or systemic therapeutic effect, in at least a sub-population of cells in an animal at a reasonable benefit/risk ratio applicable to any treatment. In some embodiments, a therapeutically effective amount of a substance will depend on the substance's therapeutic index, solubility, pharmacokinetics, half-life, and the like. Toxicity and therapeutic efficacy of subject compounds may be determined by standard pharmaceutical procedures in cell cultures or experimental animals, *e.g.*, for determining the LD₅₀ and the ED₅₀. In some embodiments, compositions that exhibit large therapeutic indices are used. In some embodiments, the LD₅₀ (lethal dosage) may be measured and may be, for example, at least 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90%, 100%, 200%, 300%, 400%, 500%, 600%, 700%, 800%,

900%, 1000% or more reduced for the agent relative to no administration of the agent. Similarly, the ED₅₀ (*i.e.*, the concentration which achieves a half-maximal inhibition of symptoms) may be measured and may be, for example, at least 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90%, 100%, 200%, 300%, 400%, 500%, 600%, 700%, 800%, 900%, 1000% or more increased for the agent relative to no administration of the agent. Also, similarly, the IC₅₀ may be measured and may be, for example, at least 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90%, 100%, 200%, 300%, 400%, 500%, 600%, 700%, 800%, 900%, 1000% or more increased for the agent relative to no administration of the agent. In some embodiments, T cell immune response in an assay may be increased by at least about 10%, 15%, 20%, 25%, 30%, 35%, 40%, 45%, 50%, 55%, 60%, 65%, 70%, 75%, 80%, 85%, 90%, 95%, or even 100%. In another embodiment, at least about a 10%, 15%, 20%, 25%, 30%, 35%, 40%, 45%, 50%, 55%, 60%, 65%, 70%, 75%, 80%, 85%, 90%, 95%, or even 100% decrease in a viral load may be achieved.

The term “treat” refers to the therapeutic management or improvement of a condition (*e.g.*, a disease or disorder) of interest. Treatment may include, but is not limited to, administering an agent or composition (*e.g.*, a pharmaceutical composition) to a subject. Treatment is typically undertaken in an effort to alter the course of a disease (which term is used to indicate any disease, disorder, syndrome or undesirable condition warranting or potentially warranting therapy) in a manner beneficial to the subject. The effect of treatment may include reversing, alleviating, reducing severity of, delaying the onset of, curing, inhibiting the progression of, and/or reducing the likelihood of occurrence or recurrence of the disease or one or more symptoms or manifestations of the disease. Desirable effects of treatment include, but are not limited to, preventing occurrence or recurrence of disease, alleviation of symptoms, diminishment of any direct or indirect pathological consequences of the disease, preventing metastasis, decreasing the rate of disease progression, amelioration or palliation of the disease state, and remission or improved prognosis. A therapeutic agent may be administered to a subject who has a disease or is at increased risk of developing a disease relative to a member of the general population. In some embodiments, a therapeutic agent may be administered to a subject who has had a disease but no longer shows evidence of the disease. The agent may be administered *e.g.*, to reduce the likelihood of recurrence of evident disease. A therapeutic agent may be administered prophylactically, *i.e.*, before development of any symptom or manifestation of a disease. “Prophylactic treatment” refers to providing medical and/or

surgical management to a subject who has not developed a disease or does not show evidence of a disease in order, *e.g.*, to reduce the likelihood that the disease will occur or to reduce the severity of the disease should it occur. The subject may have been identified as being at risk of developing the disease (*e.g.*, at increased risk relative to the general population or as having a risk factor that increases the likelihood of developing the disease.

The term “unresponsiveness” includes refractivity of cancer cells to therapy or refractivity of therapeutic cells, such as immune cells, to stimulation, *e.g.*, stimulation via an activating receptor or a cytokine. Unresponsiveness may occur, *e.g.*, because of exposure to immunosuppressants or exposure to high doses of antigen. As used herein, the term “anergy” or “tolerance” includes refractivity to activating receptor-mediated stimulation. Such refractivity is generally antigen-specific and persists after exposure to the tolerizing antigen has ceased. For example, anergy in T cells (as opposed to unresponsiveness) is characterized by lack of cytokine production, *e.g.*, IL-2. T cell anergy occurs when T cells are exposed to antigen and receive a first signal (a T cell receptor or CD-3 mediated signal) in the absence of a second signal (a costimulatory signal). Under these conditions, reexposure of the cells to the same antigen (even if reexposure occurs in the presence of a costimulatory polypeptide) results in failure to produce cytokines and, thus, failure to proliferate. Anergic T cells may, however, proliferate if cultured with cytokines (*e.g.*, IL-2). For example, T cell anergy may also be observed by the lack of IL-2 production by T lymphocytes as measured by ELISA or by a proliferation assay using an indicator cell line. Alternatively, a reporter gene construct may be used. For example, anergic T cells fail to initiate IL-2 gene transcription induced by a heterologous promoter under the control of the 5' IL-2 gene enhancer or by a multimer of the AP1 sequence that may be found within the enhancer (Kang *et al.* (1992) *Science* 257:1134).

The term "variable region" or "variable domain" refers to the domain of an immunoglobulin superfamily binding protein (*e.g.*, a TCR α -chain or β -chain (or γ chain and δ chain for $\gamma\delta$ TCRs)) that is involved in binding of the immunoglobulin superfamily binding protein (*e.g.*, TCR) to antigen. The variable domains of the α -chain and β -chain (V_α and V_β , respectively) of a native TCR generally have similar structures, with each domain comprising four conserved framework regions (FRs) and three CDRs. The V_α domain is encoded by two separate DNA segments, the variable gene segment and the joining gene segment (V-J); the V_β domain is encoded by three separate DNA segments, the variable gene segment, the diversity gene segment, and the joining gene segment (V-D-J).

A single V_{α} or V_{β} domain may be sufficient to confer antigen-binding specificity. Furthermore, TCRs that bind a particular antigen may be isolated using a V_{α} or V_{β} domain from a TCR that binds the antigen to screen a library of complementary V_{α} or V_{β} domains, respectively.

The term “vector” refers to a nucleic acid molecule capable of transporting another nucleic acid to which it has been linked. In some embodiments, a vector is an episome, *i.e.*, a nucleic acid capable of extra-chromosomal replication. In some embodiments, vectors are those capable of autonomous replication and/or expression of nucleic acids to which they are linked. Vectors capable of directing the expression of genes to which they are operatively linked are referred to herein as “expression vectors”. In general, expression vectors of utility in recombinant DNA techniques are often in the form of “plasmids” which refer generally to circular double stranded DNA loops, which, in their vector form are not bound to the chromosome. In the present specification, “plasmid” and “vector” are used interchangeably as the plasmid is the most commonly used form of vector. However, as will be appreciated by those skilled in the art, the present invention is intended to include such other forms of expression vectors that serve equivalent functions and which become subsequently known in the art.

There is a known and definite correspondence between the amino acid sequence of a particular protein and the nucleotide sequences that can code for the protein, as defined by the genetic code (shown below). Likewise, there is a known and definite correspondence between the nucleotide sequence of a particular nucleic acid and the amino acid sequence encoded by that nucleic acid, as defined by the genetic code.

GENETIC CODE

Alanine (Ala, A)	GCA, GCC, GCG, GCT
Arginine (Arg, R)	AGA, ACG, CGA, CGC, CGG, CGT
Asparagine (Asn, N)	AAC, AAT
Aspartic acid (Asp, D)	GAC, GAT
Cysteine (Cys, C)	TGC, TGT
Glutamic acid (Glu, E)	GAA, GAG
Glutamine (Gln, Q)	CAA, CAG
Glycine (Gly, G)	GGA, GGC, GGG, GGT
Histidine (His, H)	CAC, CAT
Isoleucine (Ile, I)	ATA, ATC, ATT

Leucine (Leu, L)	CTA, CTC, CTG, CTT, TTA, TTG
Lysine (Lys, K)	AAA, AAG
Methionine (Met, M)	ATG
Phenylalanine (Phe, F)	TTC, TTT
Proline (Pro, P)	CCA, CCC, CCG, CCT
Serine (Ser, S)	AGC, AGT, TCA, TCC, TCG, TCT
Threonine (Thr, T)	ACA, ACC, ACG, ACT
Tryptophan (Trp, W)	TGG
Tyrosine (Tyr, Y)	TAC, TAT
Valine (Val, V)	GTA, GTC, GTG, GTT
Termination signal (end)	TAA, TAG, TGA

An important and well-known feature of the genetic code is its redundancy, whereby, for most of the amino acids used to make proteins, more than one coding nucleotide triplet may be employed (illustrated above). Therefore, a number of different nucleotide sequences may code for a given amino acid sequence. Such nucleotide sequences are considered functionally equivalent since they result in the production of the same amino acid sequence in all organisms (although certain organisms may translate some sequences more efficiently than they do others). Moreover, occasionally, a methylated variant of a purine or pyrimidine may be found in a given nucleotide sequence. Such methylations do not affect the coding relationship between the trinucleotide codon and the corresponding amino acid.

In view of the foregoing, the nucleotide sequence of a DNA or RNA encoding a biomarker nucleic acid (or any portion thereof) may be used to derive the polypeptide amino acid sequence, using the genetic code to translate the DNA or RNA into an amino acid sequence. Likewise, for polypeptide amino acid sequence, corresponding nucleotide sequences that can encode the polypeptide can be deduced from the genetic code (which, because of its redundancy, will produce multiple nucleic acid sequences for any given amino acid sequence). Thus, description and/or disclosure herein of a nucleotide sequence which encodes a polypeptide should be considered to also include description and/or disclosure of the amino acid sequence encoded by the nucleotide sequence. Similarly, description and/or disclosure of a polypeptide amino acid sequence herein should be considered to also include description and/or disclosure of all possible nucleotide sequences that can encode the amino acid sequence.

II. Binding Proteins

In an aspect encompassed by the present invention, provided herein are binding proteins that bind (*e.g.*, specifically and/or selectively) to a peptide-MHC (pMHC) complex comprising an HPV16 E7₁₁₋₁₉ immunogenic peptide in the context of an MHC molecule (*e.g.*, a MHC class I molecule). In some embodiments, the binding protein is capable of binding (*e.g.*, specifically and/or selectively) to an HPV16 E7₁₁₋₁₉ peptide-MHC (pMHC) complex with a K_d less than or equal to about 5×10^{-4} M, less than or equal to about 1×10^{-4} M, less than or equal to about 5×10^{-5} M, less than or equal to about 1×10^{-5} M, less than or equal to about 5×10^{-6} M, less than or equal to about 1×10^{-6} M, less than or equal to about 5×10^{-7} M, less than or equal to about 1×10^{-7} M, less than or equal to about 5×10^{-8} M, less than or equal to about 1×10^{-8} M, less than or equal to about 5×10^{-9} M, less than or equal to about 1×10^{-9} M, less than or equal to about 5×10^{-10} M, less than or equal to about 1×10^{-10} M, less than or equal to about 5×10^{-11} M, less than or equal to about 1×10^{-11} M, less than or equal to about 5×10^{-12} M, less than or equal to about 1×10^{-12} M, or any range in between, inclusive, such as between about 1-50 micromolar, 1-100 micromolar, 0.1-500 micromolar, and the like. In some embodiments, the MHC molecule comprises an MHC alpha chain that is an HLA serotype HLA-A*02. In some embodiments, the HLA allele is selected from the group consisting of HLA-A*0201, HLA-A*0202, HLA-A*0203, HLA-A*0205, HLA-A*0206, and HLA-A*0207 allele. In a specific embodiment, the HLA allele is HLA-A*0201. In some embodiments, the binding proteins provided herein are genetically engineered, isolated, and/or purified.

In some embodiments, the binding proteins have a higher binding affinity to the HPV16 E7₁₁₋₁₉ peptide-MHC (pMHC) than does a known T-cell receptor (*e.g.*, a Kite TCR described herein). For example, the binding proteins may have at least 1.2 fold, 1.5 fold, 1.8 fold, 2.0 fold, 2.2 fold, 2.5 fold, 2.8 fold, 3 fold, 3.5 fold, 4 fold, 4.5 fold, 5 fold, 5.5 fold, 6 fold, 6.5 fold, 7 fold, 7.5 fold, 8 fold, 8.5 fold, 9 fold, 9.5 fold, 10 fold, 11 fold, 12 fold, 13 fold, 14 fold, 15 fold, 16 fold, 17 fold, 18 fold, 19 fold, 20 fold, 25 fold, 30 fold, 35 fold, 40 fold, 45 fold, 50 fold, 60 fold, 70 fold, 80 fold, 90 fold, 100 fold, 1000 fold, 5000 fold, 10000 fold, 50000 fold, 100000 fold, 500000 fold, 1000000 fold, or more, or any range in between, inclusive, such as 1.2 fold to 2 fold, higher binding affinity to the HPV16 E7₁₁₋₁₉ peptide-MHC (pMHC) than does a known T-cell receptor (*e.g.*, a Kite TCR described herein).

In some embodiments, the binding protein induces higher T cell expansion, cytokine release, and/or cytotoxic killing than does a known T-cell receptor (*e.g.*, a Kite TCR described herein) when contacted with target cells with expression of HPV16 E7₁₁₋₁₉ at a certain level or below. For example, in some embodiments of any aspect described herein, HPV16 E7₁₁₋₁₉ level can be expressed in terms of transcripts per million and may be, for example, less than or equal to about 1,000 transcript per million transcripts (TPM), 950 TPM, 900 TPM, 850 TPM, 800 TPM, 750 TPM, 700 TPM, 650 TPM, 600 TPM, 550 TPM, 500 TPM, 450 TPM, 400 TPM, 350 TPM, 300 TPM, 250 TPM, 200 TPM, 150 TPM, 100 TPM, 95 TPM, 90 TPM, 85 TPM, 80 TPM, 75 TPM, 70 TPM, 65 TPM, 60 TPM, 55 TPM, 50 TPM, 45 TPM, 40 TPM, 35 TPM, 34 TPM, 33 TPM, 32 TPM, 31 TPM, 30 TPM, 29 TPM, 28 TPM, 27 TPM, 26 TPM, 25 TPM, 24 TPM, 23 TPM, 22 TPM, 21 TPM, 20 TPM, 19 TPM, 18 TPM, 17 TPM, 16 TPM, 15 TPM, 14 TPM, 13 TPM, 12 TPM, 11 TPM, 10 TPM, 9 TPM, 8 TPM, 7 TPM, 6 TPM, 5 TPM, 4 TPM, 3 TPM, 2 TPM, and 1 TPM, or any range in between, inclusive, such as less than or equal to about 1,000 TPM to less than or equal to about 35 TPM). In some embodiments, the low HPV16 E7₁₁₋₁₉ expression level is termed "heterozygous expression" meaning between about 1 TPM and about 35 TPM, or any range in between, inclusive, such as 32 TPM or 1-32 TPM. A higher expression is 36 TPM and higher. As described further herein, TPM is measured according to well-known techniques, such as RNA-Seq, and gene expression TPM data are well known in the art for a variety of cell lines, tissue types, and the like (see, for example, the Broad Institute Cancer Cell Line Encyclopedia (CCLE) on the World Wide Web at portals.broadinstitute.org). In some embodiment, the binding protein induces at least 1.2 fold, 1.5 fold, 1.8 fold, 2.0 fold, 2.2 fold, 2.5 fold, 2.8 fold, 3 fold, 3.5 fold, 4 fold, 4.5 fold, 5 fold, 5.5 fold, 6 fold, 6.5 fold, 7 fold, 7.5 fold, 8 fold, 8.5 fold, 9 fold, 9.5 fold, 10 fold, 11 fold, 12 fold, 13 fold, 14 fold, 15 fold, 16 fold, 17 fold, 18 fold, 19 fold, 20 fold, 25 fold, 30 fold, 35 fold, 40 fold, 45 fold, 50 fold, 60 fold, 70 fold, 80 fold, 90 fold, 100 fold, 1000 fold, or more, or any range in between, inclusive, such as 1.2 fold to 2 fold, increase in T cell expansion, cytokine release, and/or cytotoxic killing than does a known T-cell receptor (*e.g.*, a Kite TCR described herein) when contacted with target cells expressing HPV16 E7₁₁₋₁₉ peptide epitope.

In some embodiments, the expression of HPV16 E7₁₁₋₁₉ is detected using RNA-sequencing (RNA-seq). RNA-seq generally comprises the following steps: obtaining a sample containing genetic material, isolating total RNA from the sample obtained, preparing an amplified cDNA library from the total RNA, sequencing the amplified cDNA

library, and analyzing and profiling the amplified cDNA to assess the expression level of different transcripts. The sample can be a population of cells, a tissue sample, a biopsy sample, a cell culture, or a single cell. Total RNA can be isolated from the biological sample using any method known in the art. In certain embodiments, total RNA is extracted from plasma. Plasma RNA extraction is described in Enders et al., "The Concentration of Circulating Corticotropin-Releasing Homer mRNA in Material Plasma Is Inclined in Preclampsia," Clinr. As described therein, the plasma collected after the centrifugation step is mixed with Trizol LS reagent (Invitrogen) and chloroform. The mixture is centrifuged and the aqueous layer is transferred to a new tube. Ethanol is added to this aqueous layer. The mixture is then placed in an RNeasy mini column (Qiagen) and processed according to the manufacturer's recommendations.

In some embodiments, RNA-seq described herein includes the step of preparing amplified cDNA from total RNA. For example, cDNA is prepared and the isolated RNA sample is randomly amplified without dilution, or the mixture of genetic material in the isolated RNA is dispersed into individual reaction samples. In certain embodiments, amplification is initiated randomly at the 3' end and throughout the entire transcriptome in the sample to amplify both mRNA and non-polyadenylated transcripts. In this way, double-stranded cDNA amplification products are optimized for the generation of sequencing libraries for next generation sequencing platforms. A kit suitable for amplification of cDNA by the method encompassed by the present invention includes, for example, Ovation® RNA-Seq System.

In some embodiments, RNA-seq described herein includes the step of sequencing the amplified cDNA. Any known sequencing method can be used to sequence the amplified cDNA mixture including the single molecule sequencing method. In certain embodiments, the amplified cDNA is sequenced by whole transcriptome shotgun sequencing. Whole transcriptome shotgun sequencing can be performed using various next generation sequencing platforms such as Illumina® Genome Analyzer platform, ABI SOLiD™ Sequencing platform, or Life Science's 454 Sequencing platform.

In some embodiments, RNA-seq described herein further comprises performing digital counting and analysis on the cDNA. The number of amplified sequences for each transcript in the amplified sample can be quantified by sequence reading (one reading per amplified strand). In some embodiments, transcript per million (TPM) is used to quantify the expression level of a particular transcript. TPM may be calculated as shown in Wagner

et al. (2012) *Theory in Biosciences* 131:281-285, the content of which is incorporated by reference herein in its entirety.

In some embodiments, the binding proteins do not bind to a peptide-MHC (pMHC) complex, optionally wherein the peptide is derived from SPTA1, MPL, HERC1, CPAMD8, INTS4, NUTM1, or XM_00172256.

In some embodiments, the binding protein does not bind to a SPTA1-, MPL-, HERC1-, CPAMD8-, INTS4-, NUTM1-, and/or XM_00172256-peptide-MHC (pMHC) complex.

In some embodiments, the binding proteins provided herein include (*e.g.*, comprise, consist essentially of, or consist of): a) a TCR alpha chain sequence with at least about 80%, 81%, 82%, 83%, 84%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or more identity to a TCR alpha chain sequence selected from the group consisting of the TCR alpha chain sequences listed in Table 1; and/or b) a TCR beta chain sequence with at least about 80%, 81%, 82%, 83%, 84%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or more identity to a TCR beta chain sequence selected from the group consisting of the TCR beta chain sequences listed in Table 1.

In some embodiments, the binding proteins provided herein include (*e.g.*, comprise, consist essentially of, or consist of): a) a TCR alpha chain sequence selected from the group consisting of the TCR alpha chain sequences listed in Table 1; and/or b) a TCR beta chain sequence selected from the group consisting of the TCR beta chain sequences listed in Table 1.

In some embodiments, the binding proteins provided herein include (*e.g.*, comprise, consist essentially of, or consist of): a) a TCR alpha chain variable (V_{α}) domain sequence with at least about 80%, 81%, 82%, 83%, 84%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or more identity to a TCR alpha chain variable (V_{α}) domain sequence selected from the group consisting of the TCR V_{α} domain sequences listed in Table 1; and/or b) a TCR beta chain variable (V_{β}) domain sequence with at least about 80%, 81%, 82%, 83%, 84%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or more identity to a TCR beta chain variable (V_{β}) domain sequence selected from the group consisting of the TCR V_{β} domain sequences listed in Table 1.

In some embodiments, the binding proteins provided herein include (*e.g.*, comprise, consist essentially of, or consist of): a) a TCR alpha chain variable (V_{α}) domain sequence selected from the group consisting of the TCR V_{α} domain sequences listed in Table 1; and/or b) a TCR beta chain variable (V_{β}) domain sequence selected from the group consisting of the TCR V_{β} domain sequences listed in Table 1.

In some embodiments, the binding proteins provided herein include (*e.g.*, comprise, consist essentially of, or consist of at least one (*e.g.*, one, two or three, such as CDR3 alone or in combination with a CDR1 and CDR2)) TCR alpha chain complementarity determining region (CDR) sequence with at least about 80%, 81%, 82%, 83%, 84%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or more identity to a TCR alpha chain CDR sequence selected from the group consisting of the TCR alpha chain CDR sequences listed in Table 1. CDR3 is believed to be the main CDR responsible for recognizing processed antigen and CDR1 and CDR2 mainly interact with the MHC, so, in some embodiments, binding protein comprising a CDR3 alone from a TCR alpha chain and/or a CDR3 alone from a TCR beta chain listed in Table 1, each CDR3 having a sequence homology as recited in this paragraph, are provided.

In some embodiments, the binding proteins provided herein may also include (*e.g.*, comprise, consist essentially of, or consist of at least one (*e.g.*, one, two or three, such as CDR3 alone or in combination with a CDR1 and CDR2)) TCR beta chain complementarity determining region (CDR) sequence with at least about 80%, 81%, 82%, 83%, 84%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or more identity to a TCR beta chain CDR sequence selected from the group consisting of the TCR beta chain CDR sequences listed in Table 1. As described above, CDR3 is believed to be the main CDR responsible for recognizing processed antigen and CDR1 and CDR2 mainly interact with the MHC, so, in some embodiments, binding protein comprising a CDR3 alone from a TCR beta chain and/or a CDR3 alone from a TCR alpha chain listed in Table 1, each CDR3 having a sequence homology as recited in this paragraph, are provided.

In some embodiments, the binding proteins provided herein include (*e.g.*, comprise, consist essentially of, or consist of at least one (*e.g.*, one, two or three)) TCR alpha chain complementarity determining region (CDR) listed in Table 1.

In some embodiments, the binding proteins provided herein may also include (*e.g.*, comprise, consist essentially of, or consist of at least one (*e.g.*, one, two or three)) TCR beta chain complementarity determining region (CDR) listed in Table 1.

In some embodiments, the binding proteins provided herein include (*e.g.*, comprise, consist essentially of, or consist of) a TCR alpha chain constant region ($C\alpha$) sequence with at least about 80%, 81%, 82%, 83%, 84%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or more identity to a TCR $C\alpha$ sequence listed in Table 1.

In some embodiments, the binding proteins provided herein may also include (*e.g.*, comprise, consist essentially of, or consist of) a TCR beta chain constant region ($C\beta$) sequence with at least about 80%, 81%, 82%, 83%, 84%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or more identity to a TCR $C\beta$ sequence listed in Table 1.

In some embodiments, the binding proteins provided herein include (*e.g.*, comprise, consist essentially of, or consist of) a TCR alpha chain constant region ($C\alpha$) sequence selected from the group consisting of the TCR $C\alpha$ sequences listed in Table 1.

In some embodiments, the binding proteins provided herein may also include (*e.g.*, comprise, consist essentially of, or consist of) a TCR beta chain constant region ($C\beta$) sequence selected from the group consisting of the TCR $C\beta$ sequences listed in Table 1.

In some embodiments, the binding proteins provided herein comprise a constant region that is chimeric, humanized, human, primate, or rodent (*e.g.*, rat or mouse). For example, a human variable region may be chimerized with a murine constant region or a murine variable region may be humanized with a human constant region and/or human framework regions. In some embodiments, the constant regions may be mutated to modify functionality (*e.g.*, introduction of non-naturally occurring cysteine substitutions in opposing residue locations in TCR alpha and beta chains to provide disulfide bonds useful for increasing affinity between the TCR alpha and beta chains). Similarly, mutations may be made in the transmembrane domain of the constant region to modify functionality (*e.g.*, increase hydrophobicity by introducing a non-naturally occurring substitution of a residue with a hydrophobic amino acid). In some embodiments, mutations may be made to the constant region to increase cell surface expression.

Table 1

E7-11-28 WT sequence (same CDRs as “E7-11-28 MGMTM”)

Alpha chain:

TRAV25/TRAJ37/TRAC

Alpha chain DNA sequence

ATGCTGCTGATCACCTCCATGCTGGTGCTGTGGATGCAGCTGAGCCAAGTGAAC
 GGCCAGCAAGTGATGCAGATCCCTCAGTACCAGCACGTGCAAGAAGGCGAGGA
 CTTACACCTACTGCAACAGCAGCACCACACTGAGCAACATCCAGTGGTACA
 AGCAGCGGCCTGGCGGACACCCTGTGTTTCTGATCCAGCTGGTCAAGTCCGGC
GAAGTGAAGAAGCAGAAGCGGCTGACCTTCCAGTTCGGCGAGGCCAAGAAGA
 ACAGCAGCCTGCACATCACCGCCACACAGACCACAGATGTGGGCACCTACTTC
TGCGCTGGCATCGGTAGCAGCAACACCGGTAAGCTCATCTTTGGGCAAGGG
 ACAACTTTACAAGTAAAACCA Gataccagaaccctgaccctgccgtgtaccagctgagagactctaaatcca
 gtgacaagtctgtctgcctattcaccgattttgattctcaaaacaatgtgtcacaaagtaaggattctgatgtatatacagacaaaac
 tgtgctagacatgaggtctatggacttcaagagcaacagtgtgtggcctggagcaacaatctgactttgcatgtgcaaacgccttc
 aacaacagcattattccagaagacaccttctccccagccagaaagttcctgtgatgtcaagctggcgcagaaaagcttgaacag
 atacgaacctaaacttcaaaacctgtcagtgattgggtccgaatcctcctctgaaagtggccgggttaactctgctcatgacgctgc
 ggctgtgggtccagc

Alpha chain protein sequence

MLLITSMVLVLMQLSQVNGQQVMQIPQYQHVQEGEDFTTYCNSSTTLSNIQWYK
 QRPGGHPVFLIQLLYKSGEVKKQKRLTFQFGEAKKNSSLHITATQTTDVGTYFCAGI
GSSNTGKLIFGQGTTTLQVKPDiqnpdpavyqlrdsksdksvclftdfdsqtnvsqskdsdvtyitdkvtldmr
 smdfksnsavawnsksdfacanafnnsiipedtffpspesscdvklveksfetdtnlnfqnlsvigfrilllkvagnllmtrlrws
 s

Beta chain:

TRBV2/TRBJ2-7/TRBC1

Beta chain DNA sequence

ATGGATACCTGGCTCGTGTGTTGGGCCATCTTTAGCCTGCTGAAGGCCGGACTG
 ACCGAGCCTGAAGTGACCCAGACTCCAAGCCATCAAGTGACTCAGATGGGGCA
 AGAAGTCATTCTGCGTTGCGTGCCCATCAGCAACCACCTGTACTTTTTATTGGTA
 TCGCCAGATCCTGGGCCAGAAAGTGGAATTCCTGGTGTCTTTCTACAACAATG
AGATCTCCGAGAAGTCCGAGATCTTCGACGACCAGTTCTCCGTGGAAAGACCC
 GACGGCAGCAACTTCACACTGAAGATCCGGTCTACCAAACCTTGAGGACTCCGC
 TATGTATTTTTTGTGCAATCACAGGTGCGGTTTCATATGAGCAATATTTCGGG
 CCGGGCACCAGGCTCACGGTCACAGaggacctaacaaggtgttccacccgaggtcgtgtgttgagcc
 atcagaagcagagatctccacacccaaaaggccacactgggtgtgcttgccacaggtcttccctgaccacgtggagctgagct
 ggtgggtgaatgggaaggaggtgcacagtgggtgcagcagcagcccgagccctcaaggagcagcccgccctcaatgactcc
 agatactgcctgagcagccgcctgagggtctcgccaccttctgcagaacccccgaaccactccgctgtcaagtccagttcta
 cgggctctcgagaatgacgagtgaccagagataggccaaacccgtcaccagatcgtcagcgcgaggtcgggttagag
 cagactgtggctttacctcggtgtcctaccagaaggggtcctgtctgccaccatcctctatgagatcctgtaggaaggccacct
 gtatgctgtgctgagcgccttgtgtgatggccatggtcaagagaaggaatttc

Beta chain protein sequence

MDTWLVCWAIIFSLLKAGLTEPEVTQTPSHQVTQMGQEVILRCVPISNHLYFYWYR
 QILGQKVEFLVSFYNNEISEKSEIFDDQFSVERPDGSNFTLKIRSTKLEDSAMYFCAI
TGRVSYEQYFGPGTRLTVTEdlnkvfppevavfepseacishtqkatlvclatgffpdhvelswwvngkevhs
 gvstdpqplkeqpalsrlyclssrlrvsatfwqnpnrnhfrqvvfyglsendewtqdrakpvtqivsacawgradcgftsvsy
 qqgvlsatilyeillgkatlyavlvsalvlmamvkrkdf

E7-11-176 WT sequence

Alpha chain:

TRAV29DV5/TRAJ41/TRAC

Alpha chain DNA sequence

Atggccatgctgctgggagccagcgtgctgattcttggctccagcctgactgggtcaacagccagcagaagaacgacgatcagc
aagtgaagcagaacagccccagcctgagcgtgcaagaaggcagaatctccatctgaactgcgactacaccaaactctatgttcg
actacttcctgtggtacaagaagtaccccgccgagggaccaccttctgatcagcatcagctccatcaaggacaagaacgagg
acggccggttcaccgtgttctgaacaagagcgccaagcactgagcctgcacatcgtgccttctcagcctggggattccgccgtgt
atttctgcGCCGCAAAAAATTCAAATTCAGGTTATGCCCTCAACTTTGGCAAAGG
CACCTCGCTGTTGGTACACCCCatatccagaacctgacctgccgtgtaccagctgagagactctaaatcc
agtgacaagtctgtctgcctattcaccgattttgattctcaacaaatgtgtcacaagaagattctgatgtgtatcacagacaaaa
ctgtgctagacatgaggtctatggacttcaagagcaacagtgtgtggcctggagcaacaatctgacttgcagtgtgcaaacgcctt
caacaacagcattattccagaagacaccttctccccagccagaaagttcctgtgatgtcaagctggcagagaaaagcttgaaca
gatacgaacctaaacttcaaacctgtcagtgattgggtccgaatcctcctctgaaagtggccgggttaactgtctcatgacgct
cgcgctgtgtgccagc

Alpha chain protein sequence

MAMLLGASVLILWLQPDWVNSQQKNDDQQVKQNSPSLSVQEGRISILNCDYTNS
MFDYFLWYKKYPAEGPTFLISISSIKDKNEDGRFTVFLNKS AKHLSLHIVPSQPGDS
AVYFCAAKNSNSGYALNFGKGTSLLVTPHIqnpdpavyqlrdsksdksvclftdfdsqtnvsqskds
dvyitdktlvldmrsmdfksnsavawnsksdfacanafnnsiipdttffspessedvklveksfetdtnlnfnqlnsvigfrillk
vagfnllmtrlwss

Beta chain:

TRBV24-1/TRBJ2-6/TRBC1

Beta chain DNA sequence

ATGGCCAGCCTGCTGTTCTTCTGCGGCGCCTTTTATCTGCTCGGCACCGGCTCTA
TGGACGCCGACGTTACACAGACCCCTCGGAACAGAATACCAAGACCGGCAAG
CGGATCATGCTGGAATGCAGCCAGACCAAAGGGCCACGACCGGATGTACTGGT
ACAGACAGGATCCAGGACTGGGCCTGCAGCTGATCTACTACAGCTTCGACGTG
AAGGACATCAACAAGGGCGAGATCAGCGACGGCTACAGCGTGTCAAGACAGG
CCCAGGCCAAGTTCAGCCTGAGCCTGGAAAGCGCTATCCCCAACCAGACTGCC
CTGTACTTCTTGCGCCACTTCCGATCGCTCCTCCGGCGCCAACGTTCTTACCT
TTGGGGCCGGCAGCAGGCTGACCGTGCTGGaggacctgaacaaggtgtccacccgaggtcgtgt
gtttgagccatcagaagcagagatctccacacccaaaaggccacactggtgtgctggccacaggtcttccctgaccacgtgg
agctgagctggtgggtgaatgggaaggaggtgcacagtgggtgcagcacggacccgcagccctcaaggagcagccgcct
caatgactccagatactgctgagcagccgctgaggtctcgccacctctggcagaacccccgaaccacttccgtgtcaag
tccagttctacgggctctcgagaatgacgagtggaaccaggatagggccaaacccgtcacccagatcgtcagcgccgagcgct
ggggtagagcagactgtggtttacctcggtgtctaccagcaagggtcctgtctgccaccatcctctatgagatcctgtaggga
aggccacctgtatgctgtgctggtcagcgccctgtgttgatggccatggtcaagagaaaggatttc

Beta chain protein sequence

MASLLFFCGAFYLLGTGSMDADVTQTPRNRITKTGKRIMLECSQTKGHDRMYWY
RQDPGLGLQLIYYSFDVKDINKGEISDGYSVSRQAQAKFSLSLSAIPNQALYFCA
TSRSSGANVLTFGAGSRLTVLEdlnkvfppevavfepseacishtqkatlvclatgffpdhvelswvngk
evhsgvstpqplkeqpalsrlyclssrlrvsatfwqnprnhfrcqvfyglsendewtqdrakpvtqivsaeawgradcgft
svsyqqgvlsatilyeillgkatlyavlvsalvlmamvkrkdf

E7-11-194 WT sequence

Alpha chain:

TRAV25/TRAJ37/TRAC

Alpha chain DNA sequence

Atgctgctgatcacctccatgctggtgctgtggatgcagctgagccaagtgaacggccagcaagtgatgcagatccctcagtacca
gcacgtgcaagaagcgaggacttcaccacctactgcaacagcagcaccacactgagcaaacatccagtggtagaagcagcgg
cctggcggaacacctgtgtttctgatccagctgggtcaagtccggcgaagtgaagaagcagaagcggctgacctccagttcggcg
aggccaagaagaacagcagcctgcacatcaccgccacacagaccacagatgtgggcacctacttcTGCGCTGGGCT
CGGTTCTCTAATACTGGTAACTGATTTTTGGGCAAGGGACAACCTTTACAA
GTAAACCAAGataccagaacctgacctgccgtgtaccagctgagagactctaaatccagtgcagaagctgtctgccta
ttcaccgattttgatttcaacaacatgtgtcacaagtaaggattctgatgttatatcacagacaaaactgtgctagacatgaggtcta
tggacttcaaggaacagtgctgtggcctggagcaacaaatctgactttgcatgtgcaaacgccttcaacaacagcattattccaga
agacaccttcttccccagcccagaaagtctctgtgatgtcaagctggcgcagaaaagctttgaaacagatacgaacctaaacttcaa
aacctgtcagtgattgggttcgaatcctcctcctgaaagtggccgggttaatctgctcatgacgctgcggctgtgtccagc

Alpha chain protein sequence

MLLITSMVLVLMQLSQVNGQQVMQIPQYQHVQEGEDFTTYCNSSTTLSNIQWYK
QRPGGHPVFLIQLLVKSGEVKKQKRLTFQFGEAKKNSSLHITATQTDDVGTIFYCAG
LGSSNTGKLIFFGQGTTLQVKPDiqn dpavyqlrdsksdksvclftdfdsqtnvsqskdsdv yitdktvldm
rsmdfksnsavawsnk sdfacanafnnsiipedtffpspesscdvklveksfetdtnlnfnqlsvigfrilllkvagfnllmtrlw
ss

Beta chain:

TRBV2/ TRBJ2-7/TRBC1

Beta chain DNA sequence

ATGGATACCTGGCTCGTGTGTTGGGCCATCTTTAGCCTGCTGAAGGCCGGACTG
ACCGAGCCTGAAGTGACCCAGACTCCAAGCCATCAAGTGACTCAGATGGGGCA
AGAAGTCATTCTGCGTTGCGTGCCCATCAGCAACCACCTGTACTTTTTATTGGTA
TCGCCAGATCCTGGGCCAGAAAGTGGAATTCCTGGTGTCTTTCTACAACAATG
AGATCTCCGAGAAGTCCGAGATCTTCGACGACCAGTTCTCCGTGGAAAGACCC
GACGGCAGCAACTTCACACTGAAGATCCGGTCTACCAAACCTTGAGGACTCCGC
TATGTATTTTTTGCGCAACTACTGGTTCGCGCAAGTTACGAACAGTACTTTGGG
CCGGGCACCAGGCTCACGGTCACAGaggacctgaacaaggtgtccacccagagtcgctgtgttgagcc
atcagaagcagagatctccacacccaaaaggccacactgggtgtcctggccacaggtcttccctgaccacgtggagctgagct
gggtgggtgaatgggaaggaggtgcacagtgggtgcagcagcagcccgagccctcaaggagcagcccgccctcaatgactcc
agatactgctgagcagccgcctgagggtctcgccacctctggcagaacccccgaaccactccgctgtcaagtcagttcta
cgggctctcgagaatgacgagtgagaccaggataggccaaacccgtcaccagatcgtcagcggcgaggcctgggtagag
cagactgtggctttacctcggtgtcctaccagaaggggtcctgtctgccaccatcctctatgagatcctgtaggaagggccacct
gtatgctgtgctggtcagcgccttgtgtgatggccatggtcaagagaaggaatttc

Beta chain protein sequence

MDTWLVCWAIIFSLLKAGLTEPEVTQTPSHQVTQMGQEVILRCVPISNHLYFYWYR
QILGQKVEFLVSFYNNEISEKSEIFDDQFSVERPDGSNFTLKIRSTKLEDSAMYFCAT
TGRASYEQYFGPGTRLTVTEdlnkvfppevavfepseacishtqkatlvclatgffpdhvelswwvngkevhs
gvstdpqpplkeqp alndsrlyclssrlrvsatfwqnpnrnhfrcqvfygl sendewtqdrakpvtqivsaeawgradcgftsvsy
qqgvlsatilyeillkatlyavlvsalvlmamvkrkdf

E7-11-455 WT sequence
Alpha chain:
TRAV12-3/TRAJ37/TRAC

Alpha chain DNA sequence

Atgatgaagtcctcgccgtgctgctgattttgtggctgcagctgtcttgggtctggtccagcaaaaagaggtggaacagga
ccctggacctctgtctgtgctgaaggcgccattgttcctgaactgtacctacagc[aacagcgcccttcagttatgtggtac](#)
aggcagtacagccggaaggccctgagctgctgatgtac[acatacagcagcggaac](#)aaagaggacggcagattcacagccc
aggtggacaagtcagcaagtacatctcctgttcacccgggacagccagcctagcgatagcgccacctacctgtgtGCCAT
GGCTGGCTCAGGGAATACTGGCAAGCTCATCTTCGGGCAAGGGACAACCTT
ACAAGTAAAACCAG
atatccagaacctgacctgccgtgtaccagctgagagactctaaatccagtgcagaagtctgtctgcctattcaccgattttgattctc
aaacaaatgtgtcacaagaagattctgatgtgtatatcacagacaaaactgtgctagacatgaggtctatggacttcaagagcaa
cagtgtgtggcctggagcaacaaatctgactttgcatgtgcaaacgccctcaacaacagcattattccagaagacacctcttcccc
agcccagaaagttcctgtgatgtcaagctggcgcagaaaaagcttgaacagatagcaacctaactttcaaacctgtcagtgattg
ggttccgaatctcctcctgaaagtggccgggttaactgtgcatgacgctgcggctgtgtggtccagc

Alpha chain protein sequence

MMKSLRVLLVILWLQLSWVWSQQKEVEQDPGLSVPEGAIIVSLNCTYSN**SAFOYF**
MWYRQYSRKGPPELLMY**TYSSGN**KEDGRFTAQVDKSSKYISLFIRDSQPSDSATYL
CAMAGSGNTGKLIFGQGTTLQVKPDiqnpdpavyqlrdsksdksvclftdfdsqtnvsqskdsdvitd
ktvldmrsmdfksnsavawsnksdfacanafnnsiipedtffpspesscdvklveksfetdnlnfnqlnsvigfrilllkvagfnll
mtlrlwss

Beta chain:
TRBV7-9/TRBJ2-4/TRBC1

Beta chain DNA sequence

ATGGGAACCTCTCTGCTGTGCTGGATGGCCCTGTGTCTGCTGGGAGCCGATCAT
GCCGATACGGGAGTGTCCCAGGATCCTCGGCACAAGATTACCAAGAGGGGCCA
GAACGTGACCTTCCGCTGTGACCCTATC**AGCGAGCACAAACCGGCTGTATTGGT**
ACAGACAGACACTCGGCCAGGGCCTGAATTTCTCACATACT**TTCCAGAACGAA**
GCCCAGCTGGAAAAGTCCCGGCTGCTGAGCGATAGATTTTCCGCCGAGAGGCC
CAAGGGCTCCTTCAGCACTCTGGAAATTCAGCGCACCGAGCAGGGCGACTCTG
CCATGTATCTGT**TGCGCCTCATCATCCTCTACAAAAAATATTCAGTATTTCCG**
CGCCGGGACCCGGCTCTCAGTGCTGGaggacctgaacaaggtgtccacccagagtcgtgtttgagc
catcagaagcagagatctccacacccaaaagccacactggtgtgctggccacaggcttctccctgaccacgtggagctgag
ctggtgggtgaatgggaaggaggtgcacagtgggtcagcacggaccgcagccctcaaggagcagccgcccctaatgact
ccagatactgcctgagcagccgctgagggtctcgccaccttctggcagaaccccgcaaccacttcgctgtcaagtcagttc
tacgggctctcgagaatgacgagtgagccagcatagggccaaaccgtcaccagatcgtcagcggcaggcctgggtag
agcagactgtggctttacctcggtgtctaccagaaggggtcctgtctgccaccatcctctatgagatcctgtaggaagggcac
cctgtatgctgtgctgtcagcgccttgtgtgatggccatggtcaagagaaaggatttc

Beta chain protein sequence

MGTSLLCWMALCLLGADHADTGVSQDPRHKITKRGQNVTFRCDP**ISEHNRLY**WY
RQTLGQGPEFLTY**FQNEAQ**LEKSRLLSDRFSAERPKGFSSTLEIQRTEQGDSAMYL
CASSSTKNIQYFGAGTRLSVLEdlmkvfpevavfepseaeishtkatlvlatgffpdhvelswwngk
evhsgvstpqplkeqpalndsryclssrlrvsatfwqnprnhfrcqvqfyglsendewtqdrakpvtqivsaeawgradcgft
svsyqqgvsatilyeillkatlyavlvsalvlmamvkrkdf

E7-11-28 MGTM codon optimized sequence (also known as “TCR28” or “28” or “TCR-200-A02”. In some embodiments, the codon optimized alpha chain and beta chain DNA sequences encoding the TCR can be used as shown in a vector provided in Table 3, such as vector pNVVD160.)

