T7 ALPHA VIRAL VECTOR SYSTEM

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of US Provisional Appl. No. 62/256,788, filed November 18, 2015, the entire disclosure of which is hereby incorporated by reference in its entirety.

BACKGROUND

[0002] Alphaviruses are single-stranded RNA viruses with an envelope structure belonging to the family of Togaviridae. Alphavirus-based vectors are attractive candidates for vaccine development because they express high levels of recombinant proteins in mammalian cells, can elicit neutralizing antibodies and protection against challenges with tumor cells or lethal doses of viruses in animal models. Lundstrom *et al. Gene Ther. Mol. Biol.* 3:15-23 (1999). Alphavirus vectors are usually based on RNA replicons in which the viral structural genes have been deleted and substituted by a heterologous gene. The alphavirus replicon contains an ORF coding for a viral replicase at its 5'end, which is translated upon transfection of the RNA into eukaryotic cells. *See* Casales *et al., Virology* 376: 242-251 (2008). These vectors have been developed from different viruses, which include Sindbis virus (SIN), Semliki Forest virus (SFV), and Venezuelan equine encephalitis virus (VEE). *See* Xiong *et al., Science* 243: 1188-1191 (1989), Liljestrom *et al., Biotechnology* 9:1356-1361 (1991), Pushko *et al., Virology* 239:389-401(1997), and Casales *et al., Virology* 376: 242-251 (2008). A major problem associated with alphavirus-based vectors, however, is that an unmodified alphavirus vector is cytopathic in most mammalian cells due to mechanisms not yet fully understood. But a number of mutations in the alphavirus replicase that are capable of rendering theses vectors noncytopathic have been discovered, and most of these mutations have been detected in the nsp2 subunit of the RNA replicase. *See* Frolove *et al., J.*

Virol. 73:3854-3865 (1999); Perri *et al., J. Virol.* 74:9802-9807 (2000), Lundstrom *et al.,Expert Rev. Vaccines* 2:447-459 (2003), and Petrakova *et al., J. Virol.* 79:7597-7608 (2005).

[0003] Several types of alphavirus vector systems have been engineered, including naked RNA, recombinant virus particles, and layered DNA vectors. Naked RNA has the problem of low stability, leading to the variability of gene products due to degradation. Recombinant virus particles have the risk of generating replication-proficient viral particles through non-homologous recombination. The layered DNA/RNA vector consists of delivery of a DNA vector providing foreign gene expression from a CMV promoter, but transfection efficiencies can be reduced because the DNA must go into the nucleus for expression due to the type of promoter used, and DNA can insert into the host chromosome. Therefore, a need for efficient gene expression system based on alphavirus vectors still exists. The present invention satisfies this need.

SUMMARY OF THE INVENTION

[0004] In one aspect, the present invention provides a gene expression system in eukaryotic cells for gene expression in the cytoplasm. In some embodiments, the gene expression system comprises a vector which has the following components: a bacteriophage promoter, an alphavirus replicon operatively linked to the bacteriophage promoter, a first capping sequence, a subgenomic promoter, a second capping sequence, and a gene of interest. The gene expression system also comprises an exogenous RNA polymerase co-delivered with the vector into a cell, which transcribes the alphavirus replicon by recognizing the bacteriophage promoter.

[0005] In some embodiments, the alphavirus replicon is derived from an alpha virus selected from the group consisting of Sindbis virus (SIN), Semliki Forest virus (SFV), and Venezuelan equine encephalitis virus (VEE). In a preferred embodiment, the alphavirus replicon is noncytopathic, wherein the alphavirus replicon contains one or more mutations in the nsp2 subunit.

[0006] In some embodiments, the bacteriophage promoter is selected from the group consisting of T7, T3, and SP6 promoter. In some other embodiments, both the first and second capping sequences are the internal ribosome entry site sequence derived from encephalomyocarditis

virus. In some embodiments, the gene of interest encodes for an antigen, which can be a viral antigen, a bacterial antigen, or a cancer antigen. In some embodiments, the subgenomic promoter is derived from an alphavirus. In a preferred embodiment, the bacteriophage promoter is T7 promoter, and the exogenous RNA polymerase is T7 polymerase.

[0007] In another aspect, the present invention provides a vector comprising a bacteriophage promoter, an alphavirus replicon operatively linked to the bacteriophage promoter, a first capping sequence, a subgenomic promoter, a second capping sequence, and a gene of interest. In some embodiments, the bacteriophage promoter is T7 promoter. In some embodiments, both the first and second capping sequences are the internal ribosome entry site sequence derived from encephalomyocarditis virus. In some embodiments, the gene of interest encodes for an antigen, which can be a viral antigen, a bacterial antigen, or a cancer antigen.

[0008] In yet another aspect, the present invention provides a method for producing an induced pluripotent stem cell, comprising (a) introducing into a mammalian somatic cell a gene expression system comprising a vector, wherein the vector comprises a sequence encodes one or more mammal-derived reprogramming factor, and an exogenous RNA polymerase co-delivered with the vector, and (b) culturing the transduced somatic cell in the presence of a cytokine on a fibroblast feeder layer or extracellular matrix under conditions for maintaining pluripotency and self-renewal. In some embodiments, the reprogramming factor is selected from the group consisting of Oct 3/4, Sox2, Klf4, and c-Myc. In a preferred embodiment, the combination of reprogramming factor Oct 4, Sox2, Klf4, and c-Myc are expressed. In some other embodiments, the method is carried out in the presence of a substance for improving the efficiency of establishment of the pluripotent stem cell. In some embodiments, the substance for improving an efficiency of establishment is a histone deacetylase (HDAC) inhibitor, a histone methyltransferase (G9a) inhibitor, or a DNA methylase (Dnmt) inhibitor.

[0009] In another aspect, the present invention provides a vaccine comprising the gene expression system, wherein the gene of interest encodes an antigen, which can be a viral antigen, a bacterial antigen, and a cancer antigen. In a preferred embodiment, the vaccine comprises influenza hemagglutin, and is capable of eliciting an immune response against influenza virus.

[0010] In another aspect, the present invention provides a method for eliciting an immune response to an antigen in a subject, wherein the method comprises delivering into the subject the gene expression system, wherein the gene of interest encodes for an antigen; and inducing in the subject an immune response to the antigen in the subject. The present invention contemplates both prophylactic and therapeutic uses of the compositions and methods disclosed herein.

[0011] In another aspect, the present invention provides a therapeutic composition, comprising a dendritic cell transfected with the gene expression system, wherein the gene of interest encodes for an antigen capable of being displayed on the surface of the dendritic cell, wherein the therapeutic composition is capable of activating T cells to produce an immune response. In some embodiments, the antigen is a tumor antigen. In a preferred embodiment, the tumor antigen is a melanoma antigen selected from the group consisting of tyrosinase, tyrosinase related protein 1 (TRP-1), and tyrosinase related protein 2 (TRP-2).

[0012] In yet another aspect, the present invention provides a method for treating cancer, comprising administering to a patient in need thereof the therapeutic composition. In a preferred embodiment, cancer being treated is melanoma.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013] FIG. 1 illustrates the alphavirus vector of the present invention. The alphavirus replicase gene is cloned under the T7 promoter. The gene of interest is inserted after the replicase region, and under the control of a subgenomic promoter of SFV. Two copies of the IREs sequence are present in the vector, one is inserted between the T7 promoter and the replicase, and the other is inserted between the SFV subgenomic promoter and the gene of interest. The poly A and T7 terminator sequence are placed after the gene of interest. An additional selection marker such as GFP and hygromycin can be inserted between the gene of interest and the T7 terminator sequence.

DETAILED DESCRIPTION

Definition

[0014] The following terms are used throughout the application. Unless otherwise indicated, the terms are defined as follows.

[0015] A "polynucleotide" is a nucleic acid polymer. A "polynucleotide" can include both double- and single-stranded sequences, and can include naturally derived and synthetic DNA sequences. The term also includes sequences that include any of the known base analogs of DNA and RNA, and includes modifications, such as deletions, additions and substitutions (generally conservative in nature) to native sequences.

[0016] The terms "polypeptide" and "protein" refer to a polymer of amino acid residues and are not limited to a minimum length of the product. Thus, peptides, oligopeptides, dimers, multimers, and the like, are included within the definition. Both full-length proteins and fragments thereof are encompassed by the definition. The terms also include modifications, such as deletions, additions and substitutions (generally conservative in nature), to native sequence.

[0017] The term "antigen" refers to a molecule that contains one or more epitopes capable of stimulating an immunological response. Normally, an epitope will include between about 3-15, generally about 5-15, amino acids. Epitopes of a given protein can be identified using any number of epitope mapping techniques, well known in the art. *See*, e.g., *Epitope Mapping Protocols* in Methods in Molecular Biology, Vol. 66 (Glenn E. Morris, Ed., 1996) Humana Press, Totowa, N.J. For example, linear epitopes may be determined by concurrently synthesizing large numbers of peptides on solid supports, the peptides corresponding to portions of the protein molecule, and reacting the peptides with antibodies while the peptides are still attached to the supports. Such techniques are known in the art and described in, e.g., U.S. Pat. 4,708,871; Geysen et al. *Proc. Natl. Acad. Sci. USA* 81:3998-4002(1984); Geysen et al. *Molec. Immunol.* 23:709-715 (1986), all incorporated herein by reference in their entireties. Similarly, conformational epitopes are readily identified by determining spatial conformation of amino

acids such as by x-ray crystallography and 2-dimensional nuclear magnetic resonance. See, e.g., Epitope Mapping Protocols, *supra*.

[0018] For purposes of the present invention, antigens can be derived from any of several known viruses, bacteria, parasites and fungi, as well as any of the various tumors. Furthermore, for purposes of the present invention, an "antigen" refers to a protein, which includes modifications, such as deletions, additions and substitutions (generally conservative in nature), to the native sequence, so long as the ability to elicit an immunological response is maintained. These modifications may be deliberate, as through site-directed mutagenesis, or may be accidental, such as through mutations of hosts that produce the antigens.

[0019] An "immunological response" or "immune response" is the development in a subject of a humoral and/or a cellular immune response to molecules present in the composition of interest. For purposes of the present invention, a "humoral immune response" refers to an immune response mediated by antibody molecules, while a "cellular immune response" is one mediated by T-lymphocytes and/or other white blood cells. Thus, an immunological response as used herein may be one which stimulates the production of cytotoxic T cells, and/or the production or activation of helper T-cells. Such responses can be determined using standard immunoassays and neutralization assays, well known in the art.

[0020] As used herein, the term "alphavirus" means a genus of viruses, all of which are members of the Togaviridae family. Known alphaviruses include Eastern Equine Encephalitis virus (EEE), Venezuelan Equine Encephalitis virus (VEE), Everglades virus, Mucambo virus, Pixuna virus, Western Equine Encephalitis virus (WEE), Sindbis virus, South African arbovirus 86 (S.A.AR86) Semliki Forest virus, Middleburg virus, Chikungunya virus, O'nyong-nyong virus, Ross River virus, Barmah Forest virus, Getah virus, Sagiyama virus, Bebaru virus, Mayaro virus, Una virus, Aura virus, Whataroa virus, Babanki virus, Kyzylagach virus, Highlands J virus, Fort Morgan virus, Ndumu virus, and Buggy Creek virus.