Alpha chain:

TRAV25/TRAJ37/MGTM modified TRAC

Alpha chain DNA sequence

ATGCTGCTGATCACCTCCATGCTGGTGTGTGGATGCAGCTGAGCCAAGTGAAC
GGCCAGCAAGTGATGCAGATCCCTCAGTACCAGCACGTGCAAGAAGGCGAGGA
CTTACACCTACTGCAACAGCAGCACCACACTGAGCAACATCCAGTGGTACA
AGCAGCGGCCTGGCGGACACCCTGTGTTTCTGATCCAGCTGGTCAAGTCCGGC
GAAGTGAAAGAAGCAGAAGCGGCTGACCTTCCAGTTCGGCGAGGCCAAGAAGA
ACAGCAGCCTGCACATCACCGCCACACAGACCACAGATGTGGGCACCTACTTC
TGCGCTGGCATCGGTAGCAGCAACACCGGTAAGCTCATCTTTGGGCAAGGG
ACAACTTTACAAGTAAAACCAgacatccagaaccccgaccccgccgtgtaccagctgagggactccaagtc
cagcgacaagagcgtgtgtctgtttacggacttcgacagccagaccaacgtgagtcaaagcaaggacagcgactctacataacg
gataagaccgtgctggacatcgaggagcatggacttcaagagcaacagcgccgtggcctgtccaacaagagcgacttcgcctgc
gccaacgccttcaacaacagcatcatccccgaggacaccttctccccagcagcgacgtgccctgcgacgtgaaactgggtggaga
agtccttcgagacagacaccaatctgaactttcagaacctgctggtgatcgtgctgcggattctgctgctgaaagtggccggcttcaa
tctgctgatgacctgcggctgtggagc

Alpha chain protein sequence

MLLITSMVLVWMQLSQVNGQQVMQIPQYQHVQEGEDFTTYCNSSTTLSNIQWYK
QRPGGHPVFLIQLVKSGEVKKQKRLTFQFGEAKKNSSLHITATQTDTVGTIFYCAGI
GSSNTGKLIFGQGTTTLQVKPDiqnpgdpavyqlrdsksdksvclftdfdsqtnvsqskdsdvyyidktvldmr
smdfksnsavawnsksdfacanafnnsiipedtffpsdvpdcvklveksfetdtnlnfnqllvivlrillkvagfnllmtlrws

Beta chain:

TRBV2/TRBJ2-7/MGTM modified TRBC

Beta chain DNA sequence

ATGGATACCTGGCTCGTGTGTGGGCCATCTTTAGCCTGCTGAAGGCCGGACTG
ACCGAGCCTGAAGTGACCCAGACTCCAAGCCATCAAGTGACTCAGATGGGGCA
AGAAGTCATTCTGCGTTGCGTGCCCATCAGCAACCACCTGTACTTTTTATTGGTA
TCGCCAGATCCTGGGCCAGAAAGTGGAATTCTCTGGTGTCCTTCTACAACAATG
AGATCTCCGAGAAGTCCGAGATCTTCGACGACCAGTTCTCCGTGGAAAGACCC
GACGGCAGCAACTTCACACTGAAGATCCGGTCTACCAAACCTTGAGGACTCCGC
TATGTATTTTTGTGCAATCACAGGTCGCGTTTCATATGAGCAATATTTCGGG
CCGGGCACCAGGCTCACGGTCACAgaatctgaacaagggtgtccctccagaggtggccgtgttcgagcct
tctaagccgagatgcccacacacaaaaagccacctcgtgtgcttgccaccggcttttccccgaccacgtggaactgtcttg
gtgggtcaacggcaaagaggtgcactccggcgtgtcaacggatccccagcctctgaagaacagcctgccctgaacgacagccg
gtactgctgagctccagactgagagtgtccgccaccttctgcagaacccccggaaccacttcagatgccaggtgcagttttacg
gcctgagcgagaacgacgagtggaccagagacagcaagcccgtagacaaaatcgtgctgctggaagcctggggaagagc
cgattggcgcatcaccagcgctctatcaccagggcgtgctgagcgccacaatcctgtacgaaatcctgctgggcaaggccacc
ctgtacccgtgctggtgtctgctgctgctgatggccatggtcaagcgggaaggactttggcagcggcagagccaaaaggtccg
ggagcgggt

Beta chain protein sequence

MDTWLVCWAIFSLLKAGLTEPEVTQTPSHQVTQMGQEVILRCVPISNHL~~YFYWYR~~
 QILGQKVEFLVSFYNNEISEKSEIFDDQFSVERPDGSNFTLKIRSTKLEDSAMYFCAI
TGRVSYEQYFGPGLTRLTVTEdlnkvfppevavfepskaeiahtqkatlvclatgffpdhvelswwwngkevh
 sgvstppqlkeqpalsrlyclssrlrvsatfwqnpnrnhfrcqvfyglsendewtqdrakpvtqivsaeawgradcgitsas
 yhqgvlstilyeillgkatlyavlvsalvlmamvkrkdfgsgkrakrsgsg

Complete Beta and Alpha ORF DNA Sequence (The underlined italic region in the “Furin-P2A” site encodes a sequence allowing for expression of two polypeptide chains in a single cassette”)

ATACCTGGCTCGTGTGTTGGGCCATCTTTAGCCTGCTGAAGGCCGGAAGTACCG
 AGCCTGAAGTGACCCAGACTCCAAGCCATCAAGTGAAGTCAAGTGGGGCAAGAA
 GTCATTCTGCGTTGCGTGCCCATCAGCAACCACCTGTACTTTTATTGGTATCGC
 CAGATCCTGGGCCAGAAAGTGGAAATTCCTGGTGTCTTCTACAACAATGAGAT
 CTCCGAGAAGTCCGAGATCTTCGACGACCAGTTCTCCGTGGAAAGACCCGACG
 GCAGCAACTTCACACTGAAGATCCGGTCTACCAAACCTTGAGGACTCCGCTATGT
 ATTTTGTGCAATCACAGGTCGCGTTTCATATGAGCAATATTTCCGGGCCGGG
 CACCAGGCTCACGGTCACAGaagatctgaacaaggtgtccctccagaggtggcgtgttcgagccttctaaggc
 cgagatgcccacacacaaaaagccaccctcgtgtgctggccaccggcttttccccgaccacgtggaactgtcttggtggtca
 acggcaaaagaggtgactccggcgtgtcaacggatccccagcctctgaagaacagcctgcctgaacgacagccggtactgcc
 tgagctccagactgagagtgccggccacctctggcagaacccccggaaccactcagatgccaggtgcagttttacggcctgagc
 gagaacgacaggtggaccagacagagccaagcccgtgacacaaatcgtgtctgcgaagcctggggaagagccgattgcg
 gcatcaccagcgcctctatcaccaggcgctgctgagcggcacaatcctgtacgaaatcctgctgggcaagccaccctgtacgc
 cgtgctggtgtctgctgctgctgatggccatggtcaagcgggaaggactttggcagcggcagagccaaaaggtccgggagcgtg
GCGACAAACTTTAGCCTGTTGAAACAAGCCGGCGACGTTGAAGAGAACCCCGGACC
 TATGCTGCTGATCACCTCCATGCTGGTGCTGTGGATGCAGCTGAGCCAAGTGAA
 CGGCCAGCAAGTGATGCAGATCCCTCAGTACCAGCACGTGCAAGAAGGCGAGG
 ACTTCACCACCTACTGCAACAGCAGCACCACACTGAGCAACATCCAGTGGTAC
 AAGCAGCGGCCTGGCGGACACCCTGTGTTTCTGATCCAGCTGGTCAAGTCCGG
CGAAGTGAAGAAGCAGAAGCGGCTGACCTTCCAGTTCGGCGAGGCCAAGAAG
 AACAGCAGCCTGCACATCACCGCCACACAGACCACAGATGTGGGCACCTACTT
CTGCGCTGGCATCGGTAGCAGCAACACCGGTAAGCTCATCTTTGGGCAAGG
 GACAACTTTACAAGTAAACACAGacatccagaaccccgacccgcccgtgtaccagctgagggactccaagt
 ccagcgacaagagcgtgtgtgtgtttacggacttcgacagccagaccaacgtgagtcagaagcaagacagcgacgtctacataac
 ggataagaccgtgctggacatgaggagcatggactcaagagcaacagcggcgtggcctgttccaacaagagcgacttcgctg
 cgccaacgccttcaacaacagcatcatccccgaggacaccttctccccagcagcgacgtgccctgcgacgtgaaactggtggag
 aagtccttcgagacagacaccaatctgaacttcagaacctgctggtgatcgtgctgcggattctgctgctgaaagtggccggttca
 atctgctgatgacctgcggctgtggagc

Complete Beta and Alpha ORF Protein Sequence (The underlined italic region in the “Furin-P2A” site allows expression of two polypeptide chains in a single cassette”)

MDTWLVCWAIFSLLKAGLTEPEVTQTPSHQVTQMGQEVILRCVPISNHL~~YFYWYR~~
 QILGQKVEFLVSFYNNEISEKSEIFDDQFSVERPDGSNFTLKIRSTKLEDSAMYFCAI
TGRVSYEQYFGPGLTRLTVTEdlnkvfppevavfepskaeiahtqkatlvclatgffpdhvelswwwngkevh
 sgvstppqlkeqpalsrlyclssrlrvsatfwqnpnrnhfrcqvfyglsendewtqdrakpvtqivsaeawgradcgitsas
 yhqgvlstilyeillgkatlyavlvsalvlmamvkrkdfgsgkrakrsgsgATNFSLLKOAGDVEENPGPMLLIT
 SMLVLWMQLSQVNGQQVMQIPQYQHVQEGEDFTTYCNSSITLSNIQWYKQRPBG
 HPVFLIQLVKSGEVKKQKRLTFQFGEAKKNSSLHITATQTTDVGTYFCAGIGSSNT

GKLIFGQGTTLQVKPDiqn dpav yqlrds kssdks vclftdfdsqtnvsqskdsdvyitdktvldmrsmdfksn
savawnsksdfacanafnnsiipedtffpssdvpdcklvksfetdtnlnfnqllvivlrilllkvagfnllmtrlrws

E7-11-176 MGTM codon optimized sequence (also known as “TCR176” or “176”)

Alpha chain:

TRAV29DV5/TRAJ41/MGTM modified TRAC

Alpha chain DNA sequence

Atggccatgctgctgggagccagcgtgctgattctttggctccagcctgactgggtcaacagccagcagaagaacgacgatcagc
aagtgaagcagaacagccccagcctgagcgtgcaagaaggcagaatccatcctgaactgcgactacaccaactctatgttcg
actacttcctgtgtgtacaagaagtaccccgccgagggacccacctttgatcagccatcagctccatcaaggacaagaaacgagg
acggccggttcacgcgtgtttctgaacaagagcgccaagcacctgagcctgcacatcgtgccttctcagcctggggattccgcccgtgt
atttgcGCCGCAAAAAATTCAAATTCAGGTTATGCCCTCAACTTTGGCAAAGG
CACCTCGCTGTTGGTACACCCCCacatccagaaccccgaccccgccgtgtaccagctgagggactccaagtc
cagcgacaagagcgtgtgtgtgtttacggacttcgacagccagaccaacgtgagtc aaagcaaggacagcgacgtctacataacg
gataagaccgtgctggacatgcggagcatggacttcaagagcaacagcgccgtggcctgttccaacaagagcgacttcgcctgc
gccaacgccttaacaacagcatcatccccgaggacaccttctccccagcagcgacgtgccctgcgacgtgaaactgggtggaga
agtccttcgagacagacaccaatctgaacttcaagaacctgtggtgatcgtgctgcgattctgctgctgaaagtggccggttcaa
tctgctgatgacctgcggctgtggagc

Alpha chain protein sequence

MAMLLGASVLILWLQPDWVNSQQKNDDQQVKQNSPSLSVQEGRISILNCDYTNS
MFDFYFLWYKKYPAEGPTFLISISSIKDKNEDGRFTVFLNKS AKHLSLHIVPSQPGDS
AVYFCAAKNSNSGYALNFGKGTSLLVTPHiqnpdpav yqlrds kssdks vclftdfdsqtnvsqskds
dvyitdktvldmrsmdfksnsavawnsksdfacanafnnsiipedtffpssdvpdcklvksfetdtnlnfnqllvivlrilllk
vagfnllmtrlrws

Beta chain:

TRBV24-1/TRBJ2-6/MGTM modified TRBC

Beta chain DNA sequence

ATGGCCAGCCTGCTGTTCTTCTGCGGCGCCTTTTATCTGCTCGGCACCGGCTCTA
TGGACGCCGACGTTACACAGACCCCTCGGAACAGAATACCAAGACCGGCAAG
CGGATCATGCTGGAATGCAGCCAGACCAAAGGGCCACGACCGGATGTACTGGT
ACAGACAGGATCCAGGACTGGGCCTGCAGCTGATCTACTACAGCTTCGACGTG
AAGGACATCAACAAGGGCGAGATCAGCGACGGCTACAGCGTGTCAAGACAGG
CCCAGGCCAAGTTTACGCCTGAGCCTGGAAAGCGCTATCCCCAACCAGACTGCC
CTGTACTTCTTGCGCCACTTCCGATCGCTCCTCCGGCGCCAACGTTCTTACCT
TTGGGGCCGGCAGCAGGCTGACCGTGCTGgaagatctgaacaagggtgtccctccagaggtggccgtg
ttcgagccttctaaggccgagatgcccacacacaaaaagccaccctcgtgtgctggccaccggcttttccccgaccacgtgga
actgtcttggtgggtcaacggcaagaggtgcactccggcgtgtcaacggatccccagcctctgaaagaacgctgcctgaac
gacagccggtactgcctgagctccagactgagagtgtccgccaccttctggcagaacccccggaaccacttcagatgccaggtgc
agttttacggcctgagcgagaacgacgagtggaccaggacagagccaagcccgtagacaaaatcgtgtctgccgaagcctggg
gaagagccgattcgggcatcaccagcgccctctatcaccagggcgtgctgagcgccacaatcctgtacgaaatcctgctgggcaa
ggccaccctgtacgcgtgctggtgtctgctggtgctgatggccatggtcaagcggaaggactttggcagcggcagagccaaa
aggtccgggagcggt

Beta chain protein sequence

MASLLFFCGAFYLLGTGSMDADVTQTPRNRITKTGKRIMLECSQTKGHDRMYWY
RQDPGLGLQLIYYSFDVKDINKGEISDGYSVSRQAQAKFSLSLESAIPNQALYFCA

TSDRSSGANVLTFGAGSRLTVLEdlnkvfppevavfepskaeiahtqkatlvclatgffpdhvelswvwnv
kevhsgvstdpqplkeqpalndsryclssrlrvsatfwqnpnrhfrqcvqfyglsendewtqdrakpvtqivsacawgradcgi
tsasyhqgvlstilyeillgkatlyavlvsalvlmamvkrkdfgsgrakrsgsg

Complete Beta and Alpha ORF DNA Sequence (The underlined italic region in the “Furin-P2A” site encodes a sequence allowing for expression of two polypeptide chains in a single cassette”)

ATGGCCAGCCTGCTGTTCTTCTGCGGCGCCTTTTATCTGCTCGGCACCGGCTCTA
TGGACGCCGACGTTACACAGACCCCTCGGAACAGAATCACCAAGACCGGCAAG
CGGATCATGCTGGAATGCAGCCAGACCA**AAGGGCCACGACCGG**ATGTACTGGT
ACAGACAGGATCCAGGACTGGGCCTGCAGCTGATCTACTAC**AGCTTCGACGTG**
AAGGACATCAACAAGGGCGAGATCAGCGACGGCTACAGCGTGTCAAGACAGG
CCCAGGCCAAGTTCAGCCTGAGCCTGGAAAGCGCTATCCCCAACCAGACTGCC
CTGTACTTCT**TGCGCCACTTCCGATCGCTCCTCCGGCGCCAACGTTCTTACCT**
TTGGGGCCGGCAGCAGGCTGACCGTGCTGgaagatctgaacaaggtgttcctccagaggtggcctg
ttcgagccttctaaagccgagatcgccacacacaaaaagccaccctcgtgtgcctggccaccggcttttccccgaccacgtgga
actgtcttgggtggtcaacggcaaagaggtgcactccggcgtgtcaacggatccccagcctctgaagaacagcctgcctgaac
gacagccggtactgcctgagctccagactgagagtgccgccacctctggcagaacccccggaaccacttcagatgccaggtgc
agttttacggcctgagcgagaacgacgagtggaaccaggacagagccaagccgtgacacaaatcgtgtctgccgaagcctggg
gaagagccgattcgggcatcaccagcgctcctatcaccagggcgtgctgagcgccacaatcctgtacgaaatcctgctgggcaa
ggccaccctgtacgccgtgctgtgtctgtctgtgctgatggccatggtaagcggaagactttggcagcggcagagccaaa
aggtccgggagcggt**GCGACAAACTTTAGCCTGTTGAAACAAGCCGGCGACGTTGAAGAGA**
ACCCCGGACCTATGGCCATGCTGCTGGGAGCCAGCGTGCTGATTCTTTGGCTCC
AGCCTGACTGGGTCAACAGCCAGCAGAAGAACGACGATCAGCAAGTGAAGCA
GAACAGCCCCAGCCTGAGCGTGCAAGAAGGCAGAATCTCCATCCTGAAGTGC
ACTACACCA**AACTCTATGTTTCGACTACT**TCTCTGTGGTACAAGAAGTACCCCGCC
GAGGGACCCACCTTTCTGATCAGC**ATCAGCTCCATCAAGGACAAG**AACGAGG
ACGGCCGGTTACCGTGTTTCTGAACAAGAGCGCCAAGCACCTGAGCCTGCAC
ATCGTGCCTTCTCAGCCTGGGGATTCCGCCGTGTATTTC**TGCGCCGCAAAAAA**
TTCAAATTCAGGTTATGCCCTCAACTTTTGGCAAAGGCACCTCGCTGTTGGTCA
CACCCAcacatcagaaccccgaccccgccgtgtaccagctgagggactccaagtccagcgacaagagcgtgtgtctgtttac
ggacttcgacagccagaccaacgtgagtcaagcaagacagcgacgtctacataacggataagaccgtgtggacatcgaggag
catggacttcaagagaacagcgccgtggcctgtgccaacaagagcgacttcgctgcgccaacgccttcaacaacagcatc
cccagagacaccttctccccagcagcgacgtgcctgcgacgtgaaactggtggagaagtccttcgagacagacaccaatctga
actttcagaacctgctggtgatcgtgctgcggattctgctgctgaaagtggccggcttcaatctgctgatgacctgcggctgtggag
c

Complete Beta and Alpha ORF Protein Sequence (The underlined italic region in the
“Furin-P2A” site allows expression of two polypeptide chains in a single cassette”)
MASLLFFCGAFYLLGTGSMDADVTQTPRNRITKTGKRIMLECSQT**KGHDR**MYWY
RQDPGLGLQLIYY**SFDVKD**INKGEISDGYSVSRQAQAKFSLSLES AIPNQ TALYF**CA**
TSDRSSGANVLTFGAGSRLTVLEdlnkvfppevavfepskaeiahtqkatlvclatgffpdhvelswvwnv
kevhsgvstdpqplkeqpalndsryclssrlrvsatfwqnpnrhfrqcvqfyglsendewtqdrakpvtqivsacawgradcgi
tsasyhqgvlstilyeillgkatlyavlvsalvlmamvkrkdfgsgrakrsgsg**ATNFSLLKQAGDVEENPGPMA**
MLLGASVLILWLQPDWVNSQQKNDDQVVKQNSPSLSVQEGRISILNCDYT**NSMFD**
YFLWYKKYPAEGPTFLIS**ISSIKDK**NEDGRFTVFLNKS AKHLSLHIVPSQPGDSAVY
F**CAAKNSNSGYALNF**GKGTSLLVTPHIqnpdpavyqlrdsksdksvclftdfdsqtnvsqskdsdyitd
ktvldmrsmdfksnsavawsnksdfacanafnnsiipedtffpsdvpdcvklveksfetdtnlnfnqllvivlrlillkvagfnll
mtlrlws

E7-11-194 MGTM codon optimized sequence (also known as “TCR194” or “194”)

Alpha chain:

TRAV25/TRAJ37/MGTM modified TRAC

Alpha chain DNA sequence

Atgctgctgatcacctccatgctggtgctgtggatgcagctgagccaagtgaacggccagcaagtgatgcagatccctcagtacca
gcacgtgcaagaagcgaggacttcaccacctactgcaacagcagcaccacactgagcaacatccagtggtagaagcagcgg
cctggcgacacacctgtgttctgatccagctggtaagtccggcgaagtgaagaagcagaagcggctgacctccagttcggcg
aggccaagaagaacagcagcctgcacatcaccgccacacagaccacagatgtgggcacctacttcTGCGCTGGGCT
CGGTTCTCTAATACTGGTAACTGATTTTTGGGCAAGGGACAACCTTTACAA
GTAAACCAgacatccagaaccccgaccccgcctgtaccagctgagggactccaagtccagcgacaagagcgtgtgt
ctgtttacggacttcgacagccagaccaacgtgagtc aaagcaaggacagcgacgtctacataacggataagaccgtgctggaca
tgcggagcatggacttcaagagaacagcgccgtggcctggccaacaagagcgacttcgcctgcgccaacgccttcaacaaca
gcatcatccccgaggacaccttcttccccagcagcgacgtgccctgcgacgtgaaactggaggagaagtccttcgagacagacac
caatctgaactttcagaacctgctggtgatcgtgctgcggattctgctgctgaaagtggccggcttcaatctgctgatgacctgcgg
ctgtggagc

Alpha chain protein sequence

MLLITSMVLVLMQLSQVNGQQVMQIPQYQHVQEGEDFTTYCNSSTLSNIQWYK
QRPGGHPVFLIQLLVKSGEVKKQKRLTFQFGEAKKNSSLHITATQTDTVGTYFCAG
LGSSNTGKLIFGGQTTLQVKPDiqn dpavyqlrdsksdksvclfdfsqtnvsqksdsdvyitdktlvdm
rsmdfksnsavawnsksdfacanafnnsiipedtffpsdvpdcvklveksfetdtnlnfnllvivlrlillkvagfnllmtrlw
s

Beta chain:

TRBV2/ TRBJ2-7/MGTM modified TRBC

Beta chain DNA sequence

ATGGATACCTGGCTCGTGTGTTGGGCCATCTTTAGCCTGCTGAAGGCCGGACTG
ACCGAGCCTGAAGTGACCCAGACTCCAAGCCATCAAGTGACTCAGATGGGGCA
AGAAGTCATTCTGCGTTGCGTGCCCATCAGCAACCACCTGTACTTTTTATTGGTA
TCGCCAGATCCTGGGCCAGAAAGTGGAATTCCTGGTGTCTTCTACAACAATG
AGATCTCCGAGAAGTCCGAGATCTTCGACGACCAGTTCTCCGTGGAAAGACCC
GACGGCAGCAACTTCACACTGAAGATCCGGTCTACCAAACCTTGAGGACTCCGC
TATGTATTTTTTGCGCAACTACTGGTCGCGCAAGTTACGAACAGTACTTTGGG
CCGGGCACCAGGCTCACGGTCACAGaatctgaacaaggtgttccctccagaggtggccgtgttcgagcct
tctaagcccgagatgccccacacaaaaagccacctcgtgtgctggccaccggcttttccccgaccacgtggaactgtcttg
gtgggtcaacggcaaagaggtgcactccggcgtgtcaacggatccccagcctctgaagaacagcctgcctgaacgacagccg
gtactgcctgagtcagactgagagtgtccgccaccttctggcagaacccccgaaccacttcagatgccaggtgcagttttacg
gcctgagcgagaacgacgagtggaaccaggacagagccaagccgtgacacaaatcgtgtctgccgaagcctggggaagagc
cgattgcggcatcaccagcgctcctatcaccagggcgtgctgagcgccacaatcgtgtacgaaatcgtgtgggaagccacc
ctgtacccgtgctggtgtctgctgctgctgatggccatggtcaagcggaaggactttggcagcggcagagccaaaaggtccg
ggagcgg

Beta chain protein sequence

MDTWLVCWAIFSLLKAGLTEPEVTQTPSHQVTQMGQEVILRCVPISNHLYFYWYR
QILGQKVEFLVSFYNNEISEKSEIFDDQFSVERPDGSNFTLKIRSTKLEDSAMYFCAT
TGRASYEQYFGPGRTRLVTedlnkvfppevavfepskaeiahtqkatlvclatgffpdhvelswwwngkev

sgvstdpqpplkeqpalndsryclssrlrvsatfwqnpnrhfrqvyfgylsendewtqdrakpvtqivsaeawgradcgitsas
yhqgvlsatilyeillgkatlyavlvsalvlmamvkrkdfgsggrakrsgsg

Complete Beta and Alpha ORF DNA Sequence (The underlined italic region in the “Furin-P2A” site encodes a sequence allowing for expression of two polypeptide chains in a single cassette”)

ATGGATACCTGGCTCGTGTGTTGGGCCATCTTTAGCCTGCTGAAGGCCGGACTG
ACCGAGCCTGAAGTGACCCAGACTCCAAGCCATCAAGTGAAGTCAAGTGGGGCA
AGAAGTCATTCTGCGTTGCGTGCCCATCAGCAACCACTGTACTTTTATTGGTA
TCGCCAGATCCTGGGCCAGAAAGTGGAATTCCTGGTGTCTTCTACAACAATG
AGATCTCCGAGAAAGTCCGAGATCTTCGACGACCAGTTCTCCGTGGAAGACCC
GACGGCAGCAACTTCACACTGAAGATCCGGTCTACCAAACCTTGAGGACTCCGC
TATGTATTTTTGCGCAACTACTGGTCGCGCAAGTTACGAACAGTACTTTGGG
CCGGGCACCAGGCTCACGGTCACAgaagatctgaacaaggtgtccctccagaggtggccgtgttcgagcct
tctaagcccagatcgccacacacaaaaagccacctcgtgtgcctggccaccggcttttccccgaccacgtggaactgtcttg
gtgggtcaacggcgaagaggtgcactcggcgtgtcaacggatccccagcctctgaagaacagcctgcctgaacgacagccg
gtactgcctgagctccagactgagagtgtccgccactctctggcagaacccccgaaccacttcagatgccaggtgcagttttacg
gcctgagcgagaacgacgagtggaaccagagcagagccaagcccgtgacacaaatcgtgtctgccgaagcctggggaagagc
cgattgcggcatcaccagcgctcctatcaccagggcgtgctgagcgccacaatcctgtacgaaatcctgctgggcaagggcacc
ctgtacgccgtgctggtgtctgctggtgctgatggccatggtcaagcgaaggactttggcagcggcagagccaaaaggtccg
ggagcgggTGCGACAACTTTAGCCTGTTGAAACAAGCCGGCGACGTTGAAGAGAACCCC
GGACCTATGCTGCTGATCACCTCCATGCTGGTGCTGTGGATGCAGCTGAGCCAA
GTGAACGGCCAGCAAGTGATGCAGATCCCTCAGTACCAGCACGTGCAAGAAGG
CGAGGACTTCACCACCTACTGCAACAGCAGCACCACACTGAGCAACATCCAGT
GGTACAAGCAGCGGCCTGGCGGACACCCTGTGTTTCTGATCCAGCTGGTCAAG
TCCGGCGAAGTGAAGAAGCAGAAGCGGCTGACCTTCCAGTTCGGCGAGGCCA
AGAAGAACAGCAGCCTGCACATCACCGCCACACAGACCACAGATGTGGGCACC
TACTTCTTGCGCTGGGCTCGGTTCTCTAATACTGGTAAACTGATTTTTGGGC
AAGGGACAACCTTTACAAGTAAAACCAAGacatccagaaccccgaccccgccgtgtaccagctgagggac
tccaagtccagcgacaagagcgtgtgtgtttacggacttcgacagccagaccaacgtgagtcgaagcaaggacagcgactct
acataacggataagaccgtgtgtggacatcgaggacatggaactcaagagcaacagcgccgtggcctgtccaacaagagcgact
tcgctgcgccaacgccttcaacaacagcatcatccccgaggacaccttctccccagcagcgacgtgccctgcgacgtgaaactg
gtggagaagtccttcgagacagacaccaatctgaactttcagaacctgctggtgatcgtgctgcggattctgctgctgaaagtggc
ggcttcaatctgctgatgacctgcggctgtggagc

Complete Beta and Alpha ORF Protein Sequence (The underlined italic region in the “Furin-P2A” site allows expression of two polypeptide chains in a single cassette”)

MDTWLVCWAIIFSLLKAGLTEPEVTQTPSHQVTQMGEVILRCVPISNHLYFYWYR
QILGQKVEFLVSFYNNEISEKSEIFDDQFSVERPDGSNFTLKIRSTKLEDSAMYFCAT
TGRASYEQYFGPGTRLTVTEdlnkvfppevavfepskaeiahtqkatlvclatgffpdhvelswwvngkevh
sgvstdpqpplkeqpalndsryclssrlrvsatfwqnpnrhfrqvyfgylsendewtqdrakpvtqivsaeawgradcgitsas
yhqgvlsatilyeillgkatlyavlvsalvlmamvkrkdfgsggrakrsgsgATNFSLLKOAGDVEENPGPMLLIT
SMLVLWMQLSQVNGQQVMQIPQYQHVQEGEDFTTYCNSSTTLSNIQWYKQRPGG
HPVFLIQLVKSGEVKKQKRLTFQFGEAKKNSSLHITATQTTDVGTYFCAGLGSSNT
GKLIFGQGTTLQVKPDiqnpdpavyqlrdsksdksvelftdfdsqtnvsqskdsdvyitdktvldmrsmdfksn
savawnsksdfacanafnnsiipedtffpssdvpdvklveksfetdtnlnfnllvivlrlillkvagfnllmtrlws

E7-11-455 MGMT codon optimized sequence (also known as “TCR455” or “455”)

Alpha chain:

TRAV12-3/TRAJ37/ MGMT modified TRAC

Alpha chain DNA sequence

Atgatgaagtcctgcgggtgctgctgctgattttgtggctgcagctgtcttgggtctggtccagcaaaaagaggtggaacagga
ccctggacctctgtctgtgctgaaggcgccattgtgacctgaactgtacctacagcaacagcgcttccagtacittatgtgttac
aggcagtagacccggaaggccctgagctgctgatgtacacatacagcagcgcaacaagaggacggcagattcacagccc
aggtggacaagtcagcaagtagctcctgttcacccgggacagccagcctagcgatagcgccacctacgtgtGCCAT
GGCTGGCTCAGGGAATACTGGCAAGCTCATCTTCGGGCAAGGGACAACTTT
ACAAGTAAAACCAAGacatccagaaccccgaccccgccgtgtaccagctgagggactccaagtccagcgacaagag
cgtgtgtctgtttacggacttcgacagccagaccaacgtgagtcacaaggaagcagcgacgtctacataacggataagaccgtgc
tggacatgcggagcatggacttcaagagcaacagcgccgtggcctggccaacaagagcgacttcgctgcgccaacgccttca
acaacagcatcatccccgaggacaccttctccccagcagcgacgtgacctgcgacgtgaaactggtggagaagtccttcgagac
agacaccaatctgaacttcagaacctgctggtgatcgtgctgaggattctgctgctgaaagtggcggcttcaatctgctgatgacc
ctgcggctgtggagc

Alpha chain protein sequence

MMKSLRVLLVILWLQLSWVWSQQKEVEQDPGLSVPEGAIIVSLNCTYSNSAFQYF
MWYRQYSRKGPPELLMYTYSSGNKEDGRFTAQVDKSSKYISLFIRDSQPSDSATYL
CAMAGSGNTGKLIFGQGTTLQVKPDiqnpdpavylrdsksdksvclftdfdsqtnvsqskdsdvitd
ktvldmrsmdfksnsavawsnksdfacanafnnsiipedtffpsdvpdcvklveksfetdtnlnfnllvivlrlillkvagfnll
mtlrlws

Beta chain:

TRBV7-9/TRBJ2-4/MGMT modified TRBC

Beta chain DNA sequence

ATGGGAACCTCTCTGCTGTGCTGGATGGCCCTGTGTCTGCTGGGAGCCGATCAT
GCCGATACGGGAGTGTCCCAGGATCCTCGGCACAAGATTACCAAGAGGGGCCA
GAACGTGACCTTCCGCTGTGACCCTATCAGCGAGCACAAACCGGCTGTATTGGT
ACAGACAGACACTCGGCCAGGGGCTGAATTTCTCACATACTTCCAGAACGAA
GCCCAGCTGGAAAAGTCCCGGCTGCTGAGCGATAGATTTTCCGCCGAGAGGCC
CAAGGGCTCCTTCAGCACTCTGGAAATTCAGCGCACCGAGCAGGGCGACTCTG
CCATGTATCTGTGCGCCTCATCATCCTCTACAAAAAATATTCAGTATTTCCG
CGCCGGGACCCGGCTCTCAGTGCTGgaagatctgaacaaggtgtccctccagaggtggcctgttcgagc
cttctaaggccgagatcgccacacacaaaaagccacctctgtgctggtgcccaccgcttttccccgaccagtggaaactgtctt
ggtgggtcaacggcaaagaggtgcactccggcgtgtcaacggatccccagcctctgaagaacagcctgcctgaacgacagcc
ggtactgctgagctccagactgagagtgtccgccacctctgtgcagaacccccggaaccacttcagatgccaggtgcagttttac
ggcctgagcgagaacgacgagtggacccaggacagagccaagccgtgacacaaatcgtgtctgccgaagcctggggaagag
ccgattgcggcatcaccagcgctcctatcaccaggcggtgctgagcgccacaatcctgtacgaaatcctgctgggcaagggcac
cctgtacgccgtgctggtgtctgctggtgctgatggccatggtcaagcggaaggactttggcagcggcagagccaaaaggtcc
gggagcgggt

Beta chain protein sequence

MGTSLLCWMALCLLGADHADTGVSQDPRHKITKRGQNVTFRCDPISSEHNRLYWY
RQTLGQGPEFLTYFQNEAQLEKSRLLSDRFSAERPKGFSFSTLEIQRTEQGDSAMYL
CASSSTKNIQYFGAGTRLSVLEdlnkvfppevavfepskaeiahtqkatlvclatgffpdhvelswwngk
evhsgvstpqplkeqpalsrlyclssrlrvsatfwqnprnhfrqvfqylsendewtqdrakpvtqivsaeawgradcgit
sasyhqgvsatilyeillkatlyavlvsalvlmamvkrkdfgsggrakrsgsg

Complete Beta and Alpha ORF DNA Sequence (The underlined italic region in the “Furin-P2A” site encodes a sequence allowing for expression of two polypeptide chains in a single cassette”)

ATGGGAACCTCTGCTGCTGTGCTGGATGGCCCTGTGTCTGCTGCGGAGCCGATCAT
GCCGATACGGGAGTGTCCCAGGATCCTCGGCACAAGATTACCAAGAGGGGCCA
GAACGTGACCTTCCGCTGTGACCCTATCAGCGAGCACAAACGGCTGTATTGGT
ACAGACAGACACTCGGCCAGGGGCTGAATTTCTCACATACTTCCAGAACGAA
GCCCAGCTGGAAAAGTCCCGGCTGCTGAGCGATAGATTTTCCGCCGAGAGGCC
CAAGGGCTCCTTACGCACTCTGGAAATTCAGCGCACCAGAGCAGGGCGACTCTG
CCATGTATCTGTGCGCCTCATCATCCTCTACAAAAAATATTCAGTATTTTCG
CGCCGGGACCCGGCTCTCAGTGCTGgaagatctgaacaagggtgtccctccagagggtggcgtgttcgagc
cttctaaggccgagatcgccacacacaaaaagccaccctcgtgtgctgtgccaccggcttttccccgaccacgtggaactgtctt
ggfgggtcaaccggcaagagggtgcactcggcgtgtcaacggatccccagcctctgaagaacagcctgccctgaacgacagcc
ggtactgctgagctccagactgagagtgctccgccaccttctggcagaacccccgaaccacttcagatgccagggtgcagttttac
ggcctgagcgagaacgacgagtgaggaccaggacagagccaagcccgtgacacaaatcgtgtctgccgaagcctggggaagag
ccgattgcggcatcaccagcgctcctatcaccaggggcgtgctgagcgccacaatcctgtacgaaatcctgctgggcaaggccac
cctgtacgccgtgctgggtgtctgctgtgctgatggccatgtgtcaagcgggaaggactttggcagcggcgagagccaaaaggtcc
gggagcgggtGCGACAAACTTTAGCCTGTTGAAACAAGCCGGCGCAGTTGAAGAGAACCC
CGGACCTATGATGAAGTCCCTGCGGGTGCTGCTCGTGATTTTGTGGCTGCAGT
GTCTTGGGTCTGGTCCCAGCAAAAAGAGGTGGAACAGGACCCTGGACCTCTGT
CTGTGCCTGAAGGCGCCATTGTGTCCCTGAACTGTACCTACAGCAACAGCGCC
TTCCAGTACTTTTATGTGGTACAGGCAGTACAGCCGGAAGGGCCCTGAGCTGCT
GATGTACACATACAGCAGCGGCAACAAAGAGGACGGCAGATTCACAGCCAG
GTGGACAAGTCCAGCAAGTACATCTCCCTGTTTCATCCGGGACAGCCAGCCTAGC
GATAGCGCCACCTACCTGTTGTGCCATGGCTGGCTCAGGGAATACTGGCAAG
CTCATCTTCGGGCAAGGGACAACTTTACAAGTAAACCAGacatccagaacccccgacccc
gccgtgtaccagctgagggactccaagtccagcgacaagagcgtgtgtctgtttacggacttcgacagccagaccaacgtgagtc
aaagcaaggacagcgacgtctacataacggataagaccgtgctggacatgcggagcatggacttcaagagcaacagcgccgtg
gcctggtccaacaagagcgacttcgctgcgccaacgccttcaacaacagcatcctcccaggacaccttctcccagcagcg
acgtgccctgcgacgtgaaactggtggaagaagtccttcgagacagacaccaatctgaacttcagaacctgctgggtgatcgtgctgc
gattctgctgctgaaagtggccggccttcaatctgctgatgccctgcggcgtgtggagc

Complete Beta and Alpha ORF Protein Sequence (The underlined italic region in the “Furin-P2A” site allows expression of two polypeptide chains in a single cassette)”)
 MGTSLLCWMALCLLGADHADTGVSDPRHKITKRQNVTFRCDPIS**EHNR**LYWY
 RQTLGQGPEFLTY**FQNEAQ**LEKSRLSDRFS AERP KGSFSTLEIQRTEQGDSAMYL
CASSSTKNIQYFGAGTRLSVLEdlnkvfppevavfepskaeiahtqkatlvclatgffpdhvelswvngk
 evhsgvstpdpplkeqpalndrsryclssrlrvsatfwqnpnrhfrqcqvfyglsendewtqdrakpvtqivsaewgradcgit
 sasyhqvlsatilyeillgkatlyavlvlsalvlmamvkrkdfgsggrakrsgsg*ATNFSLLKQAGDVEENPGPMM*
 KSLRVLLVILWLQLSWVWSQQKEVEQDPGLSPVEGAIVSLNCTYS**NSAFQY**FMW
 YRQYSRKGPPELLMY**TYSSGN**KEDGRFTAQVDKSSKYISLFIRDSQPSDSATYL**CAM**
AGSGNTGKLIFGQGTTTLQVKPDiqnpdpavyqlrdsksdksvclftdfdsqtnvsqksdsdvyitdktvld
 mrsmdfksnsavawsnksdfacanafnnsiipedtffpssdvpcdvklveksfetdtnlnfqnlvivlrlillkvagfnllmtrl
 ws

Table 2

Kite TCR sequence (also known as “comparator”):

Alpha chain:

TRAV1-2/TRAJ7/codon optimized mouse constant alpha

Alpha chain DNA sequence

ATGTGGGGTGTCTTCCTTTTGTACGTCAGCATGAAGATGGGAGGCACTACTGGG
CAAAACATAGATCAGCCTACCGAAATGACTGCTACCGAGGGAGCCATTGTCCA
AATCAACTGCACCTATCAGACTAGCGGCTTCAATGGACTCTTCTGGTACCAAC
AGCATGCGGGCGAAGCACCTACCTTCTTGTCTATAATGTCTTGGATGGTCTC
GAAGAGAAAGGCAGATTCTCCAGTTTCTCAGCCGGAGCAAGGGATACTCATA
TCTTCTCTGAAAGAGCTTCAGATGAAGGATTCTGCATCCTATCTCTTGTGCTTC
AGTCGATGGCAATAACCGACTCGCCTTTTGGAAAAGGGAATCAAGTGGTCGTC
ATACCGaattattcagaaccccgaccgcttatcatggtgaaggacccaagatctcaggatagtagctctgtttgttacgg
actttgactcacaatacaacgtcccgaagactatggaagtgtgtacgttcacacagataagtgctgttctggacatgaaggctatgga
ctcaaagagcaacggggcaattgcttggtccaaccagacaagctttacgtgcaggacatttttaaggagactaatgctacttatccct
ccagcgactgtccgtgtgatgcgactctaccgagaagcttttgagaccgatatgaatctcaactccagaatctgctgggtatcgttc
tgcggatcctgcttctgaaggttgaggattcaatctcttatgactctccgctctggtcttca

Alpha chain protein sequence

MWGVFLLYVSMKMGGTTGQNIDQPTMTATEGAIVQINCTYQTSGFNGLFWYQQ
HAGEAPTFLSYNVLDGLEEKGRFSSFLSRSKGYSYLLKELQMKDSASYLCASVD
GNNRLAFFGKGNQVVVIPNiqnpepavyqlkdpqsqdstlclftdfdsqinvpktmesgtfjdkcvldmkamd
sksnaiawnsqtsftcqdketnatypssdvpdatltekstetdmnlfnqllvmvrlrlllkvagfllmlrlwss

Beta chain:

TRBV5-6/TRBJ2-1/codon optimized mouse constant beta

Beta chain DNA sequence

ATGGCCCCGGGGCTTTTGTGTTGGGCCTTGCTTTGTTTGCTTGGGGCAGGCTTGG
TGGATGCTGGAGTCACACAGTCACCCACACACCTCATTAAAACCAGGGGACAA
CAAGTCACTCTGCGCTGCAGTCCTAAGTTCAGGCCATGACACAGTTTCCTGGTA
TCAACAGGCTCTGGGGCAGGGCCCTCAGTTCATTTTCCAATTATTACGAGGAAG
AGGAACCGCCAACGCGGTAATTTCCCCGATCGGTTCTCTGGGCACCAGTTCCCAA
ACTACTCAAGTGAGTTGAACGTAAATGCTCTCCTCCTCGGAGACTCCGCCCTCT
ACTTGTGTGCCAGTTCTCTTGGTTGGCGGGGCGGCCGATACAATGAACAAT
TTTTTGGACCTGGTACTCGGCTGACCGTGCTAGaggacctgcgaacgtcacccacaaaggctc
agtttgttgagccatcaaaggcggagatcgccaacaaacagaaagctacgtcgtgtgttggtcggggcttctccagaccac
gtagaactttctggtgggtcaatggaaaggaggttcattccggagtgtgactgatcccaagcgtacaaggaatccaactatagc
tactgtctctcatctcggtccgggtgagtgcgacattctggcataatctctgggaaccactttcagccaagtgcagtttcatgggtg
agcgaggaagacaagtggcccgaggcagtcctaaccagtcactcaaaacataagcgccgagggcatgggtagagccgattg
tgggattactagcgctcataccaacaaggggtattgagcgctacaattctttacgaaattctctcggaaggcgacgtctacgcc
gtactggtgtctactctcggttatggcaatggtgaaacggaaaaacagc

Beta chain protein sequence

MAPGLLCWALLCLLGAGLVDAGVTQSPTHLIKTRGQQVTLRCSPKSGHDTVSWY
QQALGQGPQFIFQYYEEEEERQRGNFDRFSGHQFPNYSSELNVNALLLGDSALYLC
ASSLGWRGGRYNEOFFGPGTRLTVLEdlrnvtppkvslfepskaeiankqkatlvelargffpdhvelsw
wvngkevhshgvcldpqaykesnysylssrlrvsatfwhnprnhfrcqvqfhlseedkwpegsppkpvtnisaewgrad
cgitsasyqqgvlstilyeillgkatlyavlvtlvmamvkrkns

Complete Beta and Alpha ORF DNA sequence

ATGGCCCCGGGGCTTTTGTGTTGGGCCTTGCTTTGTTTGCTTGGGGCAGGCTTGG
 TGGATGCTGGAGTCACACAGTCACCCACACACCTCATTAACCAGGGGACAA
 CAAGTCACTCTGCGCTGCAGTCCTAAGTTCAGGCCATGACACAGTTTCCTGGTA
 TCAACAGGCTCTGGGGCAGGGCCCTCAGTTTCATTTTCCATATTACGAGGAAG
AGGAACGCCAACGCGGTAATTTCCCGATCGGTTCTCTGGGCACCAGTTCCCAA
 ACTACTCAAGTGAGTTGAACGTAAATGCTCTCCTCCTCGGAGACTCCGCCCTCT
 ACTTGTGTGCCAGTTCTCTTGTTGGCGGGGCGCCGATACAATGAACAAT
TTTTTGGACCTGGTACTCGGCTGACCGTGCTAGgaggacctgcgcaacgtcaccaccacaaaggtc
 agtttggttagccatcaaaggcgagatcgccaacaaacagaaagctacgctcgtgtgttggtcggttcttccagaccac
 gtagaactttcctggtgggcaatgaaaggaggttcattccggagtgctgcactgatcccaagcgtacaaggaatccaactatagc
 tactgtctctcatctcggctccgggtgagtgcgacattctggcataatcctcggaaccactttcgtatgccaagtgcagtttcatgggtg
 agcgaggaagacaagtggcccgagggcagtcctaaaccagtcactcaaacataagcgccgagggcatggggtagagccgattg
 tgggattactagcgcttcataccaacaaggggtattgagcgctacaattcttacgaaattctcctcggaagcgacgctctacgcc
 gtactggtgtctactctcgtggttatggcaatggtgaaacggaaaaacagcAGAGCCAAAAGAGTGGTTCGGC
 GCGACGAATTTAGTTTGCTTAAGCAAGCCGGAGATGTGGAGGAAAATCCTGGACCG
 ATGTGGGGTGTCTTCTTTGTACGTCAGCATGAAGATGGGAGGCACTACTGGG
 CAAAACATAGATCAGCCTACCGAAATGACTGCTACCGAGGGAGCCATTGTCCA
 AATCAACTGCACCTATCAGACTAGCGGCTTCAATGGACTCTTCTGGTACCAAC
 AGCATGCGGGCGAAGCACCTACCTTCTTGTCTTATAATGTCTTGGATGGTCTC
 GAAGAGAAAGGCAGATTCTCCAGTTTCCTCAGCCGGAGCAAGGGATACTCATA
 TCTTCTCTGAAAGAGCTTCAGATGAAGGATTCTGCATCCTATCTCTTGTGCTTC
AGTCGATGGCAATAACCGACTCGCCTTTTGAAAAGGGAATCAAGTGGTCGTC
 ATACCGaatattcagaaccccgaccgctatatcagttgaaggaccaagatctcagatagtagactctgtttgttacgg
 actttgactcacaatcaacgtcccgaagactatgaaagtgtgacgttcacacagataagtgctgttgacatgaaggctatgga
 ctcaaagagcaacgggcaattgcttggtccaaccagacaagctttacgtgcaggacatttttaaggagactaatgctactatccct
 ccagcgacgttcggtgatgcgactctaccgagaagcttttgagaccgatgaatctcaactccagaatctgctggtgatcgttc
 tgcggatcctgcttgaaggttcaggttcaatctcttactctcggctcgtgttca

Complete Beta and Alpha ORF protein sequence

MAPGLLCWALLCLLGAGLVDAGVTQSPTHLIKTRGQQVTLRCSPKSGHDTVSWY
 QQALGQGPQFIFQYEEEEERQQRGNFPDRFSGHQFPNYSELNVNALLLGDSALYLC
ASSLGWRGGRYNEOFFGPGTRLTVLEdlrntppkvsfepskaeiankqkatlvclargffpdhvelsw
 wvngkevhsgvctdpqaykesnysyclssrlrvsatfwhnprnhfrcqvqfhglseedkwpegsppkpvtnisacawgrad
 cgitsasyqqgylsatilyeillgkatlyavlsvtlvmamvkrknsRAKRSSGSATNFSLLKQAGDVEENPGP
 MWGVFLLYVSMKMGGTTGQNIQPTMTATEGAIVQINCTYQTSGENGLFWYQQ
 HAGEAPTFLSYNVLDGLEEEKGRFSSFLSRKGYSYLLKELQMKDSASYLCCASVD
GNNRLAFGKGNQVVVIPNiqnpepavyqlkdrsqdstlclftdfdsqinvpktmesgtfkdckvldmkamd
 sksngaiawsnqstfcqdifketnatypssdvpcdatlteksfetdmnlfnqllvmvrlrillkvagfnllmtlrwss

* Table 1 providing representative TCR sequences are grouped according to MHC serotype presentation and sub-grouped according to different peptides presented by the MHC serotype and bound by the sub-grouped TCRs. Individual TCRs, such as those representatively exemplified in the tables, are described and claimed, as well as the genus of binding proteins that bind a peptide epitope sequence described herein either alone or in a complex with an MHC, such as those grouped in the tables provided herein. In addition, TRAV, TRAJ, and TRAC genes for each TCR alpha chain described herein, and TRBV,

TRBJ, and TRBC genes for each TCR beta chain described herein, are provided. Sequences for each TCR described herein are provided as pairs of cognate alpha chain and beta chains for each named TCR. TCR sequences described herein are annotated. Variable domain sequences are capitalized. Constant domain sequences are in lower case. CDR1, CDR2, and CDR3 sequences are annotated using bold and underlined text. CDR1, CDR2, and CDR3 are shown in standard order of appearance from left (N-terminus) to right (C-terminus). TRAV, TRAJ, and TRAC genes for each TCR alpha chain described herein, and TRBV, TRBJ, and TRBC genes for each TCR beta chain described herein, are annotated according to well-known IMGT nomenclature described herein. Similarly, CDR1 and CDR2 of TRAV and TRBV are well-known in the art since they are based on well-known and annotated TRAV and TRBV sequences (*e.g.*, as annotated in databases like IMGT available at imt.org and IEDB available at iedb.org).

Table 3**Vector: pTSLV102-MSCV-E7-11-28-MGTM-Q-CD8-opt**

tggaagggctaattcactccaaagaagacaagatatccttgatctgtggatctaccacacacaaggctacttccctgattagcagaa
ctacacaccaggggccagggtcagatatccactgaccttggatgggtgctacaagctagtaccagttgagccagataaggtagaag
aggccaataaaggagagagaacaccagcttggtaaccctgtgagcctgcatgggatggatgacccggagagagaaggttagagt
gaggttggacagccgcctagcatttcacacgtggcccgagagctgcatccggagtactcaagaactgctgatatcagcttgctac
aagggaacttccgctggggacttccaggaggcgtggcctgggaggactggggagtggcgagccctcagatcctgcatataa
gcagctgcttttgcctgactgggtctctggttagaccagatctgagcctgggagctctctggctaactagggaacccactgctta
agcctcaataaagcttgccttgagtgttcaagtagtgtgtgcccgtctgtgtgtgactctggttaactagagatccctcagaccctt
gtcagtgtggaaatctctagcagtgccgcccgaacagggacttgaagcgaaagggaaccagaggagctctctcgacgcagg
actcggcttgcctgaagcgccgacggcaagaggcgaggggcgccgactgggtgagtacgcaaaaaattttagtagcggaggcta
gaaggagagagatgggtgagagcgtcagtaataagcgggggagaattagatcgcatgggaaaaaattcggttaaggccagg
gggaaagaaaaataaataaataatagatgggcaagcaggagctagaacgattcgcagttaatcctggcctgttagaac
atcagaagctgtgacaaaactaggacagctacaaccatccctcagacaggatcagaagaacttagatcattatataatcagta
gcaaccctctattgtgtcatcaaaaggatagagataaaagacaccaagggaagctttagacaagataggaagagcaaaaaaaa
gtaagaccaccgcacagcaagcgccggccgctgatcttcagacctggaggaggagatatgagggacaattggagaagtgaatt
atataaataaagtagtaaaaattgaaccattaggagtagcaccaccaaggcaagagaagagtgtgtcagagagaaaaaaga
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TAATGTTGTCAGGTCGAAAAATAAAATTGCAAATAGAAATTTTGTTCCTTTTTT
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TGTTAGAGGTAGAGTCGACAAGCTT

Map of the pNVVD154_TSC-200-A02_TCR-28_MSCV-TCR28-CD8-EF1a-TGFR-DHFR
Vector

Created with SnapGene



Key: CD: cluster of differentiation RNA-OUT: anti-sense RNA against the bacterial levansucrase encoded by sacB. SV: simian virus TCR: T Cell Receptor, TIR: terminal inverted repeat, QBend: Mouse anti Human CD34 antibody, dnTGFbRII: Dominant-negative TGF beta Receptor II, DHFR: Dihydrofolate reductase selection marke

Vector: pNVVD160_TSC-200-A02_TCR-28_MSCV-TCR28-CD8-EF1a-TGFR-DHFR

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TGTTAGAGGTAGAGTCGACAAGCTT

Map of the pNVVD160_TSC-200-A02_TCR-28_MSCV-TCR28-CD8-EF1a-TGFR-DHFR
Vector

pNVVD160_TSC-200-A02_TCR-28_MSCV-TCR28-CD8-EF1a-TGFR-DHFR
8055 bp

Key features and elements shown on the map:

- TCR-β chain
- TCR-α chain
- CD8 α chain
- SV40 poly(A) signal
- Codon-optimized human DHFR L22F/F31S, TTAA-free
- SV40 poly(A) signal
- R6K origin
- RNA-OUT
- TCR-β chain
- Furin cleavage site
- P2A
- Qβend/10 epitope
- Furin cleavage site
- P2A
- CD8 α chain
- SV40 poly(A) signal
- Codon-optimized human DHFR L22F/F31S, TTAA-free
- SV40 poly(A) signal
- R6K origin
- RNA-OUT
- TCR-β chain

* For vectors in Table 3, annotations are as follows: MCSV promoter is in bold. Beta chain is annotated using bold and italic text. Alpha chain is annotated using bold and underlined text. Q tag is annotated using italic and underlined text. CD8-alpha is in italic. CD8-beta is underlined.

* Included in Tables 1-3 herein are peptide epitopes, as well as polypeptide molecules comprising an amino acid sequence having at least 80%, 81%, 82%, 83%, 84%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, 99.5%, or more identity across their full length with an amino acid sequence of any SEQ ID NO listed in Tables 1-4, or a portion thereof. Such polypeptides may have a function of the full-length peptide or polypeptide as described further herein.

* Included in Tables 1-3 are RNA nucleic acid molecules (*e.g.*, thymines replaced with uracines), nucleic acid molecules encoding orthologs of the encoded proteins, as well as DNA or RNA nucleic acid sequences comprising a nucleic acid sequence having at least 80%, 81%, 82%, 83%, 84%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, 99.5%, or more identity across their full length with the nucleic acid sequence of any sequence listed in Tables 1-4, or a portion thereof. Such nucleic acid molecules can have a function of the full-length nucleic acid as described further herein.