[0021] As used herein, the term **"**alphavirus RNA replicon" or "alphavirus replicon" is used to refer to an alphavirus RNA molecule expressing nonstructural protein genes such that it can direct its own replication (amplification) and comprises the 5' and 3' alphavirus replication recognition sequences, coding sequences for alphavirus nonstructural proteins, and a

polyadenosine tract. It may additionally contain a regulatory cassette and a heterologous nucleic acid of interest that is expressed from the regulatory cassette. It may also be engineered to express one but not all alphavirus structural proteins.

[0022] "Vector" as used herein relates to genetically manipulated, cyclic, usually double-stranded nucleic acid molecules which allow specific selection and the directed introduction of genetic material of interest. Such vectors are mammalian expression vectors, bacterial plasmids, bacteriophage vectors, yeast episomal vectors, artificial chromosomal vectors or viral vectors.

[0023] The term "3' end" or "3' hydroxyl end" as interchangeably used herein relates to the termination at the hydroxyl group of the third carbon in the sugar-ring of a nucleic acid molecule, and is also known as the tail end. The term "5' end" or "5' phosphate end" as interchangeably used herein designates the end of the DNA or RNA strand that has a phosphate group at the fifth carbon in the sugar-ring of the deoxyribose or ribose at its terminus.

[0024] The term "host cell" or "host" as interchangeably used herein means an organism that harbors the isolated nucleic acid molecule or vector according to the present invention. Such host cell can be a mammalian cell, a plant, a bacterium, an insect cell or a nematode. Preferably, the host is a eukaryotic cell and, more preferably, said host is a mammalian cell.

[0025] As used herein, the term "promoter" refers to a polynucleotide molecule that is involved in recognition and binding of RNA polymerase and other proteins (trans-acting transcription factors) to initiate transcription.

[0026] The term “operatively linked” means that a regulatory sequence such as a promoter controls the expression of a gene.

[0027] The term “bacteriophage promoter” means a polynucleotide molecule derived from a bacteriophage, and is involved in recognition and binding of RNA polymerase and other proteins (trans-acting transcription factors) to initiate transcription. In preferred embodiments, the bacteriophage promoters are SP6, T7 and T3 promoters.

[0028] As used herein, the term “subgenomic promoter” refers to those sequences within an RNA molecule and at the 5' end of a structural gene, which direct messenger RNA synthesis using said RNA molecule as the template. A subgenomic promoter is necessary to drive expression of genes using RNA as template; the subgenomic promoter is recognized by an RNA-

dependent RNA polymerase, which may be a viral RNA replicase. The promoter itself may be a composite of segments derived from more than one source, naturally occurring or synthetic. A preferred embodiment is the subgenomic promoter from Semliki Forest Virus.

[0029] The term "capping sequence" refers to a sequence capable for forming a cap structure found on the 5'-end of an mRNA molecule and generally consists of a guanosine nucleotide connected to the mRNA via an unusual 5' to 5' triphosphate linkage. In a preferred embodiment, the capping sequence is IRES sequence.

[0030] As used herein, the term "IRES" means an internal ribosome entry site. IRES sequences have been found in numerous transcripts from viruses that infect vertebrate and invertebrate cells as well as in transcripts from vertebrate and invertebrate genes. Examples of IRES elements suitable for use in this invention include: viral IRES elements from Picornaviruses e.g., polio virus (PV), encephalomyocarditis virus (EMCV), foot-and-mouth disease virus (FMDV), from Flaviviruses e.g. hepatitis C virus (HCV), from Pestiviruses e.g., classical swine fever virus (CSFV), from Retroviruses e.g., murine leukemia virus (MLV), from Lentiviruses e.g., simian immunodeficiency virus (SIV), or cellular mRNA IRES elements such as those from translation initiation factors e.g., eIF4G or DAP5, from Transcription factors e.g., c-Myc (Yang and Sarnow, *Nucleic Acids Research* 25:2800-2807 (1997)) or NF-κB-repressing factor (NRF), from growth factors e.g., vascular endothelial growth factor (VEGF), fibroblast growth factor (FGF-2), platelet-derived growth factor B (PDGF B), from homeotic genes e.g., Antennapedia, from survival proteins e.g. X-Linked inhibitor of apoptosis (XIAP) or Apaf-1, or chaperones e.g. the immunoglobulin heavy-chain binding protein BiP (Martinez-Salas *et al.*, *Journal of General Virology* 82:973-984 (2001)). In a preferred embodiment, the IRES sequence is derived from encephalomyocarditis virus (EMCV, ATCC accession # NC001479).

[0031] The term "exogenous" in the context of the present invention means that the gene or enzyme is not normally present in the host organism in nature. The term "exogenous RNA polymerase" in the context of the present invention means that the RNA polymerase is not normally present in the host organism in nature. The skilled artisan will appreciate that the exogenous RNA polymerase may be delivered to the cells using methods well known in the art.

In a preferred embodiment, the exogenous RNA polymerase is prebound to a vector, or co-deliver with a vector into the cell.

[0032] The term "dendritic cells" is used herein to refer to antigen presenting cells characterized by their peculiar dendritic morphology and multiple thin-membrane projections, and by their high density of class II MHC molecules. Dendritic cells include Langerhans cells of the skin, "veiled cells" of afferent lymphatics, follicular dendritic cells, dendritic cells of the spleen, and interdigitating cells of lymphoid organs. Dendritic cells can be obtained from the skin, spleen, bone marrow, lymph nodes, other lymphoid organs, and peripheral blood cord blood. Preferably, dendritic cells are obtained from blood or bone marrow for use in the invention.

Alphavirus Vector

[0033] In one aspect, the present invention provides an alphavirus vector for expressing a gene of interest in an animal or human cell. In the alphavirus vector, the alphavirus replicon is placed under the control of a promoter sequence, which initiates transcription of the alphavirus replicon, the alphavirus replicon then recognizes a subgenomic promoter and initiate transcription of the gene of interest, which is operatively linked to the subgenomic promoter. The present invention takes the advantage of the alphavirus replicon's high level transient heterologous gene expression, which makes it attractive for vaccine development.

[0034] In some embodiments, the alphavirus vector of the present invention includes the following components in the following 5' to 3' orientation: a bacteriophage promoter, a first capping sequence, a sequence encoding the alphavirus replicon, a subgenomic promoter, a second capping sequence, a gene of interest, a transcription terminator and polyA sequence. These components are operatively linked so that transcription initiates from the 5' end, proceed through the sequence encoding the alphavirus replicon, the gene of interest, and terminate at the 3' end. In addition, the alphavirus vector used herein may further contain the sequence of a multicloning site having a plurality of restriction enzyme recognition sites to facilitate insertion of a gene of interest, the sequence of IRES (internal ribosomal entry site), and the like.

[0035] Sequences encoding wild-type alphaviruses suitable for use in preparing the above-described vector can be readily obtained given the disclosure provided herein from naturally-occurring sources, or from depositories (e.g., the American Type Culture Collection, Rockville, Maryland).

[0036] Representative examples of suitable alphaviruses include Aura virus (ATCC VR-368), Bebaru virus (ATCC VR-600, ATCC VR-1240), Cabassou virus (ATCC VR-922), Chikungunya virus (ATCC VR-64, ATCC VR- 1241), Eastern equine encephalomyelitis virus (ATCC VR-65, ATCC VR-1242), Fort Morgan virus (ATCC VR-924), Getah virus (ATCC VR-369, ATCC VR-1243), Kyzylagach virus (ATCC VR-927), Mayaro virus (ATCC VR-66, ATCC VR-1277), Middleburg virus (ATCC VR-370), Mucambo virus (ATCC VR-580, ATCC VR-1244), Ndumu virus (ATCC VR-371), Pixuna virus (ATCC VR-372, ATCC VR-1245), Ross River virus (ATCC VR-373, ATCC VR-1246), Semliki Forest virus (ATCC VR-67, ATCC VR-1247), Sindbis virus (ATCC VR-68, ATCC VR-1248; see also CMCC #4640, described below), Tonate virus (ATCC VR-925), Triniti virus (ATCC VR-469), Una virus (ATCC VR-374), Venezuelan equine encephalomyelitis virus (ATCC VR-69, ATCC VR-923, ATCC VR-1250 ATCC VR-1249, ATCC VR-532), Western equine encephalomyelitis virus (ATCC VR-70, ATCC VR-1251 , ATCC VR-622, ATCC VR- 1252), Whataroa virus (ATCC VR-926), and Y-62-33 virus (ATCC VR-375).

[0037] Alphavirus cytopathic vectors are useful in various applications, such as in vitro protein production and characterization, vaccination, and cancer gene therapy studies. However, cytopathic vectors cannot be used where long term gene expression is required, such as IPS induction. In some embodiments, the alphavirus replicon in the present invention may contain one or more mutations that make the alphavirus replicon noncytopathic. A mutation can be a nucleotide deletion, addition, or substitution of one or more nucleotide(s), or a mutation that comprises rearrangement or chimeric construction which results in a loss of cytopathic effect of a live virus containing the mutation as compared to the appropriate wild-type alphavirus. Such mutations can be present in the alphavirus non-structural proteins, nsp1- nsp4 subunit. In some preferred embodiments, the mutation is present in the alphavirus nsp-2. Exemplary mutations in nsp-2 include, but are not limited to, a deletion or a substitution of an amino acid at any one or

more of the following: nsp2 amino acid position 1, nsp2 amino acid position 10, nsp2 amino acid position 469, nsp2 amino acid position 472; nsp2 amino acid position 694; nsp2 amino acid position 713; nsp2 amino acid position 718; nsp2 amino acid position 721. In some embodiments, the non-cytopathic alphavirus replicon has mutation P718T in nsp2. In some embodiments, the non-cytopathic alphavirus replicon has mutation R649H in nsp2. . In some embodiments, the non-cytopathic alphavirus replicon has both mutations P718T and R649H in nsp2. Sequences encoding non-cytopathic alphavirus replicon and method for making the non-cytopathic alphavirus replicon are known in the art, for example, described in Belli *et al.* US2003/0170871; Frolova *et al.*, *J. Virol.,* 76:11254-11264 (2002); Perri *et al., J. Virol.*, 74:9802-9807 (2000); Lundstrom *et al., Expert Rev. Vaccines* 2:447-459 (2003); Lundstrom *et al., Cell Biol.,* 115:83-91 (2001); Petrakova *et al., J. Virol.*, 79:7597-7608 (2005); Casales *et al., Virology*, 376(1):242-251 (2008). All of these references are incorporated herein by reference in their entirety.

[0038] In some embodiments, the bacteriophage promoter of the alphavirus vector is selected from the group consisting of T7, T3, or SP6 promoter. In a preferred embodiment, the bacteriophage promoter is T7 promoter. In another preferred embodiment, the transcription terminator is T7 terminator. The sequences of the T7 promoter and terminator are known in the art. See Reim *et al.* US 5122457.

[0039] In some embodiments, the first and second capping sequences are the sequence of an internal ribosome entry site (IRES). Examples of IRES suitable for use in this invention include: viral IRES elements from Picornaviruses e.g., poliovirus (PV), encephalomyocarditis virus (EMCV), foot-and-mouth disease virus (FMDV), from Flaviviruses e.g. hepatitis C virus (HCV), from Pestiviruses e.g., classical swine fever virus (CSFV), from Retroviruses e.g., murine leukemia virus (MLV), from Lentiviruses e.g., simian immunodeficiency virus (SIV), or cellular mRNA IRES elements such as those from translation initiation factors e.g., eIF4G or DAP5, from Transcription factors e.g., c-Myc (Yang and Samow, *Nucleic Acids Research* 25:2800-2807 (1997)) or NF-κB-repressing factor (NRF), from growth factors e.g., vascular endothelial growth factor (VEGF), fibroblast growth factor (FGF-2), platelet-derived growth factor B (PDGF B), from homeotic genes e.g., *Antennapedia*, from survival proteins e.g. X-Linked inhibitor of

apoptosis (XIAP) or Apaf-1, or chaperones e.g. the immunoglobulin heavy-chain binding protein BiP (reviewed in Martinez-Salas et al., *Journal of General Virology* 82:973-984 (2001)). In a preferred embodiment, the first and second capping sequences are the sequence of IRES from encephalomyocarditis virus (EMCV, ATCC accession # NC001479).