In some embodiments, the binding proteins disclosed herein may comprise a T cell receptor (TCR), an antigen-binding fragment of a TCR, or a chimeric antigen receptor (CAR). In some embodiments, the binding protein disclosed herein may comprise two polypeptide chains, each of which comprises a variable region comprising a CDR3 of a TCR alpha chain and a CDR3 of a TCR beta chain, or a CDR1, CDR2, and CDR3 of both a TCR alpha chain and a TCR beta chain. In some embodiments, a binding protein comprises a single chain TCR (scTCR), which comprises both the TCR V α and TCR V β domains, but only a single TCR constant domain (C α or C β). The term “chimeric antigen receptor” (CAR) refers to a fusion protein that is engineered to contain two or more naturally-occurring amino acid sequences linked together in a way that does not occur naturally or does not occur naturally in a host cell, which fusion protein can function as a receptor when present on a surface of a cell. CARs encompassed by the present invention may include an extracellular portion comprising an antigen-binding domain (*i.e.*, obtained or derived from an immunoglobulin or immunoglobulin-like molecule, such as an antibody or TCR, or an antigen binding domain derived or obtained from a killer immunoreceptor from an NK cell) linked to a transmembrane domain and one or more intracellular signaling domains (optionally containing co-stimulatory domain(s)) (see, *e.g.*, Sadelain *et al.* (2013)

Cancer Discov. 3:388, Harris and Kranz (2016) *Trends Pharmacol. Sci.* 37:220, and Stone *et al.* (2014) *Cancer Immunol. Immunother.* 63:1163).

In some embodiments, 1) the TCR alpha chain CDR, TCR V α domain, and/or TCR alpha chain is encoded by a TRAV, TRAJ, and/or TRAC gene or fragment thereof selected from the group of TRAV, TRAJ, and TRAC genes listed in Table 1, and/or 2) the TCR beta chain CDR, TCR V β domain, and/or TCR beta chain is encoded by a TRBV, TRBJ, and/or TRBC gene or fragment thereof selected from the group of TRBV, TRBJ, and TRBC genes listed in Table 1, and/or 3) each CDR of the binding protein has up to five amino acid substitutions, insertions, deletions, or a combination thereof as compared to the cognate reference CDR sequence listed in Table 1.

In some embodiments, the binding proteins (*e.g.*, the TCR, antigen-binding fragment of a TCR, or chimeric antigen receptor (CAR)) disclosed herein is chimeric (*e.g.*, comprises amino acid residues or motifs from more than one donor or species), humanized (*e.g.*, comprises residues from a non-human organism that are altered or substituted so as to reduce the risk of immunogenicity in a human), or human.

Methods for producing engineered binding proteins, such as TCRs, CARs, and antigen-binding fragments thereof, are well-known in the art (*e.g.*, Bowerman *et al.* (2009) *Mol. Immunol.* 5:3000; U.S. Pat. No. 6,410,319; U.S. Pat. No. 7,446,191; U.S. Pat. Publ. No. 2010/065818; U.S. Pat. No. 8,822,647; PCT Publ. No. WO 2014/031687; U.S. Pat. No. 7,514,537; and Brentjens *et al.* (2007) *Clin. Cancer Res.* 73:5426).

In some embodiments, the binding protein described herein is a TCR, or antigen-binding fragment thereof, expressed on a cell surface, wherein the cell surface-expressed TCR is capable of more efficiently associating with a CD3 protein as compared to endogenous TCR. A binding protein encompassed by the present invention, such as a TCR, when expressed on the surface of a cell like a T cell, may also have higher surface expression on the cell as compared to an endogenous binding protein, such as an endogenous TCR. In some embodiments, provided herein is a CAR, wherein the binding domain of the CAR comprises an antigen-specific TCR binding domain (see, *e.g.*, Walseng *et al.* (2017) *Scientific Reports* 7:10713).

Also provided are modified binding proteins (*e.g.*, TCRs, antigen-binding fragments of TCRs, or CARs) that may be prepared according to well-known methods using a binding protein having one or more of the V α and/or V β sequences disclosed herein as starting material to engineer a modified binding protein that may have altered properties from the

starting binding protein. A binding protein may be engineered by modifying one or more residues within one or both variable regions (*i.e.*, V_{α} and/or V_{β}), for example within one or more CDR regions and/or within one or more framework regions. Additionally or alternatively, a binding protein may be engineered by modifying residues within the constant region(s).

Another type of variable region modification is to mutate amino acid residues within the V_{α} and/or V_{β} CDR1, CDR2 and/or CDR3 regions to thereby improve one or more binding properties (*e.g.*, affinity) of the binding protein of interest. Site-directed mutagenesis or PCR-mediated mutagenesis may be performed to introduce the mutation(s) and the effect on protein binding, or other functional property of interest, may be evaluated in *in vitro*, *ex vivo*, or *in vivo* assays as described herein and provided in the Examples. In some embodiments, conservative modifications (as discussed above) may be introduced. The mutations may be amino acid substitutions, additions or deletions. In some embodiments, the mutations are substitutions. Moreover, typically no more than one, two, three, four or five residues within a CDR region are modified.

In some embodiments, binding proteins (*e.g.*, TCRs, antigen-binding fragments of TCRs, or CARs) described herein may possess one or more amino acid substitutions, deletions, or additions relative to a naturally occurring TCR. In some embodiments, each CDR of the binding protein has up to five amino acid substitutions, insertions, deletions, or a combination thereof as compared to the cognate reference CDR sequence listed in Table 1. Conservative substitutions of amino acids are well-known and may occur naturally or may be introduced when the binding protein is recombinantly produced. Amino acid substitutions, deletions, and additions may be introduced into a protein using mutagenesis methods known in the art (see, *e.g.*, Sambrook *et al.* (2001) *Molecular Cloning: A Laboratory Manual*, 3d ed., Cold Spring Harbor Laboratory Press, NY). Oligonucleotide-directed site-specific (or segment specific) mutagenesis procedures may be employed to provide an altered polynucleotide that has particular codons altered according to the substitution, deletion, or insertion desired. Alternatively, random or saturation mutagenesis techniques, such as alanine scanning mutagenesis, error prone polymerase chain reaction mutagenesis, and oligonucleotide-directed mutagenesis may be used to prepare immunogen polypeptide variants (see, *e.g.*, Sambrook *et al. supra*).

A variety of criteria known to the ordinarily skilled artisan indicate whether an amino acid that is substituted at a particular position in a peptide or polypeptide is

conservative (or similar). For example, a similar amino acid or a conservative amino acid substitution is one in which an amino acid residue is replaced with an amino acid residue having a similar side chain. Similar amino acids may be included in the following categories: amino acids with basic side chains (*e.g.*, lysine, arginine, histidine); amino acids with acidic side chains (*e.g.*, aspartic acid, glutamic acid); amino acids with uncharged polar side chains (*e.g.*, glycine, asparagine, glutamine, serine, threonine, tyrosine, cysteine, histidine); amino acids with nonpolar side chains (*e.g.*, alanine, valine, leucine, isoleucine, proline, phenylalanine, methionine, tryptophan); amino acids with beta-branched side chains (*e.g.*, threonine, valine, isoleucine), and amino acids with aromatic side chains (*e.g.*, tyrosine, phenylalanine, tryptophan). Proline, which is considered more difficult to classify, shares properties with amino acids that have aliphatic side chains (*e.g.*, leucine, valine, isoleucine, and alanine). In some embodiments, substitution of glutamine for glutamic acid or asparagine for aspartic acid may be considered a similar substitution in that glutamine and asparagine are amide derivatives of glutamic acid and aspartic acid, respectively. As understood in the art "similarity" between two polypeptides is determined by comparing the amino acid sequence and conserved amino acid substitutes thereto of the polypeptide to the sequence of a second polypeptide (*e.g.*, using GENEWORKS™, Align, the BLAST algorithm, or other algorithms described herein and practiced in the art).

In some embodiments, an encoded binding protein (*e.g.*, TCR, antigen-binding fragment of a TCR, or CAR) may comprise a "signal peptide" (also known as a leader sequence, leader peptide, or transit peptide). Signal peptides target newly synthesized polypeptides to their appropriate location inside or outside the cell. A signal peptide may be removed from the polypeptide during or once localization or secretion is completed. Polypeptides that have a signal peptide are referred to herein as a "pre-protein" and polypeptides having their signal peptide removed are referred to herein as "mature" proteins or polypeptides. In some embodiments, a binding protein (*e.g.*, TCR, antigen-binding fragment of a TCR, or CAR) described herein comprises a mature V α domain, a mature V β domain, or both. In some embodiments, a binding protein (*e.g.*, TCR, antigen-binding fragment of a TCR, or CAR) described herein comprises a mature TCR β -chain, a mature TCR α -chain, or both.

In some embodiments, the binding proteins are fusion proteins comprising: (a) an extracellular component comprising a TCR or antigen-binding fragment thereof; (b) an intracellular component comprising an effector domain or a functional portion thereof; and

(c) a transmembrane domain connecting the extracellular and intracellular components. In some embodiments, the fusion protein is capable of binding (*e.g.*, specifically and/or selectively) to a peptide-MHC (pMHC) complex comprising an HPV16 E7₁₁₋₁₉ immunogenic peptide in the context of an MHC molecule (*e.g.*, a MHC class I molecule). In some embodiments, the MHC molecule comprises an MHC alpha chain that is an HLA serotype HLA-A*02. In some embodiments, the HLA allele is selected from the group consisting of HLA-A*0201, HLA-A*0202, HLA-A*0203, HLA-A*0205, HLA-A*0206, and HLA-A*0207 allele. In specific embodiments, the HLA allele is HLA-A*0201.

As used herein, an “effector domain” or “immune effector domain” is an intracellular portion or domain of a fusion protein or receptor that can directly or indirectly promote an immune response in a cell when receiving an appropriate signal. In some embodiments, an effector domain is from an immune cell protein or portion thereof or immune cell protein complex that receives a signal when bound (*e.g.*, CD3ζ), or when the immune cell protein or portion thereof or immune cell protein complex binds directly to a target molecule and triggers signal transduction from the effector domain in an immune cell.

An effector domain may directly promote a cellular response when it contains one or more signaling domains or motifs, such as an intracellular tyrosine-based activation motif (ITAM), such as those found in costimulatory molecules. Without wishing to be bound by theory, it is believed that ITAMs are useful for T cell activation following ligand engagement by a T cell receptor or by a fusion protein comprising a T cell effector domain. In some embodiments, the intracellular component or functional portion thereof comprises an ITAM. Exemplary immune effector domains include but are not limited to those from, CD3ε, CD3δ, CD3ζ, CD25, CD79A, CD79B, CARD11, DAP10, FcRα, FcRβ, FcRγ, Fyn, HVEM, ICOS, Lck, LAG3, LAT, LRP, NKG2D, NOTCH1, NOTCH2, NOTCH3, NOTCH4, Wnt, ROR2, Ryk, SLAMF1, Slp76, pTα, TCRα, TCRβ, TRIM, Zap70, PTCH2, or any combination thereof. In some embodiments, an effector domain comprises a lymphocyte receptor signaling domain (*e.g.*, CD3ζ or a functional portion or variant thereof).

In further embodiments, the intracellular component of the fusion protein comprises a costimulatory domain or a functional portion thereof selected from CD27, CD28, 4-1BB (CD137), OX40 (CD134), CD2, CD5, ICAM-1 (CD54), LFA-1 (CD11a/CD18), ICOS (CD278), GITR, CD30, CD40, BAFF-R, HVEM, LIGHT, MKG2C, SLAMF7, NKp80,

CD160, B7-H3, a ligand that binds (*e.g.*, specifically and/or selectively) with CD83, or a functional variant thereof, or any combination thereof. In some embodiments, the intracellular component comprises a CD28 costimulatory domain or a functional portion or variant thereof (which may optionally include a LL- GG mutation at positions 186-187 of the native CD28 protein (*e.g.*, Nguyen *et al.* (2003) *Blood* 702:4320), a 4-1BB costimulatory domain or a functional portion or variant thereof, or both.

In some embodiments, an effector domain comprises a CD3ε endodomain or a functional (*e.g.*, signaling) portion thereof, or a functional variant thereof. In further embodiments, an effector domain comprises a CD27 endodomain or a functional (*e.g.*, signaling) portion thereof, or a functional variant thereof. In further embodiments, an effector domain comprises a CD28 endodomain or a functional (*e.g.*, signaling) portion thereof, or a functional variant thereof. In still further embodiments, an effector domain comprises a 4-1BB endodomain or a functional (*e.g.*, signaling) portion thereof, or a functional variant thereof. In further embodiments, an effector domain comprises an OX40 endodomain or a functional (*e.g.*, signaling) portion thereof, or a functional variant thereof. In further embodiments, an effector domain comprises a CD2 endodomain or a functional (*e.g.*, signaling) portion thereof, or a functional variant thereof. In further embodiments, an effector domain comprises a CD5 endodomain or a functional (*e.g.*, signaling) portion thereof, or a functional variant thereof. In further embodiments, an effector domain comprises an ICAM-1 endodomain or a functional (*e.g.*, signaling) portion thereof, or a functional variant thereof. In further embodiments, an effector domain comprises a LFA-1 endodomain or a functional (*e.g.*, signaling) portion thereof, or a functional variant thereof. In further embodiments, an effector domain comprises an ICOS endodomain or a functional (*e.g.*, signaling) portion thereof, or a functional variant thereof.

An extracellular component and an intracellular component encompassed by the present invention are connected by a transmembrane domain. A "transmembrane domain," as used herein, is a portion of a transmembrane protein that can insert into or span a cell membrane. Transmembrane domains have a three-dimensional structure that is thermodynamically stable in a cell membrane and generally range in length from about 15 amino acids to about 30 amino acids. The structure of a transmembrane domain may comprise an alpha helix, a beta barrel, a beta sheet, a beta helix, or any combination thereof. In some embodiments, the transmembrane domain comprises or is derived from a known transmembrane protein (*e.g.*, a CD4 transmembrane domain, a CD8 transmembrane

domain, a CD27 transmembrane domain, a CD28 transmembrane domain, or any combination thereof).

In some embodiments, the extracellular component of the fusion protein further comprises a linker disposed between the binding domain and the transmembrane domain. As used herein when referring to a component of a fusion protein that connects the binding and transmembrane domains, a “linker” may be an amino acid sequence having from about two amino acids to about 500 amino acids, which can provide flexibility and room for conformational movement between two regions, domains, motifs, fragments, or modules connected by the linker. For example, a linker encompassed by the present invention can position the binding domain away from the surface of a host cell expressing the fusion protein to enable proper contact between the host cell and a target cell, antigen binding, and activation (Patel *et al.* (1999) *Gene Therapy* 6:412-419). Linker length may be varied to maximize antigen recognition based on the selected target molecule, selected binding epitope, or antigen binding domain size and affinity (see, *e.g.*, Guest *et al.* (2005) *Immunother.* 28:203-11 and PCT Publ. No. WO 2014/031687). Exemplary linkers include those having a glycine-serine amino acid chain having from one to about ten repeats of Gly_xSer_y, wherein x and y are each independently an integer from 0 to 10, provided that x and y are not both 0 (*e.g.*, (Gly₄Ser)₂, (Gly₃Ser)₂, Gly₂Ser, or a combination thereof, such as ((Gly₃Ser)₂Gly₂Ser)).

Binding proteins encompassed by the present invention may, in some embodiments, be covalently linked to a moiety. In some embodiments, the covalently linked moiety comprises an affinity tag or a label. The affinity tag may be selected from the group consisting of Glutathione-S-Transferase (GST), calmodulin binding protein (CBP), protein C tag, Myc tag, HaloTag, HA tag, Flag tag, His tag, biotin tag, and V5 tag. The label may be a fluorescent protein. In some embodiments, the covalently linked moiety is selected from the group consisting of an inflammatory agent, an anti-inflammatory agent, a cytokine, a toxin, a cytotoxic molecule, a radioactive isotope, or an antibody such as a single-chain Fv.

A binding protein may be conjugated to an agent used in imaging, research, therapeutics, theranostics, pharmaceuticals, chemotherapy, chelation therapy, targeted drug delivery, and radiotherapy. In some embodiments, a binding protein may be conjugated to or fused with detectable agents, such as a fluorophore, a near-infrared dye, a contrast agent, a nanoparticle, a metal-containing nanoparticle, a metal chelate, an X-ray contrast agent, a

PET agent, a metal, a radioisotope, a dye, radionuclide chelator, or another suitable material that can be used in imaging. In some embodiments, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, or more detectable moieties may be linked to a binding protein. Non-limiting examples of radioisotopes include alpha emitters, beta emitters, positron emitters, and gamma emitters. In some embodiments, the metal or radioisotope is selected from the group consisting of actinium, americium, bismuth, cadmium, cesium, cobalt, europium, gadolinium, iridium, lead, lutetium, manganese, palladium, polonium, radium, ruthenium, samarium, strontium, technetium, thallium, and yttrium. In some embodiments, the metal is actinium, bismuth, lead, radium, strontium, samarium, or yttrium. In some embodiments, the radioisotope is actinium-225 or lead-212. In some embodiments, the near-infrared dyes are not easily quenched by biological tissues and fluids. In some embodiments, the fluorophore is a fluorescent agent emitting electromagnetic radiation at a wavelength between 650 nm and 4000 nm, such emissions being used to detect such agent. Non-limiting examples of fluorescent dyes that may be used as a conjugating molecule include DyLight-680, DyLight-750, VivoTag-750, DyLight-800, IRDye-800, VivoTag-680, Cy5.5, ZQ800, or indocyanine green (ICG). In some embodiments, near infrared dyes often include cyanine dyes (*e.g.*, Cy7, Cy5.5, and Cy5). Additional, non-limiting examples of fluorescent dyes for use as a conjugating molecule in accordance with present invention include acradine orange or yellow, Alexa Fluors® (*e.g.*, Alexa Fluor® 790, 750, 700, 680, 660, and 647) and any derivative thereof, 7-actinomycin D, 8-anilinonaphthalene-1-sulfonic acid, ATTO® dye and any derivative thereof, auramine-rhodamine stain and any derivative thereof, bensanthrone, bimean, 9-10-bis(phenylethynyl)anthracene, 5,12-bis(phenylethynyl)anthracene, bisbenzimidazole, brainbow, calcein, carboxyfluorescein and any derivative thereof, 1-chloro-9,10-bis(phenylethynyl)anthracene and any derivative thereof, DAPI, DiOC6, DyLight® Fluors® and any derivative thereof, epirubicin, ethidium bromide, FIAH-EDT2®, Fluo dye and any derivative thereof, FluoProbe® and any derivative thereof, fluorescein and any derivative thereof, Fura® and any derivative thereof, GelGreen® and any derivative thereof, GelRed® and any derivative thereof, fluorescent proteins and any derivative thereof, m isoform proteins and any derivative thereof such as for example mCherry, methine dye and any derivative thereof, hoeschst stain, iminocoumarin, indian yellow, indo-1 and any derivative thereof, laurdan, lucifer yellow and any derivative thereof, luciferin and any derivative thereof, luciferase and any derivative thereof, mercocyanine and any derivative thereof, Nile dyes and any derivative

thereof, perylene, phloxine, phyco dye and any derivative thereof, propium iodide, pyranine, rhodamine and any derivative thereof, ribogreen, RoGFP, rubrene, stilbene and any derivative thereof, sulforhodamine and any derivative thereof, SYBR and any derivative thereof, synapto-pHluorin, tetraphenyl butadiene, tetrasodium tris, Texas Red, Titan Yellow, TSQ, umbelliferone, violanthrone, yellow fluorescent protein and YOYO-1. Other suitable fluorescent dyes include, but are not limited to, fluorescein and fluorescein dyes (*e.g.*, fluorescein isothiocyanine or FITC, naphthofluorescein, 4', 5'-dichloro-2',7'-dimethoxyfluorescein, 6-carboxyfluorescein or FAM, *etc.*), carbocyanine, merocyanine, styryl dyes, oxonol dyes, phycoerythrin, erythrosin, eosin, rhodamine dyes (*e.g.*, carboxytetramethyl-rhodamine or TAMRA, carboxyrhodamine 6G, carboxy-X-rhodamine (ROX), lissamine rhodamine B, rhodamine 6G, rhodamine Green, rhodamine Red, tetramethylrhodamine (TMR), *etc.*), coumarin and coumarin dyes (*e.g.*, methoxycoumarin, dialkylaminocoumarin, hydroxycoumarin, aminomethylcoumarin (AMCA), *etc.*), Oregon Green™ dyes (*e.g.*, Oregon Green™ 488, 500, 514., *etc.*), Texas Red®, Texas Red®-X, SPECTRUM RED®, SPECTRUM GREEN®, cyanine dyes (*e.g.*, CY-3, Cy-5, CY-3.5, CY-5.5, *etc.*), Alexa Fluor® dyes (*e.g.*, Alexa Fluor® 350, 488, 532, 546, 568, 594, 633, 660, 680, *etc.*), BODIPY® dyes (*e.g.*, BODIPY® FL, R6G, TMR, TR, 530/550, 558/568, 564/570, 576/589, 581/591, 630/650, 650/665, *etc.*), IRD dyes (*e.g.*, IRD40™, IRD700™, IRD800™, *etc.*), and the like. Additional suitable detectable agents are well-known in the art (*e.g.*, PCT Publ. No. PCT/US14/56177). Non-limiting examples of radioisotopes include alpha emitters, beta emitters, positron emitters, and gamma emitters. In some embodiments, the metal or radioisotope is selected from the group consisting of actinium, americium, bismuth, cadmium, cesium, cobalt, europium, gadolinium, iridium, lead, lutetium, manganese, palladium, polonium, radium, ruthenium, samarium, strontium, technetium, thallium, and yttrium. In some embodiments, the metal is actinium, bismuth, lead, radium, strontium, samarium, or yttrium. In some embodiments, the radioisotope is actinium-225 or lead-212.

Binding proteins may be conjugated to a radiosensitizer or photosensitizer. Examples of radiosensitizers include but are not limited to: ABT-263, ABT-199, WEHI-539, paclitaxel, carboplatin, cisplatin, oxaliplatin, gemcitabine, etanidazole, misonidazole, tirapazamine, and nucleic acid base derivatives (*e.g.*, halogenated purines or pyrimidines, such as 5-fluorodeoxyuridine). Examples of photosensitizers include but are not limited to: fluorescent molecules or beads that generate heat when illuminated, nanoparticles,

porphyrins and porphyrin derivatives (*e.g.*, chlorins, bacteriochlorins, isobacteriochlorins, phthalocyanines, and naphthalocyanines), metalloporphyrins, metallophthalocyanines, angelicins, chalcogenapyrillium dyes, chlorophylls, coumarins, flavins and related compounds such as alloxazine and riboflavin, fullerenes, pheophorbides, pyropheophorbides, cyanines (*e.g.*, merocyanine 540), pheophytins, sapphyrins, texaphyrins, purpurins, porphycenes, phenothiaziniums, methylene blue derivatives, naphthalimides, Nile blue derivatives, quinones, perylenequinones (*e.g.*, hypericins, hypocrellins, and cercosporins), psoralens, quinones, retinoids, rhodamines, thiophenes, verdins, xanthene dyes (*e.g.*, eosins, erythrosins, rose bengals), dimeric and oligomeric forms of porphyrins, and prodrugs such as 5-aminolevulinic acid. Advantageously, this approach allows for highly specific targeting of cells of interest (*e.g.*, immune cells) using both a therapeutic agent (*e.g.*, drug) and electromagnetic energy (*e.g.*, radiation or light) concurrently. In some embodiments, the binding protein is fused with, or covalently or non-covalently linked to the agent, for example, directly or via a linker.

In some embodiments, the binding protein may be chemically modified. For example, a binding protein may be mutated to modify peptide properties such as detectability, stability, biodistribution, pharmacokinetics, half-life, surface charge, hydrophobicity, conjugation sites, pH, function, and the like. N-methylation is one example of methylation that can occur in a binding protein encompassed by the present invention. In some embodiments, a binding protein may be modified by methylation on free amines such as by reductive methylation with formaldehyde and sodium cyanoborohydride.

A chemical modification may comprise a polymer, a polyether, polyethylene glycol, a biopolymer, a zwitterionic polymer, a polyamino acid, a fatty acid, a dendrimer, an Fc region, a simple saturated carbon chain such as palmitate or myristolate, or albumin. The chemical modification of a binding protein with an Fc region may be a fusion Fc-protein. A polyamino acid may include, for example, a poly amino acid sequence with repeated single amino acids (*e.g.*, poly glycine), and a poly amino acid sequence with mixed poly amino acid sequences that may or may not follow a pattern, or any combination of the foregoing.

In some embodiments, the binding proteins encompassed by the present invention may be modified. In some embodiments, the modifications having substantial or significant sequence identity to a parent binding protein to generate a functional variant that maintains

one or more biophysical and/or biological activities of the parent binding protein (*e.g.*, maintain pMHC binding specificity). In some embodiments, the mutation is a conservative amino acid substitution.

In some embodiments, binding proteins encompassed by the present invention may comprise synthetic amino acids in place of one or more naturally-occurring amino acids. Such synthetic amino acids are well-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, β -diaminopropionic acid, homophenylalanine, and α -tert-butylglycine.

Binding proteins encompassed by the present invention may be glycosylated, amidated, carboxylated, phosphorylated, esterified, N-acylated, cyclized (*e.g.*, via a disulfide bridge), or converted into an acid addition salt and/or optionally dimerized or polymerized, or conjugated.

In some embodiments, the attachment of a hydrophobic moiety, such as to the N-terminus, the C-terminus, or an internal amino acid, may be used to extend half-life of a peptide encompassed by the present invention. In other embodiments, a binding protein may include post-translational modifications (*e.g.*, methylation and/or amidation), which can affect, for example, serum half-life. In some embodiments, simple carbon chains (*e.g.*, by myristoylation and/or palmitoylation) may be conjugated to the binding proteins. In some embodiments, the simple carbon chains may render the binding proteins easily separable from the unconjugated material. For example, methods that may be used to separate the binding proteins from the unconjugated material include, but are not limited to, solvent extraction and reverse phase chromatography. The lipophilic moieties can extend half-life through reversible binding to serum albumin. The conjugated moieties may be lipophilic moieties that extend half-life of the peptides through reversible binding to serum albumin. In some embodiments, the lipophilic moiety may be cholesterol or a cholesterol derivative,

including cholestenes, cholestanes, cholestadienes and oxysterols. In some embodiments, the binding proteins may be conjugated to myristic acid (tetradecanoic acid) or a derivative thereof. In other embodiments, a binding protein may be coupled (*e.g.*, conjugated) to a half-life modifying agent. Examples of half-life modifying agents include but are not limited to: a polymer, a polyethylene glycol (PEG), a hydroxyethyl starch, polyvinyl alcohol, a water soluble polymer, a zwitterionic water soluble polymer, a water soluble poly(amino acid), a water soluble polymer of proline, alanine and serine, a water soluble polymer containing glycine, glutamic acid, and serine, an Fc region, a fatty acid, palmitic acid, or a molecule that binds to albumin. In some embodiments, a spacer or linker may be coupled to a binding protein, such as 1, 2, 3, 4, or more amino acid residues that serve as a spacer or linker in order to facilitate conjugation or fusion to another molecule, as well as to facilitate cleavage of the peptide from such conjugated or fused molecules. In some embodiments, binding proteins may be conjugated to other moieties that, for example, can modify or effect changes to the properties of the binding proteins.

A binding protein may be produced recombinantly or synthetically, such as by solid-phase peptide synthesis or solution-phase peptide synthesis. Polypeptide synthesis may be performed by known synthetic methods, such as using fluorenylmethyloxycarbonyl (Fmoc) chemistry or by butyloxycarbonyl (Boc) chemistry. Polypeptide fragments may be joined together enzymatically or synthetically.

In an aspect encompassed by the present invention, provided herein are methods of producing a binding protein described herein, comprising the steps of: (i) culturing a transformed host cell which has been transformed by a nucleic acid comprising a sequence encoding a binding protein described herein under conditions suitable to allow expression of said binding protein; and (ii) recovering the expressed binding protein.

Methods useful for isolating and purifying recombinantly produced binding protein, by way of example, may include obtaining supernatants from suitable host cell/vector systems that secrete the binding protein into culture media and then concentrating the media using a commercially available filter. Following concentration, the concentrate may be applied to a single suitable purification matrix or to a series of suitable matrices, such as an affinity matrix or an ion exchange resin. One or more reverse phase HPLC steps may be employed to further purify a recombinant polypeptide. These purification methods may also be employed when isolating an immunogen from its natural environment. Methods for large scale production of one or more of binding proteins described herein include batch

cell culture, which is monitored and controlled to maintain appropriate culture conditions. Purification of the binding protein may be performed according to methods described herein and known in the art.

In any of the herein disclosed embodiments, the encoded binding protein is capable of bind to a peptide–MHC (pMHC) complex comprising an HPV16 E7₁₁₋₁₉ immunogenic peptide in the context of an MHC molecule (*e.g.*, a MHC class I molecule). In some embodiments, the MHC molecule comprises an MHC alpha chain that is an HLA serotype HLA-A*02. In some embodiments, the HLA allele is selected from the group consisting of HLA-A*0201, HLA-A*0202, HLA-A*0203, HLA-A*0205, HLA-A*0206, and HLA-A*0207 allele.

A variety of assays are well-known for assessing binding affinity and/or determining whether a binding molecule binds (*e.g.*, specifically and/or selectively) to a particular ligand (*e.g.*, peptide antigen-MHC complex). It is within the level of a skilled artisan to determine the binding affinity of a binding protein for a target, such as a T cell peptide epitope of a target polypeptide, such as by using any of a number of binding assays that are well-known in the art. For example, in some embodiments, a Biacore™ machine may be used to determine the binding constant of a complex between two proteins. The dissociation constant (K_D) for the complex may be determined by monitoring changes in the refractive index with respect to time as buffer is passed over the chip. Other suitable assays for measuring the binding of one protein to another include, for example, immunoassays such as enzyme linked immunosorbent assays (ELISA) and radioimmunoassays (RIA), or determination of binding by monitoring the change in the spectroscopic or optical properties of the proteins through fluorescence, UV absorption, circular dichroism, or nuclear magnetic resonance (NMR). Other exemplary assays include, but are not limited to, Western blot, ELISA, analytical ultracentrifugation, spectroscopy and surface plasmon resonance (Biacore™) analysis (see, *e.g.*, Scatchard *et al.* (1949) *Ann. N.Y. Acad. Sci.* 51:660, Wilson (2002) *Science* 295:2103, Wolff *et al.* (1993) *Cancer Res.* 53:2560, and U.S. Pat. Nos. 5,283,173 and 5,468,614), flow cytometry, sequencing and other methods for detection of expressed nucleic acids. In one example, apparent affinity for a target is measured by assessing binding to various concentrations of tetramers, for example, by flow cytometry using labeled multimers, such as MHC-antigen tetramers. In one representative example, apparent K_D of a binding protein is measured using 2-fold dilutions of labeled tetramers at a range of concentrations, followed by determination of binding curves by non-

linear regression, apparent K_D being determined as the concentration of ligand that yielded half-maximal binding.

III. Nucleic Acids and Vectors

In an aspect encompassed by the present invention, provided herein are nucleic acid molecules that encode binding proteins (*e.g.*, TCRs, antigen-binding fragments of the TCRs, CARs, and the like), peptides, and fragments thereof described herein.

In some embodiments, the nucleic acid molecule hybridizes, under stringent conditions, with the complement of a sequence with at least about at least about 80%, 81%, 82%, 83%, 84%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or more identity, such as over the full length, to a nucleic acid encoding a polypeptide selected from the group consisting of the polypeptide sequences listed in Table 1.

In some embodiments, the nucleic acid molecule hybridizes, under stringent conditions, with the complement of a nucleic acid encoding a polypeptide selected from the group consisting of polypeptide sequences listed in Table 1.

In some embodiments, the nucleic acid molecule comprises (*e.g.*, comprises, consists essentially of, or consists of) a nucleotide sequence encoding a polypeptide selected from the group consisting of polypeptide sequences listed in Table 1.

In some embodiments, the nucleic acids comprise (*e.g.*, comprise, consist essentially of, or consist of) a nucleotide sequence encoding at least one (*e.g.*, one, two, or three) TCR α -chain CDR set forth in Table 1. In some embodiments, the nucleic acids comprise (*e.g.*, comprise, consist essentially of, or consist of) a nucleotide sequence encoding a TCR V_α domain having an amino acid sequence that is at least about at least about 80%, 81%, 82%, 83%, 84%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or more identity to a TCR V_α domain sequence set forth in Table 1. In some embodiments, the nucleic acids comprise (*e.g.*, comprise, consist essentially of, or consist of) a nucleotide sequence encoding a TCR α -chain having an amino acid sequence that is at least about at least about 80%, 81%, 82%, 83%, 84%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or more identity to a TCR α -chain sequence set forth in Table 1.

In some embodiments, the nucleic acids comprise (*e.g.*, comprise, consist essentially of, or consist of) a nucleotide sequence encoding at least one (*e.g.*, one, two, or three) TCR

β -chain CDR set forth in Table 1. In some embodiments, the nucleic acids comprise (*e.g.*, comprise, consist essentially of, or consist of) a nucleotide sequence encoding a TCR V β domain having an amino acid sequence that is at least about 80%, 81%, 82%, 83%, 84%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or more identity to a TCR V β domain sequence set forth in Table 1. In some embodiments, the nucleic acids comprise (*e.g.*, comprise, consist essentially of, or consist of) a nucleotide sequence encoding a TCR β -chain having an amino acid sequence that is at least about 80%, 81%, 82%, 83%, 84%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or more identity to a TCR β -chain sequence set forth in Table 1.

The term “nucleic acid” includes “polynucleotide,” “oligonucleotide,” and “nucleic acid molecule,” and generally means a polymer of DNA or RNA, which may be single-stranded or double-stranded, synthesized or obtained (*e.g.*, isolated and/or purified) from natural sources, which may contain natural, non-natural or altered nucleotides, and which may 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. In an embodiment, the nucleic acid comprises complementary DNA (cDNA).

In some embodiments, the nucleic acids encompassed by the present 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 may replicate in a living cell, or (ii) molecules that result from the replication of those described in (i) above. For purposes herein, the replication may be *in vitro/ex vivo* replication or *in vivo* replication.

The nucleic acids can be constructed based on chemical synthesis and/or enzymatic ligation reactions using procedures known in the art. See, for example, Green and Sambrook *et al.* *supra*. For example, a nucleic acid may 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 may be used to generate the nucleic acids include, but are not limited to, 5-fluorouracil, 5-bromouracil, 5-chlorouracil, 5-iodouracil, hypoxanthine, xanthine, 4-acetylcytosine, 5-(carboxyhydroxymethyl) uracil, 5-

carboxymethylaminomethyl-2-thiouridine, 5-carboxymethylaminomethyluracil, dihydrouracil, beta-D-galactosylqueosine, inosine, N⁶-isopentenyladenine, 1-methylguanine, 1-methylinosine, 2,2-dimethylguanine, 2-methyladenine, 2-methylguanine, 3-methylcytosine, 5-methylcytosine, N⁶-substituted adenine, 7-methylguanine, 5-methylaminomethyluracil, 5-methoxyaminomethyl-2-thiouracil, beta-D-mannosylqueosine, 5'-methoxycarboxymethyluracil, 5-methoxyuracil, 2-methylthio-N⁶-isopentenyladenine, uracil-5-oxyacetic acid (v), wybutoxosine, pseudouracil, queosine, 2-thiocytosine, 5-methyl-2-thiouracil, 2-thiouracil, 4-thiouracil, 5-methyluracil, uracil-5-oxyacetic acid methylester, 3-(3-amino-3-N-2-carboxypropyl) uracil, and 2,6-diaminopurine. Alternatively, one or more of the nucleic acids encompassed by the present invention can be purchased from companies, such as Integrated DNA Technologies (Coralville, IA).

In one embodiment, the nucleic acid comprises a codon-optimized nucleotide sequence. Without being bound to a particular theory or mechanism, it is believed that codon optimization of the nucleotide sequence increases the translation efficiency of the mRNA transcripts. Codon optimization of the nucleotide sequence may involve substituting a native codon for another codon that encodes the same amino acid, but can be translated by tRNA that is more readily available within a cell, thus increasing translation efficiency. Optimization of the nucleotide sequence may also reduce secondary mRNA structures that would interfere with translation, thus increasing translation efficiency. In some embodiments, the nucleotide sequences described herein are codon-optimized for expression in a host cell (*e.g.*, an immune cell, such as a T cell).

The present invention also provides a nucleic acid comprising a nucleotide sequence which is complementary to the nucleotide sequence of any of the nucleic acids described herein or a nucleotide sequence which hybridizes under stringent conditions to the nucleotide sequence of any of the nucleic acids described herein.

The nucleotide sequence which hybridizes under stringent conditions may hybridize under high stringency conditions. By "high stringency conditions" is meant that the nucleotide sequence specifically hybridizes to a target sequence (the nucleotide sequence of any of the nucleic acids described herein) in an amount that is detectably stronger than non-specific hybridization. High stringency conditions include conditions which would distinguish a polynucleotide with an exact complementary sequence, or one containing only a few scattered mismatches from a random sequence that happened to have a few small regions (*e.g.*, 3-10 bases) that matched the nucleotide sequence. Such small regions of

complementarity are more easily melted than a full-length complement of 14-17 or more bases, and high stringency hybridization makes them easily distinguishable. Relatively high stringency conditions would include, for example, low salt and/or high temperature conditions, such as provided by about 0.02-0.1 M NaCl or the equivalent, at temperatures of about 50-70 °C. Such high stringency conditions tolerate little, if any, mismatch between the nucleotide sequence and the template or target strand, and are particularly suitable for detecting expression of any of the inventive TCRs. It is generally appreciated that conditions may be rendered more stringent by the addition of increasing amounts of formamide.

The present invention also provides a nucleic acid comprising a nucleotide sequence that is at least about 80%, 81%, 82%, 83%, 84%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or more identical to any of the nucleic acids described herein.

Typically, said nucleic acid is a DNA or RNA molecule, which may be included in a suitable vector, such as a plasmid, cosmid, episome, artificial chromosome, phage or a viral vector.

The terms “vector”, “cloning vector” and “expression vector” mean the vehicle by which a DNA or RNA sequence (*e.g.*, a foreign gene) can be introduced into a host cell, so as to transform the host and promote expression (*e.g.*, transcription and translation) of the introduced sequence. Thus, a further object encompassed by the present invention relates to a vector comprising a nucleic acid encompassed by the present invention.

Such vectors may comprise regulatory elements, such as a promoter, enhancer, terminator and the like, to cause or direct expression of said polypeptide upon administration to a subject. Examples of promoters and enhancers used in the expression vector for animal cell include early promoter and enhancer of SV40 (Mizukami T. *et al.* 1987), LTR promoter and enhancer of Moloney mouse leukemia virus (Kuwana Y *et al.* 1987), promoter (Mason J O *et al.* 1985) and enhancer (Gillies S D *et al.* 1983) of immunoglobulin H chain and the like.

Any expression vector for animal cell may be used. Examples of suitable vectors include pAGE107 (Miyaji H *et al.* 1990), pAGE103 (Mizukami T *et al.* 1987), pHSG274 (Brady G *et al.* 1984), pKCR (O'Hare K *et al.* 1981), pSG1 beta d2-4-(Miyaji H *et al.* 1990) and the like. Other representative examples of plasmids include replicating plasmids comprising an origin of replication, or integrative plasmids, such as for instance pUC,

pcDNA, pBR, and the like. Representative examples of viral vector include adenoviral, retroviral, lentiviral, herpes virus and AAV vectors. Such recombinant viruses may be produced by techniques known in the art, such as by transfecting packaging cells or by transient transfection with helper plasmids or viruses. Typical examples of virus packaging cells include PA317 cells, PsiCRIP cells, GPenv-positive cells, 293 cells, *etc.* Detailed protocols for producing such replication-defective recombinant viruses are well-known in the art and may be found, for instance, in PCT Publ. WO 95/14785, PCT. Publ. WO 96/22378, U.S. Pat. No. 5,882,877, U.S. Pat. No. 6,013,516, U.S. Pat. No. 4,861,719, U.S. Pat. No. 5,278,056, and PCT Publ. WO 94/19478.

In some embodiments, the expression vector is a nanoplasmid. The term “nanoplasmid” used herein refers to a circular DNA sequence having a reduced bacterial sequence that provides a smaller plasmid with a desired cargo insert. The reduced size of the vector is associated with limited DNA-induced toxicity upon transfection and potentially longer duration in cells, potentially longer duration in cells, potentially better viability after transfection, and potentially higher transposition efficiency. In some embodiments, the nanoplasmid is an antibiotic resistance marker-free nanoplasmid. In some embodiments, the nanoplasmid comprises a selection marker and/or nonsense suppressor marker. Due to the small backbone size, *e.g.*, <500 bp backbone, such nanoplasמידs maximize the size of the desired cargo insert. The desired cargo insert (*e.g.*, a eukaryotic transgene) can be any size that can be delivered into target cells, *e.g.*, up to 50 kb, 45 kb, 40 kb, 35 kb, 30 kb, 25 kb, 20 kb, 18 kb, 15 kb, 12 kb, 10 kb, 5.0 kb, 4.5 kb, 4.0 kb, 3.5 kb, 3.0 kb, 2.8 kb, 2.5 kb, 2.2 kb, 2 kb, 1.8 kb, 1.5 kb, 1.2 kb, 1 kb, or any range in between, inclusive, such as 8-12 kb. They also provide high transgene expression and reduce transgene silencing with a tunable integration efficiency of the cargo associated with random integration of the cargo in the genome of engineered cells.

In some embodiments, the nanoplasmid may comprise elements shown in vectors provided in Table 3 (*e.g.*, R6K and RNA-OUT). For example, in some embodiments, a nanoplasmid comprises a minimized bacterial ColE1 or R6K origin of replication (which provides for such nanoplasמידs to be replicable in a bacterial host strain), a selectable marker (*e.g.*, a bacterial RNA-selectable marker), and a eukaryotic gene region. An RNA selectable marker is a vector-borne expressed non-translated RNA that regulates a chromosomally expressed target gene to afford selection of the vector. This may be a plasmid borne nonsense suppressing tRNA that regulates a nonsense suppressible selectable

chromosomal target, such as described in U.S. Pat. No. 6,977,174 and incorporated herein by reference. This may also be a plasmid-borne antisense repressor RNA, an RNA-OUT gene that represses RNA-IN regulated targets, pMB1 plasmid origin encoded RNAI that represses RNAII regulated targets, IncB plasmid pMU720 origin encoded RNAI that represses RNA II regulated targets, ParB locus Sok of plasmid RI that represses Hok regulated targets, Flm locus FlmB of F plasmid that represses flmA regulated targets, an natural antisense repressor RNA such as those described in *e.g.*, Wagner *et al.* (2002) *Adv. Genet.* 46:361 and Franch and Gerdes (2000) *Current Opin. Microbiol.* 3:159, or an engineered repressor RNA, such as a small synthetic small RNA like the SgrS, MicC, or MicF scaffolds as described in Park *et al.* (2013) *Nature Biotechnology* 31:170-174.

Exemplary nanoplasmids produced by an antibiotic free RNA-OUT selection system and methods of making such nanoplasmids are described in *e.g.*, PCT Publ. No. WO 2008153733, U.S. Pat. No. 9,737,620, U.S. Pat. Publ. No. 2010/0303859, and U.S. Pat. No. 9,109,012, which are hereby incorporated by reference in their entirety. Additional exemplary nanoplasmids are described in *e.g.*, PCT Appl. Nos. PCT/US2013/000259, PCT/US2013/00067 and PCT/US2013/00068, and U.S. Pat. Publ. No. 2015/0275221, each of which is hereby incorporated by reference in their entirety.

Nanoplasmids are commercially available. For example, Nature Technology Corporation, a subsidiary of Aldevron, provides nanoplasmid vectors combining an RNA selectable marker with a R6K, ColE2, or ColE2-related replication origin. These nanoplasmid vectors include, *e.g.*, NTC9385C, NTC9685C, NTC9385R, NTC9685R vectors, as well as modifications thereof, such as those disclosed in PCT Appl. No. PCT/US 13/00068; NTC9385R-BE, NTC9385Ra-O1 and NTC9385Ra-O2 vectors, such as described in U.S. Pat. No. 10,144,935; and NTC9385C2, NTC9385C2a, NTC9385R2, NTC9385R2a, NTC9385R2b, NTC9385Ra, NTC9385RaF and NTC9385RbF replicative minicircle vectors such as described in U.S. Pat. Publ. No. 2021/0189407, each of which is hereby incorporated by reference in their entirety.

In some embodiments, the composition comprises an expression vector comprising an open reading frame encoding a binding protein or a polypeptide described herein or a fragment thereof. In some embodiments, the nucleic acid includes regulatory elements necessary for expression of the open reading frame. Such elements may include, for example, a promoter, an initiation codon, a stop codon, and a polyadenylation signal. In

addition, enhancers may be included. These elements may be operably linked to a sequence that encodes the binding protein, polypeptide or fragment thereof.

In some embodiments, the vector further comprises a nucleic acid sequence encoding CD8 α , CD8 β , a dominant negative TGF β receptor (*e.g.*, a DN-TGF β R), selectable protein marker, optionally wherein the selectable protein marker is dihydrofolate reductase (DHFR). In certain embodiments, the nucleic acid sequence encoding CD8 α , CD8 β , the DN-TGF β R, and/or the selectable protein marker is operably linked to a nucleic acid encoding a tag (*e.g.*, a CD34 enrichment tag). In specific embodiments, a nucleic acid sequence described herein, such as a nucleic acid sequence encoding a TCR α , TCR β , CD8 α , CD8 β , the DN-TGF β R, and/or the selectable protein marker are interconnected with an internal ribosome entry site or a nucleic acid sequence encoding a self-cleaving peptide, such as P2A, E2A, F2A or T2A, etc.

In some embodiments, the expression vector provided herein comprises a nucleotide sequence that is at least about 80%, 81%, 82%, 83%, 84%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or more identical to any of the nucleic acids set forth in SEQ ID NO. 27.

Examples of promoters include, but are not limited to, promoters from Simian Virus 40 (SV40), Mouse Mammary Tumor Virus (MMTV) promoter, Human Immunodeficiency Virus (HIV) such as the HIV Long Terminal Repeat (LTR) promoter, Moloney virus, Cytomegalovirus (CMV) such as the CMV immediate early promoter, Epstein Barr Virus (EBV), Rous Sarcoma Virus (RSV) as well as promoters from human genes such as human actin, human myosin, human hemoglobin, human muscle creatine, and human metallothionein. Examples of suitable polyadenylation signals include but are not limited to SV40 polyadenylation signals and LTR polyadenylation signals.

In addition to the regulatory elements required for expression, other elements may also be included in the nucleic acid molecule. Such additional elements include enhancers. Enhancers include the promoters described herein. In some embodiments, enhancers/promoters include, for example, human actin, human myosin, human hemoglobin, human muscle creatine and viral enhancers such as those from CMV, RSV and EBV.

In some embodiments, the nucleic acid may be operably incorporated in a carrier or delivery vector as described further below. Useful delivery vectors include but are not

limited to biodegradable microcapsules, immuno-stimulating complexes (ISCOMs) or liposomes, and genetically engineered attenuated live carriers such as viruses or bacteria.

In some embodiments, the vector is a viral vector, such as lentiviruses, retroviruses, herpes viruses, adenoviruses, adeno-associated viruses, vaccinia viruses, baculoviruses, Fowl pox, AV-pox, modified vaccinia Ankara (MVA) and other recombinant viruses. For example, a lentivirus vector may be used to infect T cells.

In some embodiments, the recombinant expression vector is capable of delivering a polynucleotide to an appropriate host cell, for example, a T cell or an antigen-presenting cell, *i.e.*, a cell that displays a peptide/MHC complex on its cell surface (*e.g.*, a dendritic cell) and lacks CD8. In some embodiments, the host cell is an immune cells, such as a human immune system cell. For example, the immune system cell may be a CD4⁺ T cell, a CD8⁺ T cell, a CD4/CD8 double negative T cell, a gd T cell, a natural killer cell, a dendritic cell, or any combination thereof. In some embodiments, wherein a T cell is the host, the T cell may be naive, a central memory T cell, an effector memory T cell, or any combination thereof. The recombinant expression vectors may therefore also include, for example, lymphoid tissue-specific transcriptional regulatory elements (TREs), such as a B lymphocyte, T lymphocyte, or dendritic cell specific TREs. Lymphoid tissue specific TREs are known in the art (see, *e.g.*, Thompson *et al.* (1992) *Mol. Cell. Biol.* 72:1043, Todd *et al.* (1993) *J. Exp. Med.* 777:1663, and Penix *et al.* (1993) *J. Exp. Med.* 775:1483).

In some embodiments, a recombinant expression vector comprises a nucleotide sequence encoding a TCR α chain, a TCR β chain, and/or a linker peptide. For example, in some embodiments, the recombinant expression vector comprises a nucleotide sequence encoding the full-length TCR alpha and TCR beta chains of the binding protein with a linker positioned between them, wherein the nucleotide sequence encoding the beta chain is positioned 5' of the nucleotide sequence encoding the alpha chain. In some embodiments, the nucleotide sequence encodes the full-length TCR alpha and TCR beta chains with a linker positioned between them, wherein the nucleotide sequence encoding the TCR beta chain is positioned 3' of the nucleotide sequence encoding the TCR alpha chain. In some embodiments, the full-length TCR alpha and/or TCR beta chains are replaced with fragments thereof.

As described further below, another aspect encompassed by the present invention relates to a cell which has been transfected, infected or transformed by a nucleic acid and/or a vector in accordance with the present invention. A host cell may include any individual

cell or cell culture which may receive a vector or the incorporation of nucleic acids and/or proteins, as well as any progeny cells. The term also encompasses progeny of the host cell, whether genetically or phenotypically the same or different. Suitable host cells may depend on the vector and may include mammalian cells, animal cells, human cells, simian cells, insect cells, yeast cells, and bacterial cells. These cells may be induced to incorporate the vector or other material by use of a viral vector, transformation via calcium phosphate precipitation, DEAE-dextran, electroporation, microinjection, or other methods (see, *e.g.*, Sambrook *et al.* (1989) *Molecular Cloning: A Laboratory Manual 2d ed.* (Cold Spring Harbor Laboratory)). The term “transformation” means the introduction of a “foreign” (*i.e.*, extrinsic or extracellular) gene, DNA or RNA sequence to a host cell, so that the host cell will express the introduced gene or sequence to produce a desired substance, typically a protein or enzyme coded by the introduced gene or sequence. A host cell that receives and expresses introduced DNA or RNA has been “transformed.”