[0040] General procedures for the constructing the above alphavirus vector are described in Sambrook, J. et al., Molecular Cloning: A Laboratory Manual, 2nd edition, Cold Spring Harbor Laboratory Press (1989); Ausubel, F.M. et al., Short protocols in Molecular Biology: A Compendium Methods from Current Protocols in Molecular Biology, John Wiley & Sons (1999); and the like.

Co-delivery of exogenous RNA polymerase

[0041] In another aspect, the present invention provides a gene expression system comprising an alphavirus vector and an exogenous RNA polymerase, which is pre-bound to the alphavirus vector, and co-delivered into a cell. A unique feature of the gene expression system is that the initiation of gene expression depends upon the binding of the exogenous RNA polymerase to the vector prior to entering into host cells. The complex of pre-bound RNA polymerase to the vector is stable without detachment during entry into cells. Once the RNA polymerase and bound vector enters the cytoplasm of the cells, transcription is initiated immediately by the pre-bound RNA polymerase, via the bacteriophage promotor in the vector. The gene expression system is designed in such a manner that the expression of the gene of interest occurs only in the cytoplasm and does not require integration into the genome of the host cells in the nucleus since the bacteriophage T7 RNA polymerases do not contain nuclear localization signals and stay in the cytoplasm. *See* Dunn et al. Gene 68, 259-266 (1988). In a preferred embodiment, the exogenous RNA polymerase is T7 RNA polymerase, the sequence of which is known in the art. See Reim *et al.* US Pat. No. 5122457.

[0042] The gene expression system of the present invention provides several advantages compared to other alphavirus based expression methods. First, gene expression is rapid because it does not require the DNA to enter into the cell nucleus for the initiation of transcription. The cytoplasmic location of its site of action also provides for a safety feature which reduces the

possibility of its integration into the host cell genome at a site adjacent to and thereby activating a dormant gene such as an oncogene. Furthermore, unlike retroviral vectors, even if DNA integration occurred, the exogenous promoter used would not be activated by eukaryotic transcription proteins. The RNA polymerase is synthesized in the cell cytoplasm, and would not be able to gain access to the nucleus for binding to its cognate promoter because it lacks any nuclear translocation signal. This gene expression system encompasses a variety of applications. For example, it is useful for rapid production of high amounts of proteins for use in immunization of animals for the generation of specific antibodies. In this regard, the present invention may be used to introduce exogenous genes into cells and tissues *in vivo* for transient expression of the gene product to elicit an antigen-specific host immune response. The short-term nature of gene expression may be ideal for its use as a vehicle for *in vivo* immunization of a host to an antigen.

Stem Cell Therapy

[0043] In one aspect, the present invention provides a method for preparing an induced pluripotent stem cell by reprogramming a mammalian somatic cell. Because the gene expression system of the present invention takes the advantage of the high transfection efficiency of the alphavirus replicon, it provides efficient transfection of somatic cells to prepare induced pluripotent stem cells. The term "induced pluripotent stem cells" or "iPS cells" as used herein refers to artificially produced cells having pluripotency, which are not so-called embryonic stem (ES) cells, but have properties analogous to those of ES cells. The iPS cells have been established from mouse somatic cells, and human somatic cells. See Takahashi and Yamanaka et. al.,*Cell* 126: 663-676 (2006); Takahashi et. al., *Cell* 13 1 : 861-872 (2007); Yu et al., *Science* 318: 1917-1920 (2007); Nakagawa et al., *Nat. Biotechnol.* 26: 101-106 (2008). The iPS cells have the following characteristics: they are capable of differentiating into various cells that compose an animal body (that is, a pluripotency); they are capable of maintaining semipermanent proliferation while also retaining the karyotype; and a group of genes that are generally expressed by ES cells is similarly expressed, for example. Hence, the iPS cells are cells

artificially induced by reprogramming of somatic cells, having properties clearly differing from those of differentiated somatic cells.

[0044] In some embodiments, the gene expression system can be used to express one or more iPS cell reprogramming factors. In some embodiments, the gene expression system comprises a vector comprising a non-cytopathic alphavirus replicon which has one or more mutations in nsp2. Exemplary mutations in nsp-2 include, but are not limited to, a deletion or a substitution of an amino acid at any one or more of the following: nsp2 amino acid position 1, nsp2 amino acid position 10, nsp2 amino acid position 469, nsp2 amino acid position 472; nsp2 amino acid position 694; nsp2 amino acid position 713; nsp2 amino acid position 718; nsp2 amino acid position 721. In some embodiments, the non-cytopathic alphavirus replicon has mutation P718T in nsp2. In some embodiments, the non-cytopathic alphavirus replicon has mutation R649H in nsp2. . In some embodiments, the non-cytopathic alphavirus replicon has both mutations P718T and R649H in nsp2.In some embodiments, the mutations in nsp2 are P718T and R649 H.