For example, in some embodiments, engineered immune cells (*e.g.*, T cells) may comprise pan T cells (both CD4⁺ and CD8⁺ T cells) engineered by transposon/transposase-mediated gene delivery to express a genetic cargo coding for elements such as the alpha and beta chains of a recombinant T cell receptor (TCR) specific to a given target antigen presented on a particular MHC (*e.g.*, class I HLA). Additional elements can be expressed by the vector, such as one or more elements selected from the group consisting of a) CD8 α and CD8 β co-receptors to enable engagement of CD4⁺ T cells; b) a CD34-derived QBEND/10 epitope tag fused to the amino-terminus of CD8 α to enable tracking of engineered cells *in vitro* and *in vivo*; c) a dominant-negative type II TGF β receptor (DN-TGF β RII) to overcome tumor-mediated immune suppression; and d) a selection marker, such as a mutated form of dihydrofolate reductase (DHFR_{dm}) to facilitate enrichment of engineered cells during the manufacturing process. The α and β chains of the exogenous TCR and the α and β chains of CD8 may be encoded by a single mRNA molecule under control of a single promoter, such as a murine stem cell virus (MSCV) promoter. Post-translational processing at self-cleaving peptide elements, such as P2A sites, can result in independent polypeptides, such as to produce the individual four polypeptides corresponding to each element in the vector. Similarly, DN-TGF β RII and DHFR_{dm} may be encoded by a single mRNA molecule driven by a single promoter, such as the human elongation factor 1 α (EF1 α) promoter. Post-translational processing at self-cleaving

peptide elements, such as P2A sites, can result in independent polypeptides corresponding to each individual element in the vector.

The nucleic acids encompassed by the present invention may be used to produce a recombinant polypeptide encompassed by the present invention in a suitable expression system. The term “expression system” means a host cell and compatible vector under suitable conditions, *e.g.*, for the expression of a protein coded for by foreign DNA carried by the vector and introduced to the host cell.

Common expression systems include *E. coli* host cells and plasmid vectors, insect host cells and *Baculovirus* vectors, and mammalian host cells and vectors. Other examples of host cells include, without limitation, prokaryotic cells (such as bacteria) and eukaryotic cells (such as yeast cells, mammalian cells, insect cells, plant cells, *etc.*). Specific examples include *E. coli*, *Kluyveromyces* or *Saccharomyces* yeasts, mammalian cell lines (*e.g.*, Vero cells, CHO cells, 3T3 cells, COS cells, *etc.*) as well as primary or established mammalian cell cultures (*e.g.*, produced from lymphoblasts, fibroblasts, embryonic cells, epithelial cells, nervous cells, adipocytes, *etc.*). Examples also include mouse SP2/0-Ag14 cell (ATCC CRL1581), mouse P3X63-Ag8.653 cell (ATCC CRL1580), CHO cell in which a dihydrofolate reductase gene (hereinafter referred to as “DHFR gene”) is defective (Urlaub *et al* (1980), rat YB2/3HL.P2.G11.16Ag.20 cell (ATCC CRL 1662, hereinafter referred to as “YB2/0 cell”), and the like. In some embodiments, the YB2/0 cell is used since ADCC activity of chimeric or humanized binding proteins is enhanced when expressed in this cell.

The present invention also encompasses methods of producing a recombinant host cell expressing binding proteins, peptides and fragments thereof encompassed by the present invention, said method comprising the steps consisting of (i) introducing *in vitro* or *ex vivo* a recombinant nucleic acid or a vector as described above into a competent host cell, (ii) culturing *in vitro* or *ex vivo* the recombinant host cell obtained and (iii), optionally, selecting the cells which express said binding proteins, peptides and fragments thereof. Such recombinant host cells may be used for the diagnostic, prognostic, and/or therapeutic method encompassed by the present invention.

In another aspect, the present invention provides isolated nucleic acids that hybridize under selective hybridization conditions to a polynucleotide disclosed herein. Thus, the polynucleotides of this embodiment may be used for isolating, detecting, and/or quantifying nucleic acids comprising such polynucleotides. For example, polynucleotides

encompassed by the present invention may be used to identify, isolate, or amplify partial or full-length clones in a deposited library. In some embodiments, the polynucleotides are genomic or cDNA sequences isolated, or otherwise complementary to, a cDNA from a human or mammalian nucleic acid library. In some embodiments, the cDNA library comprises at least about 75%, 76%, 77%, 78%, 79%, 80%, 81%, 82%, 83%, 84%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or more, or any range in between, inclusive, such as at least about 80%-100%, full-length sequences. The cDNA libraries may be normalized to increase the representation of rare sequences. Low or moderate stringency hybridization conditions are typically, but not exclusively, employed with sequences having a reduced sequence identity relative to complementary sequences. Moderate and high stringency conditions may optionally be employed for sequences of greater identity. Low stringency conditions allow selective hybridization of sequences having about 70% sequence identity and may be employed to identify orthologous or paralogous sequences. Optionally, polynucleotides encompassed by the present invention will encode at least a portion of a binding protein encoded by the polynucleotides described herein. The polynucleotides encompassed by the present invention embrace nucleic acid sequences that may be employed for selective hybridization to a polynucleotide encoding a binding protein encompassed by the present invention (see, *e.g.*, Ausubel, *supra* and Colligan, *supra*).

IV. Host Cells

In an aspect encompassed by the present invention, provided herein are host cells that express the binding proteins (*e.g.*, TCRs, antigen-binding fragments of TCRs, CARs, or fusion proteins comprising a TCR and an effector domain) described herein. In some embodiments, the host cells comprise the nucleic acids or vectors described herein.

In some embodiments, a polynucleotide encoding a binding protein is used to transform, transfect, or transduce a host cell (*e.g.*, a T cell) for use in adoptive transfer therapy. Advances in nucleic acid sequencing and particular TCR sequencing have been described (*e.g.*, Robins *et al.* (2009) *Blood* 114:4099; Robins *et al.* (2010) *Sci. Translat. Med.* 2:47ra64, Robins *et al.* (2011) *J. Imm. Meth.*, and Warren *et al.* (2011) *Genome Res.* 21:790) and may be employed in the course of practicing embodiments encompassed by the present invention. Similarly, methods for transfecting or transducing T cells with desired nucleic acids are well-known in the art (*e.g.*, U.S. Pat. Publ. No. US 2004/0087025) as have

adoptive transfer procedures using T cells of desired antigen-specificity (*e.g.*, Schmitt *et al.* (2009) *Hum. Gen.* 20:1240, Dossett *et al.* (2009) *Mol. Ther.* 77:742, Till *et al.* (2008) *Blood* 772:2261, Wang *et al.* (2007) *Hum. Gene Ther.* 18:112, Kuball *et al.* (2007) *Blood* 709:2331, U.S. Pat. Publ. 2011/0243972, U.S. Pat. Publ. 2011/0189141, and Leen *et al.* (2007) *Ann. Rev. Immunol.* 25:243).

Any suitable immune cell may be modified to include a heterologous polynucleotide encompassed by the present invention, including, for example, a T cell, a NK cell, or a NK-T cell. In some embodiments, the cell may be a primary cell or a cell of a cell line. In some embodiments, a modified immune cell comprises a CD4⁺T cell, a CD8⁺ T cell, or both. For purposes herein, the T cell may 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 may be obtained from numerous sources, including but not limited to blood, bone marrow, lymph node, the thymus, or other tissues or fluids. T cells may also be enriched for or purified. In some embodiments, the T cell is a human T cell. In some embodiments, the T cell is a T cell isolated from a human. The T cell may be any type of T cell and may be of any developmental stage, including but not limited to, cytotoxic lymphocyte, cytotoxic lymphocyte precursor cell, cytotoxic lymphocyte progenitor cell, cytotoxic lymphocyte stem cell, CD4⁺/CD8⁺ double positive T cells, CD4⁺ helper T cells, *e.g.*, Th1 and Th2 cells, CD4⁺ T cells, CD8⁺ T cells (*e.g.*, cytotoxic T cells), tumor infiltrating lymphocytes (TILs), memory T cells (*e.g.*, central memory T cells and effector memory T cells), naive T cells, and the like.

Any appropriate method may be used to transfect or transduce the cells, for example, T cells, or to administer the nucleotide sequences or compositions encompassed by methods described herein. Methods for delivering polynucleotides to host cells include, for example, use of cationic polymers, lipid-like molecules, and certain commercial products such as, for example, in vivo-jetPEI®. Other methods include *ex vivo* transduction, injection, electroporation, DEAE-dextran, sonication loading, liposome-mediated transfection, receptor-mediated transduction, microprojectile bombardment, transposon-mediated transfer, and the like. Still further methods of transfecting or transducing host cells employ vectors, described in further detail herein.

Modified immune cells as described herein may be functionally characterized using methodologies for assaying T cell activity, including determination of T cell binding,

activation or induction and also including determination of T cell responses that are antigen-specific. Examples include determination of T cell proliferation, T cell cytokine release, antigen-specific T cell stimulation, MHC restricted T cell stimulation, CTL activity (*e.g.*, by detecting ^{51}Cr release from pre-loaded target cells), changes in T cell phenotypic marker expression, and other measures of T-cell functions.

Procedures for performing these and similar assays may be found, for example, in Lefkowitz (Immunology Methods Manual: The Comprehensive Sourcebook of Techniques, 1998), as well as Current Protocols in Immunology, Weir, (1986) Handbook of Experimental Immunology, Blackwell Scientific, Boston, MA; Mishell and Shigii (eds.) (1979) Selected Methods in Cellular Immunology, Freeman Publishing, San Francisco, CA; Green and Reed (1998) *Science* 281:1309, and references cited therein.

In some embodiments, apparent affinity for a binding protein, such as a TCR or antigen-binding portion thereof, may be measured by assessing binding to various concentrations of MHC multimers. "MHC-peptide multimer staining" refers to an assay used to detect antigen-specific T cells, which, in some embodiments, features a tetramer of MHC molecules, each comprising an identical peptide having an amino acid sequence that is cognate (*e.g.*, identical or related to) at least one antigen (*e.g.*, an HPV16 E7₁₁₋₁₉ immunogenic peptide), wherein the complex is capable of binding to a binding protein, such as a TCR or antigen-binding portion thereof, that recognizes the cognate antigen. Each of the MHC molecules may be tagged with a biotin molecule. Biotinylated MHC/peptides may be multimerized (*e.g.*, tetramerized) by the addition of streptavidin, which may be fluorescently labeled.

The multimer may be detected by flow cytometry via the fluorescent label. In some embodiments, a pMHC multimer assay is used to detect or select enhanced affinity binding protein, such as a TCR or antigen-binding portion thereof, encompassed by the present invention. In some examples, apparent K_D of a binding protein, such as a TCR or antigen-binding portion thereof, is measured using 2-fold dilutions of labeled multimers at a range of concentrations, followed by determination of binding curves by non-linear regression, apparent K_D being determined as the concentration of ligand that yielded half-maximal binding.

Levels of cytokines may be determined using methods described herein, such as ELISA, ELISPOT, intracellular cytokine staining, and flow cytometry and combinations thereof (*e.g.*, intracellular cytokine staining and flow cytometry).

Immune cell proliferation and clonal expansion resulting from an antigen-specific elicitation or stimulation of an immune response may be determined by isolating lymphocytes, such as circulating lymphocytes in samples of peripheral blood cells or cells from lymph nodes, stimulating the cells with antigen, and measuring cytokine production, cell proliferation and/or cell viability, such as by incorporation of tritiated thymidine or non-radioactive assays, such as MTT assays and the like. The effect of an immunogen described herein on the balance between a Th1 immune response and a Th2 immune response may be examined, for example, by determining levels of Th1 cytokines, such as IFN- γ , IL-12, IL-2, and TNF- β , and Type 2 cytokines, such as IL-4, IL-5, IL-9, IL-10, and IL-13.

A host cell encompassed by the present invention may comprise a single polynucleotide that encodes a binding protein as described herein, or the binding protein may be encoded by more than one polynucleotide. In other words, components or portions of a binding protein may be encoded by two or more polynucleotides, which may be contained on a single nucleic acid molecule or may be contained on two or more nucleic acid molecules.

Moreover, as described further below and in the working examples, a host cell encompassed by the present invention may encode and/or express useful accessory proteins in addition to a binding protein as described herein, either on the same polynucleotide or a different polynucleotide as the binding protein or components thereof. For example, the host cell may encode and/or express CD8 α , CD8 β , a DN-TGF β R (*e.g.*, a DN-TGF β RII), and/or a selectable protein marker, optionally wherein the selectable protein marker is DHFR.

In some embodiments, a polynucleotide encoding two or more components or portions of a binding protein encompassed by the present invention comprises the two or more coding sequences operatively associated in a single open reading frame. Such an arrangement can advantageously allow coordinated expression of desired gene products, such as, for example, contemporaneous expression of alpha- and beta-chains of a TCR, such that they are produced in about a 1:1 ratio. In some embodiments, two or more substituent gene products of a binding protein encompassed by the present invention, such as a TCR (*e.g.*, alpha- and beta-chains) or CAR, are expressed as separate molecules and associate post-translationally. In further embodiments, two or more substituent gene products of a binding protein encompassed by the present invention are expressed as a

single peptide with the parts separated by a cleavable or removable segment. For instance, self-cleaving peptides useful for expression of separable polypeptides encoded by a single polynucleotide or vector are known in the art and include, for example, a porcine teschovirus-1 2A (P2A) peptide, a thosaaasigna virus 2A (T2A) peptide, an equine rhinitis A virus (ERAV) 2A (E2A) peptide, and a foot-and-mouth disease virus 2A (F2A) peptide.

In some embodiments, a binding protein encompassed by the present invention comprises one or more junction amino acids. “Junction amino acids” or “junction amino acid residues” refer to one or more (*e.g.*, 2 to about 10) amino acid residues between two adjacent motifs, regions or domains of a polypeptide, such as between a binding domain and an adjacent constant domain or between a TCR chain and an adjacent self-cleaving peptide. Junction amino acids can result from the design of a construct that encodes a fusion protein (*e.g.*, amino acid residues resulting from the use of a restriction enzyme site during the construction of a nucleic acid molecule encoding a fusion protein), or from cleavage of, for example, a self-cleaving peptide adjacent one or more domains of an encoded binding protein encompassed by the present invention (*e.g.*, a P2A peptide disposed between a TCR α -chain and a TCR β -chain, the self-cleavage of which can leave one or more junction amino acids in the α -chain, the TCR β -chain, or both).

Engineered immune cells encompassed by the present invention may be administered as therapies for, *e.g.*, a non-malignant disorder, a hyperproliferative disorder, or a relapse of a hyperproliferative disorder characterized by expression of an HPV16 E7₁₁₋₁₉ antigen. In some circumstances, it may be desirable to reduce or stop the activity associated with a cellular immunotherapy. Thus, in some embodiments, an engineered immune cell encompassed by the present invention comprises a heterologous polynucleotide encoding a binding protein and an accessory protein, such as a safety switch protein, which can be targeted using a cognate drug or other compound to selectively modulate the activity (*e.g.*, lessen or ablate) of such cells when desirable. Safety switch proteins used in this regard include, for example, a truncated EGF receptor polypeptide (huEGFRt) that is devoid of extracellular N-terminal ligand binding domains and intracellular receptor tyrosine kinase activity but retains the native amino acid sequence, type I transmembrane cell surface localization, and a conformationally intact binding epitope for pharmaceutical-grade anti-EGFR monoclonal antibody, cetuximab (Erbiximab) tEGF receptor (tEGFR; Wang *et al.* (2011) *Blood* 118:1255-1263), a caspase polypeptide (*e.g.*, iCasp9; Straathof *et al.* (2005) *Blood* 105:4247-4254, Di Stasi *et al.* (2011) *N. Engl. J.*

Med. 365:1673-1683, Zhou and Brenner (2016) *Hematol.* pii:S0301-472X:30513-30516), RQR8 (Philip *et al.* (2014) *Blood* 124:1277-1287), and a human c-myc protein tag (Kieback *et al.* (2008) *Proc. Natl. Acad. Sci. USA* 105:623-628)

Other accessory components useful for therapeutic cells comprise a tag or selection marker (*e.g.*, a CD34 enrichment tag) that allows the cells to be identified, sorted, isolated, enriched, or tracked. For example, marked immune cells having desired characteristics (*e.g.*, an antigen-specific TCR and a safety switch protein) may be sorted away from unmarked cells in a sample and more efficiently activated and expanded for inclusion in a therapeutic product of desired purity.

As used herein, the term "selection marker" comprises a nucleic acid construct that confers an identifiable change to a cell permitting detection and positive selection of immune cells transduced with a polynucleotide comprising a selection marker. For example, RQR is a selection marker that comprises a major extracellular loop of CD20 and two minimal CD34 binding sites. In some embodiments, an RQR-encoding polynucleotide comprises a polynucleotide that encodes the 16 amino acid CD34 minimal epitope. In some embodiments, such as certain embodiments provided in the examples herein, the CD34 minimal epitope is incorporated at the amino terminal position of the CD8 stalk domain (Q8). In further embodiments, the CD34 minimal binding site sequence may be combined with a target epitope for CD20 to form a compact marker/suicide gene for T cells (RQR8) (Philip *et al.* 2014). This construct allows for the selection of immune cells expressing the construct, with for example, CD34-specific antibody bound to magnetic beads (Miltenyi) and that utilizes clinically accepted pharmaceutical antibody, rituximab, that allows for the selective deletion of a transgene expressing engineered T cell (*e.g.*, Philip *et al.* (2014) *Blood* 124:1277-1287, U.S. Pat. Publ. 2015-0093401, and U.S. Pat. Publ. 2018-0051089).

Further exemplary selection markers include several truncated type I transmembrane proteins normally not expressed on T cells: the truncated low-affinity nerve growth factor, truncated CD19, and truncated CD34 (*e.g.*, Di Stasi *et al.* (2011) *N. Engl. J. Med.* 365:1673-1683, Mavilio *et al.* (1994) *Blood* 83:1988-1997, and Fehse *et al.* (2000) *Mol. Ther.* 7:448-456). A particularly attractive feature of CD19 and CD34 is the availability of the off-the-shelf Miltenyi CliniMACs™ selection system that can target these markers for clinical-grade sorting. However, CD19 and CD34 are relatively large surface proteins that may tax the vector packaging capacity and transcriptional efficiency of

an integrating vector. Surface markers containing the extracellular, non-signaling domains or various proteins (*e.g.*, CD19, CD34, LNGFR, etc.) also may be employed. Any selection marker may be employed and should be acceptable for good manufacturing practices. In some embodiments, selection markers are expressed with a polynucleotide that encodes a gene product of interest (*e.g.*, a binding protein encompassed by the present invention, such as a TCR or CAR, or antigen-binding fragment thereof). Further examples of selection markers include, for example, reporters such as GFP, EGFP, β -gal or chloramphenicol acetyltransferase (CAT). In some embodiments, a selection marker, such as, for example, CD34 is expressed by a cell and the CD34 may be used to select enrich for, or isolate (*e.g.*, by immunomagnetic selection) the transduced cells of interest for use in the methods described herein. As used herein, a CD34 marker is distinguished from an anti-CD34 antibody, or, for example, a scFv, TCR, or other antigen recognition moiety that binds to CD34.

In some embodiments, a selection marker comprises an RQR polypeptide, a truncated low-affinity nerve growth factor (tNGFR), a truncated CD19 (tCD19), a truncated CD34 (tCD34), or any combination thereof.

By way of background, inclusion of CD4⁺ T cells in an immunotherapy cell product can provide antigen-induced IL-2 secretion and augment persistence and function of transferred cytotoxic CD8⁺ T cells (*e.g.*, Kennedy *et al.* (2008) *Immunol. Rev.* 222:129 and Nakanishi *et al.* *Nature* (2009) 52:510). In some embodiments, a class I-restricted TCR in CD4⁺ T cells may require the transfer of a CD8 co-receptor to enhance sensitivity of the TCR to class I HLA peptide complexes. CD4 co-receptors differ in structure to CD8 and cannot effectively substitute for CD8 co-receptors (*e.g.*, Stone & Kranz (2013) *Front. Immunol.* 4:244 and Cole *et al.* (2012) *Immunology* 737:139). Thus, another accessory protein for use in the compositions and methods encompassed by the present invention comprises a CD8 co-receptor or component thereof. Engineered immune cells comprising a heterologous polynucleotide encoding a binding protein encompassed by the present invention may, in some embodiments, further comprise a heterologous polynucleotide encoding a CD8 co-receptor protein, or a beta-chain or alpha-chain component thereof.

A host cell may be efficiently transduced to contain, and may efficiently express, a single polynucleotide that encodes the binding protein, safety switch protein, selection marker, and CD8 co-receptor protein.

In one embodiment, the host cell encompassed by the present invention further includes a nucleic acid encoding a co-stimulatory molecule, such that the modified T cell expresses the co-stimulatory molecule. In some embodiments, the co-stimulatory domain is selected from CD3, CD27, CD28, CD83, CD86, CD127, 4-1BB, 4-1BBL, PD1 and PD1L.

In any of the foregoing embodiments, a host cell that express the binding protein described herein may be a universal immune cell. A “universal immune cell” comprises an immune cell that has been modified to reduce or eliminate expression of one or more endogenous genes that encode a polypeptide product selected from PD-1, LAG-3, CTLA4, TIM3, TIGIT, an HLA molecule, a TCR molecule, or any combination thereof. Without wishing to be bound by theory, certain endogenously expressed immune cell proteins may downregulate the immune activity of the modified immune cells (*e.g.*, PD-1, LAG-3, CTLA4, TIGIT), or may interfere with the binding activity of a heterologously expressed binding protein encompassed by the present invention (*e.g.*, an endogenous TCR that binds a non- HPV16 E7₁₁₋₁₉ antigen and interferes with the modified immune cell binding to a target cell that expresses an HPV16 E7₁₁₋₁₉ antigen such as an HPV16 E7₁₁₋₁₉ immunogenic peptide comprising the amino acid sequence YMLDLQPET in the context of a MHC molecule. Further, endogenous proteins (*e.g.*, immune cell proteins, such as an HLA allele) expressed on a donor immune cell may be recognized as foreign by an allogeneic host, which may result in elimination or suppression of the modified donor immune cell by the allogeneic host.

Accordingly, decreasing or eliminating expression or activity of such endogenous genes or proteins can improve the activity, tolerance, or persistence of the modified immune cells in an autologous or allogeneic host setting, and allows universal administration of the cells (*e.g.*, to any recipient regardless of HLA type). In some embodiments, cells in accordance with the present invention are syngeneic, meaning that they are genetically identical or sufficiently identical and immunologically compatible as to allow for transplantation. In some embodiments, a universal immune cell is a donor cell (*e.g.*, allogeneic) or an autologous cell. In some embodiments, a modified immune cell (*e.g.*, a universal immune cell) encompassed by the present invention comprises a chromosomal gene knockout of one or more of a gene that encodes PD-1, LAG-3, CTLA4, TIM3, TIGIT, an HLA component (*e.g.*, a gene that encodes an α 1 macroglobulin, an α 2 macroglobulin, an α 3 macroglobulin, a β 1 microglobulin, or a β 2 microglobulin), or a TCR component (*e.g.*, a gene that encodes a TCR variable region or a TCR constant region) (see,

e.g., Torikai *et al.* (2016) *Nature Sci. Rep.* 6:21757; Torikai *et al.* (2012) *Blood* 179:5697; and Torikai *et al.* (2013) *Blood* 722:1341, which also provide representative, exemplary gene editing techniques, compositions, and adoptive cell therapies useful according to the present invention).

As used herein, the term “chromosomal gene knockout” refers to a genetic alteration or introduced inhibitory agent in a host cell that prevents (*e.g.*, reduces, delays, suppresses, or abrogates) production, by the host cell, of a functionally active endogenous polypeptide product. Alterations resulting in a chromosomal gene knockout may include, for example, introduced nonsense mutations (including the formation of premature stop codons), missense mutations, gene deletion, and strand breaks, as well as the heterologous expression of inhibitory nucleic acid molecules that inhibit endogenous gene expression in the host cell.

In some embodiments, a chromosomal gene knock-out or gene knock-in may be made by chromosomal editing of a host cell. Chromosomal editing may be performed using, for example, endonucleases. As used herein “endonuclease” refers to an enzyme capable of catalyzing cleavage of a phosphodiester bond within a polynucleotide chain. In some embodiments, an endonuclease is capable of cleaving a targeted gene thereby inactivating or “knocking out” the targeted gene. An endonuclease may be a naturally occurring, recombinant, genetically modified, or fusion endonuclease. The nucleic acid strand breaks caused by the endonuclease are commonly repaired through the distinct mechanisms of homologous recombination or non-homologous end joining (NHEJ). During homologous recombination, a donor nucleic acid molecule may be used for a donor gene “knock-in”, for target gene “knock-out”, and optionally to inactivate a target gene through a donor gene knock in or target gene knock out event. NHEJ is an error-prone repair process that often results in changes to the DNA sequence at the site of the cleavage, *e.g.*, a substitution, deletion, or addition of at least one nucleotide. NHEJ may be used to “knock-out” a target gene. Examples of endonucleases include zinc finger nucleases, TALE-nucleases, CRISPR-Cas nucleases, meganucleases, and megaTALs.

As used herein, a “zinc finger nuclease” (ZFN) refers to a fusion protein comprising a zinc finger DNA-binding domain fused to a non-specific DNA cleavage domain, such as a FokI endonuclease. Each zinc finger motif of about 30 amino acids binds to about 3 base pairs of DNA, and amino acids at certain residues may be changed to alter triplet sequence specificity (*e.g.*, Desjarlais *et al.* (1993) *Proc. Natl. Acad. Sci.* 90:2256-2260 and Wolfe *et*

al. (1999) *J. Mol. Biol.* 255:1917-1934). Multiple zinc finger motifs may be linked in tandem to create binding specificity to desired DNA sequences, such as regions having a length ranging from about 9 to about 18 base pairs. By way of background, ZFNs mediate genome editing by catalyzing the formation of a site-specific DNA double strand break (DSB) in the genome, and targeted integration of a transgene comprising flanking sequences homologous to the genome at the site of DSB is facilitated by homology directed repair. Alternatively, a DSB generated by a ZFN can result in knock out of target gene via repair by non-homologous end joining (NHEJ), which is an error-prone cellular repair pathway that results in the insertion or deletion of nucleotides at the cleavage site. In some embodiments, a gene knockout comprises an insertion, a deletion, a mutation or a combination thereof, made using a ZFN molecule.

As used herein, a “transcription activator-like effector nuclease” (TALEN) refers to a fusion protein comprising a TALE DNA-binding domain and a DNA cleavage domain, such as a FokI endonuclease. A “TALE DNA binding domain” or “TALE” is composed of one or more TALE repeat domains/units, each generally having a highly conserved 33-35 amino acid sequence with divergent 12th and 13th amino acids. The TALE repeat domains are involved in binding of the TALE to a target DNA sequence. The divergent amino acid residues, referred to as the repeat variable diresidue (RVD), correlate with specific nucleotide recognition. The natural (canonical) code for DNA recognition of these TALEs has been determined such that an HD (histidine-aspartic acid) sequence at positions 12 and 13 of the TALE leads to the TALE binding to cytosine (C), NG (asparagine-glycine) binds to a T nucleotide, NI (asparagine-isoleucine) to A, NN (asparagine-asparagine) binds to a G or A nucleotide, and NG (asparagine-glycine) binds to a T nucleotide. Non-canonical (atypical) RVDs are also well-known in the art (*e.g.*, U.S. Pat. Publ. No. US 2011/0301073, which atypical RVDs are incorporated by reference herein in their entirety). TALENs may be used to direct site-specific double-strand breaks (DSB) in the genome of T cells. Non-homologous end joining (NHEJ) ligates DNA from both sides of a double-strand break in which there is little or no sequence overlap for annealing, thereby introducing errors that knock out gene expression. Alternatively, homology directed repair can introduce a transgene at the site of DSB providing homologous flanking sequences are present in the transgene. In some embodiments, a gene knockout comprises an insertion, a deletion, a mutation or a combination thereof, and made using a TALEN molecule.

As used herein, a “clustered regularly interspaced short palindromic repeats/Cas” (CRISPR/Cas) nuclease system refers to a system that employs a CRISPR RNA (crRNA)-guided Cas nuclease to recognize target sites within a genome (known as protospacers) via base-pairing complementarity and then to cleave the DNA if a short, conserved protospacer associated motif (PAM) immediately follows 3’ of the complementary target sequence. CRISPR/Cas systems are classified into three types (*i.e.*, type I, type II, and type III) based on the sequence and structure of the Cas nucleases. The crRNA-guided surveillance complexes in types I and III need multiple Cas subunits. Type II system, the most studied, comprises at least three components: an RNA-guided Cas9 nuclease, a crRNA, and a trans-acting crRNA (tracrRNA). The tracrRNA comprises a duplex forming region. A crRNA and a tracrRNA form a duplex that is capable of interacting with a Cas9 nuclease and guiding the Cas9/crRNA:tracrRNA complex to a specific site on the target DNA via Watson-Crick base-pairing between the spacer on the crRNA and the protospacer on the target DNA upstream from a PAM. Cas9 nuclease cleaves a double-stranded break within a region defined by the crRNA spacer. Repair by NHEJ results in insertions and/or deletions which disrupt expression of the targeted locus. Alternatively, a transgene with homologous flanking sequences may be introduced at the site of DSB via homology directed repair. The crRNA and tracrRNA may be engineered into a single guide RNA (sgRNA or gRNA) (*e.g.*, Jinek *et al.* (2012) *Science* 337:816-821). Further, the region of the guide RNA complementary to the target site may be altered or programmed to target a desired sequence (Xie *et al.* (2014) *PLOS One* 9:e100448, U.S. Pat. Publ. No. US 2014/0068797, U.S. Pat. Publ. No. US 2014/0186843, U.S. Pat. No. 8,697,359, and PCT Publ. No. WO 2015/071474). In some embodiments, a gene knockout comprises an insertion, a deletion, a mutation or a combination thereof, and made using a CRISPR/Cas nuclease system.

Exemplary gRNA sequences and methods of using the same to knock out endogenous genes that encode immune cell proteins include those described in Ren *et al.* (2017) *Clin. Cancer Res.* 23:2255-2266, which provides representative, exemplary gRNAs, CAS9 DNAs, vectors, and gene knockout techniques.

As used herein, a “meganuclease,” also referred to as a “homing endonuclease,” refers to an endodeoxyribonuclease characterized by a large recognition site (double stranded DNA sequences of about 12 to about 40 base pairs). Meganucleases may be divided into five families based on sequence and structure motifs: LAGLIDADG, GIY-

YIG, HNH, His-Cys box, and PD-(D/E)XK. Exemplary meganucleases include I-SceI, I-CeuI, PI-PspI, RI-Sce, I-SceIV, I-CsmI, I-PanI, I-SceII, I-PpoI, I-SceIII, I-CreI, I-TevI, I-TevII and I-TevIII, whose recognition sequences are well-known (*e.g.*, U.S. Pat. Nos. 5,420,032 and 6,833,252, Belfort *et al.* (1997) *Nucl. Acids Res.* 25:3379-3388, Dujon *et al.* (1989) *Gene* 52:115-118, Perler *et al.* (1994) *Nucl. Acids Res.* 22:1125-1127, Jasin (1996) *Trends Genet.* 72:224-228, Gimble *et al.* (1996) *J. Mol. Biol.* 263:163-180, and Argast *et al.* (1998) *J. Mol. Biol.* 280: 345-353).

In some embodiments, naturally-occurring meganucleases may be used to promote site-specific genome modification of a target of interest, such as an immune checkpoint, an HLA-encoding gene, or a TCR component-encoding gene.

In other embodiments, an engineered meganuclease having a novel binding specificity for a target gene is used for site-specific genome modification (see, *e.g.*, Porteus *et al.* (2005) *Nat. Biotechnol.* 23:967-73, Sussman *et al.* (2004) *J. Mol. Biol.* 342:31-41, Epinat *et al.* (2003) *Nucl. Acids Res.* 37:2952-2962, Chevalier *et al.* (2002) *Mol. Cell* 70:895-905, Ashworth *et al.* (2006) *Nature* 441:656-659, Paques *et al.* (2007) *Curr. Gene Ther.* 7:49-66, and U.S. Pat. Publ. Nos. US 2007/0117128, US 2006/0206949, US 2006/0153826, US 2006/0078552, and US 2004/0002092). In further embodiments, a chromosomal gene knockout is generated using a homing endonuclease that has been modified with modular DNA binding domains of TALENs to make a fusion protein known as a megaTAL. MegaTALs may be utilized to not only knock-out one or more target genes, but to also introduce (knock in) heterologous or exogenous polynucleotides when used in combination with an exogenous donor template encoding a polypeptide of interest.

In some embodiments, a chromosomal gene knockout comprises an inhibitory nucleic acid molecule that is introduced into a host cell (*e.g.*, an immune cell) comprising a heterologous polynucleotide encoding an antigen-specific receptor that binds (*e.g.*, specifically and/or selectively) to an HPV16 E7₁₁₋₁₉ antigen, wherein the inhibitory nucleic acid molecule encodes a target-specific inhibitor and wherein the encoded target-specific inhibitor inhibits endogenous gene expression (*i.e.*, of an immune checkpoint, an HLA component, or a TCR component, or any combination thereof) in the host immune cell.

A chromosomal gene knockout may be confirmed directly by DNA sequencing of the host immune cell following use of the knockout procedure or agent.

Chromosomal gene knockouts may also be inferred from the absence of gene expression (*e.g.*, the absence of an mRNA or polypeptide product encoded by the gene) following the knockout.

In some embodiments, a host cell encompassed by the present invention is capable of specifically and/or selectively 50% or more of target cells that comprise a peptide–MHC (pMHC) complex comprising an HPV16 E7₁₁₋₁₉ immunogenic peptide in the context of an MHC molecule.

In some embodiments, the modified immune cell is capable of producing a cytokine when contacted with target cells that comprise a peptide–MHC (pMHC) complex comprising an HPV16 E7₁₁₋₁₉ immunogenic peptide in the context of an MHC molecule.

In some embodiments, the cytokine comprises IFN- γ or IL2. In some embodiments, the cytokine comprises TNF- α .

In some embodiments, the host cell is capable of producing a higher level of cytokine or a cytotoxic molecule when contacted with a target cell with expression of HPV16 E7₁₁₋₁₉ at a level of less than or equal to about 1,000 transcript per million transcripts (TPM), 950 TPM, 900 TPM, 850 TPM, 800 TPM, 750 TPM, 700 TPM, 650 TPM, 600 TPM, 550 TPM, 500 TPM, 450 TPM, 400 TPM, 350 TPM, 300 TPM, 250 TPM, 200 TPM, 150 TPM, 100 TPM, 95 TPM, 90 TPM, 85 TPM, 80 TPM, 75 TPM, 70 TPM, 65 TPM, 60 TPM, 55 TPM, 50 TPM, 45 TPM, 40 TPM, 35 TPM, 34 TPM, 33 TPM, 32 TPM, 31 TPM, 30 TPM, 29 TPM, 28 TPM, 27 TPM, 26 TPM, 25 TPM, 24 TPM, 23 TPM, 22 TPM, 21 TPM, 20 TPM, 19 TPM, 18 TPM, 17 TPM, 16 TPM, 15 TPM, 14 TPM, 13 TPM, 12 TPM, 11 TPM, 10 TPM, 9 TPM, 8 TPM, 7 TPM, 6 TPM, 5 TPM, 4 TPM, 3 TPM, 2 TPM, and 1 TPM, or any range in between, inclusive, such as less than or equal to about 1,000 TPM to less than or equal to about 35 TPM). In some embodiments, the low HPV16 E7₁₁₋₁₉ expression level is termed "heterozygous expression" meaning between about 1 TPM and about 35 TPM, or any range in between, inclusive, such as 1-32 TPM. For example, the host cell is capable of producing an at least 1.2 fold, 1.5 fold, 1.8 fold, 2.0 fold, 2.2 fold, 2.5 fold, 2.8 fold, 3 fold, 3.5 fold, 4 fold, 4.5 fold, 5 fold, 5.5 fold, 6 fold, 6.5 fold, 7 fold, 7.5 fold, 8 fold, 8.5 fold, 9 fold, 9.5 fold, 10 fold, 11 fold, 12 fold, 13 fold, 14 fold, 15 fold, 16 fold, 17 fold, 18 fold, 19 fold, 20 fold, 25 fold, 30 fold, 35 fold, 40 fold, 45 fold, 50 fold, 60 fold, 70 fold, 80 fold, 90 fold, 100 fold, 1000 fold, or more, or any range in between, inclusive, such as 1.2 fold to 2 fold, higher level of cytokine or a cytotoxic molecule.

In some embodiments, the host cell is capable of specifically and/or selectively killing a target cell expressing HPV16 E7₁₁₋₁₉ (e.g., a hyperproliferative cell expressing HPV16 E7₁₁₋₁₉). In certain embodiments, the target cell expresses: (i) a polypeptide comprising or consisting of an amino acid sequence YMLDLQPET; and (ii) a matched MHC molecule.

In some embodiments, host cells do not express HPV16 E7₁₁₋₁₉ antigen, are not recognized by a binding protein of any one of claims 1-30, are not of serotype HLA-A*02, and/or do not express an HLA-A*02 allele, such as HLA-A*02:01, HLA-A*02:02, HLA-A*02:03, HLA-A*02:05, HLA-A*02:06, or HLA-A*02:07 allele. For example, a patient may receive host cells from a healthy donor who is HPV16 E7₁₁₋₁₉-negative or HLA-A*02:01-negative. Stem cells, such as hematopoietic stem cells, isolated from that donor (or engineered autologous cells) may be used as the source of transplant material. In parallel, T cells isolated from the same donor may be genetically engineered to recognize HPV16 E7₁₁₋₁₉, such as by expressing an HPV16 E7₁₁₋₁₉ binding protein described herein. Donor stem cells may be used to engraft cell populations, such as a reconstituted immune system, into the patient and host cells may be infused into the patient with the goal of eliciting a highly specific anti-tumor effect. The engineered donor T cells may be designed to recognize and eliminate HPV16 E7₁₁₋₁₉-expressing cells, such as all of the patient's native blood cells, including, for example, cancer cells like residual leukemia cells, which are HPV16 E7₁₁₋₁₉-positive, thereby preventing relapse and promoting complete cures. Because the patient's new healthy blood cells are derived from the donor and are therefore either HPV16 E7₁₁₋₁₉-negative, HLA-A*02 serotype negative, and/or or HLA-A*02:01-negative, engineered cells described herein may have minimal toxic side effects. Such patient-matched host cells and treatment methods may be used according to therapeutic methods described further below.

In some embodiments, the killing is determined by a killing assay. In some embodiment, the killing assay is carried out by coculturing the host cell and the target cell at a ratio from 20:1 to 0.625:1, for example, from 15:1 to 1.25:1, from 10:1 to 1.5:1, from 8:1 to 3:1, from 6:1 to 5:1, 20:1 to 5:1, 10:1 to 2.5:1 etc.. In some embodiments, the target cell is pulsed with 1 µg/mL to 50 pg/mL of HPV16 E7₁₁₋₁₉ peptide, for example, from 1 µg/mL to 10 ng/mL, 500 ng/mL to 0.5 ng/mL, from 10 ng/mL to 10 pg/mL from 250 ng/mL to 1 ng/mL, from 50 ng/mL to 5 ng/mL, from 20 ng/mL to 10 ng/mL, etc.

In some embodiments, the host cell is capable of killing a higher number of target cells when contacted with target cells with a level of HPV16 E7₁₁₋₁₉ less than or equal to about 1,000 transcript per million transcripts (TPM), 950 TPM, 900 TPM, 850 TPM, 800 TPM, 750 TPM, 700 TPM, 650 TPM, 600 TPM, 550 TPM, 500 TPM, 450 TPM, 400 TPM, 350 TPM, 300 TPM, 250 TPM, 200 TPM, 150 TPM, 100 TPM, 95 TPM, 90 TPM, 85 TPM, 80 TPM, 75 TPM, 70 TPM, 65 TPM, 60 TPM, 55 TPM, 50 TPM, 45 TPM, 40 TPM, 35 TPM, 34 TPM, 33 TPM, 32 TPM, 31 TPM, 30 TPM, 29 TPM, 28 TPM, 27 TPM, 26 TPM, 25 TPM, 24 TPM, 23 TPM, 22 TPM, 21 TPM, 20 TPM, 19 TPM, 18 TPM, 17 TPM, 16 TPM, 15 TPM, 14 TPM, 13 TPM, 12 TPM, 11 TPM, 10 TPM, 9 TPM, 8 TPM, 7 TPM, 6 TPM, 5 TPM, 4 TPM, 3 TPM, 2 TPM, and 1 TPM, or any range in between, inclusive, such as less than or equal to about 1,000 TPM to less than or equal to about 35 TPM). In some embodiments, the low HPV16 E7₁₁₋₁₉ expression level is termed "heterozygous expression" meaning between about 1 TPM and about 35 TPM, or any range in between, inclusive, such as 1-32 TPM. For example, the host cell may be capable of killing an at least 1.2 fold, 1.5 fold, 1.8 fold, 2.0 fold, 2.2 fold, 2.5 fold, 2.8 fold, 3 fold, 3.5 fold, 4 fold, 4.5 fold, 5 fold, 5.5 fold, 6 fold, 6.5 fold, 7 fold, 7.5 fold, 8 fold, 8.5 fold, 9 fold, 9.5 fold, 10 fold, 11 fold, 12 fold, 13 fold, 14 fold, 15 fold, 16 fold, 17 fold, 18 fold, 19 fold, 20 fold, 25 fold, 30 fold, 35 fold, 40 fold, 45 fold, 50 fold, 60 fold, 70 fold, 80 fold, 90 fold, 100 fold, 1000 fold, or more, or any range in between, inclusive, such as 1.2 fold to 2 fold, higher number of target cells.

The present invention further provides a population of cells comprising at least one host cell described herein. The population of cells may 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 may 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 may 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

encompassed by the present invention, the population of cells is a clonal population comprising host cells comprising a recombinant expression vector as described herein.

In an embodiment encompassed by the present invention, the numbers of cells in the population may be rapidly expanded. Expansion of the numbers of T cells may be accomplished by any of a number of methods as are well-known in the art (*e.g.*, U.S. Pat. Nos. 8,034,334 and 8,383,099, U.S. Pat. Publ. No. 2012/0244133, Dudley *et al.* (2003) *J. Immunother.* 26:332-242, and Riddell *et al.* (1990) *J. Immunol. Methods* 128:189-201). For example, expansion of the numbers of T cells may be carried out by culturing the T cells with OKT3 antibody, IL-2, and feeder PBMC (*e.g.*, irradiated allogeneic PBMC).

V. Pharmaceutical Compositions

In another aspect encompassed by the present invention, pharmaceutical compositions are provided herein comprising compositions described herein (*e.g.*, binding proteins, nucleic acids, cells, and the like) and a pharmaceutically acceptable carrier, diluent, or excipient.

The term “pharmaceutically acceptable” refers to those agents, materials, compositions, and/or dosage forms which are, within the scope of sound medical judgment, suitable for use in contact with the tissues of human beings and animals without excessive toxicity, irritation, allergic response, or other problem or complication, commensurate with a reasonable benefit/risk ratio.

Agents and other compositions encompassed by the present invention may be specially formulated for administration in solid or liquid form, including those adapted for various routes of administration, such as (1) oral administration, for example, drenches (aqueous or non-aqueous solutions or suspensions), tablets, boluses, powders, granules, pastes; (2) parenteral administration, for example, by subcutaneous, intramuscular or intravenous injection as, for example, a sterile solution or suspension; (3) topical application, for example, as a cream, ointment or spray applied to the skin; (4) intravaginally or intrarectally, for example, as a pessary, cream or foam; or (5) aerosol, for example, as an aqueous aerosol, liposomal preparation or solid particles containing the compound. Any appropriate form factor for an agent or composition described herein, such as, but not limited to, tablets, capsules, liquid syrups, soft gels, suppositories, and enemas, is contemplated.

Pharmaceutical compositions encompassed by the present invention may be presented as discrete dosage forms, such as capsules, sachets, or tablets, or liquids or aerosol sprays each containing a pre-determined amount of an active ingredient as a powder or in granules, a solution, or a suspension in an aqueous or non- aqueous liquid, an oil-in-water emulsion, a water-in-oil liquid emulsion, powders for reconstitution, powders for oral consumptions, bottles (including powders or liquids in a bottle), orally dissolving films, lozenges, pastes, tubes, gums, and packs. Such dosage forms may be prepared by any of the methods of pharmacy.

Suitable excipients include water, saline, dextrose, glycerol, or the like and combinations thereof. In some embodiments, compositions comprising host cells, binding proteins, or fusion proteins as disclosed herein further comprise a suitable infusion media. Suitable infusion media may be any isotonic medium formulation, typically normal saline, Normosol™-R (Abbott) or Plasma-Lyte™ A (Baxter), 5% dextrose in water, Ringer's lactate may be utilized. An infusion medium may be supplemented with human serum albumin or other human serum components. Unit doses comprising an effective amount of a host cell, or composition are also contemplated.

Also provided herein are unit doses that comprise an effective amount of a host cell or of a composition comprising the host cell. As described herein, host cells include immune cells, T cells (CD4⁺ T cells and/or CD8⁺ T cells), cytotoxic lymphocytes (*e.g.*, cytotoxic T cells and/or natural killer (NK) cells), and the like. For example, in some embodiments, a unit dose comprises a composition comprising at least about 30%, at least about 40%, at least about 50%, at least about 60%), at least about 70%, at least about 80%, at least about 85%, at least about 90%, or at least about 95% engineered cells, either alone or in combination with other cells, such as comprising at least about 30%, at least about 40%, at least about 50%, at least about 60%), at least about 70%, at least about 80%, at least about 85%, at least about 90%, or at least about 95% other cells. In some embodiments, undesired cells are present at a reduced amount or substantially not present, such as less than about 50%, less than about 40%, less than about 30%, less than about 20%, less than about 10%, less than about 5%, or less than about 1% the population of cells in the composition.

The amount of cells in a composition or unit dose is at least one cell (for example, at least one engineered CD8⁺ T cell, engineered CD4⁺ T cell, and/or NK cell) or is more typically greater than 10² cells, for example, up to 10⁶, up to 10⁷, up to 10⁸ cells, up to 10⁹

cells, or more than 10^{10} cells. In some embodiments, the cells are administered in a range from about 10^6 to about 10^{10} cells/ m^2 , such as in a range of about 10^5 to about 10^9 cells/ m^2 . The number of cells will depend upon the ultimate use for which the composition is intended as well the type of cells included therein. For example, cells modified to contain a binding protein specific for a particular antigen will comprise a cell population containing at least 30%, 35%, 40%, 45%, 50%, 55%, 60%, 65%, 70%, 75%, 80%, 85%, 90%, 95% or more of such cells. For uses provided herein, cells are generally in a volume of a liter or less, 500 ml or less, 250 ml or less, or 100 ml or less. In embodiments, the density of the desired cells is typically greater than 10^4 cells/ml and generally is greater than 10^7 cells/ml, generally 10^8 cells/ml or greater. The cells may be administered as a single infusion or in multiple infusions over a range of time. A clinically relevant number of immune cells may be apportioned into multiple infusions that cumulatively equal or exceed 10^6 , 10^7 , 10^8 , 10^9 , 10^{10} , or 10^{11} cells. In some embodiments, a unit dose of the engineered immune cells may be co-administered with (*e.g.*, simultaneously or contemporaneously) hematopoietic stem cells from an allogeneic donor.

Pharmaceutical compositions may be administered in a manner appropriate to the disease or condition to be treated (or prevented) as determined by persons skilled in the medical art. An appropriate dose and a suitable duration and frequency of administration of the compositions will be determined by such factors as the health condition of the patient, size of the patient (*i.e.*, weight, mass, or body area), the type and severity of the patient's condition, the particular form of the active ingredient, and the method of administration. In general, an appropriate dose and treatment regimen provide the composition(s) in an amount sufficient to provide therapeutic and/or prophylactic benefit (such as described herein, including an improved clinical outcome, such as more frequent complete or partial remissions, or longer disease-free and/or overall survival, or a lessening of symptom severity).

An effective amount of a pharmaceutical composition refers to an amount sufficient, at dosages and for periods of time needed, to achieve the desired clinical results or beneficial treatment, as described herein. An effective amount may be delivered in one or more administrations. If the administration is to a subject already known or confirmed to have a disease or disease-state, the term "therapeutically effective amount" may be used in reference to treatment, whereas "prophylactically effective amount" may be used to

describe administering an effective amount to a subject that is susceptible or at risk of developing a disease or disease-state (*e.g.*, recurrence) as a preventative course.

The pharmaceutical compositions described herein may be presented in unit-dose or multi-dose containers, such as sealed ampoules or vials. Such containers may be frozen to preserve the stability of the formulation until infusion into the patient. In some embodiments, a unit dose comprises a host cell as described herein at a dose of about 10^7 cells/ m^2 to about 10^{11} cells/ m^2 . The development of suitable dosing and treatment regimens for using the particular compositions described herein in a variety of treatment regimens, including *e.g.*, parenteral or intravenous administration or formulation.