[0045] The term "reprogramming" as used herein refers to a process or means during which differentiated cells are induced and converted into undifferentiated cells, particularly pluripotent cells. According to the present invention, the reprogramming of somatic cells into iPS cells can occur independently of germ-line cells such as ova (or eggs), oocytes, and ES cells. Reprogramming factors as used herein include proteins, nucleic acids, or combinations thereof. Examples of reprogramming factors reported to date include: Oct3/4, Sox2, and Klf4; Oct3/4, Klf4, and c-Myc; Oct3/4, Sox2, Klf4, and c-Myc; Oct3/4 and Sox2; Oct3/4, Sox2, and Nanog; Oct3/4, Sox2, and Lin28; and Oct3/4 and Klf4. The sequences of the above mentioned reprogramming factors are also available via access to the GenBank (NCBI, U.S.A.). *See* US 2011/0250692.

[0046] Amino acid and nucleotide sequences of the above reprogramming factors Oct3/4, Nanog, and Lin28, respectively, are available via access to the GenBank (NCBI, U.S.A.). Regarding Oct3/4, for example, the sequences of human Oct3/4, mouse Oct3/4, and rat Oct3/4 are registered as NM_203289 or NM_002701, NM 013633, and NM OO 1009178, respectively. Regarding Nanog, for example, the sequences of human Nanog, mouse Nanog, and rat Nanog are registered as NM_024865, NM_028016, and NM OO 1100781, respectively.

Regarding Lin28, for example, the sequences of human Lin28, mouse Lin28, and rat Lin28 are registered as NM_024674, NM 145833, and NM OOl 109269, respectively. As a factor analogous to Lin28, Lin28b belonging to the same Lin family is known. Hence, in addition to Lin28 or instead of Lin28, Lin28b can be used. Regarding Lin28b, for example, the sequences of human Lin28b and mouse Lin28b are registered as NM OO 1004317 and NM_001031772, respectively.

[0047] In a preferred embodiment, the reprogramming factors for inducing iPS cells from somatic cells according to the present invention are the combination of reprogramming factors Oct 3/4, Sox 2, Klf 4, and c-Myc. In another preferred embodiment, a combination of the above reprogramming factors can be expressed simultaneously.

[0048] Examples of reprogramming factors other than the above factors include, but are not limited to, one or more reprogramming factors (or a group of reprogramming factors) selected from among ECATl, and ECAT2 (also referred to as ESGl), ECAT3 (also referred to as Fbxl5), ECAT5 (also referred to as Eras), ECAT7, ECAT8, and ECAT9 (also referred to as Gdf3), ECAT lO (also referred to as Soxl5), ECAT15-1 (also referred to as Dppa4), ECAT 15-2 (also referred to as Dppa2), Fthl l7, Sall4, and Rexl (also referred to as Zfp42), Utfl, Tell, and Stella (also referred to as Dppa3), β-catenin (also referred to as Ctnnbl), Stat3, Grb2, c-Myc, Soxl, Sox3, N-Myc, L-Myc, Klfl, Klf2, Klf4, and Klf5 (International Publication WO2007/069666), and, FoxD3, ZNF206, Mybl2, and Otx2 (International Publication WO2008/ 118820). The sequences of the above mentioned reprogramming factors are also available via access to the GenBank (NCBI, U.S.A.). *See* US 2011/0250692.

[0049] Types of mammals from which each reprogramming factor is derived, are not limited and any mammals can be used. Examples of preferred mammals include primates (e.g., humans, monkeys, and chimpanzees), rodents (e.g., mice, rats, guinea pigs, and hamsters), Ungulata (e.g., cattle, horses, sheep, goats, and pigs), and pet animals (e.g., dogs and cats). In general, when somatic cells from a specific mammal are reprogrammed, reprogramming factors from the same mammal are preferably used. For example, when iPS cells are induced from somatic cells from a human, reprogramming factors from a human are used.

[0050] In a preferred embodiment, the nucleotide sequences encoding one or more of the reprogramming factors can be cloned into the alphavirus vector, preferably between the subgenomic sequence and the T7 terminator sequence. The alphavirus vector may further comprise a selection marker. Examples of a selection marker include drug resistance genes (e.g., a hygromycin resistance gene, a neomycin resistance gene, and a puromycin resistance gene), reporter genes (e.g., GFP (green fluorescence protein), GUS (β-gluclonidase), and FLAG), and negative selection markers (e.g., a thymidine kinase (TK) gene and a diphtheria toxin (DT) gene).

[0051] In a preferred embodiment, a plurality of reprogramming factors are tandemly ligated so that expression is possible, thereby preparing a cassette containing them. This cassette is incorporated into a vector, preferably between the subgenomic promoter and the terminator sequence. A linker sequence may be placed between reprogramming factors. For ligation of two or more reprogramming factors (or genes), any sequences which enable polycistronic expression can be employed, such as foot and mouse disease virus-derived 2 A sequence (PLoS 0NE3, e2532, 2008, Stem Cells 25, 1707, 2007), IRES sequence (U.S. Patent No. 4,937, 190).

[0052] In some embodiments, additional agents may be added to further improve or accelerate the establishment of iPS cells. Such agents may include, but are not limited to, cytokines such as a basic fibroblast growth factor (bFGF) and a stem cell factor (SCF). Furthermore, the agents may also include low-molecular-weight compounds such as: histone deacetylase (FIDAC) inhibitors, e.g., valproic acid (VPA), histone methyltransferase (G9a) inhibitors, e.g., BIX-01294 (BIX), and DNA methylase (Dnmt) inhibitors, e.g., 5'-azacytidine. *See* Huangfu, et al., *Nat. Biotechnol.*, 26 (7): 795-797 (2008); Shi, et al., *Cell Stem Cell*, 2: 525-528 (2008); Kubicek, et al., *Mol. Cell* 25 : 473-481 (2007); Shi, et al., *Cell Stem Cell*, 3: 568-574 (2008). Also, a p53 inhibitor such as shRNA or siRNA against p53 or UTFl may be introduced into cells. See Yang et al., C*ell Stem Cell*, 3: 475-479 (2008). Furthermore, concerning signal transduction, activation of the Wnt signal, inhibition of mitogen-activated protein kinase and glycogen synthase kinase-3 signal transduction, ES cell specific miRNAs can also improve an efficiency for establishment of iPS cells. *See* Marson et al., *Cell Stem Cell*, 3: 32-135, (2008), Silva et al., *PLoS Biology*, 6, pp2237-2247 2008), and Judson et al., *Nat. Biotechnol.* 27:459-461 (2009)).

[0053] Examples of somatic cells used herein include, but are not limited to, any of fetal somatic cells, neonate somatic cells, and mature somatic cells, primary cultured cells, passaged cells, and established cell lines. Examples of somatic cells further include tissue stem cells and tissue precursor cells. Specific examples of somatic cells include, but are not limited to, (1) tissue stem cells (somatic stem cells) such as neural stem cells, hematopoietic stem cells, mesenchymal stem cells, and dental pulp stem cells, (2) tissue precursor cells, and (3) differentiated cells such as lymphocytes, epithelial cells, endothelial cells, muscle cells, fibroblasts (e.g., skin cells), hair follicle cells, hepatocytes, gastric mucosal cells, enterocytes, splenocytes, pancreatic cells (e.g., pancreatic exocrine cells), brain cells, pneumocytes, renal cells, and skin cells.

[0054] Mammalian individuals, which are suitable as origins to obtain somatic cells, are, but are not limited to, preferably patients themselves or other persons who have an identical or substantially identical HLA type from the viewpoints that when iPS cells obtained are used for regenerative medicine, no rejection occurs. As used herein, the term "substantially identical" with respect to HLA types means that when cells produced by inducing differentiation of iPS cells derived from somatic cells are transplanted to a patient, the HLA type matches between donor and recipient to the extent that the transplanted cells are survivable, such as the case where major HLAs (e.g., three gene loci of HLA-A, HLA-B and HLA-DR) are identical. This is applied similarly below. When iPS cells are not administered or transplanted, for example when iPS cells are used as a cell source for screening to evaluate the presence or absence of a drug sensitivity or adverse effect in patients, it is desirable to obtain somatic cells from patients themselves or other persons who have an identical gene polymorphism correlating with drug sensitivity or adverse effect.

[0055] Somatic cells can be cultured on a basal medium, such as DMEM (Dulbecco's modified Eagle medium), MEM (minimum essential medium), α-MEM (minimum essential medium alpha modification), Ham's F 12, RPMI 1640, or a mixture thereof, supplemented with appropriately selected substances such as serum (e.g., 10% FBS), an antibiotic(s) (e.g., penicillin and/or streptomycin), Na pyruvate, glutamine, nonessential amino acids, and L-dextrose at a temperature of about 37°C in the presence of 5% CO_2. The culture procedures are known to persons skilled in the art, for example, see US 2010/0250692.

[0056] Methods for introducing reprogramming factors encoding nucleic acids into cultured somatic cells from a mammal include conventional methods, such as an electroporation method, a microinjection method, a calcium phosphate method, a viral infection method, a lipofection method, and a liposome method.

[0057] For induction of iPS cells, cultured somatic cells are brought into contact with the above reprogramming factors in an appropriate medium for animal cell culture, to introduce the reprogramming factors into somatic cells, whereby the cells are transformed or transduced. Examples of culture medium include, but are not limited to, a DMEM, DMEM/F12 or DME medium containing 10-15% FBS, which medium may further optionally contain LIF (leukemia inhibiting factor), penicillin/streptomycin, puromycin, L-glutamine, nonessential amino acids, β-mercaptoethanol, and the like), a medium for ES cell culture containing bFGF or SCF, such as medium for mouse ES cell culture (e.g., TX-WES™, COSMO BIO) or medium for primate ES cell culture (e.g., ReproCELL™, COSMO BIO). The culture procedures are known to persons skilled in the art, for example, see US 2010/0250692.

[0058] Pluripotency (or the formation of three germ layers) can be confirmed based on teratoma formation and identification of each tissue (or cells) of three germ layers (endoderm, mesoderm, and ectoderm) within teratoma tissues, for example. Specifically, in the case of mouse iPS cells, cells are injected subcutaneously into a nude mouse, or in the case of human iPS cells, cells are injected into the testis of a Scid mouse, and then tumorigenesis is confirmed. Pluripotency can be confirmed by the result that tumor tissues are composed of, for example, a cartilage tissue (or cells), a neural tube tissue (or cells), a muscle tissue (or cells), an adipose tissue (or cells), an intestine-like tissue (or cells), or the like. Furthermore, pluripotency can also be confirmed by histological staining that the thus generated teratomas contained neural tube tissues (ectoderm), cartilage tissues (mesoderm), intestine-like tissues (endoderm).

[0059] The iPS cells can be induced to form various differentiated cells, precursor cells, and tissues. Specifically, various differentiated cells such as nerve cells and cardiac muscle cells can be induced from iPS cells in the presence of a factor(s) such as activin A/BMP4 (bone morphogenetic protein 4) or VEGF (vascular endothelial growth factor). The obtained

differentiated cells can be used as regenerative medicine to treat a patient by transplanting the cells into a patient, such as patients with defective tissues.

Vaccines Against Viruses And Other Pathogens

[0060] In one aspect, the present invention provides a method for delivering vaccines. In some embodiments, the gene expression system of the present invention allows expression of a target gene, which may encode immunogenic proteins from various pathogens. In some embodiments, the pathogens are viruses. For example, the immunogenic proteins may be derived from bovine viral diarrhea virus (BVDV), cytomegalovirus (CMV), , classical swine fever virus CSFV, Dengue, Ebola, Hepatitis B, Hepatitis C, Hendra virus (HeV), human immunodeficiency virus (HIV-1), human papillomavirus (HPV), herpes simplex virus (HSV-1), infectious bursal disease virus (IBDV), Influenza, infectious salmon anemia virus (ISAV), Japanese encephalitis virus (JEV), Lassa, Louping-ill virus (LIV), Marburg virus (MBGV), Measles, Murray Valley encephalitis virus (MVE), Nipah virus (NiV), Norwalk-like virus (NLV), Rabies, respiratory syncytial virus (RSV), Rift Valley fever virus (RVFV), severe acute respiratory syndrome corona virus (SARS-CoV), Seoul virus (SEOV), simian-human immunodeficiency virus (SHIV), Sudan virus (SUDV), Vaccinia. The representative immunogenic proteins or peptides are shown in Table 1.