If the subject composition is administered parenterally, the composition may also include sterile aqueous or oleaginous solution or suspension. Suitable non-toxic parenterally acceptable diluents or solvents include water, Ringer's solution, isotonic salt solution, 1,3-butanediol, ethanol, propylene glycol or polythethylene glycols in mixtures with water. Aqueous solutions or suspensions may further comprise one or more buffering agents, such as sodium acetate, sodium citrate, sodium borate or sodium tartrate. Of course, any material used in preparing any dosage unit formulation should be pharmaceutically pure and substantially non-toxic in the amounts employed. In addition, the active compounds may be incorporated into sustained-release preparation and formulations. Dosage unit form, as used herein, refers to physically discrete units suited as unitary dosages for the subject to be treated; each unit may contain a predetermined quantity of engineered immune cells or active compound calculated to produce the desired effect in association with an appropriate pharmaceutical carrier.

In some embodiments, the pharmaceutical composition described, when administered to a subject, can elicit an immune response against a cell of interest that expresses HPV16 E7₁₁₋₁₉. Such pharmaceutical compositions may be useful as vaccines for prophylactic and/or therapeutic treatment of a non-malignant disorder, a hyperproliferative disorder, or a relapse of a hyperproliferative disorder characterized by expression of an HPV16 E7₁₁₋₁₉ antigen.

In some embodiments, the pharmaceutical composition further comprises a physiologically acceptable adjuvant. In some embodiments, the adjuvant employed provides for increased immunogenicity of the pharmaceutical composition. Such a further immune response stimulating compound or adjuvant may be (i) admixed to the pharmaceutical composition in accordance with the present invention after reconstitution of

the peptides and optional emulsification with an oil-based adjuvant as defined above, (ii) may be part of the reconstitution composition encompassed by the present invention defined above, (iii) may be physically linked to the peptide(s) to be reconstituted or (iv) may be administered separately to the subject, mammal or human, to be treated. The adjuvant may be one that provides for slow release of antigen (*e.g.*, the adjuvant may be a liposome), or it may be an adjuvant that is immunogenic in its own right thereby functioning synergistically with antigens. For example, the adjuvant may be a known adjuvant or other substance that promotes antigen uptake, recruits immune system cells to the site of administration, or facilitates the immune activation of responding lymphoid cells. Adjuvants include, but are not limited to, immunomodulatory molecules (*e.g.*, cytokines), oil and water emulsions, aluminum hydroxide, glucan, dextran sulfate, iron oxide, sodium alginate, bacto-adjuvant, synthetic polymers such as poly amino acids and co-polymers of amino acids, saponin, paraffin oil, and muramyl dipeptide. In some embodiments, the adjuvant is adjuvant 65, α -GalCer, aluminum phosphate, aluminum hydroxide, calcium phosphate, β -glucan peptide, CpG DNA, GM-CSF, GPI-0100, IFA, IFN- γ , IL-17, lipid A, lipopolysaccharide, Lipovant, Montanide™, N-acetyl-muramyl-L-alanyl-D-isoglutamine, pam3CSK4, quil A, trehalose dimycolate, or zymosan.

In some embodiments, the adjuvant is an immunomodulatory molecule. For example, the immunomodulatory molecule may be a recombinant protein cytokine, chemokine, or immunostimulatory agent or nucleic acid encoding cytokines, chemokines, or immunostimulatory agents designed to enhance the immunologic response.

Examples of immunomodulatory cytokines include interferons (*e.g.*, IFN α , IFN β and IFN γ), interleukins (*e.g.*, IL-1, IL-2, IL-3, IL-4, IL-5, IL-6, IL-7, IL-8, IL-9, IL-10, IL-12, IL-17 and IL-20), tumor necrosis factors (*e.g.*, TNF α and TNF β), erythropoietin (EPO), FLT-3 ligand, gIp10, TCA-3, MCP-1, MIF, MIP-1.alpha., MIP-1 β , Rantes, macrophage colony stimulating factor (M-CSF), granulocyte colony stimulating factor (G-CSF), and granulocyte-macrophage colony stimulating factor (GM-CSF), as well as functional fragments of any of the foregoing.

In some embodiments, an immunomodulatory chemokine that binds to a chemokine receptor, *i.e.*, a CXC, CC, C, or CX3C chemokine receptor, also may be included in the compositions provided here. Examples of chemokines include, but are not limited to, Mip1 α , Mip-1 β , Mip-3 α (Larc), Mip-3 β , Rantes, Hcc-1, Mpif-1, Mpif-2, Mcp-1, Mcp-2, Mcp-3, Mcp-4, Mcp-5, Eotaxin, Tarc, Elc, I309, IL-8, Gcp-2 Gro- α , Gro- β , Gro- γ , Nap-2,

Ena-78, Gcp-2, Ip-10, Mig, I-Tac, Sdf-1, and Bca-1 (Blc), as well as functional fragments of any of the foregoing.

In some embodiments, the composition comprises a binding protein (*e.g.*, a TCR, an antigen-binding fragment of a TCR, a CAR, or a fusion protein comprising a TCR and an effector domain), a TCR α and/or TCR β polypeptide described herein. In some embodiments, the composition comprises a nucleic acid encoding a binding protein, a TCR α and/or TCR β polypeptide described herein, such as a DNA molecule encoding a binding protein, a TCR α and/or TCR β polypeptide. In some embodiments, the composition comprises an expression vector comprising an open reading frame encoding a binding protein, a TCR α and/or TCR β polypeptide.

When taken up by a cell (*e.g.*, T cells, NK cells, *etc.*), a DNA molecule may be present in the cell as an extrachromosomal molecule and/or may integrate into the chromosome. DNA may be introduced into cells in the form of a plasmid which may remain as separate genetic material. Alternatively, linear DNAs that may integrate into the chromosome may be introduced into the cell. Optionally, when introducing DNA into a cell, reagents which promote DNA integration into chromosomes may be added.

VI. Uses and Methods

The compositions described herein may be used in a variety of diagnostic, prognostic, and therapeutic applications. In any method described herein, such as a diagnostic method, prognostic method, therapeutic method, or combination thereof, all steps of the method can be performed by a single actor or, alternatively, by more than one actor. For example, diagnosis can be performed directly by the actor providing therapeutic treatment. Alternatively, a person providing a therapeutic agent can request that a diagnostic assay be performed. The diagnostician and/or the therapeutic interventionist can interpret the diagnostic assay results to determine a therapeutic strategy. Similarly, such alternative processes can apply to other assays, such as prognostic assays.

In some uses and methods encompassed by the present invention, subjects or subject samples are utilized. In some embodiments, the subject is an animal. The animal may be of either sex and may be at any stage of development. In some embodiments, the animal is a vertebrate, such as a mammal. In some embodiments, the subject is a non-human mammal. In some embodiments, the subject is a domesticated animal, such as a dog, cat, cow, pig, horse, sheep, or goat. In some embodiments, the subject is a companion animal,

such as a dog or cat. In some embodiments, the subject is a livestock animal, such as a cow, pig, horse, sheep, or goat. In some embodiments, the subject is a zoo animal. In some embodiments, the subject is a research animal, such as a rodent (*e.g.*, mouse or rat), dog, pig, or non-human primate. In some embodiments, the animal is a genetically engineered animal. In some embodiments, the animal is a transgenic animal (*e.g.*, transgenic mice and transgenic pigs). In some embodiments, the subject is a fish or reptile.

In some embodiments, the subject is a rodent, such as a mouse. In some such embodiments, the mouse is a transgenic mouse, such as a mouse expressing human MHC (*i.e.*, HLA) molecules (*e.g.*, Nicholson *et al.* (2012) *Adv. Hematol.* 2012:404081). In some embodiments, the subject is a transgenic mouse expressing human TCRs or is an antigen-negative mouse (*e.g.*, Li *et al.* (2010) *Nat. Med.* 16:1029-1034 and Obenaus *et al.* (2015) *Nat. Biotechnol.* 33:402-407). In some embodiments, the subject is a transgenic mouse expressing human HLA molecules and human TCRs. In some embodiments, such as where the subject is a transgenic HLA mouse, the identified TCRs are modified, *e.g.*, to be chimeric or humanized. In some embodiments, the TCR scaffold is modified, such as analogous to known binding protein humanizing methods.

In some embodiments, the subject is a human. In some embodiments, the subject is an animal model of a disorder characterized by HPV16 E7₁₁₋₁₉ expression (*e.g.*, a non-malignant disorder, the hyperproliferative disorder, or the relapse of a hyperproliferative disorder characterized by expression of an HPV16 E7₁₁₋₁₉ antigen). For example, the animal model may be an orthotopic xenograft animal model of a human-derived cancer.

In some embodiments, the subject is a human, such as a human with a disorder characterized by HPV16 E7₁₁₋₁₉ expression.

The methods described herein may be used to treat a subject in need thereof. As used herein, a “subject in need thereof” includes any subject who has a disorder characterized by HPV16 E7₁₁₋₁₉ expression, a relapse of a disorder characterized by HPV16 E7₁₁₋₁₉ expression, and/or who is predisposed to a disorder characterized by HPV16 E7₁₁₋₁₉ expression. As described herein, a disorder characterized by HPV16 E7₁₁₋₁₉ expression may be a non-malignant disorder, a hyperproliferative disorder, or a relapse of a hyperproliferative disorder characterized by expression of an HPV16 E7₁₁₋₁₉ antigen.

In some embodiments of the methods encompassed by the present invention, the subject has not undergone treatment for a disorder characterized by HPV16 E7₁₁₋₁₉ expression, such as chemotherapy, radiation therapy, targeted therapy, and/or

immunotherapies. In some embodiments, the subject has undergone treatment for a disorder characterized by HPV16 E7₁₁₋₁₉ expression, such as chemotherapy, radiation therapy, targeted therapy, and/or immunotherapies.

In some embodiments, the subject has had surgery to remove cancerous or precancerous tissue. In some embodiments, the cancerous tissue has not been removed, *e.g.*, the cancerous tissue may be located in an inoperable region of the body, such as in a tissue that is essential for life, or in a region where a surgical procedure would cause considerable risk of harm to the patient.

In some embodiments, the subject or cells thereof are resistant to a therapy of relevance, such as resistant to standard of care therapy, immune checkpoint inhibitor therapy, and the like. For example, modulating one or more biomarkers encompassed by the present invention may overcome resistance to immune checkpoint inhibitor therapy.

In some embodiments, the subjects are in need of modulation according to compositions and methods described herein, such as having been identified as having an unwanted absence, presence, or aberrant HPV16 E7₁₁₋₁₉ expression.

a. Diagnostic Methods

In an aspect encompassed by the present invention, provided herein are diagnostic methods for detecting the presence or absence of an HPV16 E7₁₁₋₁₉ antigen and/or a cell of interest expressing HPV16 E7₁₁₋₁₉, comprising detecting the presence or absence of said HPV16 E7₁₁₋₁₉ antigen in a sample by use of at least one binding protein, or at least one host cell described herein. In some embodiments, the method further comprising obtaining the sample (*e.g.*, from a subject). In some embodiments, the at least one binding protein or the at least one host cell, forms a complex with an HPV16 E7₁₁₋₁₉ peptide epitope in the context of an MHC molecule, and the complex is detected in the form of fluorescence activated cell sorting (FACS), enzyme linked immunosorbent assay (ELISA), radioimmune assay (RIA), immunochemically, Western blot, or intracellular flow assay.

In an aspect encompassed by the present invention, provided herein are diagnostic methods for detecting the level of a non-malignant disorder, a hyperproliferative disorder, or a relapse of a hyperproliferative disorder characterized by expression of an HPV16 E7₁₁₋₁₉ antigen in a subject, comprising: a) contacting a sample obtained from the subject with at least one binding protein, at least one host cell, or a population of host cells described herein; and b) detecting the level of reactivity, wherein a higher level of reactivity compared to a control level indicates that the level of a non-malignant disorder, a

hyperproliferative disorder, or a relapse of a hyperproliferative disorder characterized by expression of an HPV16 E7₁₁₋₁₉ antigen in the subject.

In some embodiments, the level of reactivity is indicated by T cell activation or effector function, such as, but not limited to, T cell proliferation, killing, or cytokine release. The control level may be a reference number or a level of a healthy subject who has no exposure to a non-alignant disorder, a hyperproliferative disorder, or a relapse of a hyperproliferative disorder characterized by expression of an HPV16 E7₁₁₋₁₉ antigen.

A biological sample may be obtained from a subject for determining the presence and level of an immune response to a peptide antigen (*e.g.*, an HPV16 E7₁₁₋₁₉ antigen) as described herein. A “biological sample” as used herein may be a blood sample (from which serum or plasma may be prepared), biopsy specimen, body fluids (*e.g.*, blood, isolated PBMCs, isolated T cells, lung lavage, ascites, mucosal washings, synovial fluid, *etc.*), bone marrow, lymph nodes, tissue explant, organ culture, or any other tissue or cell preparation from the subject or a biological source. Biological samples may also be obtained from the subject prior to receiving any pharmaceutical composition, which biological sample is useful as a control for establishing baseline data.

Antigen-specific T cell responses are typically determined by comparisons of observed T cell responses according to any of the herein described T cell functional parameters (*e.g.*, proliferation, cytokine release, CTL activity, altered cell surface marker phenotype, *etc.*) that may be made between T cells that are exposed to a cognate antigen in an appropriate context (*e.g.*, the antigen used to prime or activate the T cells, when presented by immunocompatible antigen-presenting cells) and T cells from the same source population that are exposed instead to a structurally distinct or irrelevant control antigen. A response to the cognate antigen that is greater, with statistical significance, than the response to the control antigen signifies antigen-specificity.

The level of an immune response, such as a cytotoxic T lymphocyte (CTL) immune response may be determined by any one of numerous immunological methods described herein and routinely practiced in the art. For example, the level of a CTL immune response may be determined prior to and following administration of any one of the herein described binding proteins expressed by, for example, a T cell. Cytotoxicity assays for determining CTL activity may be performed using any one of several techniques and methods routinely practiced in the art (*e.g.*, Henkart *et al.*, "Cytotoxic T-Lymphocytes" in *Fundamental*

Immunology, Paul (ed.) (2003 Lippincott Williams & Wilkins, Philadelphia, PA), pages 1127-50, and references cited therein).

The present invention provides, in part, methods, systems, and code for accurately classifying whether a biological sample is associated with an output of interest, such as expression of a target of interest, such as HPV16 E7₁₁₋₁₉. In some embodiments, the present invention is useful for classifying a sample (*e.g.*, from a subject) as associated with or at risk for responding to or not responding to therapy for a disorder characterized by HPV16 E7₁₁₋₁₉ expression using a statistical algorithm and/or empirical data.

An exemplary method for detecting the amount or activity of HPV16 E7₁₁₋₁₉, and thus useful for classifying whether a sample is likely or unlikely to respond to a therapy for a disorder characterized by HPV16 E7₁₁₋₁₉ expression involves contacting a biological sample with an agent, such as an HPV16 E7₁₁₋₁₉ immunogenic peptide or binding agent described herein, capable of detecting the amount or activity of HPV16 E7₁₁₋₁₉ in the biological sample. In some embodiments, the method further comprises obtaining a biological sample, such as from a test subject. In some embodiments, at least one agent is used, wherein two, three, four, five, six, seven, eight, nine, ten, or more such agents may be used in combination (*e.g.*, in sandwich ELISAs) or in serial. In certain instances, the statistical algorithm is a single learning statistical classifier system. For example, a single learning statistical classifier system may be used to classify a sample as a based upon a prediction or probability value and the presence or level of the biomarker. The use of a single learning statistical classifier system typically classifies the sample with a sensitivity, specificity, positive predictive value, negative predictive value, and/or overall accuracy of at least about 75%, 76%, 77%, 78%, 79%, 80%, 81%, 82%, 83%, 84%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, or 99%.

Other suitable statistical algorithms are well-known to those of skill in the art. For example, learning statistical classifier systems include a machine learning algorithmic technique capable of adapting to complex data sets (*e.g.*, panel of markers of interest) and making decisions based upon such data sets. In some embodiments, a single learning statistical classifier system such as a classification tree (*e.g.*, random forest) is used. In other embodiments, a combination of 2, 3, 4, 5, 6, 7, 8, 9, 10, or more learning statistical classifier systems are used, preferably in tandem. Examples of learning statistical classifier systems include, but are not limited to, those using inductive learning (*e.g.*, decision/classification trees such as random forests, classification and regression trees

(C&RT), boosted trees, etc.), Probably Approximately Correct (PAC) learning, connectionist learning (*e.g.*, neural networks (NN), artificial neural networks (ANN), neuro fuzzy networks (NFN), network structures, perceptrons such as multi-layer perceptrons, multi-layer feed-forward networks, applications of neural networks, Bayesian learning in belief networks, etc.), reinforcement learning (*e.g.*, passive learning in a known environment such as naive learning, adaptive dynamic learning, and temporal difference learning, passive learning in an unknown environment, active learning in an unknown environment, learning action-value functions, applications of reinforcement learning, etc.), and genetic algorithms and evolutionary programming. Other learning statistical classifier systems include support vector machines (*e.g.*, Kernel methods), multivariate adaptive regression splines (MARS), Levenberg-Marquardt algorithms, Gauss-Newton algorithms, mixtures of Gaussians, gradient descent algorithms, and learning vector quantization (LVQ). In certain embodiments, the method encompassed by the present invention further comprises sending the sample classification results to a clinician, *e.g.*, an oncologist.

In some embodiments, the diagnosis of a subject (*e.g.*, including HLA typing and/or loss of heterozygosity (LOH) to determine compatibility with TCR-HLA complex binding by TCRs of interest) is followed by administering to the individual a therapeutically effective amount of a defined treatment based upon the diagnosis.

In some embodiments, the methods further involve obtaining a control biological sample (*e.g.*, biological sample from a subject who does not have a disorder characterized by HPV16 E7₁₁₋₁₉ expression, a subject who is in remission, a subject whose disorder is susceptible to therapy, a subject whose disorder is progressing, or other subjects of interest).

In some embodiments of analytical methods described herein, HPV16 E7₁₁₋₁₉ expression (*e.g.*, in a sample from a subject) is compared to a pre-determined control (standard) sample. The sample from the subject is typically from a diseased tissue, such as cancer cells or tissues. The control sample may be from the same subject or from a different subject. The control sample is typically a normal, non-diseased sample. However, in some embodiments, such as for staging of disease or for evaluating the efficacy of treatment, the control sample may be from a diseased tissue. The control sample may be a combination of samples from several different subjects. In some embodiments, the HPV16 E7₁₁₋₁₉ expression measurement(s) from a subject is compared to a pre-determined level. This pre-determined level is typically obtained from normal samples. As described herein, a “pre-determined” expression may be used to, by way of

example only, evaluate a subject that may be selected for treatment, evaluate a response to cancer, and/or evaluate a response to a combination cancer therapy. A pre-determined biomarker amount and/or activity measurement(s) may be determined in populations of patients with or without a disorder characterized by HPV16 E7₁₁₋₁₉ expression. The pre-determined biomarker amount and/or activity measurement(s) may be a single number, equally applicable to every patient, or the pre-determined biomarker amount and/or activity measurement(s) may vary according to specific sub-populations of patients. Age, weight, height, and other factors of a subject may affect the pre-determined biomarker amount and/or activity measurement(s) of the individual. Furthermore, the pre-determined biomarker amount and/or activity may be determined for each subject individually. In one embodiment, the amounts determined and/or compared in a method described herein are based on absolute measurements.

In another embodiment, the amounts determined and/or compared in a method described herein are based on relative measurements, such as ratios (*e.g.*, biomarker copy numbers, level, and/or activity before a treatment vs. after a treatment, such biomarker measurements relative to a spiked or man-made control, such biomarker measurements relative to the expression of a housekeeping gene, and the like). For example, the relative analysis may be based on the ratio of pre-treatment biomarker measurement as compared to post-treatment biomarker measurement. Pre-treatment biomarker measurement may be made at any time prior to initiation of a therapy. Post-treatment biomarker measurement may be made at any time after initiation of therapy. In some embodiments, post-treatment biomarker measurements are made 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20 weeks or more after initiation of therapy, and even longer toward indefinitely for continued monitoring. Treatment may comprise therapy to treat the disorder characterized by HPV16 E7₁₁₋₁₉ expression, either alone or in combination with other agents, such as anti-cancer agents like chemotherapy or immune checkpoint inhibitors.

The pre-determined HPV16 E7₁₁₋₁₉ expression may be any suitable standard. For example, the pre-determined HPV16 E7₁₁₋₁₉ expression may be obtained from the same or a different subject for whom a subject selection is being assessed. In one embodiment, the pre-determined biomarker amount and/or activity measurement(s) may be obtained from a previous assessment of the same patient. In such a manner, the progress of the selection of the patient may be monitored over time. In addition, the control may be obtained from an assessment of another human or multiple humans, *e.g.*, selected groups of humans, if the

subject is a human. In such a manner, the extent of the selection of the human for whom selection is being assessed may be compared to suitable other humans, *e.g.*, other humans who are in a similar situation to the human of interest, such as those suffering from similar or the same condition(s) and/or of the same ethnic group.

In some embodiments, the change of HPV16 E7₁₁₋₁₉ expression from the pre-determined level is about 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, or 5.0 fold or greater, or any range in between, inclusive. Such cut-off values apply equally when the measurement is based on relative changes, such as based on the ratio of pre-treatment biomarker measurement as compared to post-treatment biomarker measurement.

In some embodiments, HPV16 E7₁₁₋₁₉ expression may be detected and/or quantified by detecting or quantifying HPV16 E7₁₁₋₁₉ polypeptide or antigen thereof, such as by using a composition described herein. The polypeptide may be detected and quantified by any of a number of means well-known to those of skill in the art, such as by immunodiffusion, immunoelectrophoresis, radioimmunoassay (RIA), enzyme-linked immunosorbent assays (ELISAs), immunofluorescent assays, Western blotting, binder-ligand assays, immunohistochemical techniques, agglutination, complement assays, high performance liquid chromatography (HPLC), thin layer chromatography (TLC), hyperdiffusion chromatography, and the like (*e.g.*, Basic and Clinical Immunology, Sites and Terr, eds., Appleton and Lange, Norwalk, Conn. pp 217-262, 1991).

b. Therapeutic Methods

In an aspect encompassed by the present invention, provided herein are methods for preventing and/or treating a non-malignant disorder, a hyperproliferative disorder, or a relapse of a hyperproliferative disorder characterized by expression of an HPV16 E7₁₁₋₁₉ antigen, and/or for inducing an immune response against a cell of interest, such as a hyperproliferative cell, expressing an HPV16 E7₁₁₋₁₉ antigen, such as by infection with an HPV strain like HPV16. In some embodiments, the method comprises administering to a subject a therapeutically effective amount of a composition comprising cells expressing at least one binding protein described herein. The methods encompassed by the present invention also may be used to determine the responsiveness to therapy for many different disorders characterized by HPV16 E7₁₁₋₁₉ expression in subjects, such as those described herein.

In some embodiments, the disorder characterized by MAGEA1 expression is a cancer. The terms “cancer” or “tumor” or “hyperproliferative” refer to the presence of cells possessing characteristics typical of cancer-causing cells, such as uncontrolled proliferation, immortality, invasive or metastatic potential, rapid growth, and certain characteristic morphological features. In some embodiments, such cells exhibit such characteristics in part or in full due to the expression and activity of immune checkpoint proteins, such as PD-1, PD-L1, PD-L2, and/or CTLA-4.

Cancer cells are often in the form of a tumor, but such cells may exist alone within an animal, or may be a non-tumorigenic cancer cell, such as in a hematologic cancer like leukemia. As used herein, the term “cancer” includes premalignant as well as malignant cancers. Cancers include, but are not limited to, a variety of cancers, carcinoma including that of the bladder (including accelerated and metastatic bladder cancer), breast, colon (including colorectal cancer), kidney, liver, lung (including small and non-small cell lung cancer and lung adenocarcinoma), ovary, prostate, testes, genitourinary tract, lymphatic system, rectum, larynx, pancreas (including exocrine pancreatic carcinoma), esophagus, stomach, gall bladder, cervix, thyroid, and skin (including squamous cell carcinoma); hematopoietic tumors of lymphoid lineage including leukemia, acute lymphocytic leukemia, acute lymphoblastic leukemia, B-cell lymphoma, T-cell lymphoma, Hodgkins lymphoma, non-Hodgkins lymphoma, hairy cell lymphoma, histiocytic lymphoma, and Burketts lymphoma; hematopoietic tumors of myeloid lineage including acute and chronic myelogenous leukemias, myelodysplastic syndrome, myeloid leukemia, and promyelocytic leukemia; tumors of the central and peripheral nervous system including astrocytoma, neuroblastoma, glioma, and schwannomas; tumors of mesenchymal origin including fibrosarcoma, rhabdomyosarcoma, and osteosarcoma; other tumors including melanoma, xenoderma pigmentosum, keratoactanthoma, seminoma, thyroid follicular cancer, and teratocarcinoma; melanoma, unresectable stage III or IV malignant melanoma, squamous cell carcinoma, small-cell lung cancer, non-small cell lung cancer, glioma, gastrointestinal cancer, renal cancer, ovarian cancer, liver cancer, colorectal cancer, endometrial cancer, kidney cancer, prostate cancer, thyroid cancer, neuroblastoma, pancreatic cancer, glioblastoma multiforme, cervical cancer, stomach cancer, bladder cancer, hepatoma, breast cancer, colon carcinoma, head and neck cancer, gastric cancer, germ cell tumor, bone cancer, bone tumors, adult malignant fibrous histiocytoma of bone; childhood, malignant fibrous histiocytoma of bone, sarcoma, pediatric sarcoma, sinonasal natural killer,

neoplasms, plasma cell neoplasm; myelodysplastic syndromes; neuroblastoma; testicular germ cell tumor, intraocular melanoma, myelodysplastic syndromes; myelodysplastic/myeloproliferative diseases, synovial sarcoma, chronic myeloid leukemia, acute lymphoblastic leukemia, Philadelphia chromosome positive acute lymphoblastic leukemia (Ph+ ALL), multiple myeloma, acute myelogenous leukemia, chronic lymphocytic leukemia, mastocytosis and any symptom associated with mastocytosis, and any metastasis thereof. In addition, disorders include urticaria pigmentosa, mastocytoses such as diffuse cutaneous mastocytosis, solitary mastocytoma in human, as well as dog mastocytoma and some rare subtypes like bullous, erythrodermic and teleangiectatic mastocytosis, mastocytosis with an associated hematological disorder, such as a myeloproliferative or myelodysplastic syndrome, or acute leukemia, myeloproliferative disorder associated with mastocytosis, mast cell leukemia, in addition to other cancers. Other cancers are also included within the scope of disorders including, but are not limited to, the following: carcinoma, including that of the bladder, urothelial carcinoma, breast, colon, kidney, liver, lung, ovary, pancreas, stomach, cervix, thyroid, testis, particularly testicular seminomas, and skin; including squamous cell carcinoma; gastrointestinal stromal tumors ("GIST"); hematopoietic tumors of lymphoid lineage, including leukemia, acute lymphocytic leukemia, acute lymphoblastic leukemia, B-cell lymphoma, T-cell lymphoma, Hodgkins lymphoma, non-Hodgkins lymphoma, hairy cell lymphoma and Burkett's lymphoma; hematopoietic tumors of myeloid lineage, including acute and chronic myelogenous leukemias and promyelocytic leukemia; tumors of mesenchymal origin, including fibrosarcoma and rhabdomyosarcoma; other tumors, including melanoma, seminoma, teratocarcinoma, neuroblastoma and glioma; tumors of the central and peripheral nervous system, including astrocytoma, neuroblastoma, glioma, and schwannomas; tumors of mesenchymal origin, including fibrosarcoma, rhabdomyosarcoma, and osteosarcoma; and other tumors, including melanoma, xenoderma pigmentosum, keratoactanthoma, seminoma, thyroid follicular cancer, teratocarcinoma, chemotherapy refractory non-seminomatous germ-cell tumors, and Kaposi's sarcoma, and any metastasis thereof. Other non-limiting examples of types of cancers applicable to the methods encompassed by the present invention include human sarcomas and carcinomas, *e.g.*, fibrosarcoma, myxosarcoma, liposarcoma, chondrosarcoma, osteogenic sarcoma, chordoma, angiosarcoma, endotheliosarcoma, lymphangiosarcoma, lymphangioendotheliosarcoma, synovioma, mesothelioma, Ewing's tumor,

leiomyosarcoma, rhabdomyosarcoma, squamous cell carcinoma, basal cell carcinoma, adenocarcinoma, sweat gland carcinoma, sebaceous gland carcinoma, papillary carcinoma, papillary adenocarcinomas, cystadenocarcinoma, medullary carcinoma, bronchogenic carcinoma, renal cell carcinoma, hepatoma, bile duct carcinoma, choriocarcinoma, seminoma, embryonal carcinoma, Wilms' tumor, bone cancer, brain tumor, lung carcinoma (including lung adenocarcinoma), small cell lung carcinoma, bladder carcinoma, epithelial carcinoma, glioma, astrocytoma, medulloblastoma, craniopharyngioma, ependymoma, pinealoma, hemangioblastoma, acoustic neuroma, oligodendroglioma, meningioma, melanoma, neuroblastoma, retinoblastoma; leukemias, *e.g.*, acute lymphocytic leukemia and acute myelocytic leukemia (myeloblastic, promyelocytic, myelomonocytic, monocytic and erythroleukemia); chronic leukemia (chronic myelocytic (granulocytic) leukemia and chronic lymphocytic leukemia); and polycythemia vera, lymphoma (Hodgkin's disease and non-Hodgkin's disease), multiple myeloma, Waldenstrom's macroglobulinemia, and heavy chain disease. In some embodiments, cancers are epithelial in nature and include but are not limited to, bladder cancer, breast cancer, cervical cancer, colon cancer, gynecologic cancers, renal cancer, laryngeal cancer, lung cancer, oral cancer, head and neck cancer, ovarian cancer, pancreatic cancer, prostate cancer, or skin cancer. In some embodiments, the epithelial cancer is non-small-cell lung cancer, nonpapillary renal cell carcinoma, cervical carcinoma, ovarian carcinoma (*e.g.*, serous ovarian carcinoma), or breast carcinoma. The epithelial cancers may be characterized in various other ways including, but not limited to, serous, endometrioid, mucinous, clear cell, Brenner, or undifferentiated. In some embodiments, the cancer is selected from the group consisting of (advanced) non-small cell lung cancer, melanoma, head and neck squamous cell cancer, (advanced) urothelial bladder cancer, (advanced) kidney cancer (RCC), microsatellite instability-high cancer, classical Hodgkin lymphoma, (advanced) gastric cancer, (advanced) cervical cancer, primary mediastinal B-cell lymphoma, (advanced) hepatocellular carcinoma, breast invasive carcinoma, bladder urothelial carcinoma, and (advanced) merkel cell carcinoma.

In addition, the compositions described herein may also be administered in combination therapy to further modulate a desired activity. Additional agents include, without limitations, chemotherapeutic agents, hormones, antiangiogens, radiolabelled, compounds, or with surgery, cryotherapy, and/or radiotherapy. The preceding treatment methods may be administered in conjunction with other forms of conventional therapy (*e.g.*, standard-of-care treatments for cancer well-known to the skilled artisan), either

consecutively with, pre- or post-conventional therapy. For example, these modulatory agents may be administered with a therapeutically effective dose of chemotherapeutic agent. In another embodiment, these modulatory agents are administered in conjunction with chemotherapy to enhance the activity and efficacy of the chemotherapeutic agent. The Physicians' Desk Reference (PDR) discloses dosages of chemotherapeutic agents that have been used in the treatment of various cancers. The dosing regimen and dosages of these aforementioned chemotherapeutic drugs that are therapeutically effective will depend on the particular melanoma, being treated, the extent of the disease and other factors familiar to the physician of skill in the art and may be determined by the physician.

Therapy using one or more compositions described herein, either alone or in combination with other therapies, such as cancer therapies, may be used to contact HPV16 E7₁₁₋₁₉-expressing cells and/or administered to a desired subject, such as a subject that is indicated as being a likely responder to therapy. In another embodiment, such therapy may be avoided once a subject is indicated as not being a likely responder to the therapy (*e.g.*, as assessed according to a diagnostic or prognostic method described herein) and an alternative treatment regimen, such as targeted and/or untargeted cancer therapies, may be recommended and/or administered.

The term "targeted therapy" refers to administration of agents that selectively interact with a chosen biomolecule to thereby treat cancer. For example, targeted therapy regarding the inhibition of immune checkpoint inhibitor is useful in combination with the methods encompassed by the present invention.

The term "immunotherapy" or "immunotherapies" generally refers to any strategy for modulating an immune response in a beneficial manner and encompasses the treatment of a subject afflicted with, or at risk of contracting or suffering a recurrence of, a disease by a method comprising inducing, enhancing, suppressing or otherwise modifying an immune response, as well as any treatment that uses certain parts of a subject's immune system to fight diseases, such as cancer. The subject's own immune system is stimulated (or suppressed), with or without administration of one or more agent for that purpose. Immunotherapies that are designed to elicit or amplify an immune response are referred to as "activation immunotherapies." Immunotherapies that are designed to reduce or suppress an immune response are referred to as "suppression immunotherapies." In some embodiments, an immunotherapy is specific for cells of interest, such as cancer cells. In some embodiments, immunotherapy may be "untargeted," which refers to administration of

agents that do not selectively interact with immune system cells, yet modulates immune system function. Representative examples of untargeted therapies include, without limitation, chemotherapy, gene therapy, and radiation therapy.

Some forms of immunotherapy are targeted therapies that may comprise, for example, the use of cancer vaccines and/or sensitized antigen presenting cells. For example, an oncolytic virus is a virus that is able to infect and lyse cancer cells, while leaving normal cells unharmed, making them potentially useful in cancer therapy. Replication of oncolytic viruses both facilitates tumor cell destruction and also produces dose amplification at the tumor site. They may also act as vectors for anticancer genes, allowing them to be specifically delivered to the tumor site. The immunotherapy may involve passive immunity for short-term protection of a host, achieved by the administration of pre-formed antibody directed against a cancer antigen or disease antigen (*e.g.*, administration of a monoclonal antibody, optionally linked to a chemotherapeutic agent or toxin, to a tumor antigen). Immunotherapy may also focus on using the cytotoxic lymphocyte-recognized epitopes of cancer cell lines. Alternatively, antisense polynucleotides, ribozymes, RNA interference molecules, triple helix polynucleotides and the like, may be used to selectively modulate biomolecules that are linked to the initiation, progression, and/or pathology of a tumor or cancer. Similarly, immunotherapy may take the form of cell-based therapies. For example, adoptive cellular immunotherapy is a type of immunotherapy using immune cells, such as T cells, that have a natural or genetically engineered reactivity to a patient's cancer are generated and then transferred back into the cancer patient. The injection of a large number of activated tumor-specific T cells may induce complete and durable regression of cancers.

Immunotherapy may involve passive immunity for short-term protection of a host, achieved by the administration of pre-formed antibody directed against a cancer antigen or disease antigen (*e.g.*, administration of a monoclonal antibody, optionally linked to a chemotherapeutic agent or toxin, to a tumor antigen). Immunotherapy may also focus on using the cytotoxic lymphocyte-recognized epitopes of cancer cell lines. Alternatively, antisense polynucleotides, ribozymes, RNA interference molecules, triple helix polynucleotides and the like, may be used to selectively modulate biomolecules that are linked to the initiation, progression, and/or pathology of a tumor or cancer.

In some embodiments, an immunotherapeutic agent is an agonist of an immune-stimulatory molecule; an antagonist of an immune-inhibitory molecule; an antagonist of a

chemokine; an agonist of a cytokine that stimulates T cell activation; an agent that antagonizes or inhibits a cytokine that inhibits T cell activation; and/or an agent that binds to a membrane bound protein of the B7 family. In some embodiments, the immunotherapeutic agent is an antagonist of an immune-inhibitory molecule. In some embodiments, the immunotherapeutic agents may be agents for cytokines, chemokines and growth factors, for examples, neutralizing antibodies that neutralize the inhibitory effect of tumor associated cytokines, chemokines, growth factors and other soluble factors, including IL-10, TGF- β and VEGF.

In some embodiments, immunotherapy comprises inhibitors of one or more immune checkpoints. The term “immune checkpoint” refers to a group of molecules on the cell surface of CD4+ and/or CD8+ T cells that fine-tune immune responses by modulating anti-cancer immune responses, such as down-modulating or inhibiting an anti-tumor immune response. Immune checkpoint proteins are well-known in the art and include, without limitation, CTLA-4, PD-1, VISTA, B7-H2, B7-H3, PD-L1, B7-H4, B7-H6, ICOS, HVEM, PD-L2, CD200R, CD160, gp49B, PIR-B, KIRLG-1, KIR family receptors, TIM-1, TIM-3, TIM-4, LAG-3 (CD223), IDO, GITR, 4-1BB, OX-40, BTLA, SIRPalpha (CD47), CD48, 2B4 (CD244), B7.1, B7.2, ILT-2, ILT-4, TIGIT, HHLA2, butyrophilins, and A2aR (see, for example, WO 2012/177624). The term further encompasses biologically active protein fragments, as well as nucleic acids encoding full-length immune checkpoint proteins.

Some immune checkpoints are “immune-inhibitory immune checkpoints” encompassing molecules (*e.g.*, proteins) that inhibit, down-regulate, or suppress a function of the immune system (*e.g.*, an immune response). For example, PD-L1 (programmed death-ligand 1), also known as CD274 or B7-H1, is a protein that transmits an inhibitory signal that reduces proliferation of T cells to suppress the immune system. CTLA-4 (cytotoxic T-lymphocyte-associated protein 4), also known as CD152, is a protein receptor on the surface of antigen-presenting cells that serves as an immune checkpoint (“off” switch) to downregulate immune responses. TIM-3 (T-cell immunoglobulin and mucin-domain containing-3), also known as HAVCR2, is a cell surface protein that serves as an immune checkpoint to regulate macrophage activation. VISTA (V-domain Ig suppressor of T cell activation) is a type I transmembrane protein that functions as an immune checkpoint to inhibit T cell effector function and maintain peripheral tolerance. LAG-3 (lymphocyte-activation gene 3) is an immune checkpoint receptor that negatively regulates proliferation, activation, and homeostasis of T cells. BTLA (B- and T-lymphocyte attenuator) is a protein

that displays T cell inhibition via interactions with tumor necrosis family receptors (TNF-R). KIR (killer-cell immunoglobulin-like receptor) is a family of proteins expressed on NK cells, and a minority of T cells, that suppress the cytotoxic activity of NK cells. In some embodiments, immunotherapeutic agents may be agents specific to immunosuppressive enzymes such as inhibitors that may block the activities of arginase (ARG) and indoleamine 2,3-dioxygenase (IDO), an immune checkpoint protein that suppresses T cells and NK cells, which change the catabolism of the amino acids arginine and tryptophan in the immunosuppressive tumor microenvironment. The inhibitors may include, but are not limited to, *N*-hydroxy-L-Arg (NOHA) targeting to ARG-expressing M2 macrophages, nitroaspirin or sildenafil (Viagra®), which blocks ARG and nitric oxide synthase (NOS) simultaneously; and IDO inhibitors, such as 1-methyl-tryptophan. The term further encompasses biologically active protein fragment, as well as nucleic acids encoding full-length immune checkpoint proteins and biologically active protein fragments thereof. In some embodiment, the term further encompasses any fragment according to homology descriptions provided herein.

By contrast, other immune checkpoints are “immune-stimulatory” encompassing molecules (*e.g.*, proteins) that activate, stimulate, or promote a function of the immune system (*e.g.*, an immune response). In some embodiments, the immune-stimulatory molecule is CD28, CD80 (B7.1), CD86 (B7.2), 4-1BB (CD137), 4-1BBL (CD137L), CD27, CD70, CD40, CD40L, CD122, CD226, CD30, CD30L, OX40, OX40L, HVEM, BTLA, GITR and its ligand GITRL, LIGHT, LT β R, LT $\alpha\beta$, ICOS (CD278), ICOSL (B7-H2), and NKG2D. CD40 (cluster of differentiation 40) is a costimulatory protein found on antigen presenting cells that is required for their activation. OX40, also known as tumor necrosis factor receptor superfamily member 4 (TNFRSF4) or CD134, is involved in maintenance of an immune response after activation by preventing T-cell death and subsequently increasing cytokine production. CD137 is a member of the tumor necrosis factor receptor (TNF-R) family that co-stimulates activated T cells to enhance proliferation and T cell survival. CD122 is a subunit of the interleukin-2 receptor (IL-2) protein, which promotes differentiation of immature T cells into regulatory, effector, or memory T cells. CD27 is a member of the tumor necrosis factor receptor superfamily and serves as a co-stimulatory immune checkpoint molecule. CD28 (cluster of differentiation 28) is a protein expressed on T cells that provides co-stimulatory signals required for T cell activation and survival. GITR (glucocorticoid-induced TNFR-related protein), also known as TNFRSF18

and AITR, is a protein that plays a key role in dominant immunological self-tolerance maintained by regulatory T cells. ICOS (inducible T-cell co-stimulator), also known as CD278, is a CD28-superfamily costimulatory molecule that is expressed on activated T cells and play a role in T cell signaling and immune responses.

Immune checkpoints and their sequences are well-known in the art and representative embodiments are described further below. Immune checkpoints generally relate to pairs of inhibitory receptors and the natural binding partners (*e.g.*, ligands). For example, PD-1 polypeptides are inhibitory receptors capable of transmitting an inhibitory signal to an immune cell to thereby inhibit immune cell effector function, or are capable of promoting costimulation (*e.g.*, by competitive inhibition) of immune cells, *e.g.*, when present in soluble, monomeric form. Preferred PD-1 family members share sequence identity with PD-1 and bind to one or more B7 family members, *e.g.*, B7-1, B7-2, PD-1 ligand, and/or other polypeptides on antigen presenting cells. The term “PD-1 activity,” includes the ability of a PD-1 polypeptide to modulate an inhibitory signal in an activated immune cell, *e.g.*, by engaging a natural PD-1 ligand on an antigen presenting cell. Modulation of an inhibitory signal in an immune cell results in modulation of proliferation of, and/or cytokine secretion by, an immune cell. Thus, the term “PD-1 activity” includes the ability of a PD-1 polypeptide to bind its natural ligand(s), the ability to modulate immune cell inhibitory signals, and the ability to modulate the immune response. The term “PD-1 ligand” refers to binding partners of the PD-1 receptor and includes both PD-L1 (Freeman *et al.* (2000) *J. Exp. Med.* 192:1027-1034) and PD-L2 (Latchman *et al.* (2001) *Nat. Immunol.* 2:261). The term “PD-1 ligand activity” includes the ability of a PD-1 ligand polypeptide to bind its natural receptor(s) (*e.g.*, PD-1 or B7-1), the ability to modulate immune cell inhibitory signals, and the ability to modulate the immune response.

As used herein, the term “immune checkpoint therapy” refers to the use of agents that inhibit immune-inhibitory immune checkpoints, such as inhibiting their nucleic acids and/or proteins. Inhibition of one or more such immune checkpoints may block or otherwise neutralize inhibitory signaling to thereby upregulate an immune response in order to more efficaciously treat cancer. Exemplary agents useful for inhibiting immune checkpoints include antibodies, small molecules, peptides, peptidomimetics, natural ligands, and derivatives of natural ligands, that may either bind and/or inactivate or inhibit immune checkpoint proteins, or fragments thereof; as well as RNA interference, antisense, nucleic acid aptamers, etc. that may downregulate the expression and/or activity of immune

checkpoint nucleic acids, or fragments thereof. Exemplary agents for upregulating an immune response include antibodies against one or more immune checkpoint proteins that block the interaction between the proteins and its natural receptor(s); a non-activating form of one or more immune checkpoint proteins (*e.g.*, a dominant negative polypeptide); small molecules or peptides that block the interaction between one or more immune checkpoint proteins and its natural receptor(s); fusion proteins (*e.g.*, the extracellular portion of an immune checkpoint inhibition protein fused to the Fc portion of an antibody or immunoglobulin) that bind to its natural receptor(s); nucleic acid molecules that block immune checkpoint nucleic acid transcription or translation; and the like. Such agents may directly block the interaction between the one or more immune checkpoints and its natural receptor(s) (*e.g.*, antibodies) to prevent inhibitory signaling and upregulate an immune response. Alternatively, agents may indirectly block the interaction between one or more immune checkpoint proteins and its natural receptor(s) to prevent inhibitory signaling and upregulate an immune response. For example, a soluble version of an immune checkpoint protein ligand such as a stabilized extracellular domain may binding to its receptor to indirectly reduce the effective concentration of the receptor to bind to an appropriate ligand. In one embodiment, anti-PD-1 antibodies, anti-PD-L1 antibodies, and/or anti-PD-L2 antibodies, either alone or in combination, are used to inhibit immune checkpoints. Therapeutic agents used for blocking the PD-1 pathway include antagonistic antibodies and soluble PD-L1 ligands. The antagonist agents against PD-1 and PD-L1/2 inhibitory pathway may include, but are not limited to, antagonistic antibodies to PD-1 or PD-L1/2 (*e.g.*, 17D8, 2D3, 4H1, 5C4 (also known as nivolumab or BMS-936558), 4A11, 7D3 and 5F4 disclosed in U.S. Pat. No. 8,008,449; AMP-224, pidilizumab (CT-011), pembrolizumab, and antibodies disclosed in U.S. Pat. Numbers 8,779,105; 8,552,154; 8,217,149; 8,168,757; 8,008,449; 7,488,802; 7,943,743; 7,635,757; and 6,808,710. Similarly, additional representative checkpoint inhibitors may be, but are not limited to, antibodies against inhibitory regulator CTLA-4 (anti-cytotoxic T-lymphocyte antigen 4 anti-cytotoxic T-lymphocyte antigen 4), such as ipilimumab, tremelimumab (fully humanized), anti-CD28 antibodies, anti-CTLA-4 adnectins, anti-CTLA-4 domain antibodies, single chain anti-CTLA-4 antibody fragments, heavy chain anti-CTLA-4 fragments, light chain anti-CTLA-4 fragments, and other antibodies, such as those disclosed in U.S. Pat. Numbers 8,748, 815; 8,529,902; 8,318,916; 8,017,114; 7,744,875; 7,605,238; 7,465,446; 7,109,003; 7,132,281; 6,984,720; 6,682,736; 6,207,156; and 5,977,318, as well

as EP Pat. No. 1212422, U.S. Pat Publ. Numbers 2002/0039581 and 2002/086014, and Hurwitz *et al.* (1998) *Proc. Natl. Acad. Sci. U.S.A.* 95:10067-10071.

The representative definitions of immune checkpoint activity, ligand, blockade, and the like exemplified for PD-1, PD-L1, PD-L2, and CTLA-4 apply generally to other immune checkpoints.

The term “untargeted therapy” refers to administration of agents that do not selectively interact with a chosen biomolecule yet treat cancer. Representative examples of untargeted therapies include, without limitation, chemotherapy, gene therapy, and radiation therapy.

In one embodiment, chemotherapy is used. Chemotherapy includes the administration of a chemotherapeutic agent. Such a chemotherapeutic agent may be, but is not limited to, those selected from among the following groups of compounds: platinum compounds, cytotoxic antibiotics, antimetabolites, anti-mitotic agents, alkylating agents, arsenic compounds, DNA topoisomerase inhibitors, taxanes, nucleoside analogues, plant alkaloids, and toxins; and synthetic derivatives thereof. Exemplary agents include, but are not limited to, alkylating agents: nitrogen mustards (*e.g.*, cyclophosphamide, ifosfamide, trofosfamide, chlorambucil, estramustine, and melphalan), nitrosoureas (*e.g.*, carmustine (BCNU) and lomustine (CCNU)), alkylsulphonates (*e.g.*, busulfan and treosulfan), triazenes (*e.g.*, dacarbazine, temozolomide), cisplatin, treosulfan, and trofosfamide; plant alkaloids: vinblastine, paclitaxel, docetaxol; DNA topoisomerase inhibitors: teniposide, crisanolol, and mitomycin; anti-folates: methotrexate, mycophenolic acid, and hydroxyurea; pyrimidine analogs: 5-fluorouracil, doxifluridine, and cytosine arabinoside; purine analogs: mercaptopurine and thioguanine; DNA antimetabolites: 2'-deoxy-5-fluorouridine, aphidicolin glycinate, and pyrazoloimidazole; and antimitotic agents: halichondrin, colchicine, and rhizoxin. Similarly, additional exemplary agents including platinum-containing compounds (*e.g.*, cisplatin, carboplatin, oxaliplatin), vinca alkaloids (*e.g.*, vincristine, vinblastine, vindesine, and vinorelbine), taxoids (*e.g.*, paclitaxel or a paclitaxel equivalent such as nanoparticle albumin-bound paclitaxel (ABRAXANE), docosahexaenoic acid bound-paclitaxel (DHA-paclitaxel, Taxoprexin), polyglutamate bound-paclitaxel (PG-paclitaxel, paclitaxel poliglumex, CT-2103, XYOTAX), the tumor-activated prodrug (TAP) ANG1005 (Angiopep-2 bound to three molecules of paclitaxel), paclitaxel-EC-1 (paclitaxel bound to the erbB2-recognizing peptide EC-1), and glucose-conjugated paclitaxel, *e.g.*, 2'-paclitaxel methyl 2-glucopyranosyl succinate; docetaxel, taxol), epipodophyllins (*e.g.*,

etoposide, etoposide phosphate, teniposide, topotecan, 9-aminocamptothecin, camptoirinotecan, irinotecan, crisnatol, mytomyacin C), anti-metabolites, DHFR inhibitors (*e.g.*, methotrexate, dichloromethotrexate, trimetrexate, edatrexate), IMP dehydrogenase inhibitors (*e.g.*, mycophenolic acid, tiazofurin, ribavirin, and EICAR), ribonucleotide reductase inhibitors (*e.g.*, hydroxyurea and deferoxamine), uracil analogs (*e.g.*, 5-fluorouracil (5-FU), floxuridine, doxifluridine, ratitrexed, tegafur-uracil, capecitabine), cytosine analogs (*e.g.*, cytarabine (ara C), cytosine arabinoside, and fludarabine), purine analogs (*e.g.*, mercaptopurine and Thioguanine), Vitamin D3 analogs (*e.g.*, EB 1089, CB 1093, and KH 1060), isoprenylation inhibitors (*e.g.*, lovastatin), dopaminergic neurotoxins (*e.g.*, 1-methyl-4-phenylpyridinium ion), cell cycle inhibitors (*e.g.*, staurosporine), actinomycin (*e.g.*, actinomycin D, dactinomycin), bleomycin (*e.g.*, bleomycin A2, bleomycin B2, peplomycin), anthracycline (*e.g.*, daunorubicin, doxorubicin, pegylated liposomal doxorubicin, idarubicin, epirubicin, pirarubicin, zorubicin, mitoxantrone), MDR inhibitors (*e.g.*, verapamil), Ca²⁺ ATPase inhibitors (*e.g.*, thapsigargin), imatinib, thalidomide, lenalidomide, tyrosine kinase inhibitors (*e.g.*, axitinib (AG013736), bosutinib (SKI-606), cediranib (RECENTINTM, AZD2171), dasatinib (SPRYCEL®, BMS-354825), erlotinib (TARCEVA®), gefitinib (IRESSA®), imatinib (Gleevec®, CGP57148B, STI-571), lapatinib (TYKERB®, TYVERB®), lestaurtinib (CEP-701), neratinib (HKI-272), nilotinib (TASIGNA®), semaxanib (semaxinib, SU5416), sunitinib (SUTENT®, SU11248), toceranib (PALLADIA®), vandetanib (ZACTIMA®, ZD6474), vatalanib (PTK787, PTK/ZK), trastuzumab (HERCEPTIN®), bevacizumab (AVASTIN®), rituximab (RITUXAN®), cetuximab (ERBITUX®), panitumumab (VECTIBIX®), ranibizumab (Lucentis®), nilotinib (TASIGNA®), sorafenib (NEXAVAR®), everolimus (AFINITOR®), alemtuzumab (CAMPATH®), gemtuzumab ozogamicin (MYLOTARG®), temsirolimus (TORISEL®), ENMD-2076, PCI-32765, AC220, dovitinib lactate (TKI258, CHIR-258), BIBW 2992 (TOVOKTM), SGX523, PF-04217903, PF-02341066, PF-299804, BMS-777607, ABT-869, MP470, BIBF 1120 (VARGATEF®), AP24534, JNJ-26483327, MGCD265, DCC-2036, BMS-690154, CEP-11981, tivozanib (AV-951), OSI-930, MM-121, XL-184, XL-647, and/or XL228), proteasome inhibitors (*e.g.*, bortezomib (VELCADE®)), mTOR inhibitors (*e.g.*, rapamycin, temsirolimus (CCI-779), everolimus (RAD-001), ridaforolimus, AP23573 (Ariad), AZD8055 (AstraZeneca), BEZ235 (Novartis), BGT226 (Novartis), XL765 (Sanofi Aventis), PF-4691502 (Pfizer), GDC0980 (Genentech), SF1126 (Semafoe) and OSI-027 (OSI)), oblimersen, gemcitabine,

carminomycin, leucovorin, pemetrexed, cyclophosphamide, dacarbazine, procarbazine, prednisolone, dexamethasone, campathecin, plicamycin, asparaginase, aminopterin, methopterin, porfiromycin, melphalan, leurosidine, leurosine, chlorambucil, trabectedin, procarbazine, discodermolide, carminomycin,, aminopterin, and hexamethyl melamine. Compositions comprising one or more chemotherapeutic agents (*e.g.*, FLAG, CHOP) may also be used. FLAG comprises fludarabine, cytosine arabinoside (Ara-C) and G-CSF. CHOP comprises cyclophosphamide, vincristine, doxorubicin, and prednisone. In another embodiment, PARP (*e.g.*, PARP-1 and/or PARP-2) inhibitors are used and such inhibitors are well-known in the art (*e.g.*, Olaparib, ABT-888, BSI-201, BGP-15 (N-Gene Research Laboratories, Inc.); INO-1001 (Inotek Pharmaceuticals Inc.); PJ34 (Soriano *et al.*, 2001; Pacher *et al.*, 2002b); 3-aminobenzamide (Trevigen); 4-amino-1,8-naphthalimide; (Trevigen); 6(5H)-phenanthridinone (Trevigen); benzamide (U.S. Pat. Re. 36,397); and NU1025 (Bowman *et al.*). The mechanism of action is generally related to the ability of PARP inhibitors to bind PARP and decrease its activity. PARP catalyzes the conversion of beta-nicotinamide adenine dinucleotide (NAD⁺) into nicotinamide and poly-ADP-ribose (PAR). Both poly (ADP-ribose) and PARP have been linked to regulation of transcription, cell proliferation, genomic stability, and carcinogenesis (Bouchard *et.al.* (2003) *Exp. Hematol.* 31:446-454); Herceg (2001) *Mut. Res.* 477:97-110). Poly(ADP-ribose) polymerase 1 (PARP1) is a key molecule in the repair of DNA single-strand breaks (SSBs) (de Murcia J. *et al.* (1997) *Proc. Natl. Acad. Sci. U.S.A.* 94:7303-7307; Schreiber *et al.* (2006) *Nat. Rev. Mol. Cell Biol.* 7:517-528; Wang *et al.* (1997) *Genes Dev.* 11:2347-2358). Knockout of SSB repair by inhibition of PARP1 function induces DNA double-strand breaks (DSBs) that may trigger synthetic lethality in cancer cells with defective homology-directed DSB repair (Bryant *et al.* (2005) *Nature* 434:913-917; Farmer *et al.* (2005) *Nature* 434:917-921). The foregoing examples of chemotherapeutic agents are illustrative and are not intended to be limiting.

In another embodiment, radiation therapy is used. The radiation used in radiation therapy may be ionizing radiation. Radiation therapy may also be gamma rays, X-rays, or proton beams. Examples of radiation therapy include, but are not limited to, external-beam radiation therapy, interstitial implantation of radioisotopes (I-125, palladium, iridium), radioisotopes such as strontium-89, thoracic radiation therapy, intraperitoneal P-32 radiation therapy, and/or total abdominal and pelvic radiation therapy. For a general overview of radiation therapy, see Hellman, Chapter 16: Principles of Cancer Management:

Radiation Therapy, 6th edition, 2001, DeVita *et al.*, eds., J. B. Lippencott Company, Philadelphia. The radiation therapy may be administered as external beam radiation or teletherapy wherein the radiation is directed from a remote source. The radiation treatment may also be administered as internal therapy or brachytherapy wherein a radioactive source is placed inside the body close to cancer cells or a tumor mass. Also encompassed is the use of photodynamic therapy comprising the administration of photosensitizers, such as hematoporphyrin and its derivatives, Vertoporphin (BPD-MA), phthalocyanine, photosensitizer Pc4, demethoxy-hypocrellin A; and 2BA-2-DMHA.

In another embodiment, hormone therapy is used. Hormonal therapeutic treatments may comprise, for example, hormonal agonists, hormonal antagonists (*e.g.*, flutamide, bicalutamide, tamoxifen, raloxifene, leuprolide acetate (LUPRON), LH-RH antagonists), inhibitors of hormone biosynthesis and processing, and steroids (*e.g.*, dexamethasone, retinoids, deltoids, betamethasone, cortisol, cortisone, prednisone, dehydrotestosterone, glucocorticoids, mineralocorticoids, estrogen, testosterone, progestins), vitamin A derivatives (*e.g.*, all-trans retinoic acid (ATRA)); vitamin D3 analogs; antigestagens (*e.g.*, mifepristone, onapristone), or antiandrogens (*e.g.*, cyproterone acetate).

In one aspect, provided herein is a method of eliciting in a subject an immune response to a cell that expresses an HPV16 E7₁₁₋₁₉ antigen. In some embodiments, the method comprises administering to the subject a pharmaceutical composition described herein, wherein the pharmaceutical composition, when administered to the subject, elicits an immune response to the cell that expresses an HPV16 E7₁₁₋₁₉ antigen.

In some embodiments, the immune response can include a cell-mediated immune response. A cellular immune response is a response that involves T cells and may be determined *in vitro*, *ex vivo*, or *in vivo*. For example, a general cellular immune response may be determined as the T cell proliferative activity in cells (*e.g.*, peripheral blood leukocytes (PBLs)) sampled from the subject at a suitable time following the administering of a pharmaceutical composition. Following incubation of *e.g.*, PBMCs with a stimulator for an appropriate period, [³H]thymidine incorporation may be determined. The subset of T cells that is proliferating may be determined using flow cytometry.

In another aspect encompassed by the present invention, the methods provided herein include administering to both human and non-human mammals as described above. Veterinary applications also are contemplated. In some embodiments, the subject may be any living organism in which an immune response may be elicited.

In some embodiments, the pharmaceutical composition may be administered at any time that is appropriate. For example, the administering may be conducted before or during treatment of a subject having a non-malignant disorder, a hyperproliferative disorder, or a relapse of a hyperproliferative disorder characterized by expression of an HPV16 E7₁₁₋₁₉ antigen, and continued after the non-malignant disorder, hyperproliferative disorder, or the relapse of a hyperproliferative disorder characterized by expression of an HPV16 E7₁₁₋₁₉ antigen becomes clinically undetectable. The administering also may be continued in a subject showing signs of recurrence.

In some embodiments, the pharmaceutical composition may be administered in a therapeutically or a prophylactically effective amount. Administering the pharmaceutical composition to the subject may be carried out using known procedures, and at dosages and for periods of time sufficient to achieve a desired effect.

In some embodiments, the pharmaceutical composition may be administered to the subject at any suitable site. Administration may be accomplished using methods generally known in the art. Agents, including cells, may be introduced to the desired site by direct injection, or by any other means used in the art including, but are not limited to, intravascular, intracerebral, parenteral, intraperitoneal, intravenous, epidural, intraspinal, intrasternal, intra-articular, intra-synovial, intrathecal, intra-arterial, intracardiac, or intramuscular administration. For example, subjects of interest may be engrafted with the transplanted cells by various routes. Such routes include, but are not limited to, intravenous administration, subcutaneous administration, administration to a specific tissue (*e.g.*, focal transplantation), injection into the femur bone marrow cavity, injection into the spleen, administration under the renal capsule of fetal liver, and the like. In certain embodiment, the cancer vaccine encompassed by the present invention is injected to the subject intratumorally or subcutaneously. Cells may be administered in one infusion, or through successive infusions over a defined time period sufficient to generate a desired effect. Exemplary methods for transplantation, engraftment assessment, and marker phenotyping analysis of transplanted cells are well-known in the art (see, for example, Pearson *et al.* (2008) *Curr. Protoc. Immunol.* 81:15.21.1-15.21.21; Ito *et al.* (2002) *Blood* 100:3175-3182; Traggiai *et al.* (2004) *Science* 304:104-107; Ishikawa *et al.* *Blood* (2005) 106:1565-1573; Shultz *et al.* (2005) *J. Immunol.* 174:6477-6489; and Holyoake *et al.* (1999) *Exp. Hematol.* 27:1418-1427). In some embodiments, the dose may be administered in an amount and for a period of time effective in bringing about a desired response, be it

eliciting the immune response or the prophylactic or therapeutic treatment of a non-malignant disorder, a hyperproliferative disorder, or a relapse of a hyperproliferative disorder characterized by expression of an HPV16 E7₁₁₋₁₉ antigen and/or symptoms associated therewith.

The pharmaceutical composition may be given subsequent to, preceding, or contemporaneously with other therapies including therapies that also elicit an immune response in the subject. For example, the subject may previously or concurrently be treated by other forms of immunomodulatory agents, such other therapies may be provided in such a way so as not to interfere with the immunogenicity of the compositions described herein.

Administering may be properly timed by the care giver (*e.g.*, physician, veterinarian), and may depend on the clinical condition of the subject, the objectives of administering, and/or other therapies also being contemplated or administered. In some embodiments, an initial dose may be administered, and the subject monitored for an immunological and/or clinical response. Suitable means of immunological monitoring include using patient's peripheral blood lymphocyte (PBL) as responders and immunogenic peptides or peptide-MHC complexes described herein as stimulators. An immunological reaction also may be determined by a delayed inflammatory response at the site of administering. One or more doses subsequent to the initial dose may be given as appropriate, typically on a monthly, semimonthly, or a weekly basis, until the desired effect is achieved. Thereafter, additional booster or maintenance doses may be given as required, particularly when the immunological or clinical benefit appears to subside.

In general, an appropriate dosage and treatment regimen provides the active molecules or cells in an amount sufficient to provide a benefit. Such a response may be monitored by establishing an improved clinical outcome (*e.g.*, more frequent remissions, complete or partial, or longer disease-free survival) in treated subjects as compared to non-treated subjects. Increases in preexisting immune responses to a viral protein generally correlate with an improved clinical outcome. Such immune responses may generally be evaluated using standard proliferation, cytotoxicity or cytokine assays, which are routine.

For prophylactic use, a dose should be sufficient to prevent, delay the onset of, or diminish the severity of a disease associated with disease or disorder. Prophylactic benefit of the immunogenic compositions administered according to the methods described herein can be determined by performing pre-clinical (including *in vitro*, *ex vivo*, and *in vivo* animal studies) and clinical studies and analyzing data obtained therefrom by appropriate

statistical, biological, and clinical methods and techniques, all of which can readily be practiced by an ordinarily skilled artisan.

As used herein, administration of a composition refers to delivering the same to a subject, regardless of the route or mode of delivery. Administration may be effected continuously or intermittently, and parenterally. Administration may be for treating a subject already confirmed as having a recognized condition, disease or disease state, or for treating a subject susceptible to or at risk of developing such a condition, disease or disease state. Co-administration with an adjunctive therapy may include simultaneous and/or sequential delivery of multiple agents in any order and on any dosing schedule (*e.g.*, engineered immune cells with one or more cytokines; immunosuppressive therapy such as calcineurin inhibitors, corticosteroids, microtubule inhibitors, low dose of a mycophenolic acid prodrug, or any combination thereof).

In some embodiments, a plurality of doses of a host cell (*e.g.*, an engineered immune cell) described herein is administered to the subject, which may be administered at intervals between administrations of about two to about four weeks.

Treatment or prevention methods encompassed by the present invention may be administered to a subject as part of a treatment course or regimen, which may comprise additional treatments prior to, or after, administration of the instantly disclosed unit doses, cells, or compositions. For example, in some embodiments, a subject receiving a unit dose of the host cell (*e.g.*, an engineered immune cell) is receiving or had previously received a hematopoietic cell transplant (HCT; including myeloablative and non-myeloablative HCT). In any of the foregoing embodiments, a hematopoietic cell used in an HCT may be a “universal donor” cell that is modified to reduce or eliminate expression of one or more endogenous genes that encode a polypeptide product selected from an MHC, antigen, and a binding protein (*e.g.*, by a chromosomal gene knockout according to the methods described herein).

Techniques and regimens for performing cell transplantation are known in the art and may comprise transplantation of any suitable donor cell, such as a cell derived from umbilical cord blood, bone marrow, or peripheral blood, a hematopoietic stem cell, a mobilized stem cell, or a cell from amniotic fluid. Accordingly, in some embodiments, a host cell (*e.g.*, an engineered immune cell) encompassed by the present invention may be administered with or shortly after stem cell therapy.

Methods encompassed by the present invention may, in some embodiments, further include administering one or more additional agents to treat the disease or disorder (*e.g.*, a non-malignant disorder, a hyperproliferative disorder, or a relapse of a hyperproliferative disorder characterized by expression of an HPV16 E7₁₁₋₁₉ antigen) in a combination therapy. For example, in some embodiments, a combination therapy comprises administering host cell or binding protein encompassed by the present invention with (concurrently, simultaneously, or sequentially) an antiviral agent. In some embodiments, a combination therapy comprises administering a host cell or binding protein encompassed by the present invention with lopinavir/ritonavir, chloroquine, ribavirin, steroid drugs, hydroxychloroquine, and/or interferon α . In some embodiments, a combination therapy comprises administering a host cell, composition, or unit dose of the host cells encompassed by the present invention with a secondary therapy, such as a surgery, an antibody, a vaccine, or any combination thereof.

In some embodiments, the subject is a human, such as a human with a non-malignant disorder, a hyperproliferative disorder, or a relapse of a hyperproliferative disorder characterized by expression of an HPV16 E7₁₁₋₁₉ antigen. In some embodiments, the subject is a rodent, such as a mouse. In some such embodiments, the mouse is a transgenic mouse, such as a mouse expressing human MHC (*i.e.*, HLA) molecules, such as HLA-A2 (*e.g.*, Nicholson *et al.* (2012) *Adv. Hematol.* 2012:404081).

In some embodiments, the subject is a transgenic mouse expressing human TCRs or is an antigen-negative mouse (*e.g.*, Li *et al.* (2010) *Nat. Med.* 16:1029-1034 and Obenaus *et al.* (2015) *Nat. Biotechnol.* 33:402-407). In some embodiments, the subject is a transgenic mouse expressing human HLA molecules and human TCRs.

In some embodiments, such as where the subject is a transgenic HLA mouse, the identified TCRs are modified, *e.g.*, to be chimeric or humanized. In some embodiments, the TCR scaffold is modified, such as analogous to known binding protein humanizing methods.

c. Screening Methods

Another aspect encompassed by the present invention encompasses screening assays.

The present invention encompasses assays for screening agents, such as test proteins, that bind to, or modulate the activity of, HPV16 E7₁₁₋₁₉ or an antigen thereof. Such agents include, without limitation, antibodies, proteins, fusion proteins, small

molecules, and nucleic acids. In some embodiments, a method for identifying an agent which modulates an immune response entails determining the ability of the candidate agent to modulate HPV16 E7₁₁₋₁₉ activity and further modulate an immune response of interest, such as modulated cytotoxic T cell activation and/or activity, sensitivity of cancer cells to immune checkpoint therapy, and the like.

In some embodiments, an assay is a cell-free or cell-based assay, comprising contacting a target, with a test agent, and determining the ability of the test agent to modulate (*e.g.*, upregulate or downregulate) the amount and/or activity of the target, such as by measuring direct or indirect parameters as described below.

In some embodiments, an assay is a cell-based assay, such as one comprising contacting (a) a cell of interest with a test agent and determining the ability of the test agent to modulate the amount and/or activity of the target, such as binding characteristics. Determining the ability of the polypeptides to bind to, or interact with, each other may be accomplished, *e.g.*, by measuring direct binding or by measuring a parameter of immune cell activation or function.

In another embodiment, an assay is a cell-based assay, comprising contacting a cell such as a cancer cell with immune cells (*e.g.*, cytotoxic T cells) and a test agent, and determining the ability of the test agent to modulate the amount and/or activity of the target, and/or modulated immune responses, such as by measuring direct or indirect parameters as described below.

The methods described above and herein may also be adapted to test one or more agents that are already known to modulate the amount and/or activity of one or more biomarkers described herein to confirm modulation of the one or more biomarkers and/or to confirm the effects of the agents on readouts of a desired phenotype, such as modulated immune responses, sensitivity to immune checkpoint blockade, and the like.

In some embodiments, determining the ability of a test agent (*e.g.* antibodies, fusion proteins, peptides, or small molecules) to modulate the interaction between a given set of polypeptides may be accomplished by determining the activity of one or more members of the set of polypeptides. For example, the activity of a protein and/or one or more binding partners may be determined by detecting induction of a cellular second messenger (*e.g.*, intracellular signaling), detecting catalytic/enzymatic activity of an appropriate substrate, detecting the induction of a reporter gene (comprising a target-responsive regulatory element operatively linked to a nucleic acid encoding a detectable marker, *e.g.*,

chloramphenicol acetyl transferase), or detecting a cellular response regulated by the protein and/or the one or more binding partners. Determining the ability of the test agent to bind to or interact with said polypeptide may be accomplished, for example, by measuring the ability of a compound to modulate immune cell costimulation or inhibition in a proliferation assay, or by interfering with the ability of said polypeptide to bind to antibodies that recognize a portion thereof.

Agents that modulate target amount and/or activity, such as interactions with one or more binding partners, may be identified by their ability to inhibit immune cell proliferation, and/or effector function, or to induce anergy, clonal deletion, and/or exhaustion when added to an *in vitro* assay. For example, cells may be cultured in the presence of an agent that stimulates signal transduction via an activating receptor. A number of recognized readouts of cell activation may be employed to measure, cell proliferation or effector function (*e.g.*, antibody production, cytokine production, phagocytosis) in the presence of the agent. The ability of a test agent to block this activation may be readily determined by measuring the ability of the agent to effect a decrease in proliferation or effector function being measured, using techniques known in the art.

For example, agents encompassed by the present invention may be tested for the ability to inhibit or enhance costimulation in a T cell assay, as described in Freeman *et al.* (2000) *J. Exp. Med.* 192:1027 and Latchman *et al.* (2001) *Nat. Immunol.* 2:261. CD4⁺ T cells may be isolated from human PBMCs and stimulated with activating anti-CD3 antibody. Proliferation of T cells may be measured by ³H thymidine incorporation. An assay may be performed with or without CD28 costimulation in the assay. Similar assays may be performed with Jurkat T cells and PHA-blasts from PBMCs.

Alternatively, agents encompassed by the present invention may be tested for the ability to modulate cellular production of cytokines which are produced by or whose production is enhanced or inhibited in immune cells in response to modulation of the one or more biomarkers. Indicative cytokines released by immune cells of interest may be identified by ELISA or by the ability of an antibody which blocks the cytokine to inhibit immune cell proliferation or proliferation of other cell types that is induced by the cytokine, such as those described in the Examples section. An *in vitro* immune cell costimulation assay may also be used in a method for identifying cytokines which may be modulated by modulation of the one or more biomarkers. For example, if a particular activity induced

upon costimulation, *e.g.*, immune cell proliferation, cannot be inhibited by addition of blocking antibodies to known cytokines, the activity may result from the action of an unknown cytokine. Following costimulation, this cytokine may be purified from the media by conventional methods and its activity measured by its ability to induce immune cell proliferation. To identify cytokines which may play a role the induction of tolerance, an *in vitro* T cell costimulation assay as described above may be used. In this case, T cells would be given the primary activation signal and contacted with a selected cytokine, but would not be given the costimulatory signal. After washing and resting the immune cells, the cells would be rechallenged with both a primary activation signal and a costimulatory signal. If the immune cells do not respond (*e.g.*, proliferate or produce cytokines) they have become tolerized and the cytokine has not prevented the induction of tolerance. However, if the immune cells respond, induction of tolerance has been prevented by the cytokine. Those cytokines which are capable of preventing the induction of tolerance may be targeted for blockage *in vivo* in conjunction with reagents which block B lymphocyte antigens as a more efficient means to induce tolerance in transplant recipients or subjects with autoimmune diseases.

In some embodiments, an assay encompassed by the present invention is a cell-free assay for screening for agents that modulate the interaction between a biomarker and/or one or more binding partners, comprising contacting a polypeptide and one or more natural binding partners, or biologically active portion thereof, with a test agent and determining the ability of the test compound to modulate the interaction between the polypeptide and one or more natural binding partners, or biologically active portion thereof. Binding of the test compound may be determined either directly or indirectly as described above. In one embodiment, the assay includes contacting the polypeptide, or biologically active portion thereof, with its binding partner to form an assay mixture, contacting the assay mixture with a test compound, and determining the ability of the test agent to interact with the polypeptide in the assay mixture, wherein determining the ability of the test agent to interact with the polypeptide comprises determining the ability of the test agent to preferentially bind to the polypeptide or biologically active portion thereof, as compared to the binding partner.

In some embodiments, whether for cell-based or cell-free assays, a test agent may further be assayed to determine whether it affects binding and/or activity of the interaction between the polypeptide and the one or more binding partners, with other binding partners.

Other useful binding analysis methods include the use of real-time Biomolecular Interaction Analysis (BIA) (Sjolander and Urbaniczky (1991) *Anal. Chem.* 63:2338-2345 and Szabo *et al.* (1995) *Curr. Opin. Struct. Biol.* 5:699-705). As used herein, "BIA" is a technology for studying biospecific interactions in real time, without labeling any of the interactants (*e.g.*, Biacore®). Changes in the optical phenomenon of surface plasmon resonance (SPR) may be used as an indication of real-time reactions between biological polypeptides.

Polypeptides of interest may be immobilized on a Biacore® chip and multiple agents (blocking antibodies, fusion proteins, peptides, or small molecules) may be tested for binding to the polypeptide of interest. An example of using the BIA technology is described by Fitz *et al.* (1997) *Oncogene* 15:613.

The cell-free assays encompassed by the present invention are amenable to use of both soluble and/or membrane-bound forms of proteins. In the case of cell-free assays in which a membrane-bound form protein is used it may be desirable to utilize a solubilizing agent such that the membrane-bound form of the protein is maintained in solution. Examples of such solubilizing agents include non-ionic detergents such as n-octylglucoside, n-dodecylglucoside, n-dodecylmaltoside, octanoyl-N-methylglucamide, decanoyl-N-methylglucamide, Triton® X-100, Triton® X-114, Thesit®, Isotridecypoly(ethylene glycol ether)_n, 3-[(3-cholamidopropyl)dimethylamminio]-1-propane sulfonate (CHAPS), 3-[(3-cholamidopropyl)dimethylamminio]-2-hydroxy-1-propane sulfonate (CHAPSO), or N-dodecyl=N,N-dimethyl-3-ammonio-1-propane sulfonate.

In one or more embodiments of the above described assay methods, it may be desirable to immobilize either polypeptides to facilitate separation of complexed from uncomplexed forms of one or both of the proteins, as well as to accommodate automation of the assay. Binding of a test compound to a polypeptide, may be accomplished in any vessel suitable for containing the reactants. Examples of such vessels include microtiter plates, test tubes, and micro-centrifuge tubes. In one embodiment, a fusion protein may be provided which adds a domain that allows one or both of the proteins to be bound to a matrix. For example, glutathione-S-transferase-based polypeptide fusion proteins, or glutathione-S-transferase/target fusion proteins, may be adsorbed onto glutathione sepharose beads (Sigma Chemical, St. Louis, MO) or glutathione derivatized microtiter plates, which are then combined with the test compound, and the mixture incubated under conditions conducive to complex formation (*e.g.*, at physiological conditions for salt and pH). Following incubation, the beads or microtiter plate wells are washed to remove any

unbound components, the matrix immobilized in the case of beads, complex determined either directly or indirectly, for example, as described above. Alternatively, the complexes may be dissociated from the matrix, and the level of polypeptide binding or activity determined using standard techniques.

The present invention further pertains to novel agents identified by the above-described screening assays. Accordingly, it is within the scope of the present invention to further use an agent identified as described herein in an appropriate model system. For example, an agent identified as described herein may be used in a model system to determine the efficacy, toxicity, or side effects of treatment with such an agent. Alternatively, an agent identified as described herein may be used in a model system to determine the mechanism of action of such an agent. Furthermore, the present invention pertains to uses of novel agents identified by the above-described screening assays for treatments as described herein.

d. Monitoring of Effects During Clinical Trials

Monitoring the influence of a non-malignant disorder, a hyperproliferative disorder, or a relapse of a hyperproliferative disorder characterized by expression of an HPV16 E7₁₁₋₁₉ antigen therapy (*e.g.*, compounds, drugs, vaccines, cell therapies, and the like) on immune responses, such as T cell reactivity (*e.g.*, the presence of binding and/or T cell activation and/or effector function), may be applied not only in basic candidate HPV16 E7₁₁₋₁₉ antigen binding molecule screening, but also in clinical trials. For example, the effectiveness of binding proteins and related compositions described herein, such as nucleic acids, host cells, pharmaceutical formulations, and the like, to increase immune response (*e.g.*, T cell immune response) against cells of interest, such as hyperproliferative cells, expressing an HPV16 E7₁₁₋₁₉ antigen, may be monitored in clinical trials of subjects afflicted with a non-malignant disorder, a hyperproliferative disorder, or a relapse of a hyperproliferative disorder characterized by expression of an HPV16 E7₁₁₋₁₉ antigen. In such clinical trials, the presence of binding and/or T cell activation and/or effector function (*e.g.*, T cell proliferation, killing, and/or cytokine release), may be used as a “read out” or marker of the phenotype of a particular cell, tissue, or system. Similarly, the effectiveness of an adaptive T cell therapy with T cells engineered to express a binding protein (*e.g.*, a TCR, an antigen-binding fragment of a TCR, a CAR, or a fusion protein comprising a TCR and an effector domain) as described herein to increase immune response to cells of interest, such as hyperproliferative cells, that are expressing an HPV16 E7₁₁₋₁₉ antigen, may

be monitored in clinical trials of subjects having a non-malignant disorder, a hyperproliferative disorder, or a relapse of a hyperproliferative disorder characterized by expression of an HPV16 E7₁₁₋₁₉ antigen. In such clinical trials, the presence of binding and/or T cell activation and/or effector function (*e.g.*, T cell proliferation, killing, or cytokine release), may be used as a “read out” or marker of the phenotype of a particular cell, tissue, or system.

For example, increased administration of a non-malignant disorder, the hyperproliferative disorder, or the relapse of the hyperproliferative disorder characterized by expression of an HPV16 E7₁₁₋₁₉ antigen therapy may be desirable to increase the presence or level of reactivity between a sample obtained from the subject and one or more binding proteins or related composition, such as to increase the effectiveness of the non-malignant disorder, the hyperproliferative disorder, or the relapse of the hyperproliferative disorder characterized by expression of an HPV16 E7₁₁₋₁₉ antigen therapy. According to such an embodiment, the presence or level of reactivity between a sample obtained from the subject and one or more binding proteins or related composition may be used as an indicator of the effectiveness of a non-malignant disorder, a hyperproliferative disorder, or a relapse of a hyperproliferative disorder characterized by expression of an HPV16 E7₁₁₋₁₉ antigen therapy, even in the absence of an observable phenotypic response. Similarly, analysis of the presence or level of reactivity between a sample obtained from the subject and one or more binding proteins or related composition, such as by a direct binding assay, fluorescence activated cell sorting (FACS), enzyme linked immunosorbent assay (ELISA), radioimmune assay (RIA), immunochemically, Western blot, or intracellular flow assay, may also be used to select patients who will receive the non-malignant disorder, the hyperproliferative disorder, or the relapse of the hyperproliferative disorder characterized by expression of an HPV16 E7₁₁₋₁₉ antigen therapy.

For example, in a direct binding assay, immunogenic peptides or antigen peptide-MHC (pMHC) complexes may be coupled with a radioisotope or enzymatic label such that binding may be determined by detecting the labeled immunogenic peptides or pMHC complexes. For example, the immunogenic peptides or pMHC complexes may be labeled with ¹²⁵I, ³⁵S, ¹⁴C, or ³H, either directly or indirectly, and the radioisotope detected by direct counting of radioemission or by scintillation counting. Alternatively, the immunogenic peptides or pMHC complexes may be enzymatically labeled with, for example, horseradish peroxidase, alkaline phosphatase, or luciferase, and the enzymatic label detected by

determination of conversion of an appropriate substrate to product. Determining the interaction between immunogenic peptides or pMHC complexes and immune cells, such as T cells and/or NK cells, may also be accomplished using standard binding or enzymatic analysis assays. In one or more embodiments of the above described assay methods, it may be desirable to immobilize immunogenic peptides or pMHC complexes to accommodate automation of the assay.

It is also within the scope of the present invention to determine the ability of an agent to modulate a parameter of interest without the labeling of any of the interactants. For example, a microphysiometer may be used to detect interaction between polypeptides without the labeling of polypeptides to be monitored (McConnell *et al.* (1992) *Science* 257:1906-1912). As used herein, a “microphysiometer” (*e.g.*, Cytosensor®) is an analytical instrument that measures the rate at which a cell acidifies its environment using a light-addressable potentiometric sensor (LAPS). Changes in this acidification rate may be used as an indicator of the interaction between compound and receptor.

Binding of immunogenic peptides or pMHC complexes to immune cells, such as T cells and/or NK cells, may be accomplished in any vessel suitable for containing the reactants. Non-limiting examples of such vessels include microtiter plates, test tubes, and micro-centrifuge tubes. Immobilized forms of the immunogenic peptides or pMHC complexes may also include immunogenic peptides or pMHC complexes bound to a solid phase like a porous, microporous (with an average pore diameter less than about one micron) or macroporous (with an average pore diameter of more than about 10 microns) material, such as a membrane, cellulose, nitrocellulose, or glass fibers; a bead, such as that made of agarose or polyacrylamide or latex; or a surface of a dish, plate, or well, such as one made of polystyrene.

In some embodiments, the reactivity of a sample obtained from the subject to one or more binding proteins or to one or more host cells described herein may be measured by detecting the presence of binding and/or T cell activation and/or effector function. The term “T cell activation” refers to T lymphocytes selected from proliferation, differentiation, cytokine secretion, release of cytotoxic effector molecules, cytotoxic activity, and expression of activation markers, particularly refers to one or more cellular responses of cytotoxic T lymphocytes.

Cytokine production and/or release may be measured by methods well-known in the art, for example, ELISA, enzyme-linked immune absorbent spot (ELISPOT),

Luminex® assay, intracellular cytokine staining, and flow cytometry, and combinations thereof (*e.g.*, intracellular cytokine staining and flow cytometry). It may be determined according to the method implemented.

The term “cytokine” as used herein refers to a molecule that mediates and/ or regulates a biological or cellular function or process (*e.g.*, immunity, inflammation, and hematopoiesis). The term “cytokine” as used herein includes “lymphokines”, “chemokines”, “monokines”, and “interleukins”. Examples of useful cytokines are GM-CSF, IL-1 α , IL-1 β , IL-2, IL-3, IL-4, IL-5, IL-6, IL-7, IL-8, IL-10, IL-12, IL-15, IFN- α , IFN- β , IFN- γ , MIP-1 α , MIP-1 β , TGF- β , TNF- α , and TNF- β .

The proliferation and clonal expansion of T cells resulting from antigen-specific induction or stimulation of an immune response may be determined, for example, through incorporation of a non-radioactive assay such as a tritiated thymidine assay or MTT assay.

Cytotoxicity assays to determine CTL activity may be performed using any one of several techniques and methods routinely practiced in the art (*e.g.*, Henkart *et al.* (2003) *Fund. Immunol.* 1127-1150). Additional description of methods for measuring antigen-specific T cell reactivity can be found in, for example, U.S. Pat. No. 10,208,086 and U.S. Pat. Publ. No. 2017/0209573.

e. Predictive Medicine

The present invention also pertains to the field of predictive medicine in which diagnostic assays, prognostic assays, and monitoring clinical trials are used for prognostic (predictive) purposes to thereby treat an individual prophylactically. Accordingly, one aspect encompassed by the present invention encompasses diagnostic assays for determining (*e.g.*, detecting) the presence, absence, amount, and/or activity level of HPV16 E7₁₁₋₁₉ or reactivity to HPV16 E7₁₁₋₁₉ in the context of a biological sample (*e.g.*, blood, serum, cells, or tissue) to thereby determine whether an individual afflicted with a disorder characterized by HPV16 E7₁₁₋₁₉ expression is likely to respond to therapy, whether in an original state or as a recurrence. Such assays may be used for prognostic or predictive purpose to thereby prophylactically treat an individual prior to the onset or after recurrence of a disorder characterized by HPV16 E7₁₁₋₁₉ expression.

The diagnostic methods described herein may furthermore be utilized to identify subjects having or at risk of developing a disorder associated with expression or lack thereof of HPV16 E7₁₁₋₁₉. As used herein, the term “aberrant” includes an upregulation or downregulation of HPV16 E7₁₁₋₁₉ from normal levels. Aberrant expression or activity

includes increased or decreased expression or activity, as well as expression or activity which does not follow the normal developmental pattern of expression or the subcellular pattern of expression. For example, aberrant levels is intended to include the cases in which a mutation in the biomarker gene or regulatory sequence, or amplification of the chromosomal gene, thereof causes upregulation or downregulation of the biomarker of interest. As used herein, the term “unwanted” includes an unwanted phenomenon involved in a biological response, such as immune cell activity.

The assays described herein, such as the preceding diagnostic assays or the following assays, may be utilized to identify a subject having or at risk of developing a disorder associated with HPV16 E7₁₁₋₁₉ misregulation. Thus, the present invention provides a method for identifying a disorder associated with aberrant or unwanted HPV16 E7₁₁₋₁₉ regulation in which a test sample is obtained from a subject and HPV16 E7₁₁₋₁₉ expression is detected, wherein the presence of HPV16 E7₁₁₋₁₉ expression is diagnostic for a subject having or at risk of developing the disorder associated with aberrant or unwanted HPV16 E7₁₁₋₁₉ expression. As used herein, a “test sample” refers to a biological sample obtained from a subject of interest. For example, a test sample may be a biological fluid (*e.g.*, cerebrospinal fluid or serum), cell sample, or tissue, such as a histopathological slide of the tumor microenvironment, peritumoral area, and/or intratumoral area.

Furthermore, the prognostic assays described herein may be used to determine whether a subject may be administered an agent described herein to treat such a disorder associated with aberrant or unwanted HPV16 E7₁₁₋₁₉ expression. For example, such methods may be used to determine whether a subject may be effectively treated with one or a combination of agents. Thus, the present invention provides methods for determining whether a subject may be effectively treated with one or more agents described herein for treating a disorder associated with aberrant or unwanted HPV16 E7₁₁₋₁₉ expression.

The methods described herein may be performed, for example, by utilizing pre-packaged diagnostic kits comprising at least one antibody reagent described herein, which may be conveniently used, *e.g.*, in clinical settings to diagnose patients exhibiting symptoms or family history of a disease or illness involving the biomarker of interest.

Furthermore, any cell type or tissue in which the biomarker of interest is expressed may be utilized in the prognostic assays described herein.

In addition, the prognostic methods described herein may be used to determine whether a subject may be administered a therapeutic agent to treat a disorder characterized by HPV16 E7₁₁₋₁₉ expression.

f. Clinical Efficacy

Clinical efficacy may be measured by any method known in the art. For example, the response to a therapy relates to any response of the disorder characterized by HPV16 E7₁₁₋₁₉ expression, *e.g.*, a tumor, to the therapy, preferably to a change in the number of cancer cells, tumor mass, and/or tumor volume, such as after initiation of neoadjuvant or adjuvant chemotherapy. Tumor response may be assessed in a neoadjuvant or adjuvant situation where the size of a tumor after systemic intervention may be compared to the initial size and dimensions as measured by CT, PET, mammogram, ultrasound or palpation and the cellularity of a tumor may be estimated histologically and compared to the cellularity of a tumor biopsy taken before initiation of treatment. Response may also be assessed by caliper measurement or pathological examination of the tumor after biopsy or surgical resection. Response may be recorded in a quantitative fashion such as percentage change in tumor volume or cellularity or by using a semi-quantitative scoring system such as residual cancer burden (Symmans *et al.* (2007) *J. Clin. Oncol.* 25:4414-4422) or Miller-Payne score (Ogston *et al.* (2003) *Breast* (Edinburgh, Scotland) 12:320-327) in a qualitative fashion like “pathological complete response” (pCR), “clinical complete remission” (cCR), “clinical partial remission” (cPR), “clinical stable disease” (cSD), “clinical progressive disease” (cPD) or other qualitative criteria. Assessment of tumor response may be performed early after the onset of neoadjuvant or adjuvant therapy (*e.g.*, after a few hours, days, weeks or preferably after a few months). A typical endpoint for response assessment is upon termination of neoadjuvant chemotherapy or upon surgical removal of residual tumor cells and/or the tumor bed. Additional guidance is provided in definitions of terms listed in Section I above.

VII. Cell Therapy

In another aspect encompassed by the present invention, the methods include adoptive cell therapy, whereby genetically engineered cells expressing the provided molecules targeting an MHC-restricted epitope (*e.g.*, cells expressing a binding protein (*e.g.*, a TCR or CAR) or antigen-binding fragment thereof) are administered to subjects. Such administration may promote activation of immune cells (*e.g.*, T cell activation) in an

antigen-targeted manner, such that the cells of interest such as hyperproliferative cells, express an HPV16 E7₁₁₋₁₉ antigen are targeted for destruction.

Thus, the provided methods and uses include methods and uses for adoptive cell therapy. In some embodiments, the methods include administration of the cells or a composition containing the cells to a subject, tissue, or cell, such as one having, at risk for, or suspected of having the disease, condition or disorder. In some embodiments, the cells, populations, and compositions are administered to a subject having the particular disease or condition to be treated (*e.g.*, via adoptive cell therapy, such as by adoptive T cell therapy). In some embodiments, the cells or compositions are administered to the subject, such as a subject having or at risk for the disease or condition. In some embodiments, the methods thereby treat, *e.g.*, ameliorate one or more symptom of the disease or condition.

Methods for administration of cells for adoptive cell therapy are known and may be used in connection with the provided methods and compositions (*e.g.*, U.S. Pat. Publ. No. 2003/0170238, U.S. Pat. No. 4,690,915, Rosenberg (2011) *Nat. Rev. Clin. Oncol.* 8:577-585, Themeli *et al.* (2013) *Nat. Biotechnol.* 31:928-933, Tsukahara *et al.* (2013) *Biochem. Biophys. Res. Commun.* 438:84-89, and Davila *et al.* (2013) *PLoS ONE* 8:e61338).

In some embodiments, cell therapy (*e.g.*, adoptive cell therapy, such as adoptive T cell therapy) may be carried out by autologous transfer, in which the cells are isolated and/or otherwise prepared from the subject who is to receive the cell therapy, or from a sample derived from such a subject. Thus, in some embodiments, the cells are derived from a subject, *e.g.*, patient, in need of a treatment and the cells, following isolation and processing are administered to the same subject.

In some embodiments, the cell therapy (*e.g.*, adoptive cell therapy, such as adoptive T cell therapy) may be carried out by allogeneic transfer, in which the cells are isolated and/or otherwise prepared from a subject other than a subject who is to receive or who ultimately receives the cell therapy, *e.g.*, a first subject. In such embodiments, the cells then are administered to a different subject, *e.g.*, a second subject, of the same species. In some embodiments, the first and second subjects are genetically identical (syngeneic). In some embodiments, the first and second subjects are genetically similar. In some embodiments, the second subject expresses the same HLA class or supertype as the first subject.

In some embodiments, the subject, to whom the cells, cell populations, or compositions are administered is a primate, such as a human. In some embodiments, the

primate is a monkey or an ape. The subject may be male or female and may be any suitable age, including infant, juvenile, adolescent, adult, and geriatric subjects. In some embodiments, the subject is a non-primate mammal, such as a rodent. In some examples, the patient or subject is a validated animal model for disease, adoptive cell therapy, and/or for assessing toxic outcomes such as cytokine release syndrome (CRS).

The binding molecules, such as TCRs, antigen-binding fragments of TCRs (*e.g.*, scTCRs) and chimeric receptors (*e.g.*, CARs) containing the TCR, and cells expressing the same, may be administered by any suitable means, for example, by injection, *e.g.*, intravenous or subcutaneous injections, intraocular injection, periocular injection, subretinal injection, intravitreal injection, trans-septal injection, subcleral injection, intrachoroidal injection, intracameral injection, subconjunctival injection, subconjunctival injection, sub-Tenon's injection, retrobulbar injection, peribulbar injection, or posterior juxtasceral delivery. In some embodiments, they are administered by parenteral, intrapulmonary, and intranasal, and, if desired for local treatment, intralesional administration. Parenteral infusions include intramuscular, intravenous, intraarterial, intraperitoneal, or subcutaneous administration. Dosing and administration may depend in part on whether the administration is brief or chronic. Various dosing schedules include but are not limited to single or multiple administrations over various time-points, bolus administration, and pulse infusion.

For the prevention or treatment of disease, the appropriate dosage of the binding molecule or cell may depend on the type of disease to be treated, the type of binding molecule, the severity and course of the disease, whether the binding molecule is administered for preventive or therapeutic purposes, previous therapy, the patient's clinical history and response to the binding molecule, and the discretion of the attending physician. The compositions and molecules and cells are in some embodiments suitably administered to the patient at one time or over a series of treatments.

In some embodiments, cells may be administered at 0.1×10^6 , 0.2×10^6 , 0.3×10^6 , 0.4×10^6 , 0.5×10^6 , 0.6×10^6 , 0.7×10^6 , 0.8×10^6 , 0.9×10^6 , 1.0×10^6 , 5.0×10^6 , 1.0×10^7 , 5.0×10^7 , 1.0×10^8 , 5.0×10^8 , or more, or any range in between or any value in between, cells per kilogram of subject body weight. The number of cells transplanted may be adjusted based on the desired level of engraftment in a given amount of time. Generally, 1×10^5 to about 1×10^9 cells/kg of body weight, from about 1×10^6 to about 1×10^8 cells/kg of body weight, or about 1×10^7 cells/kg of body weight, or more cells, as necessary, may be

transplanted. In some embodiment, transplantation of at least about 0.1×10^6 , 0.5×10^6 , 1.0×10^6 , 2.0×10^6 , 3.0×10^6 , 4.0×10^6 , or 5.0×10^6 total cells relative to an average size mouse is effective. For example, in some embodiments, cells, or individual populations of sub-types of cells, may be administered to the subject at a range of about one million to about 100 billion cells and/or that amount of cells per kilogram of body weight, such as, *e.g.*, 1 million to about 50 billion cells (*e.g.*, about 5 million cells, about 25 million cells, about 500 million cells, about 1 billion cells, about 5 billion cells, about 20 billion cells, about 30 billion cells, about 40 billion cells, or a range defined by any two of the foregoing values), such as about 10 million to about 100 billion cells (*e.g.*, about 20 million cells, about 30 million cells, about 40 million cells, about 60 million cells, about 70 million cells, about 80 million cells, about 90 million cells, about 10 billion cells, about 25 billion cells, about 50 billion cells, about 75 billion cells, about 90 billion cells, or a range defined by any two of the foregoing values), and in some cases about 100 million cells to about 50 billion cells (*e.g.*, about 120 million cells, about 250 million cells, about 350 million cells, about 450 million cells, about 650 million cells, about 800 million cells, about 900 million cells, about 3 billion cells, about 30 billion cells, about 45 billion cells) or any value in between these ranges and/or per kilogram of body weight. Dosages may vary depending on attributes particular to the disease or disorder and/or patient and/or other treatments.

Engraftment of transplanted cells may be assessed by any of various methods, such as, but not limited to, tumor volume, cytokine levels, time of administration, flow cytometric analysis of cells of interest obtained from the subject at one or more time points following transplantation, and the like. For example, a time-based analysis of waiting 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28 days or may signal the time for tumor harvesting. Any such metrics are variables that may be adjusted according to well-known parameters in order to determine the effect of the variable on a response to anti-cancer immunotherapy. In addition, the transplanted cells may be co-transplanted with other agents, such as cytokines, extracellular matrices, cell culture supports, and the like.

Cells may also be administered before, concurrently with, or after, other anti-cancer agents.

Two or more cell types may be combined and administered, such as cell-based therapy and adoptive cell transfer of stem cells, cancer vaccines and cell-based therapy, and the like. For example, adoptive cell-based immunotherapies may be combined with the

cell-based therapies encompassed by the present invention. In some embodiments, the cell-based agents may be used alone or in combination with additional cell-based agents, such as immunotherapies like adoptive T cell therapy (ACT). For example, T cells genetically engineered to recognize CD19 used to treat follicular B cell lymphoma. Immune cells for ACT may be dendritic cells, T cells such as CD8⁺ T cells and CD4⁺ T cells, natural killer (NK) cells, NK T cells, cytotoxic T lymphocytes (CTLs), tumor infiltrating lymphocytes (TILs), lymphokine activated killer (LAK) cells, memory T cells, regulatory T cells (Tregs), helper T cells, cytokine-induced killer (CIK) cells, and any combination thereof. Well-known adoptive cell-based immunotherapeutic modalities, including, without limitation, irradiated autologous or allogeneic tumor cells, tumor lysates or apoptotic tumor cells, antigen-presenting cell-based immunotherapy, dendritic cell-based immunotherapy, adoptive T cell transfer, adoptive CAR T cell therapy, autologous immune enhancement therapy (AIET), cancer vaccines, and/or antigen presenting cells. Such cell-based immunotherapies may be further modified to express one or more gene products to further modulate immune responses, such as expressing cytokines like GM-CSF, and/or to express tumor-associated antigen (TAA) antigens, such as Mage-1, gp-100, and the like. The ratio of an agent encompassed by the present invention, such as cancer cells, to another agent encompassed by the present invention or other composition may be 1:1 relative to each other (*e.g.*, equal amounts of 2 agents, 3 agents, 4 agents, etc.), but may modulated in any amount desired (*e.g.*, 1:1, 1.1:1, 1.2:1, 1.3:1, 1.4:1, 1.5:1, 2:1, 2.5:1, 3:1, 3.5:1, 4:1, 4.5:1, 5:1, 5.5:1, 6:1, 6.5:1, 7:1, 7.5:1, 8:1, 8.5:1, 9:1, 9.5:1, 10:1, or greater).

In some embodiments, for example, where the subject is a human, the dose includes fewer than about 1×10^8 total binding protein (*e.g.*, TCR or CAR)-expressing cells, T cells, or peripheral blood mononuclear cells (PBMCs), *e.g.*, in the range of about 1×10^6 to 1×10^8 such cells, such as 2×10^6 , 5×10^6 , 1×10^7 , 5×10^7 , or 1×10^8 or total such cells, or the range between any two of the foregoing values.

In some embodiments, the cells or related compositions described herein, such as nucleic acids, host cells, pharmaceutical formulations, and the like, may be administered as part of a combination treatment, such as simultaneously with or sequentially with, in any order, another therapeutic intervention, such as another antibody or engineered cell or receptor or agent, such as a cytotoxic or therapeutic agent.

In some embodiments, the cells or related composition may be co-administered with one or more additional therapeutic agents or in connection with another therapeutic

intervention, either simultaneously or sequentially in any order. In some contexts, the cells or related composition are co-administered with another therapy sufficiently close in time such that the cell populations enhance the effect of one or more additional therapeutic agents, or vice versa. In some embodiments, the cells or related composition are administered prior to the one or more additional therapeutic agents. In some embodiments, the cells or related composition are administered after to the one or more additional therapeutic agents.

In some embodiments, the biological activity of the cells or related composition is measured by any of a number of known methods once the cells or related composition are administered to a subject (*e.g.*, a human). Parameters to assess include specific binding of an engineered or natural T cell or other immune cell to antigen, *in vivo*, *e.g.*, by imaging, or *in vitro/ex vivo*, *e.g.*, by ELISA or flow cytometry. In some embodiments, the ability of the cells to destroy target cells (cytotoxicity) may be measured using any suitable assay or method known in the art (*e.g.*, Kochenderfer *et al.* (2009) *J. Immunother.* 32: 689-702 and Herman *et al.* (2004) *J. Immunol. Meth.* 285:25-40). In some embodiments, the biological activity of the cells also may be measured by assaying expression and/or secretion of certain cytokines, such as CD107a, IFN γ , IL-2, and TNF alpha. In some embodiments, the biological activity is measured by assessing clinical outcome, such as reduction in viral burden or load.

In some embodiments, cells are modified in any number of ways, such that their therapeutic or prophylactic efficacy is increased. For example, the binding protein (*e.g.*, engineered TCR, CAR, or antigen-binding fragment thereof) expressed by the population may be conjugated either directly or indirectly through a linker to a targeting moiety. The practice of conjugating compounds to targeting moieties is well-known in the art (*e.g.*, Wadwa *et al.* (1995) *J. Drug Targeting* 3:111 and U.S. Pat. No. 5,087,616).

Immune cells, such as cytotoxic lymphocytes, may be obtained from any suitable source such as peripheral blood, spleen, and lymph nodes. The immune cells may be used as crude preparations or as partially purified or substantially purified preparations, which may be obtained by standard techniques, including, but not limited to, methods involving immunomagnetic or flow cytometry techniques using antibodies.

In another aspect encompassed by the present invention, provided herein is a method for eliciting an immune response to a cell that expresses an HPV16 E7₁₁₋₁₉ antigen, the method comprising administering to the subject cells described herein expressing a

binding protein (*e.g.*, engineered TCR, CAR, or antigen-binding fragment thereof) in effective amounts sufficient to elicit the immune response. In some embodiments, provided herein is a method for treatment or prophylaxis of a non-malignant disorder, a hyperproliferative disorder, or a relapse of a hyperproliferative disorder characterized by expression of an HPV16 E7₁₁₋₁₉ antigen, the method comprising administering to the subject an effective amount of the cells described herein expressing a binding protein (*e.g.*, engineered TCR, CAR, or antigen-binding fragment thereof). In one embodiment, the cells are administered systemically, such as by injection. Alternately, one may administer locally rather than systemically, for example, via injection directly into tissue, such as in a depot or sustained release formulation.

In some embodiments, the cells described herein expressing a binding protein (*e.g.*, engineered TCR, CAR, or antigen-binding fragment thereof) may be used as active compounds in immunomodulating compositions for prophylactic or therapeutic treatment of a non-malignant disorder, a hyperproliferative disorder, or a relapse of a hyperproliferative disorder characterized by expression of an HPV16 E7₁₁₋₁₉ antigen. In some embodiments, HPV16 E7₁₁₋₁₉-primed antigen-presenting cells may be used for generating lymphocytes (*e.g.*, CD8⁺ T lymphocytes, CD4⁺ T lymphocytes, and/or B lymphocytes), for further use in adoptive transfer to the subject with the cells described herein expressing a binding protein (*e.g.*, engineered TCR, CAR, or antigen-binding fragment thereof).

In some embodiments, the cells described herein expressing a binding protein (*e.g.*, engineered TCR, CAR, or antigen-binding fragment thereof), either alone or in combination with the lymphocytes, may be administered to a subject for eliciting an immune response, particularly for eliciting an immune response to cells are expressing an HPV16 E7₁₁₋₁₉ antigen.

As described above, single or multiple administrations of the cells described herein expressing a binding protein (*e.g.*, engineered TCR, CAR, or antigen-binding fragment thereof) cells, either alone or in combination with the lymphocytes, may be carried out with cell numbers and treatment being selected by the care provider (*e.g.*, physician). Similarly, the cells, either alone or in combination with lymphocytes, may be administered in a pharmaceutically acceptable carrier. Suitable carriers may be growth medium in which the cells were grown, or any suitable buffering medium such as phosphate buffered saline.

Cells may be administered alone or as an adjunct therapy in conjunction with other therapeutics.

VIII. Kits and Devices

The present invention also encompasses kits and devices. For example, the kit or device may comprise binding proteins, nucleic acids or vectors comprising sequences encoding binding proteins, host cells comprising nucleic acids or vectors and/or expressing the binding proteins as described herein, stable MHC-peptide complexes, adjuvants, detection reagents, and combinations thereof, packaged in a suitable container and may further comprise instructions for using such reagents. The kit or device may also contain other components, such as administration tools packaged in a separate container. The kit or device may be promoted, distributed, or sold as a unit for performing the methods encompassed by the present invention.

The disclosure is further illustrated by the following examples which should not be construed as limiting.

EXAMPLES

Example 1: Materials and Methods for Example 2

a. Lentiviral packaging and quantification of lentiviral titer

Lenti-X™ GoStix™ Plus (Takara Bio USA, Mountain View, CA) was used to package and quantify HPV16-E7₁₁₋₁₉ viral constructs. Briefly, HPV16-E7₁₁₋₁₉ viral constructs were diluted 1:100 with PBS. Twenty (20) ul of HPV16-E7₁₁₋₁₉ viral supernatant was applied to the Lenti-X™ GoStix™ Plus cassette sample well and then 80 ul of Chase buffer was applied. A lateral flow test was run for 10 minutes, and a test band (T) will start to appear within 5 minutes and reach maximum intensity at 10 minutes if your sample contains sufficient lentivirus. The control band (C) will always appear when the test is functioning properly. After 10 minutes, proper alignment and focal length for imaging is achieved by using the outline of the cassette in the scanning window. The sample name appeared below the outline of the cassette. Once proper alignment was achieved, the outline turned green, and the cassette was automatically scanned. To calculate the actual IFU/ml for an unknown stock, a reference virus with known titer measured by CD8 expression was used (a virus stock for which the IFU/ml is known) and tested to obtain both an infectious unit value as well as a GoStix™ Value GV. The IFU/GV ratio was calculated

for the reference virus. The unknown sample was analyzed using Lenti-X™ GoStix™ Plus to obtain the GV (ng/ml p24) and the following calculation [Formula: $GV \text{ (unknown)} \times (IFU/ml)/GV \text{ (reference)} = IFU/ml \text{ (unknown)}$] was performed to determine the IFU/ml.

b. Evaluating HPV16-E7₁₁₋₁₉ TCR function

(i) *Engineering T cells to express HPV16-E7₁₁₋₁₉-specific TCRs*

Pan T cells were isolated from HLA-A*02:01-positive healthy donor PBMCs using the EasySep Human T Cell isolation kit (StemCell Technologies) as per the manufacturer's instructions. Isolated T cells were activated with ImmunoCult CD3/CD28/CD2 T cell activator cocktail (StemCell Technologies) and cultured overnight in complete T cell media (X-VIVO 15 [Lonza, Morristown, NJ] supplemented with 5% human serum [Sigma Aldrich], 1% penicillin-streptomycin [Thermo Fisher Scientific], 1X GlutaMax™ supplement [Thermo Fisher Scientific], 5 ng/mL IL-7 [R&D Systems] and 50 IU/mL IL-2 [Sigma Aldrich]). 24 hours post-activation, T cells were transduced with HPV16-E7₁₁₋₁₉ TCR viral supernatants. 24 hours post-transduction, T cells were washed and transferred to G-Rex plates (Wilson Wolf, New Brighton, MN) or VECCELL 96-well plates (Cosmo Bio, Carlsbad, CA), and expanded for a total of 7-11 days post-activation. T cell cultures were supplemented with fresh IL-2 (50 IU/mL) and IL-7 (5 ng/mL) every 2-3 days and/or split to maintain optimal cell densities.

(ii) *Flow cytometry of engineered HPV16-E7₁₁₋₁₉ TCR-transduced pan T cells*

Engineered pan T cells were stained with HLA-A*02:01 HPV16-E7₁₁₋₁₉ (YMLDLQPET) (Immudex) dextramer, TCR α/β PE-Cy7 (IP26, BioLegend), CD8 PerCP-Cy5.5 (HIT8a, BioLegend), CD4 APC-Cy7 (OKT4, Biolegend), and CD34 Alex Fluor 488 (QBEND/10, R&D Systems) and DAPI as per the manufacturers' instructions. Cells were then run on the CytoFLEX flow cytometer (Beckman Coulter) and analyzed using FlowJo software (version 10, TreeStar).

(iii) *Cell lines*

The T lymphoblast cell line T2 (ATCC CRL-1992), adenocarcinoma cell line NCI-H1792 (ATCC CRL-5895), epidermoid carcinoma cell line Ca Ski (ATCC CRL-1550); and squamous cell carcinoma cell lines SCC152 (ATCC CRL-3240), SCC090 (ATCC CRL-3239), and SiHa (ATCC HTB-35) were purchased from the American Type Culture Collection (ATCC). T2 cells were cultured in IMDM containing 20% heat-inactivated FBS 1% penicillin-streptomycin [Thermo Fisher Scientific]. Ca Ski and NCI-H1792 cells were cultured in RPMI 1640 containing 10% heat-inactivated FBS and 1% penicillin-

streptomycin [Thermo Fisher Scientific]. SCC152, SCC090, and SiHa were maintained in EMEM containing 10% heat-inactivated FBS, 1% penicillin-streptomycin [Thermo Fisher Scientific], and 1X GlutaMax supplement [Thermo Fisher Scientific].

(iv) *Generation of stable cell lines expressing Incucyte® Nuclight Red*

T2, NCI-H1792, Ca Ski, SiHa, SCC090, and SCC152 cells were transduced with IncuCyte® NucLight Red Lentivirus Reagent (EF-1 α promoter, puromycin selection) (Sartorius) in serum-free media at an MOI of 5. 24 hours post-transduction, cells were washed and resuspended in their respective cell line media and cultured at 37°C, 5% CO₂. 3 days post-transduction, puromycin (Gibco, Waltham, MA) was added to the cultures at a pre-determined concentration (ranging from 0.5 μ g/mL to 1 μ g/mL) to select for transduced cells. Cultures were expanded under puromycin selection until they were at least 98% Incucyte® NucLight Red-positive as determined by flow cytometric analysis.

(v) *In vitro cytotoxicity assay*

In vitro cytotoxicity assays for T2 cells were performed in 96-well flat-bottom tissue culture plates coated with poly-L-ornithine (Sigma Aldrich) for 30 minutes at room temperature (RT), after which the coating solution was removed, and plates were allowed to dry for another 30 minutes at RT. *In vitro* cytotoxicity assays for adherent cell lines were performed in 96-well flat-bottom tissue culture plates without coating with poly-L-ornithine, where the adherent cells were plated and allowed to attach the day before T cells were added. Where indicated, T cells were co-cultured with Incucyte® NucLight™ Red-expressing NCI-H1792, Ca Ski, SiHa, SCC090, SCC152 or peptide-pulsed T2 cells (1 ng/ml of HPV16-E7₁₁₋₁₉ peptide [YMLDLQPET, Genscript]) at E:T ratios ranging from 20:1 to 1.25:1. Data were acquired on an Incucyte® S3 instrument (Sartorius), and target cell growth was quantified on the Incucyte S3 as a readout of T cell cytotoxicity.

(vi) *Cytokine production assay*

T cells were co-cultured with Incucyte® NucLight™ Red-expressing NCI-H1792, Ca Ski, SiHa, SCC090, and SCC152 cells or peptide-pulsed T2 cells (1 ng/ml of HPV16-E7₁₁₋₁₉ peptide [YMLDLQPET, Genscript]) at an E:T of 1:1. Supernatants were harvested 24 hours later and frozen at -80°C. Supernatants were thawed and loaded on a multiAnalyte cartridge (ProteinSimple, San Jose, CA) to evaluate the levels of IFN- γ , TNF- α , IL-2 and granzyme B using the Ella instrument (ProteinSimple).

(vii) *Proliferation assay*

T cells were labeled with 2.5 μ M CellTrace™ Violet (Thermo Fisher Scientific) as per the manufacturer's instructions. T cells were co-cultured with Incucyte® NucLight™ Red-expressing CaSki, SCC152, SCC090, SiHa and NCI-H1792. After 96 hours, cells were harvested and stained with Fixable viability dye eFluor® 660 (Thermo Fisher Scientific), TCR α/β PE-Cy7 (IP26, BioLegend), CD4 APC-Cy7 (OKT4, BioLegend) and CD8 PerCP-Cy5.5 (HIT8a, BioLegend) antibodies. Cells were washed with EasySep™ buffer and fixed with BD Cytofix™ fixation buffer (BD Biosciences, Franklin Lakes, NJ). CountBright™ Absolute Counting Beads (Thermo Fisher Scientific) were diluted in EasySep™ buffer and added to samples prior to acquisition on the CytoFLEX flow cytometer to assess dilution of CellTrace™ Violet as an indicator of T cell proliferation. Data were analyzed using FlowJo software (version 10, TreeStar), and absolute counts of divided CD8 and CD4 T cells were determined using the formula:

CD8 or CD4 T cells in sample = (# CD8 or CD4 T cell events in gate/# bead events in gate) x lot-specific assigned bead count.

c. Alloreactivity and safety screens

(i) *Generation of 96-well-based MHC-expressing arrays for alloreactivity screens*

Endogenous HLA-A/B/C were knocked out in HEK293T cells using CRISPR-Cas engineering. Guide RNAs (gRNAs) were designed against sequences conserved across the HLA-A, HLA-B and HLA-C loci using the multicrispr.net tool (Prykhodzhiy *et al.*, *Plos One*, 2015). The following guides were selected: CRISPR-ALL-1:

CGGCTACTACAACCAGAGCG, CRISPR-ALL-2: AGATCACACTGACCTGGCAG, CRISPR-ALL-3: AGGTCAGTGTGATCTCCGCA. gRNAs were cloned into the

LentiCRISPR V2 vector using BsmBI sites. HEK293T cells were transfected with plasmid guide constructs using Mirus TransIT (Mirus Bio, Madison, WI). After 7 days, MHC-knockout (MHC-KO) cells were sorted using a pan-MHC antibody (BioLegend). Single-cell clones were expanded, and the absence of MHC was verified by flow cytometry.

B2M-knockout (B2M-KO) cells were used as a positive control for the complete absence of surface MHC expression. B2M was knocked out in HEK293T cells by electroporating CRISPR RNPs targeting B2M using the guide RNA: GGCCACGGAGCGAGACATCT.

MHC-null HEK293T cells were transduced with IncuCyte® NucLight™ Red virus (Essen BioScience). Transduced cells were sorted for NucLight™ Red expression using a Sony SH800 sorter. To generate an MHC-expressing array, MHC-null NucLight™ Red-

expressing HEK293T cells were transduced with the most common 110 MHCs (pHAGE-EF1a-MHC-UBC-NAT) in individual wells in 96-well plates. Transduced cells were selected with nourseothricin (400 µg/ml) for one week. Cells expressing the most common 110 MHCs were passaged and stored in 96-well plates as an array. Expression of individual MHC alleles was verified by staining using a pan-MHC antibody (BioLegend).

To generate the positive control for the assay, MHC-null HEK293T cells were transduced with IncuCyte® NucLight™ Red virus (Essen BioScience) and sorted for NucLight™ Red expression using a Sony SH800 sorter. HLA-A*02:01 (pHAGE-EF1a-MHC-UBC-NAT) was then introduced into the cells using lentiviral transduction. Transduced cells were selected with nourseothricin (400 µg/ml) for one week. These cells were then transduced with a 90-mer construct (pHAGE-CMV-FHA-HPV16-E7.1-EFS-AmCyan) expressing a fragment of HPV16-E7, which contains the HPV16-E7₁₁₋₁₉ epitope (YMLDLQPET). Transduced cells were then sorted for AmCyan expression using a Bigfoot Spectral Cell Sorter (Thermo Fisher Scientific).

(ii) *Lentiviral packaging and transduction*

To package the lentiviruses of the 110 MHC expression constructs (pHAGE-EF1a-MHC-UBC-NAT), MHC-null HEK293T cells were plated at 75% confluency in 96 wells and transfected using jetPRIME® transfection reagent (Polyplus, Illkirch, France). Individual MHC expression constructs were mixed with packaging plasmids (pREV/pTAT/pVSVG/pGAGPOL) and incubated with jetPRIME® reagent according to the manufacturer's protocol, and DMEM medium was added at 24 hours post-transfection. Viral supernatants were harvested 48 hours after transfection and used for transduction of the 110 MHCs in a 96-well-based array format. To package the lentiviruses of other constructs, Lenti-X® cells (Takara Bio USA, Mountain View, CA) were plated at 75% confluency and transfected using jetPRIME® transfection reagent (Polyplus, Illkirch, France). Expression constructs were mixed with packaging plasmids (pREV/pTAT/pVSVG/pGAGPOL) and incubated with jetPRIME® reagent according to the manufacturer's protocol, and OptiPRO™ SFM medium was added at 24 hours post-transfection. Viral supernatants were harvested 48 hours after transfection and were concentrated using either Vivaspin® 20 centrifugal concentrators or Vivaflow® 50 cassettes (Sartorius, Bohemia, NY).

All viral transduction involving cell lines derived from HEK293T cells was done with polybrene (4 µg/ml).

(iii) *Co-culture for alloreactivity profiling*

Pan T cells were engineered as described above and frozen. On Day 0, T cells were restimulated in upright T25 flasks with 1.0×10^6 T cells, 2.0×10^6 irradiated PBMCs, recombinant human IL-2, and CD3 monoclonal antibody (OKT3) [0.1 μ g/mL, eBioscience]. Half the volume of media was exchanged on Days 2, 4, 5, and 6 with RPMI 1640 supplemented with 10% heat-inactivated fetal bovine serum [FBS], 100 IU/mL penicillin, 100 μ g/mL streptomycin, and recombinant human IL-2 [50 U/mL, PeproTech, Cranbury, NJ]. Cells were harvested for assay on Day 7.

The assay was performed in triplicates. On Day 5, target cells in the 96-well array were passaged and seeded in 384-well plates. On Day 6, engineered CD8+ T cells expressing the recombinant E7-11-28 TCR (also known as “TCR 28” or “28” or “TCR-200-A02”) or untransduced control T cells were added at an effector to target (E: T) ratio of 5:1 and incubated with target cells for 48 hours. Target cell numbers were measured over time using IncuCyte® by measuring the number of NucLight™ Red-positive cells. Cell inhibition at 48 h by the recombinant TCR of interest on each MHC in the assay was calculated as $1 - (\text{Cell doubling}[\text{Incubated with E7-11-28-expressing T cells}] / \text{Cell doubling}[\text{Incubated with untransduced control T cells}])$.

(iv) *Generation of TCR E7-11-28-expressing CD8 T cells for safety screens*

Primary CD8+ T cells from an A*02:01-negative donor were isolated using the StraightFrom® Leukopak® CD8 Microbead Kit (Miltenyi Biotec) according to the manufacturer's protocol. Isolated cells were frozen in CryoStor® CS10 (Stem Cell Technologies) and stored in liquid nitrogen until use. On Day -1, CD8+ T cells were thawed, washed with complete T cell medium (RPMI 1640 supplemented with 10% heat-inactivated fetal bovine serum (FBS), 100 IU/mL penicillin, 100 μ g/mL streptomycin, recombinant human IL-2 [50 U/mL, PeproTech, Cranbury, NJ], recombinant human IL-15 [5 ng/mL, R&D Systems], and recombinant human IL-7 [5 ng/mL, R&D Systems]). On Day 0, CD8+ T cells were washed and resuspended in fresh T cell medium and activated using ImmunoCult™ human CD3/CD28/CD2 T cell activator (5 μ L per 1×10^6 CD8+ T cells, Stem Cell Technologies). On Day 1, cells were washed and resuspended in fresh complete T cell medium and transduced with lentiviral particles to express TCR E7-11-28 at an MOI of 10. On Day 2, cells were washed and resuspended in fresh complete T cell medium and expanded until Day 5 in G-Rex® 24 well plates (Wilson Wolf). On Day 5, cells were harvested and resuspended in EasySep™ buffer (Stem Cell) and HLA-A*02:01

HPV16₁₁₋₁₉ dextramer-APC (Immudex) was added at a 1:25 dilution for 20 minutes at room temperature. Anti-CD34-Alexa Fluor®488 (Clone: QBEnd10, R&D Systems) was added at 1:50 dilution and incubated for 10 minutes at room temperature. Cells were washed with EasySep™ buffer and resuspended in EasySep™ buffer containing 7-AAD at 1:200 dilution. Live dextramer-binding cells (DAPI- Dextramer+ CD34+) cells were isolated by cell sorting (Beckman Coulter MoFlo Astrios EQ). Sorted cells were washed and resuspended in fresh complete T cell medium and expanded in G-Rex® 10 flasks (Wilson Wolf) until day 12, at which point cells were frozen in CryoStor® CS10 and stored at liquid nitrogen until used.

CD8+ T cells expressing E7-11-28 were thawed and restimulated (further expanded) by co-culturing T cells with irradiated (60 grays) allogeneic HLA-A*02:01 PBMCs in the presence of 0.1 ug/mL anti-CD3 (OKT3, eBioscience) and 50 U/mL recombinant IL-2 (Peprotech) in fresh T cell medium (RPMI 1640 supplemented with 10% heat-inactivated fetal bovine serum (FBS), 100 IU/mL penicillin, 100 µg/mL streptomycin, recombinant human IL-2 [50 U/mL, PeproTech]) in GRex® 100 flasks (Wilson Wolf). 50 U/mL recombinant IL-2 was added to expanding cells every other day until day 6. On day 6, half of culture medium was replaced with fresh T cell medium containing 50 U/mL recombinant IL-2. Cells were used for screens on day 7.

(v) *Quality control (QC) of T cell on-target killing*

On day 5 of restimulation, reporter cells (expressing the peptidome library) were labeled with CellTrace™ Violet (Thermo Fisher) for 10 minutes at room temperature. The labeling reaction was quenched with a 5X excess of complete DMEM media (1X DMEM supplemented with 10% FBS, 100 IU/mL penicillin, 100 ug/mL streptomycin). After centrifugation, cells were seeded for subsequent assays. For off-target screening, 400 x 10⁶ labeled reporter cells were seeded in a CellSTACK® flask. For QC of T cell on-target killing, 25,000 reporter cells were seeded per well of a 96-well flat bottom plate.

On day 6 of TCR E7-11-28 restimulation, T cells were tested for activity against HPV16₁₁₋₁₉ peptide. As a positive control, a fraction of reporter cells was pulsed with 100 ng/mL of HPV16₁₁₋₁₉ peptide (Genscript) for one hour. T cells were added to reporter cells at four effector:target (E:T) ratios (2:1, 1:1, 1:2, 1:4) in triplicate. After four hours of incubation at 37°C, cells were resuspended by pipetting up and down before data acquisition on a CytoFLEX flow cytometer (Beckman Coulter).

(vi) *Screen co-culture, target cell enrichment and sorting*

On day 7 of TCR E7-11-28 expansion, T cells were added to library-transduced reporter cells and incubated at 37°C for four hours. After incubation, all cells were harvested by trypsinization and centrifugation, cells were resuspended in 1X Annexin V binding buffer (Miltenyi Biotec) and centrifuged. Cells were resuspended with Annexin V magnetic microbeads (Miltenyi Biotec) in 1X Annexin V binding buffer (1 mL microbeads in 9 mL Annexin V binding buffer per 1×10^9 total cells) and incubated at room temperature for 15 minutes. Cells were washed with 5X volume of Annexin V binding buffer and centrifuged. Cells were resuspended in Annexin V binding buffer and then divided over 2 “megareps” and filtered using a 70 μ M cell strainer (Corning). Annexin V-labeled cells were positively selected using an autoMACS® Pro (Miltenyi Biotec). The elution of each “megarep” was further divided over four “replicates” for a total of 8 technical replicates per screen. IFP⁺ cells were sorted using a MoFlo® Astrios EQ cell sorter (Beckman Coulter).

(vii) *Next generation sequencing*

Genomic DNA (gDNA) was extracted from sorted cells using the GeneJET™ Genomic DNA Purification Kit (Thermo Fisher Scientific). The antigen cassette was amplified from the extracted gDNA by PCR then appended with sequencing adaptors and sample-specific index sequences in a second PCR reaction. Amplicons were sequenced on an Illumina NextSeq™ machine using the standard Illumina sequencing primer.

(viii) *Data analysis*

Nucleotide sequences were mapped to individual nucleotide tiles. The proportion of read counts for each tile was calculated for each screen replicate (n=8) and for the input for each pool of transduced reporter cells, and enrichments of each tile were calculated by dividing the proportion of the tile in the screen replicate by the proportion of the tile in the input library. A modified geometric mean of the enrichment of an identical tile across the 8 screen replicates was used to identify reproducible screen hits. Specific MHC-binding epitopes for each tile above the threshold of 1.5-fold enrichment were predicted using NetMHC4.0. Candidate epitopes for each tile were selected by identifying predicted strong-binding epitopes shared across overlapping adjacent and redundant tiles that were enriched in the screen.

d. Safety evaluation of TCR E7-11-28

(i) *Cancer cell lines expressing putative off-targets of TCR E7-11-28*

Cancer cell lines were cultured in the media described in the following Table 4:

Table 4: Cancer cell lines and their culture media

Cancer Cell Lines	Culture Medium
CAL-12T	DMEM + 10% HIFBS + 1X Pen/Strep
THP-1	RPMI-1640 + 10% HIFBS + 1X Pen/Strep + 2-mercaptoethanol (0.05 mM)
4.1TF-1	RPMI-1640 + 10% HIFBS + 1X Pen/Strep + GM-CSF (2 ng/mL)
OVCAR-3	RPMI-1640 + 10% HIFBS + 1X Pen/Strep + bovine insulin (0.01 mg/mL)
SNU-475	RPMI-1640 + 10% HIFBS + 1X Pen/Strep
NCI-H1792	RPMI-1640 + 10% HIFBS + 1X Pen/Strep
ChaGo-K-1	RPMI-1640 + 10% HIFBS + 1X Pen/Strep
JVM-2	RPMI-1640 + 10% HIFBS + 1X Pen/Strep
L363	RPMI-1640 + 10% HIFBS + 1X Pen/Strep
SET-2	RPMI-1640 + 20% HIFBS + 1X Pen/Strep
CMK	RPMI-1640 + 20% HIFBS + 1X Pen/Strep
OCI-M1	IMDM + 20% HIFBS + 1X Pen/Strep
OCI-M2	IMDM + 20% HIFBS + 1X Pen/Strep
HEK-293	DMEM + 10% HIFBS + 1X Pen/Strep

(ii) *Healthy human primary/iPS-derived cells expressing putative off-targets of TCR E7-11-28*

Primary cells or iPS-derived cells from healthy donors were thawed and cultured in the media described in Table 5 below as per manufacturer's instructions. Subcutaneous human white preadipocytes (HWP) were cultured in preadipocyte growth medium (ready-to-use) until 80-90% confluent and differentiated to adipocytes by changing the medium to preadipocyte differentiation medium (ready-to-use) for 72 hours. They were further cultured in adipocyte nutrition medium for 14 days to complete the differentiation process.

Table 5: Healthy human primary/iPS derived cells and their culture media

Cells	Cell lot #	Culture medium
Human Umbilical Vein Endothelial Cells (HUVEC)	466Z026, 0000246083	Endothelial Cell Growth Medium (Ready-to-use)
Human Pulmonary Fibroblasts (HPF)	474Z024.2, 446Z03, 1474Z031.2, 1081503.2	Fibroblast Growth Medium (Ready-to-use)
Human Small Airway Epithelial Cells (HSAEpC)	467Z033, 467Z025.2	Airway Epithelial Cell Growth Medium (Ready-to-use)
Subcutaneous Human White Preadipocytes (HWP)	454Z006, 467Z014	Preadipocyte Growth Medium (Ready-to-use)
Human Aortic Smooth Muscle Cells (HAoSMC)	453Z011.6, 470Z011.2	Smooth Muscle Cell Growth Medium 2 (Ready-to-use)

Human Cardiac Myocytes (HCM)	463Z016.2, 470Z011.9, 472Z002.3	Myocyte Growth Medium (Ready-to-use)
iCell Astrocytes	01434	DMEM medium/F-12, HEPES + 2% FBS + 1X N-2 supplement
Normal Human Astrocytes (NHA)	0000672445	AGM™ Astrocyte Growth Medium BulletKit™
Human Hepatic Stellate Cells (HHStC)	C212011, C212641	SuperCult® Stellate Cell Medium
Human Hepatic Stellate Cells (HHStC)	25914	Stellate Cell Medium
Normal Human Dermal Fibroblasts (NHDF)	472Z001.3, 471Z018.2, 477Z023.2	Fibroblast Growth Medium (Ready-to-use)
Human cardiac fibroblasts (HCF)	472Z002.2, 475Z017.1	Fibroblast Growth Medium 3 (Ready-to-use)
Normal Human Epidermal Keratinocytes (NHEK)	451Z014.1 HH1052, HH1165, HH1186	Keratinocyte Growth Medium 2 (Ready-to-use) UPCM – Universal Primary Cell Plating Medium
Hepatocytes		
Human Small Intestinal Epithelial Cells (HSIEpC)	201457	Epithelial Cell Growth Medium
Human Cervical Epithelial Cells (HCerEpC)	202099	Epithelial Cell Growth Medium Cervical Epithelial Cell Basal Medium+ Cervical Epithelial Cell Growth Kit
Human Cervical Epithelial Cells (HCerEpC)	70029809	Mammary Epithelial Cell Basal Medium+ Mammary Epithelial Cell Growth Kit
Human Mammary Epithelial Cells (HMEpC)	70043304	Mesenchymal Stem Cell Basal Medium for Adipose, Umbilical and Bone Marrow-derived MSCs+ Primary Skeletal Muscle Growth Kit
Skeletal Muscle Cells (SkMC)	81202212	
Human bone marrow mononuclear cells (HBMMNC)	2208422001, 2208412006, 2208412008	RPMI-1640 + 10% HIFBS + 1X Pen/Strep

(iii) *Quantitative RT-PCR*

Total RNA was extracted from cancer cell lines or healthy human primary cells using the Qiagen RNeasy® Mini Kit (Qiagen, Valencia, CA) according to manufacturer's instructions. The quality and concentration of RNA in samples was determined using a NanoDrop™ One^C machine (Thermo Fisher Scientific, Waltham, MA). Equal amounts of RNA (2 µg) from different samples were used for cDNA synthesis using the SuperScript™ IV VILO™ synthesis kit (Thermo Fisher Scientific, Waltham, MA) according to manufacturer's instructions using the T100™ Thermal Cycler (Bio-Rad Laboratories,

Hercules, CA) with cycling conditions as follows: anneal primers at 25°C for 10 min, reverse transcribe RNA at 50°C for 10 min, and inactivate enzyme at 85°C for 5 min.

All qPCR assays were performed in triplicate using the QuantStudio™ 7 Pro PCR System (Thermo Fisher Scientific, Waltham, MA) in a 20 µL reaction volume containing 10 µL TaqMan® Fast Advanced Master Mix (Thermo Fisher Scientific, Waltham, MA), 5 µL diluted cDNA (50 ng), 4 µL of RNase/DNase free water, and 1 µL each of gene specific TaqMan® assay probes (Thermo Fisher Scientific, Waltham, MA): TATA-box binding protein (Hs00427620_m1), INTS4 (Hs00369250_m1), CPAMD8, (Hs00610855_m1) HERC1 (Hs01032486_m1), MPL (Hs00180489_m1), SPTA1 (Hs00162179_m1), and NUTM1 (Hs01395191_m1). The following standard PCR reaction conditions were used for all transcripts: 50°C 2 min, 95°C 2 min; 40 cycles of 95°C 1 sec, 60°C 20 sec. Data were analyzed using the QuantStudio™ Design and Analysis manager software (Version 2.6) for the quantification cycle (Cq) measurements. The $2^{-\Delta C_T}$ method was applied for internal normalization using the geometric mean of the housekeeping gene TATA-box binding protein.

(iv) *Cytokine assay for safety evaluation of TCR E7-11-28*

Twenty four (24) hours prior to co-culture assays, cancer cell lines were detached from their culture flasks using Gibco TrypLE™ reagent, washed with media and seeded in 96-well flat-bottom culture plates at a density of 50,000 cells/well and allowed to adhere overnight. Cells were pulsed with 1 ng/mL or 100 ng/mL of E7₁₁₋₁₉ peptide for 2 hours or left un-pulsed in their respective media. Following pulsing, wells were gently washed three times with media. E7-11-28 or NTD cells were then added at a density of 50,000 cells/well in complete T cell media. 24 hours post co-culture, supernatants were collected and frozen at -80°C. Supernatants were thawed and analyzed for IFN-γ levels by loading on a Simple Plex Human IFN-gamma (3rd Gen) Cartridge (ProteinSimple, San Jose, CA) using the Ella™ instrument. 24 hours prior to co-culture assays, HUVECs, HPFs, HSAEpCs, HAoSMCs, NHAs and HHStECs were detached from their culture flasks or plates using the DetachKit™ (PromoCell, Germany), washed and plated in their respective media at a density of 25,000 cells/well. They were peptide-pulsed or non-pulsed the following day, washed and cocultured with 50,000 cells/well of E7-11-28 or NTD cells. Subcutaneous HWPes were plated directly in 96-well flat-bottom culture plates after thawing at the density recommended by the supplier and differentiated to mature adipocytes without detaching them. HCMs were also directly plated in 96-well flat-bottom culture plates after thawing at

the supplier-recommended density and cultured for 40 days to allow them to mature. Adipocytes and HCMs were then peptide-pulsed or non-pulsed and cocultured with 50,000 cells/well of E7-11-28 or NTD. iCell astrocytes were thawed and plated as per manufacturer's instructions in 24-well culture plates for 7 days. They were peptide-pulsed or non-pulsed the following day, washed and cocultured with 250,000 cells/well of E7-11-28 or NTD cells. Supernatants were collected 24 hours post-coculture of all primary/iPS derived cells and T cells, and analyzed for IFN- γ levels on the Ella™ instrument.

e. *Mouse xenograft studies*

The *in vivo* anti-tumor efficacy of TCR E7-11-28 was evaluated in two xenograft models by subcutaneous cell injection of CaSki and SCC152 cells into 7–9-week-old female NCG mice (NOD-*Prkdc^{em26Cd52}Il2rg^{em26Cd22}*/NjuCrl, Charles River). The animal care and use program at Explora BioLabs is accredited by the Association for Assessment and Accreditation of Laboratory Animal Care International (AAALAC), which assures compliance with accepted standards for the care and use of laboratory animals. CaSki and SCC152 cells were grown as adherent cultures in RPMI-1640 and EMEM medium containing 10% fetal bovine serum, respectively. 1×10^6 CaSki or SCC152 tumor cells in 100 μ L volume consisting of 50% PBS and 50% Matrigel® were injected subcutaneously into the right flank. Ten- or fourteen-days post-injection, animals were randomized into experimental groups based on tumor volume (measured with calipers) according to the formula: Volume = $1/2(\text{tumor length} \times \text{perpendicular tumor width}^2)$.

On the days of dosing, T cells were thawed in complete T cell media, washed and resuspended in sterile PBS at a density of 2×10^7 live cells per 0.2 mL. The vehicle (PBS), 2×10^7 live NTD or TCR E7-11-28 T-cells were injected intravenously into the tail vein of each test animal in a fixed volume of 0.2 mL

Effects on tumor growth were evaluated by measuring growth biweekly.

f. Engineering of HPV16 E7-11-28 and DN-TGF β RII double positive T cells and evaluation of DN-TGF β RII function

Engineering of T cells with lentivirus was performed as described in the section 'Engineering T cells to express HPV16 E7₁₁₋₁₉-specific TCRs' (see Section b(i) above), except that T cells were co-transduced with two lentiviruses encoding (1) TCR E7-11-28 and Q-tagged CD8 α and (2) DN-TGF β RII. Expression of TCR E7-11-28, Q-tagged CD8

and DN-TGF β R2 was verified by flow cytometry. Subsequently, cells were stained with antibody for TGF β R2 (W17055, BioLegend) and FACS-sorted into DN-TGF β R2-positive (TGF β R2 bright) and DN-TGF β R2-negative (TGF β R2 dim) fractions. T cells were rested overnight in T cell medium supplemented with 50 IU/mL IL-2 (Sigma Aldrich) and 5 ng/mL IL-7 (R&D Systems) and were then plated in 12-well plates in T cell medium containing 0 or 5 ng/mL TGF β 1 (R&D Systems). After 24 hr incubation in the presence vs. absence of TGF β 1, a co-culture assay with peptide-pulsed T2 cells was set up. To this end, T2 cells were pulsed with E7₁₁₋₁₉ peptide (YMLDLQPET, Genscript) at various concentrations (0.7 pg/mL, 7.4 pg/mL, 22 pg/mL, 67 pg/mL, 200 pg/mL and 2,000 pg/mL), and plated with T cells at an E:T of 1:1 in 50% T cell medium and 50% target cell medium (RPMI 1640 containing 10% heat-inactivated FBS and 1% Penicillin/Streptomycin (Thermo Fisher Scientific)); TGF β 1 was added to a final concentration of 0 or 5 ng/mL. After 20 hrs, GolgiPlug™ (BD Biosciences) was added to the co-culture. Cells were incubated for an additional 4 hrs and then stained for intracellular IFN γ . Non-specific binding to Fc receptor was inhibited by incubating cells for 15 minutes with Fc block (Thermo Fisher Scientific). Subsequently, cells were stained with biotinylated anti-human CD34 (QBEND10, Thermo Fisher Scientific) followed by Brilliant Violet™ 421-conjugated streptavidin (BD Biosciences), anti-human CD3 FITC (HIT3a, BioLegend) and fixable near-infrared LIVE/DEAD™ dye (Thermo Fisher Scientific). Cells were fixed with Cytofix™ (BD Biosciences), permeabilized with Perm/Wash™ buffer (BD Biosciences), and stained with anti-human IFN γ -PE (B27, BioLegend). Samples were acquired on a CytoFLEX flow cytometer (Beckman Coulter) and analyzed using FlowJo software (version 10, TreeStar). The percentage of IFN γ + cells within the Q-tagged live T cell population (LIVE/DEAD™-CD3+CD34+) was determined.

As described further below, the term “TSC-200-A02” refers to an engineered whole T cell population, including CD8+ T cells and CD4+ T cells, expressing E7-11-28 (*i.e.*, TCR-200-A02 sequence described above in Table 1) in addition to other components, including CD8 α , CD8 β , CD34 enrichment tag (*e.g.*, Q tag), and DN-TGF β R2.

g. ReceptorScan screens

(i) DC culture

Monocyte isolation was performed on day -4 using PBMCs isolated from HLA-A*02:01-positive healthy donors with the EasySep™ Human CD14 Positive Selection Kit

II (StemCell Technologies) according to the manufacturer's instructions. Purity and co-stimulatory molecule expression were assessed using fluorescently-labeled antibodies specific for CD14 (M5E2, BioLegend, Dedham, MA), HLA-A2 (BB7.2, BioLegend), CD80 (2D10, BioLegend), CD83 (HB15e, BioLegend), and CD86 (IT2.2, BioLegend). CD14 expression was >90%. CD14⁺ monocytes were resuspended in AIM-V™ media (Thermo Fisher Scientific, Waltham, MA) supplemented with recombinant human GM-CSF and IL-4 (R&D Systems, Minneapolis, MN) at final concentrations of 800 IU/mL and 1000 IU/mL, respectively. On day -2, recombinant human TNF- α (10 ng/mL), IL-6 (1000 IU/mL), and IL-1 β (2 ng/mL) (R&D Systems), as well as PGE2 (1 μ g/mL, StemCell Technologies), were added to cultured monocytes.

(ii) *CD8 naïve T cell isolation*

On day -1, autologous CD8 naïve T cells were isolated from PBMCs from HLA-A*02:01-expressing healthy donors using the EasySep™ Human Naïve CD8⁺ T Cell Isolation Kit II (StemCell Technologies) according to the manufacturer's instructions. Purity was assessed using fluorescently-labeled antibodies specific for CD8 α (HIT8a, BioLegend), CD45RO (UCHL1, BioLegend), CD45RA (HI100, BioLegend), CD56 (5.1H11, BioLegend), CD57 (HCD57, BioLegend), and CCR7 (G043H7, BioLegend). Purity of naïve CD8 α ⁺ T cells was >90%. Cells were rested overnight at 37°C, 5% CO₂ in T cell medium (X-VIVO™ 15 serum-free medium [Lonza, Rockland, MD] or LymphoONE™ [LymphoONE T-cell expansion Xeno-Free medium, Takara, WK552] containing 10% human serum [Sigma Aldrich, St. Louis, MO], 1% penicillin-streptomycin [Thermo Fisher Scientific], 1% GlutaMAX [Thermo Fisher]), and supplemented with 10 ng/ml recombinant human IL-7 (R&D Systems).

(iii) *Co-culture*

On day 0, CD8 T cell purity was reassessed using the identical antibody panel as on day -1, and DC maturation was confirmed by upregulation of HLA-A2, CD80, CD83, and CD86 and downregulation of CD14. DCs were pulsed with 1 μ M HPV16 E7₁₁₋₁₉ peptide (YMLDLQPET, GenScript [Piscataway, NJ]) as well as with additional peptides with various antigen specificities (*i.e.*, multiplex screens) for 3 hours at 37°C, 5% CO₂. Pulsed DCs were co-cultured with rested CD8 naïve T cells in T cell medium supplemented with recombinant human IL-12 (10 ng/mL) and IL-21 (60 ng/mL) (R&D Systems). Co-cultures were supplemented with recombinant human IL-7 and IL-15 (R&D Systems) between days 3 and 10. Dextramer staining for HPV16 E7₁₁₋₁₉-specific cells was performed on day 10 or

11 using an A*02:01 HPV16 E7₁₁₋₁₉ (YMLDLQPET) dCODE dextramer® (Immudex, Copenhagen, Denmark, WB3823-PfBC0621), CD8 α and TCR α/β (IP26, BioLegend), and DAPI (Thermo Fisher Scientific) according to the manufacturer's instructions.

(iv) *Antigen-specific cell sorting*

On day 12, cells were collected and stained with A*02:01 HPV16 E7₁₁₋₁₉ (YMLDLQPET) dCODE dextramer® (Immudex) together with dCODE dextramers® (Immudex) specific for various other antigens according to the manufacturer's instructions. Cells were washed and then stained with antibodies specific for CD8 α and TCR α/β , and with DAPI as on day 10-11, and dextramer-positive cells (CD8 α ⁺, DAPI⁺, TCR α/β ⁺, dextramer⁺) were sorted using a Sony SH800S cell sorter (Sony Biotechnology, San Jose, CA), BigFoot Cell Sorter (ThermoFisher Scientific), or MoFlo® Astrios Cell Sorter (Beckman Coulter, Brea, CA). Sorted cells were subjected to single cell TCR α/β sequencing using the 10x Genomics platform (Pleasanton, CA).

(v) *Multiplexed NGS and analysis using the 10x Genomics platform*

Single-cell libraries were prepared according to the 10x Chromium Next GEM Single Cell 5' Reagent Kit v2 (Dual Index) with feature barcode technology for cell surface protein & immune receptor mapping (10x Genomics, protocol CG000330 Rev A). Up to 15,000 cells were captured in droplets (GEMs) and processed according to the manufacturer's instructions to obtain libraries that yielded VDJ and cell surface protein information. The fully assembled libraries were sequenced on an Illumina NextSeq™ 2000 instrument (Illumina).

Sequenced VDJ and cell surface protein libraries were processed using the Cell Ranger 6.0.0 VDJ and COUNT pipelines (10x Genomics), respectively. The cell surface protein dataset measuring the dCODE dextramers® (Immudex) was utilized to demultiplex the VDJ data to determine which epitope was recognized by each TCR. A target epitope was assigned to a cell barcode if for a given cell barcode, the total dextramer counts were greater than 10 and one dextramer accounted for >90% of the total counts. Utilizing the shared cell barcodes between the VDJ and cell surface protein libraries allowed for identification of the target of each sequenced TCR.

h. Engineering T cells to express HPV16-E7₁₁₋₁₉ -specific TCRs (Fig. 15)

PBMCS were isolated from HLA-A*02:01-positive healthy donor leukopaks using an automated cell processing system. Isolated, washed, and concentrated PBMCs were

electroporated to deliver transposase-encoding mRNA and transposon nanoplasmid vectors. Following electroporation, the cells were allowed to rest overnight in basal culture medium. 24 hours post-electroporation, the cells were activated with CD3/CD28/CD2 T-cell activator and growth-stimulating cytokines. Enrichment of engineered cells was performed during the culture expansion phase via selective growth advantage in the presence of a small molecule. Expanded cells were harvested on day 15 and reformulated into cryopreservation medium. Cells were cryopreserved using an automated controlled rate freezing program. Data are shown in Fig. 15.

i. Materials

Cell lines

- Lenti-X: Takara Bio USA, 632180
- HEK293T cells: ATCC, CRL-3216
- T2: ATCC, CRL-1992
- CaSki: ATCC, CRL-1550
- NCI-H1792: ATCC, 5895
- SCC090: ATCC, CRL-3239
- SCC152: ATCC, CRL-3240
- SiHa: ATCC, HTB-35
- CAL-12T: DSMZ, ACC 443
- THP-1: ATCC, TIB202
- TF-1: ATCC, CRL-2003
- OVCAR-3: ATCC, HTB-161
- SNU-475: ATCC, CRL-2236
- ChaGo-K-1: ATCC, HTB-168
- JVM2: ATCC, CRL-3002
- L363: DSMZ, ACC 49
- SET-2: DSMZ, ACC 608
- CMK: DSMZ, ACC 392
- OCI-M1: DSMZ, ACC529
- OCI-M2: DSMZ, ACC619

Healthy human primary/iPS-derived cells

- Human Umbilical Vein Endothelial Cells (HUVEC): PromoCell, C-12200 (Lot # 466Z026)
- HUVEC – Human Umbilical Vein Endothelial Cells, Single Donor, in EGM™: Lonza, CC-2517 (Lot # 0000246083)
- Human Pulmonary Fibroblasts (HPF): PromoCell, C-12360 (Lot # 474Z024.2, 446Z03, 1474Z031.2, 1081503.2)
- Human Small Airway Epithelial Cells (HSAEpC): PromoCell, C-12642 (Lot # 467Z033, 467Z025.2)
- Subcutaneous Human White Preadipocytes (HWP): PromoCell, C-12735 (Lot # 454Z006, 467Z014)
- Human Aortic Smooth Muscle Cells (HAoSMC): PromoCell, C-12533 (Lot # 453Z011.6, 470Z011.2)
- Human Cardiac Myocytes (HCM): PromoCell, C-12810 (Lot # 463Z016.2, 470Z011.9, 472Z002.3)
- iCell Astrocytes Kit, 01434: Fujifilm Cellular Dynamics
- Normal Human Astrocytes (NHA): Lonza, CC-2656 (Lot # 0000672445)
- Human Hepatic Stellate Cells (HHStEC): Creative Bioarray, CSC-C1496 (Lot # C212011, C212641)
- Human Hepatic Stellate Cells (HHStEC): ScienCell Research Laboratories, 5300 (Lot # 25914)
- Normal Human Epidermal Cells (NHDF): PromoCell, C-12300 (Lot # 471Z018.2), C-12302 (Lot # 472Z001.3, 477Z023.2)
- Human Cardiac Fibroblasts (HCF): PromoCell, C-12360 (Lot # 472Z002.2, 475Z017.1)
- Normal Human Epidermal Keratinocytes (NHEK): PromoCell, C-12003 (Lot # 451Z014.1)
- Hepatocytes: In Vitro ADMET Laboratories, 82006 (Lot # HH1052, HH1165, HH1186)
- Human Cervical Epithelial Cells (HCerEpC): iXCells Biotechnologies, 10HU-237 (Lot # 202099)
- Human Small Intestinal Epithelial Cells (HSIEpC): iXCells Biotechnologies, 10HU-237 (Lot # 201457)
- Human Cervical Epithelial Cells (HCerEpC): ATCC, PCS-480-011 (Lot # 70029809)

- Human Mammary Epithelial Cells (HMEpC): ATCC, PCS-600-010 (Lot # 70043304)
- Skeletal Muscle Cells (SkMC): ATCC, PCS-950-010 (Lot # 81202212)
- Human bone marrow mononuclear cells (HBMMNC): StemCell Technologies, 70001.2 (Lot # 2208422001, 2208412006, 2208412008)

Animals

- NCG mouse (NOD-*Prkdc*^{em26Cd52}*Il2rg*^{em26Cd22}/NjuCrl): Charles River Laboratories

Media and supplements

- X-VIVO 15, serum-free hematopoietic cell medium, with L-Glutamine, gentamycin and phenol red: Lonza, 04-418Q
- Human male AB serum (heat-inactivated): Sigma Aldrich, H3667-100ML
- Penicillin streptomycin: Gibco, 15149-122
- GlutaMAX™ supplement: Fisher Scientific, 35050061
- RPMI-1640 medium: ATCC, 30-2001
- Fetal bovine serum (FBS), heat-inactivated: Gibco, A3840102
- IMDM: ATCC, 30-2005
- RPMI medium 1640 (1x) [+] 4.5 g/L D-glucose, [+] 2.383 g/L HEPES buffer, [+] L-glutamine, [+] 1.5 g/L sodium bicarbonate, [+] 110 mg/L sodium pyruvate: Gibco, A10491-01
- DMEM medium (1X) [+] 4.5 g/L D-glucose, [+] L-glutamine, [+] 3.7 g/L sodium bicarbonate: Thermo Fisher Scientific, 11965084
- DMEM (1x) [+] 4.5 g/L D-glucose, [+] L-glutamine, [-] Sodium Pyruvate: Gibco, 11965
- OptiPRO™ SFM medium: Thermo Fisher Scientific, 12309019
- EMEM medium: ATCC, 30-2003
- Endothelial Cell Growth Medium (Ready-to-use): PromoCell, C-22010
- Fibroblast Growth Medium (Ready-to-use): PromoCell, C-23010
- Airway Epithelial Cell Growth Medium (Ready-to-use): PromoCell, C-21060
- Preadipocyte Growth Medium (Ready-to-use): PromoCell, C-27410
- Preadipocyte Differentiation Medium (Ready-to-use): PromoCell, C-27436
- Adipocyte Nutrition Medium (Ready-to-use): PromoCell, C-27438
- Smooth Muscle Cell Growth Medium 2 (Ready-to-use): PromoCell, C-22062

- Myocyte Growth Medium (Ready-to-use): PromoCell, CC-22070
- DMEM medium/F-12, HEPES: Thermo Fisher Scientific, 11330
- N-2 supplement: Thermo Fisher Scientific, 17502048
- AGM™ Astrocyte Growth Medium BulletKit™: Lonza, CC-3186
- SuperCult® Stellate Cell Medium: Creative Bioarray, CM-1193W
- Stellate Cell Medium: ScienCell Research Laboratories, 5301
- DetachKit™: PromoCell, C-41220
- TrypLE™ Express: Thermo Fisher Scientific, 12605-010
- Fibroblast Growth Medium 3 (Ready-to-use): PromoCell, C-23025
- UCRM™ - Universal Cryopreservation Recovery Medium, 50 mL: In Vitro ADMET Laboratories, 81015
- UPCM™ - Universal Primary Cell Plating Medium, 50 mL: In Vitro ADMET Laboratories, 81016
- Keratinocyte Growth Medium 2 (Ready-to-use): PromoCell, C-20011
- Epithelial Cell Growth Medium: iXCells Biotechnologies, MD-0041
- Mammary Epithelial Cell Basal Medium: ATCC, PCS-600-030
- Mammary Epithelial Cell Growth Kit: ATCC, PCS-600-040
- Mesenchymal Stem Cell Basal Medium for Adipose, Umbilical and Bone Marrow-derived MSCs: ATCC, PCS-500-030
- Primary Skeletal Muscle Growth Kit: ATCC, PCS-950-040

Buffers

- EasySep buffer: StemCell Technologies, 20144
- DPBS (no Ca²⁺/Mg²⁺): Gibco, 14190-122

Cytokines

- Recombinant human IL-2: Sigma Aldrich, 11147528001
- Recombinant human IL-2: PeproTech, 200-02
- Recombinant human IL-7: R&D Systems, 219-IL-025
- Recombinant human IL-15: R&D Systems, 247-ILB-005
- Recombinant human TGFβ1: R&D Systems, 7754-BH-025/CF

Kits

- EasySep™ Human T Cell Isolation Kit: StemCell Technologies: 17951

- Ella™ simple plex kit for 32 samples: ProteinSimple: SPCKB-PS-003027
- StraightFrom® Leukopak® CD8 Microbead Kit: Miltenyi Biotech, 130-117-019
- Annexin V MicroBead Kit: Miltenyi Biotech, 130-090-201
- Simple Plex Human IFN-gamma (3rd Gen) Cartridge: ProteinSimple, SPCKB-PS-002574

Antibodies and staining reagents

- CD3 monoclonal antibody (OKT), functional grade: eBioscience 16-0037-81
- Anti-human CD8 α PerCp-Cy5.5 (clone: HIT8a): BioLegend: 300924
- Anti-human CD4 APC-Cy7 (Clone: OKT4): BioLegend: 317418
- Anti-human CD56 PE (clone: 5.1H11): BioLegend: 362508
- Anti-human CD57 PE (clone: HCD57): BioLegend: 322312
- Anti-human CD34 Alexa Fluor 488: (Clone: QBEND/10): R&D Systems, FAB7227G
- Anti-human HLA-A2 PE (clone: BB7.2): BioLegend, 343306
- Anti-human TCR α/β PE-Cy7 (clone: IP26): BioLegend: 306720
- Anti-human HLA-A,B,C APC Antibody: BioLegend, 311410
- Fixable viability Dye eFluor 660 (APC Channel) Thermo Fisher Scientific: 65-0864-14
- DAPI: Thermo Scientific: Thermo Scientific, 62248
- Cytofix: BD Biosciences, 554655
- Anti-human CD3 FITC: (clone HIT3a): Biolegend:300306
- Anti-human CD34 biotinylated: (Clone QBEND/10): Thermo Fisher Scientific: MA5-16924
- Anti-human TGF β R2 PE: (clone W17055) Biolegend: 399704
- Anti-IFN γ PE: (clone B27): Biolegend: 506507
- Anti-human Fc Receptor Binding Inhibitor: Thermo Fisher Scientific: 16-9161-73
- LIVE/DEAD™ Fixable Near-Infrared Dye: Thermo Fisher Scientific: L10119
- Streptavidin Brilliant Violet™ 41: BD Biosciences: 563259
- GolgiPlug™: BD Biosciences: 555029
- Perm/Wash™ Buffer: BD Biosciences: 554723
- CellTrace™ Violet (CTV): Thermofisher, C34557
- Fixable viability Dye eFluor® 660: Thermo Fisher Scientific: 65-0864-14
- CountBright™ Absolute Counting Beads: Fisher Scientific: C36950

- 7-AAD Viability Staining Solution: BioLegend, 420404

Peptides

- HPV16-E7₁₁₋₁₉ (YMLDLQPET): Genscript

Dextramers

- HLA-A*02:01 YMLDLQPET HPV16-E7₁₁₋₁₉ dextramer: Immudex

CRISPR-Cas9 and electroporation reagents

- Alt-R® S.p. Cas9 Nuclease V3 (Lot #0000417827): IDT, 1081059
- Alt-R® CRISPR-Cas9 tracrRNA (Lot #0000415438): IDT, 1072534
- 4D-Nucleofector™ Core Unit: Lonza, AAF-1002B
- 4D-Nucleofector™ X Unit: Lonza, AAF-1002X
- SE Cell Line 4D-Nucleofector™ X Kit L: Lonza V4XC-1012

Tissue culture plates

- G-Rex® 24-well plate: Wilson Wolf, 80192M
- G-Rex® 6-well plate: Wilson Wolf, 80240M
- G-Rex® 100: WilsonWolf, 800400
- VECCELL 96-well plate: Cosmo Bio Co., VCL-V96WGPB-10-EX
- TC-treated 6-well plate: Corning Costar, 3506
- TC-treated 24-well plates: Corning Costar, 3524
- 96-well flat-bottom plates: Corning Costar, 3595
- 384-well flat-bottom plates: Corning Costar, 3764
- HYPERflask® M: Corning, 10020
- CellSTACK®, 5 Chamber with Vent Caps, Corning, 3313
- 70uM Nylon Cell Strainer, Corning, 431751
- CellAdhere™ Collagen I-Coated, 96-well flat-bottom plate: StemCell Technologies, 100-0366
- PureCol™ Coated 6-Well Plates: MilliporeSigma, CC302

Packaging and lentivirus production reagents

- Lenti-X™ GoStix™ Plus: Takara, 631281
- jetPRIME® transfection reagent: Polyplus-transfection, 114-75

- Vivaspin® 20: Sartorius, VS2041
- Vivaflow® 50 cassettes: Sartorius, VF05P4

Quantitative RT-PCR Reagents

- RNeasy® Mini Kit: Qiagen, 74104
- TaqMan® Fast Advanced Master Mix: Thermo Fisher Scientific, 4444557
- SuperScript™ IV VILO™: Thermo Fisher Scientific, 11756050
- RT-PCR Grade Water: Thermo Fisher Scientific, AM9935

Leukopak processing reagents:

- Multi-24 Column Block: Miltenyi, 130-095-692
- Lymphocyte Separation Medium: Corning, 25-072-CV

Other reagents

- ImmunoCult™ Human CD3/CD28/CD2 T cell activator: StemCell Technologies, 10970
- Poly-L-ornithine solution 0.01%: Millipore-Sigma, P4957-50ML
- CryoStor CS10: StemCell Technologies, 07930
- ViaStain AO/PI staining solution in PBS: Nexcelom Bioscience, CS2-0106-5mL
- Nourseothricin: GoldBio, N-500-1
- Puromycin: Gibco, A11138-03
- Mirus TransIT, Mirus Bio MIR 2704
- Polybrene: EMD Millipore, TR-1003-G
- Incucyte® NucLight Red Lentivirus Reagent (EF-1 Alpha Promoter, Puromycin selection), Sartorius, 4476
- Laminin: Millipore-Sigma, L2020
- Poly-L-Lysine 10 mg/mL: ScienCell Research Laboratories, 0413
- Corning® Matrigel® Basement Membrane Matrix High Concentration (HC), LDEV-free, 10 mL, Product Number 354248

Example 2: Discovery of TCRs specific for HPV16-E7₁₁₋₁₉ (YMLDLQPET)

A high-throughput TCR discovery platform that enables rapid cloning of antigen-specific TCRs from primary human naïve CD8 T cells was developed and used to identify

TCRs specific for HPV16-E7₁₁₋₁₉ (YMLDLQPET) (FIG. 1). A total of 459 TCRs were discovered. 59/293 and 15/161 HPV16-E7₁₁₋₁₉-specific TCRs were identified from two separate proprietary VAYG screens, respectively (FIG. 2 and FIG. 6). A subset of the TCRs was identified as having desired cell surface expression and effector function such as cytotoxicity or cytokine production (FIG. 3, FIG. 4, and FIG. 7) using a variety of cell lines (see Table 6). FIG. 8 provides summary results demonstrating that TCR-28 shows comparable cytotoxicity and superior effector function relative to the comparator TCR.

Table 6: Reference for cell line expression

Cell line	Cell line origin	HLA-A*02:01	HPV16
CaSki	Cervical carcinoma	+	+
SCC152	Squamous cell carcinoma of hypopharynx	+	+
SCC090	Squamous cell carcinoma of base of the tongue	+	+
SiHa	Cervical carcinoma	-	+
NCI-H1792	Lung carcinoma	+	-

In addition, HPV16-E7₁₁₋₁₉-specific TCR E7-11-28 was screened in an alloreactivity assay. TCR28 exhibited minimal allo-reactivity generally as defined by target cell inhibition of more than 20% (*e.g.*, no detectable allo-reactivity to 108 of 110 different HLA types tested) (FIG. 5), induced antigen-specific T cell proliferation (FIG. 9), did not react with cancer cell lines expressing putative off-targets (FIG. 11) or healthy human primary cells (FIG. 12), and efficiently controlled tumor growth *in vivo* (FIG. 13). Moreover, it was demonstrated that suppressing TGF β signaling, such as by using DN-TGF β RII, renders TSC-200-A02 T cells resistant to TGF β -mediated suppression (FIG. 14). Indeed, expression and evaluation of TCR E7-11-28 in representative pNVVD154 and pNVVD160 vectors further confirm functional TCR activity (FIG. 15A-15C).

Thus, a variety of HPV16-E7₁₁₋₁₉-specific TCRs having desirable characteristics (*e.g.*, target recognition, cell surface expression, cytotoxic function, low alloreactivity, etc.) have been identified and described herein.

Incorporation by Reference

All publications, patents, and patent applications mentioned herein are hereby incorporated by reference in their entirety as if each individual publication, patent or patent application was specifically and individually indicated to be incorporated by reference. In case of conflict, the present application, including any definitions herein, will control.

Also incorporated by reference in their entirety are any polynucleotide and polypeptide sequences which reference an accession number correlating to an entry in a public database, such as those maintained by The Institute for Genomic Research (TIGR) on the World Wide Web at tigr.org and/or the National Center for Biotechnology Information (NCBI) on the World Wide Web at ncbi.nlm.nih.gov.

Equivalents and Scope

The details of one or more embodiments encompassed by the present invention are set forth in the description above. Although representative, exemplary materials and methods have been described above, any materials and methods similar or equivalent to those described herein may be used in the practice or testing of embodiments encompassed by the present invention. Other features, objects and advantages related to the present invention are apparent from the description. Unless defined otherwise, all technical and scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art to which the present invention belongs. In the case of conflict, the present description provided above will control.

Those skilled in the art will recognize or be able to ascertain using no more than routine experimentation, many equivalents to the specific embodiments encompassed by the present invention described herein. The scope encompassed by the present invention is not intended to be limited to the description provided herein and such equivalents are intended to be encompassed by the appended claims.

It is also noted that the term “comprising” is intended to be open and permits but does not require the inclusion of additional elements or steps. When the term “comprising” is used herein, the term “consisting of” is thus also encompassed and disclosed.

Where ranges are given, endpoints are included. Furthermore, it is to be understood that unless otherwise indicated or otherwise evident from the context and understanding of one of ordinary skill in the art, values that are expressed as ranges may assume any specific

value or subrange within the stated ranges in different embodiments encompassed by the present invention, to the tenth of the unit of the lower limit of the range, unless the context clearly dictates otherwise.

In addition, it is to be understood that any particular embodiment encompassed by the present invention that falls within the prior art may be explicitly excluded from any one or more of the claims. Since such embodiments are deemed to be known to one of ordinary skill in the art, they may be excluded even if the exclusion is not set forth explicitly herein. Any particular embodiment of the compositions encompassed by the present invention (*e.g.*, any antibiotic, therapeutic or active ingredient; any method of production; any method of use; etc.) may be excluded from any one or more claims, for any reason, whether or not related to the existence of prior art.

It is to be understood that the words which have been used are words of description rather than limitation, and that changes may be made within the purview of the appended claims without departing from the true scope and spirit encompassed by the present invention in its broader aspects.

While the present invention has been described at some length and with some particularity with respect to several described embodiments, it is not intended that it should be limited to any such particulars or embodiments or any particular embodiment, but it is to be construed with references to the appended claims so as to provide the broadest possible interpretation of such claims in view of the prior art and, therefore, to effectively encompass the intended scope encompassed by the present invention.

What is claimed is:

1. A binding protein comprising:
 - a) a T cell receptor (TCR) alpha chain CDR sequence with at least about 80% identity to a TCR alpha chain CDR sequence selected from the group consisting of TCR alpha chain CDR sequences listed in Table 1; and/or
 - b) a TCR beta chain CDR sequence with at least about 80% identity to a TCR beta chain CDR sequence selected from the group consisting of TCR beta chain CDR sequences listed in Table 1, wherein the binding protein is capable of binding to an HPV16 E7₁₁₋₁₉ immunogenic peptide-MHC (pMHC) complex, optionally wherein the binding affinity has a K_d less than or equal to about 5×10^{-4} M.
2. A binding protein comprising:
 - a) a TCR alpha chain variable (V_α) domain sequence with at least about 80% identity to a TCR V_α domain sequence selected from the group consisting of TCR V_α domain sequences listed in Table 1; and/or
 - b) a TCR beta chain variable (V_β) domain sequence with at least about 80% identity to a TCR V_β domain sequence selected from the group consisting of TCR V_β domain sequences listed in Table 1, wherein the binding protein is capable of binding to an HPV16 E7₁₁₋₁₉ immunogenic peptide-MHC (pMHC) complex, optionally wherein the binding affinity has a K_d less than or equal to about 5×10^{-4} M.
3. A binding protein comprising:
 - a) a TCR alpha chain sequence with at least about 80% identity to a TCR alpha chain sequence selected from the group consisting of TCR alpha chain sequences listed in Table 1; and/or
 - b) a TCR beta chain sequence with at least about 80% identity to a TCR beta chain sequence selected from the group consisting of TCR beta chain sequences listed in Table 1, wherein the binding protein is capable of binding to an HPV16 E7₁₁₋₁₉ immunogenic peptide-MHC (pMHC) complex, optionally wherein the binding affinity has a K_d less than or equal to about 5×10^{-4} M.
4. A binding protein comprising:
 - a) a TCR alpha chain CDR sequence selected from the group consisting of TCR alpha chain CDR sequences listed in Table 1; and/or

b) a TCR beta chain CDR sequence selected from the group consisting of TCR beta chain CDR sequences listed in Table 1, wherein the binding protein is capable of binding to an HPV16 E7₁₁₋₁₉ immunogenic peptide-MHC (pMHC) complex, optionally wherein the binding affinity has a K_d less than or equal to about 5×10^{-4} M.

5. A binding protein comprising:

a) a TCR alpha chain variable (V_α) domain sequence selected from the group consisting of TCR V_α domain sequences listed in Table 1; and/or

b) a TCR beta chain variable (V_β) domain sequence selected from the group consisting of TCR V_β domain sequences listed in Table 1, wherein the binding protein is capable of binding to an HPV16 E7₁₁₋₁₉ immunogenic peptide-MHC (pMHC) complex, optionally wherein the binding affinity has a K_d less than or equal to about 5×10^{-4} M.

6. A binding protein comprising:

a) a TCR alpha chain sequence selected from the group consisting of TCR alpha chain sequences listed in Table 1; and/or

b) a TCR beta chain sequence selected from the group consisting of TCR beta chain sequences listed in Table 1, wherein the binding protein is capable of binding to an HPV16 E7₁₁₋₁₉ immunogenic peptide-MHC (pMHC) complex, optionally wherein the binding affinity has a K_d less than or equal to about 5×10^{-4} M.

7. The binding protein of any one of claims 1-6, wherein 1) the TCR alpha chain CDR, TCR V_α domain, and/or TCR alpha chain is encoded by a TRAV, TRAJ, and/or TRAC gene or fragment thereof selected from the group of TRAV, TRAJ, and TRAC genes listed in Table 1, and/or 2) the TCR beta chain CDR, TCR V_β domain, and/or TCR beta chain is encoded by a TRBV, TRBJ, and/or TRBC gene or fragment thereof selected from the group of TRBV, TRBJ, and TRBC genes listed in Table 1, and/or 3) each CDR of the binding protein has up to five amino acid substitutions, insertions, deletions, or a combination thereof as compared to the cognate reference CDR sequence listed in Table 1.

8. The binding protein of any one of claims 1-7, wherein the HPV16 E7₁₁₋₁₉ immunogenic peptide comprises the amino acid sequence YMLDLQPET.

9. The binding protein of any one of claims 1-8, wherein the binding protein is chimeric, humanized, or human.

10. The binding protein of any one of claims 1-9, wherein the binding protein is a TCR, an antigen-binding fragment of a TCR, a single chain TCR (scTCR), a chimeric antigen receptor (CAR), or a fusion protein comprising a TCR and an effector domain, optionally wherein the binding domain comprises a transmembrane domain and an effector domain that is intracellular.
11. The binding protein of any one of claims 1-10, wherein the TCR alpha chain and the TCR beta chain are covalently linked, optionally wherein the TCR alpha chain and the TCR beta chain are covalently linked through a linker peptide.
12. The binding protein of any one of claims 1-11, wherein the TCR alpha chain and/or the TCR beta chain are covalently linked to a moiety, optionally wherein the covalently linked moiety comprises an affinity tag or a label.
13. The binding protein of claim 12, wherein the affinity tag is selected from the group consisting of CD34 enrichment tag, Glutathione-S-Transferase (GST), calmodulin binding protein (CBP), protein C tag, Myc tag, HaloTag, HA tag, Flag tag, His tag, biotin tag, and V5 tag, and/or wherein the label is a fluorescent protein.
14. The binding protein of any one of claims 1-13, wherein the covalently linked moiety is selected from the group consisting of an inflammatory agent, cytokine, toxin, cytotoxic molecule, radioactive isotope, or antibody or antigen-binding fragment thereof.
15. The binding protein of any one of claims 1-14, wherein the binding protein binds to the pMHC complex on a cell surface.
16. The binding protein of any one of claims 1-15, wherein the MHC is a MHC multimer, optionally wherein the MHC multimer is a tetramer.
17. The binding protein of any one of claims 1-16, wherein the MHC is a MHC class I molecule.
18. The binding protein of any one of claims 1-17, wherein the MHC comprises an MHC alpha chain that is an HLA serotype HLA-A*02.

19. The binding protein of any one of claims 1-18, wherein the HLA allele is selected from the group consisting of HLA-A*0201, HLA-A*0202, HLA-A*0203, HLA-A*0205, HLA-A*0206, and HLA-A*0207 allele.
20. The binding protein of any one of claims 1-19, wherein binding of the binding protein to the HPV16 E7₁₁₋₁₉ peptide-MHC (pMHC) complex elicits an immune response, optionally wherein the immune response is a T cell response.
21. The binding protein of any one of claims 1-20, wherein the T cell response is selected from the group consisting of T cell expansion, cytokine release, and/or cytotoxic killing.
22. The binding protein of any one of claims 1-21, the binding protein is capable of specifically and/or selectively binding to the HPV16 E7₁₁₋₁₉ immunogenic peptide-MHC (pMHC) complex with a K_d less than or equal to about 1×10^{-4} M, less than or equal to about 5×10^{-5} M, less than or equal to about 1×10^{-5} M, less than or equal to about 5×10^{-6} M, less than or equal to about 1×10^{-6} M, less than or equal to about 5×10^{-7} M, less than or equal to about 1×10^{-7} M, less than or equal to about 5×10^{-8} M, less than or equal to about 1×10^{-8} M, less than or equal to about 5×10^{-9} M, less than or equal to about 1×10^{-9} M, less than or equal to about 5×10^{-10} M, less than or equal to about 1×10^{-10} M, less than or equal to about 5×10^{-11} M, less than or equal to about 1×10^{-11} M, less than or equal to about 5×10^{-12} M, or less than or equal to about 1×10^{-12} M.
23. The binding protein of any one of claims 1-22, wherein the binding protein has a higher binding affinity to the peptide-MHC (pMHC) than does a known T-cell receptor.
24. The binding protein of any one of claims 1-23, wherein the binding protein has at least 1.05 fold higher binding affinity to the peptide-MHC (pMHC) than does a known T-cell receptor.
25. The binding protein of any one of claims 1-24, wherein the binding protein induces higher T cell expansion, cytokine release, and/or cytotoxic killing than does a known T-cell receptor when contacted with target cells expressing HPV16 E7₁₁₋₁₉ peptide epitope.
26. The binding protein of any one of claims 1-25, wherein the binding protein induces at least 1.05-fold increase in T cell expansion, cytokine release, and/or cytotoxic killing

than does a known T-cell receptor when contacted with target cells expressing HPV16 E7₁₁₋₁₉ peptide epitope.

27. The binding protein of claim 25 or 26, wherein the target cell is CaSki, SCC152, or SCC090 cell line.

28. The binding protein of claim 25 or 26, wherein the target cell is a cancer cell, optionally wherein the cancer cell is a head & neck cancer cell, an oropharyngeal cancer cell, a cervical cancer cell, an anal cancer cancer cell, a vaginal cancer cell, a vulval cancer cell, or a penile cancer cell.

29. The binding protein of any one of claims 22-28, wherein the binding protein does not bind to a peptide-MHC (pMHC) complex, optionally wherein the peptide is derived from SPTA1, MPL, HERC1, CPAMD8, INTS4, NUTM1, or XM_00172256.

30. The binding protein of any one of claims 22-29, wherein the binding protein does not bind to a SPTA1-, MPL-, HERC1-, CPAMD8-, INTS4-, NUTM1-, and/or XM_00172256- peptide-MHC (pMHC) complex.

31. A TCR alpha chain and/or beta chain selected from the group consisting of TCR alpha chain and beta chain sequences listed in Table 1.

32. An isolated nucleic acid molecule that hybridizes, under stringent conditions, with the complement of a nucleic acid encoding a polypeptide selected from the group consisting of polypeptide sequences listed in Table 1, or a sequence with at least about 80% homology to a nucleic acid encoding a polypeptide selected from the group consisting of the polypeptide sequences listed in Table 1, optionally wherein the isolated nucleic acid molecule comprises 1) a TRAV, TRAJ, and/or TRAC gene or fragment thereof selected from the group of TRAV, TRAJ, and TRAC genes listed in Table 1 and/or 2) a TRBV, TRBJ, and/or TRBC gene or fragment thereof selected from the group of TRBV, TRBJ, and TRBC genes listed in Table 1.

33. The isolated nucleic acid of claim of claim 32, wherein the nucleic acid is codon optimized for expression in a host cell.

34. A vector comprising the isolated nucleic acid of claim 32 or 33.

35. The vector of claim 34, wherein the vector is a cloning vector, expression vector, or viral vector.
36. The vector of claim 34 or 35, wherein the vector further comprises a nucleic acid sequence encoding CD8 α , CD8 β , a dominant negative TGF β receptor II (DN-TGF β RII), selectable protein marker, optionally wherein the selectable protein marker is dihydrofolate reductase (DHFR).
37. The vector of any one of claims 34-36, wherein the nucleic acid sequence encoding CD8 α , CD8 β , the DN-TGF β RII, and/or the selectable protein marker is operably linked to a nucleic acid encoding a tag.
38. The vector of any one of claims 34-37, wherein the nucleic acid encoding a tag is at the 5' upstream of the nucleic acid sequence encoding CD8 α , CD8 β , the DN-TGF β RII, and/or the selectable protein marker such that the tag is fused to the N-terminal of CD8 α , CD8 β , the DN-TGF β RII, and/or the selectable protein marker.
39. The vector of any one of claims 34-38, wherein the tag is a CD34 enrichment tag.
40. The nucleic acid or vector of any one of claims 32-39, wherein the isolated nucleic acid of claim 23 or 24, and/or the nucleic acid sequence encoding TCR8 α , TCR8 β , CD8 α , CD8 β , the DN-TGF β RII, and/or the selectable protein marker are interconnected with an internal ribosome entry site or a nucleic acid sequence encoding a self-cleaving peptide.
41. The nucleic acid or vector of any one of claims 32-40, wherein the self-cleaving peptide is P2A, E2A, F2A or T2A.
42. A host cell which comprises the isolated nucleic acid of claim 32 or 33, comprises the vector of any one of claims 34-41, and/or expresses the binding protein of any one of claims 1-30, optionally wherein the cell is genetically engineered.
43. The host cell of claim 42, wherein the host cell comprises a chromosomal gene knockout of a TCR gene, an HLA gene, or both.

44. The host cell of claim 42 or 43, wherein the host cell comprises a knockout of an HLA gene selected from an $\alpha 1$ macroglobulin gene, $\alpha 2$ macroglobulin gene, $\alpha 3$ macroglobulin gene, $\beta 1$ microglobulin gene, $\beta 2$ microglobulin gene, and combinations thereof.
45. The host cell of any one of claims 42-44, wherein the host cell comprises a knockout of a TCR gene selected from a TCR α variable region gene, TCR β variable region gene, TCR constant region gene, and combinations thereof.
46. The host cell of any one claims 42-45, wherein the host cell expresses CD8 α , CD8 β , a DN-TGF β RII, and/or a selectable protein marker, optionally wherein the selectable protein marker is DHFR.
47. The host cell of claims 46, wherein the CD8 α , CD8 β , the DN-TGF β RII, and/or the selectable protein marker is fused to a CD34 enrichment tag.
48. The host cell of claim 47, wherein host cells are enriched using the CD34 enrichment tag.
49. The host cell of any one of claims 42-48, wherein the host cell is an immune cell.
50. The host cell of any one of claims 42-49, wherein the immune cell is a cytotoxic lymphocyte, cytotoxic lymphocyte precursor cell, cytotoxic lymphocyte progenitor cell, cytotoxic lymphocyte stem cell, CD4 $^{+}$ T cell, CD8 $^{+}$ T cell, CD4/CD8 double negative T cell, gamma delta ($\gamma\delta$) T cell, natural killer (NK) cell, NK-T cell, dendritic cell, or combination thereof.
51. The host cell of any one of claims 42-50, wherein the T cell is a naive T cell, central memory T cell, effector memory T cell, or a combination thereof.
52. The host cell of any one of claims 42-51, wherein the T cell is a primary T cell or a cell of a T cell line.
53. The host cell of any one of claims 42-52, wherein the T cell does not express or has a lower surface expression of an endogenous TCR.

54. The host cell of any one of claims 42-53, wherein the host cell is capable of producing a cytokine or a cytotoxic molecule when contacted with a target cell that comprises a peptide-MHC (pMHC) complex comprising the HPV16 E7₁₁₋₁₉ peptide epitope in the context of an MHC molecule.
55. The host cell of claim 54, wherein the host cell is contacted with the target cell *in vitro*, *ex vivo*, or *in vivo*.
56. The host cell of claim 54 or 55, wherein the cytokine is TNF- α , IL-2, and/or IFN- γ .
57. The host cell of any one of claims 54-56, wherein the cytotoxic molecule is perforins and/or granzymes, optionally wherein the cytotoxic molecule is granzyme B.
58. The host cell of any one of claims 54-57, wherein the host cell is capable of producing a higher level of cytokine or a cytotoxic molecule when contacted with a target cell expressing HPV16 E7₁₁₋₁₉ peptide epitope.
59. The host cell of claim 58, wherein the host cell is capable of producing an at least 1.05-fold higher level of cytokine or a cytotoxic molecule.
60. The host cell of any one of claims 54-59, wherein the host cell is capable of killing a target cell that comprises a peptide-MHC (pMHC) complex comprising the HPV16 E7₁₁₋₁₉ peptide epitope in the context of an MHC molecule.
61. The host cell of claim 61, wherein the killing is determined by a killing assay.
62. The host cell of claim 60 or 61, wherein the ratio of the host cell and the target cell in the killing assay is from 20:1 to 0.625:1.
63. The host cell of any one of claims 60-62, wherein a target cell is a T2 cell pulsed with 1 μ g/mL to 50 pg/mL of HPV16 E7₁₁₋₁₉ peptide.
64. The host cell of any one of claims 60-62, wherein the host cell is capable of killing a higher number of target cells when contacted with target cells expressing HPV16 E7₁₁₋₁₉ peptide epitope.

65. The host cell of claim 64, wherein the host cell is capable of killing an at least 1.05-fold higher number of target cells.
66. The host cell of any one of claims 60, 61, 64 and 65, wherein the target cell is CaSki, SCC152, or SCC090 cell line.
67. The host cell of any one of claims 54-66, wherein the HPV16 E7₁₁₋₁₉ immunogenic peptide comprises the amino acid sequence YMLDLQPET.
68. The host cell of any one of claims 54-67, wherein the MHC molecule is a MHC class I molecule.
69. The host cell of any one of claims 54-68, wherein the MHC molecule comprises an MHC alpha chain that is an HLA serotype HLA-A*02.
70. The host cell of any one of claims 54-69, wherein the HLA allele is selected from the group consisting of HLA-A*02:01, HLA-A*02:02, HLA-A*02:03, HLA-A*02:05, HLA-A*02:06, and HLA-A*02:07 allele.
71. The host cell of any one of claims 54-70, wherein the target cell is a cell line selected from the group consisting of CaSki, SCC152 and SCC090 cell lines, is a cancer cell expressing HPV16 E7₁₁₋₁₉ immunogenic peptide, or is not SiHa cell line and/or is not NCI-H1792 cell line.
72. The host cell of claim 71, wherein the cancer cell is selected from the group consisting of head & neck cancer cell, an oropharyngeal cancer cell, a cervical cancer cell, an anal cancer cancer cell, a vaginal cancer cell, a vulval cancer cell, and a penile cancer cell.
73. The host cell of any one of claims 54-72, wherein a) the host cell does not induce T cell expansion, cytokine release, or cytotoxic killing when contacted with a target cell that comprises a peptide-MHC (pMHC) complex comprising a SPTA1, MPL, HERC1, CPAMD8, INTS4, NUTM1, or XM_00172256 peptide epitope in the context of an MHC molecule and/or b) the host cell does not express HPV16 E7₁₁₋₁₉ antigen, is not recognized by a binding protein of any one of claims 1-30, is not of serotype HLA-A*02, and/or does

not express an HLA-A*02 allele, optionally wherein the HLA-A*02 allele is HLA-A*02:01 and/or HLA-A*02:06.

74. A population of host cells of any one of claims 42-73.

75. A composition comprising: a) a binding protein according to any one of claims 1-30, b) an isolated nucleic acid according to claim 32 or 33, c) a vector according to any one of claims 34-41, d) a host cell according to any one of claims 42-73, and/or e) a population of host cells according to claim 74, and a carrier.

76. A device or kit comprising: a) a binding protein according to any one of claims 1-30, b) an isolated nucleic acid according to claim 32 or 33, c) a vector according to any one of claims 34-41, d) a host cell according to any one of claims 42-73, and/or e) a population of host cells according to claim 74, said device or kit optionally comprising a reagent to detect binding of a), d) and/or e) to a pMHC complex.

77. A method of producing a binding protein according to any one of claims 1-30, wherein the method comprises the steps of: (i) culturing a transformed host cell which has been transformed by a nucleic acid comprising a sequence encoding a binding protein according to any one of claims 1-30 under conditions suitable to allow expression of said binding protein; and (ii) recovering the expressed binding protein.

78. A method of producing a host cell expressing a binding protein according to any one of claims 1-30, wherein the method comprises the steps of: (i) introducing a nucleic acid comprising a sequence encoding a binding protein according to any one of claims 1-30 into the host cell; (ii) culturing the transformed host cell under conditions suitable to allow expression of said binding protein.

79. A method of detecting the presence or absence of an HPV16 E7₁₁₋₁₉ antigen and/or a cell expressing HPV16 E7₁₁₋₁₉, optionally wherein the cell is a hyperproliferative cell, comprising detecting the presence or absence of said HPV16 E7₁₁₋₁₉ antigen in a sample by use of at least one binding protein according to any one of claims 1-30, or at least one host cell according to any one of claims 42-73, wherein detection of the HPV16 E7₁₁₋₁₉ antigen is indicative of the presence of an HPV16 E7₁₁₋₁₉ antigen and/or cell expressing HPV16 E7₁₁₋₁₉.

80. The method of claim 79, wherein the at least one binding protein, or the at least one host cell, forms a complex with the HPV16 E7₁₁₋₁₉ peptide in the context of an MHC molecule, and the complex is detected in the form of fluorescence activated cell sorting (FACS), enzyme linked immunosorbent assay (ELISA), radioimmune assay (RIA), immunochemically, Western blot, or intracellular flow assay.

81. The method of claim 79 or 80, further comprising obtaining the sample from a subject.

82. The method of any one of claims 79-81, further comprising confirming cells expressing HPV16 E7₁₁₋₁₉ by bone marrow biopsy.

83. A method of detecting the level of a non-malignant disorder, a hyperproliferative disorder, or a relapse of a hyperproliferative disorder characterized by expression of an HPV16 E7₁₁₋₁₉ antigen in a subject, comprising:

a) contacting a sample obtained from the subject with at least one binding protein according to any one of claims 1-30, at least one host cell according to any one of claims 42-73, or a population of host cells according to claim 74; and

b) detecting the level of reactivity,

wherein a higher level of reactivity compared to a control level indicates the level of a non-malignant disorder, a hyperproliferative disorder, or a relapse of a hyperproliferative disorder characterized by expression of an HPV16 E7₁₁₋₁₉ antigen in the subject.

84. The method of claim 83, wherein the control level is a reference number.

85. The method of claim 83, wherein the control level is a level of a subject without the non-malignant disorder, a hyperproliferative disorder, or a relapse of a hyperproliferative disorder characterized by expression of an HPV16 E7₁₁₋₁₉ antigen.

86. A method for monitoring the progression of a non-malignant disorder, a hyperproliferative disorder, or a relapse of a hyperproliferative disorder characterized by expression of an HPV16 E7₁₁₋₁₉ antigen in a subject, the method comprising:

a) detecting in a subject sample at a first point in time the level of the HPV16 E7₁₁₋₁₉ antigen or the cell of interest expressing HPV16 E7₁₁₋₁₉, according to any one of claims 79-85;

b) repeating step a) at a subsequent point in time; and
c) comparing the level of HPV16 E7₁₁₋₁₉ antigen or the cell of interest expressing HPV16 E7₁₁₋₁₉ detected in steps a) and b) to monitor the progression of a non-malignant disorder, a hyperproliferative disorder, or a relapse of a hyperproliferative disorder characterized by expression of an HPV16 E7₁₁₋₁₉ antigen in the subject, wherein an absent or reduced level of the HPV16 E7₁₁₋₁₉ antigen or the cell of interest expressing HPV16 E7₁₁₋₁₉ detected in step b) compared to step a) indicates an inhibited progression of the non-malignant disorder, the hyperproliferative disorder, or the relapse of a hyperproliferative disorder characterized by expression of an HPV16 E7₁₁₋₁₉ antigen in the subject.

87. The method of claim 86, wherein between the first point in time and the subsequent point in time, the subject has undergone treatment to treat the non-malignant disorder, the hyperproliferative disorder, or the relapse of a hyperproliferative disorder characterized by expression of an HPV16 E7₁₁₋₁₉ antigen.

88. A method of assessing the efficacy of a therapy for a non-malignant disorder, a hyperproliferative disorder, or a relapse of a hyperproliferative disorder characterized by expression of an HPV16 E7₁₁₋₁₉ antigen comprising:

a) determining the presence or level of reactivity between a sample obtained from the subject and at least one binding protein according to any one of claims 1-30, at least one host cell according to any one of claims 42-73, or a population of host cells according to claim 74, in a first sample obtained from a subject prior to providing at least a portion of the therapy for the non-malignant disorder, the hyperproliferative disorder, or the relapse of a hyperproliferative disorder characterized by expression of an HPV16 E7₁₁₋₁₉ antigen to the subject, and

b) determining the presence or level of reactivity between a sample obtained from the subject and at least one binding protein according to any one of claims 1-30, at least one host cell according to any one of claims 42-73, or a population of host cells according to claim 74, in a second sample obtained from the subject following provision of the portion of the therapy for the non-malignant disorder, the hyperproliferative disorder, or the relapse of a hyperproliferative disorder characterized by expression of an HPV16 E7₁₁₋₁₉ antigen,

wherein the absence or a reduced level of reactivity in the second sample, relative to the first sample, is an indication that the therapy is efficacious for treating the non-

malignant disorder, the hyperproliferative disorder, or the relapse of a hyperproliferative disorder characterized by expression of an HPV16 E7₁₁₋₁₉ antigen in the subject.

89. The method of any one of claims 83-89, wherein the level of reactivity is indicated by a) the presence of binding and/or b) T cell activation and/or effector function

90. The method of claim 89, wherein the T cell activation or effector function is T cell proliferation, killing, or cytokine release.

91. The method of any one of claims 83-90, wherein the T cell binding, activation, and/or effector function is detected using fluorescence activated cell sorting (FACS), enzyme linked immunosorbent assay (ELISA), radioimmune assay (RIA), immunochemically, Western blot, or intracellular flow assay.

92. A method of preventing and/or treating a non-malignant disorder, a hyperproliferative disorder or a relapse of a hyperproliferative disorder characterized by expression of an HPV16 E7₁₁₋₁₉ antigen in a subject comprising administering to the subject a therapeutically effective amount of a composition comprising cells expressing at least one binding protein of any one of claims 1-30.

93. The method of claim 92, wherein the cell is an allogeneic cell, syngeneic cell, or autologous cell.

94. The method of claim 92 or 93, wherein the cell is genetically modified.

95. The method of any one of claims 92-94, wherein the cell comprises a chromosomal gene knockout of a TCR gene, an HLA gene, or both a TCR gene and an HLA gene.

96. The method of any one of claims 92-95, wherein the cell comprises a knockout of an HLA gene selected from an α 1 macroglobulin gene, α 2 macroglobulin gene, α 3 macroglobulin gene, β 1 microglobulin gene, β 2 microglobulin gene, and a combination thereof.

97. The method of any one of claims 92-96, wherein the cell comprises a knockout of a TCR gene selected from a TCR α variable region gene, TCR β variable region gene, TCR constant region gene, and combinations thereof.

98. The method of any one claims 92-97, wherein the cell expresses CD8 α , CD8 β , a DN-TGF β RII, and/or a selectable protein marker, optionally wherein the selectable protein marker is DHFR and further optionally wherein the CD8 α , CD8 β , the DN-TGF β RII, and/or the selectable protein marker is fused to a CD34 enrichment tag.
99. The method of claim 98, wherein cells are enriched using the CD34 enrichment tag.
100. The method of any one of claims 92-99, wherein the cell is an immune cell.
101. The method of any one of claims 92-100, wherein the immune cell is a cytotoxic lymphocyte, cytotoxic lymphocyte precursor cell, cytotoxic lymphocyte progenitor cell, cytotoxic lymphocyte stem cell, CD4⁺ T cell, CD8⁺ T cell, CD4/CD8 double negative T cell, gamma delta ($\gamma\delta$) T cell, natural killer (NK) cell, NK-T cell, dendritic cell, or combination thereof.
102. The method of any one of claims 92-101, wherein the T cell is a naive T cell, central memory T cell, effector memory T cell, or combination thereof.
103. The method of any one of claims 92-102, wherein the T cell is a primary T cell or a cell of a T cell line.
104. The method of any one of claims 92-103, wherein the T cell does not express or has a lower surface expression of an endogenous TCR.
105. The method of any one of claims 92-104, wherein the cell is capable of producing a cytokine or a cytotoxic molecule when contacted with a target cell that comprises a peptide-MHC (pMHC) complex comprising the HPV16 E7₁₁₋₁₉ peptide epitope in the context of an MHC molecule.
106. The method of any one of claims 92-105, wherein the cytokine is TNF- α , IL-2, and/or IFN- γ .
107. The method of any one of claims 92-106, wherein the cytotoxic molecule is perforins and/or granzymes, optionally wherein the cytotoxic molecule is granzyme B.

108. The method of any one of claims 92-107, wherein the cell is capable of producing a higher level of cytokine or a cytotoxic molecule when contacted with a target cell expressing HPV16 E7₁₁₋₁₉ peptide epitope.

109. The method of claim 108, wherein the cell is capable of producing an at least 1.05-fold higher level of cytokine or a cytotoxic molecule.

110. The method of any one of claims 92-109, wherein the host cell is capable of killing a target cell that comprises a peptide-MHC (pMHC) complex comprising an HPV16 E7₁₁₋₁₉ peptide epitope in the context of an MHC molecule.

111. The method of any one of claims 92-110, wherein the host cell is capable of killing a higher number of target cells when contacted with target cells expressing HPV16 E7₁₁₋₁₉ peptide epitope.

112. The method of claim 111, wherein the host cell is capable of killing an at least 1.05-fold higher number of target cells.

113. The method of any one of claims 92-112, wherein the HPV16 E7₁₁₋₁₉ immunogenic peptide comprises the amino acid sequence YMLDLQPET.

114. The method of any one of claims 92-113, wherein the MHC molecule is an MHC class I molecule.

115. The method of any one of claims 92-114, wherein the MHC molecule comprises an MHC alpha chain that is an HLA serotype HLA-A*02.

116. The method of any one of claims 92-115, wherein the HLA allele is selected from the group consisting of HLA-A*02:01, HLA-A*02:02, HLA-A*02:03, HLA-A*02:05, HLA-A*02:06, and HLA-A*02:07 allele.

117. The method of any one of claims 92-116, wherein the target cell is a non-malignant cell or a hyperproliferating cell expressing the HPV16 E7₁₁₋₁₉ antigen in the subject.

118. The method of any one of claims 92-117, wherein the composition further comprises a pharmaceutically acceptable carrier.

119. The method of any one of claims 92-118, wherein the composition induces an immune response against the non-malignant cells or the hyperproliferating cells expressing the HPV16 E7₁₁₋₁₉ antigen in the subject.
120. The method of any one of claims 92-119, wherein the composition induces an antigen-specific T cell immune response against the non-malignant cells or the hyperproliferating cells expressing the HPV16 E7₁₁₋₁₉ antigen in the subject.
121. The method of any one of claims 92-120, wherein the antigen-specific T cell immune response comprises at least one of a CD4⁺ helper T lymphocyte (Th) response and a CD8⁺ cytotoxic T lymphocyte (CTL) response.
122. The method of any one of claims 83-121, wherein the disorder is associated with HPV infection.
123. The method of any one of claims 83-122, wherein the HPV infection is HPV16 infection.
124. The method of any one of claims 83-123, wherein the cancer is a head & neck cancer.
125. The method of any one of claims 83-124, wherein the cancer is a head & neck squamous cell carcinoma (HNSCC).
126. The method of any one of claims 83-124, wherein the cancer is an oropharyngeal cancer.
127. The method of any one of claims 83-124, wherein the cancer is a cervical cancer.
128. The method of any one of claims 83-124, wherein the cancer is an anal cancer.
129. The method of any one of claims 83-124, wherein the cancer is a vaginal cancer.
130. The method of any one of claims 83-124, wherein the cancer is a vulvar cancer.
131. The method of any one of claims 83-124, wherein the cancer is a penile cancer.

132. The method of any one of claims 92-131, wherein the subject is receiving or previously received a hematopoietic cell transplant (HCT), optionally wherein the HCT comprises cells that do not express HPV16 E7₁₁₋₁₉ antigen, are not recognized by a binding protein of any one of claims 1-30, are not of serotype HLA-A*02, and/or do not express an HLA-A*02:01 allele.

133. The method of claim 132, wherein the HCT comprises a donor hematopoietic cell comprising a chromosomal knockout of a gene that encodes an HLA component, a chromosomal knockout of a gene that encodes a TCR component, or both.

134. The method of any one of claims 92-133, wherein the subject had previously received lymphodepleting chemotherapy.

135. The method of claim 134, wherein the lymphodepleting chemotherapy comprised cyclophosphamide, fludarabine, anti-thymocyte globulin, or a combination thereof.

136. The method of any one of claims 92-135, further comprising administering at least one additional treatment for the non-malignant disorder, the hyperproliferative disorder or the relapse of a hyperproliferative disorder to the subject.

137. The method of any one of claims 92-136, wherein the at least one additional treatment for the non-malignant disorder, the hyperproliferative disorder or the relapse of a hyperproliferative disorder is administered concurrently or sequentially with the composition.

138. The method of any one of claims 81-137, wherein the subject is an animal model of a disorder characterized by HPV16 E7₁₁₋₁₉ expression and/or the mammal, optionally wherein the mammal is a human, a primate, or a rodent.

139. An expression vector comprising a promoter operably linked to a nucleic acid sequence encoding CD8 α , CD8 β , a DN-TGF β RII, and/or a selectable protein marker, optionally wherein the selectable protein marker is DHFR.

140. The vector of claim 139, wherein the nucleic acid sequence encoding CD8 α , CD8 β , the DN-TGF β RII, and/or the selectable protein marker is operably linked to a nucleic acid

encoding a tag such that the tag is fused to the CD8 α , CD8 β , the DN-TGF β RII, and/or the selectable protein marker.

141. The vector of claim 139 or 140, wherein the nucleic acid encoding a tag is at the 5' upstream of the nucleic acid sequence encoding CD8 α , CD8 β , the DN-TGF β RII, and/or the selectable protein marker such that the tag is fused to the N-terminal of CD8 α , CD8 β , the DN-TGF β RII, and/or the selectable protein marker.

142. The vector of any one of claims 139-141, wherein the tag is a CD34 enrichment tag.

143. The vector of any one of claims 139-142, wherein the vector further comprises a nucleic sequence encoding a TCR α and/or TCR β .

144. The vector of any one of claims 139-143, wherein the TCR α , TCR β , and/or the DN-TGF β RII comprises a mutated transmembrane domain and/or a mutated constant domain.

145. The vector of any one of claims 139-144, wherein the mutated transmembrane domain and/or mutated constant domain enhance cellular surface expression of TCR α , TCR β , and/or the DN-TGF β RII, while decreasing expression of endogenous TCR α , TCR β , and/or TGF β RII.

146. The vector of any one of claims 139-145, wherein the nucleic acid sequence encoding CD8 α , CD8 β , the DN-TGF β RII, the selectable protein marker, the TCR α , and/or the TCR β , are interconnected with an internal ribosome entry site or a nucleic acid sequence encoding a self-cleaving peptide.

147. The vector of any one of claims 139-146, wherein the self-cleaving peptide is P2A, E2A, F2A or T2A.

148. The vector of any one of claims 139-147, wherein the vector further comprises a nucleic sequence encoding a polypeptide selected from the group consisting of polypeptide sequences listed in Table 1, or a sequence with at least about 80% homology to a nucleic acid encoding a polypeptide selected from the group consisting of the polypeptide sequences listed in Table 1, optionally wherein the isolated nucleic acid molecule comprises 1) a TRAV, TRAJ, and/or TRAC gene or fragment thereof selected from the

group of TRAV, TRAJ, and TRAC genes listed in Table 1 and/or 2) a TRBV, TRBJ, and/or TRBC gene or fragment thereof selected from the group of TRBV, TRBJ, and TRBC genes listed in Table 1.

149. The vector of any one of claims 139-148, wherein the vector has or comprises a nucleic acid sequence set forth in Table 3, or a fragment thereof, optionally wherein the fragment encodes DN-TGF β RII.