Table 1. Viral Immunogenic Proteins

Virus	Target
Bovine viral diarrhea virus (BVDV)	E2, NS3 (p80)
Cytomegalovirus (CMV)	gB/pp65-1E1
Classical swine fever virus (CSFV)	E2
Dengue	PrME, E85
Ebola	NP, GP, VP24, VP30, VP35, VP30

Virus	Target
Hepatitis B	cAg, sAg
Hepatitis C	cAg, NS3, nsPs
Hendra virus (HeV)	Glycoprotein
Human immunodeficiency virus (HIV-1)	Env, gp41, MA/CA
Human papillomavirus (HPV)	16E7, VP22
Herpes simplex virus (HSV-1)	gpB
Infectious bursal disease virus (IBDV)	VP2
Influenza	HA, NP
Infectious salmon anemia virus (ISAV)	HE
Japanese encephalitis virus (JEV)	prM-E, NS1-2A
Lassa	N
Louping-ill virus (LIV)	prME, NS1
Marburg virus (MBGV)	GP, NP, VP35
Measles	HA, FUd
Murray Valley encephalitis virus (MVE)	prME, E
Nipah virus (NiV)	Glycoproteins
Norwalk-like virus (NLV)	VLP
Rabies	G
Respiratory syncytial virus (RSV)	F, G
Rift Valley fever virus (RVFV)	Gn
Severe acute respiratory syndrome corona virus (SARS-CoV)	Glycoprotein

Virus	Target
Seoul virus (SEOV)	M, S
Simian-human immunodeficiency virus (SHIV)	Env
Sudan virus (SUDV)	GP
Vaccinia	A33R, B5R

[0061] In some embodiments, the immunogenic proteins or peptides may be derived from non-viral pathogens. For example, the immunogenic proteins may be derived from *B. anthracis, B. abortus, C. Botulinum,* Malaria, *M. tuberculosis, P. falciparum*, Prion, *Staphylococcus*. The exemplary immunogenic proteins are shown in Table 2.

Table 2. Non-viral pathogenic immunogens

Agent	Target
B. anthracis	PA
B. abortus	IF3
C. botulinum	BoNTA-Hc
Malaria	CS
M. tuberculosis	Ag85A
P. falciparum	Ag Pf332
Prion	NP
Staphylococcus	enterotoxin B

[0062] Any suitable vaccine and method of vaccination (*i.e.*, immunization) known in the art may be employed in carrying out the present invention, as long as an active immune response against the antigen is elicited.

[0063] In a preferred embodiment, the vaccine method is naked DNA vaccines. DNA vaccination involves administering a polynucleotide that encodes an antigen *in vivo* to induce the

production of an antigen within the target cells. The introduction of the DNA vaccine will cause the antigen to be displayed on the cellular surface of the transfected cells in conjunction with the Major Histocompatibility Complex (HMC) of the normal cell . Furthermore, the antigens expressed by the transfected cells can also be picked up by antigen-presenting cells to trigger systemic humoral antibody responses.

[0064] In some embodiments, the gene expression system can be incorporated into a vaccine composition, which may further comprises an adjuvant. As used herein, "adjuvant" describes a substance, which can be any immunomodulating substance capable of being combined with the polypeptide or nucleic acid vaccine to enhance, improve or otherwise modulate an immune response in a subject without deleterious effect on the subject. For example, an adjuvant of this invention can be, but is not limited to, an immunostimulatory cytokine (including, but not limited to, GM/CSF, interleukin-2, interleukin-12, interferon-gamma, interleukin-4, tumor necrosis factor-alpha, interleukin-1, hematopoietic factor flt3L, CD40L, B7.1co-stimulatory molecules and B7.2 co-stimulatory molecules). Suitable adjuvants also include oil-in-water, saponin, an aluminum salt such as aluminum hydroxide gel (alum), aluminum phosphate, or algannmulin, but may also be a salt of calcium, iron or zinc, or may be an insoluble suspension of acylated tyrosine, or acylated sugars, cationically or anionically derivatized polysaccharides, or polyphosphazenes. Vaccines may also be formulated with a pharmaceutically acceptable excipient. Such excipients are well known in the art, and typically should be physiologically tolerable and inert or enhancing with respect to the vaccine properties of the inventive compositions. Examples include liquid vehicles such as sterile, physiological saline. When using an excipient, it may be added at any point in formulating the vaccine or it may be admixed with the completed vaccine composition.

[0065] In some embodiments, the vaccine administered may be in an amount of about 1-5 ug of DNA per dose and will depend on the subject to be treated, capacity of the subject's immune system to develop the desired immune response, and the degree of protection desired. Precise amounts of the vaccine to be administered may depend on the judgment of the practitioner and may be peculiar to each subject and antigen.

[0066] The vaccine may be given in a single dose schedule, or preferably a multiple dose schedule in which a primary course of vaccination may be with 1-10 separate doses, followed by other doses given at subsequent time intervals required to maintain and or reinforce the immune response, for example, at 1-4 months for a second dose, and if needed, a subsequent dose(s) after several months. Examples of suitable immunization schedules include: (i) 0, 1 months and 6 months, (ii) 0, 7 days and 1 month, (iii) 0 and 1 month, (iv) 0 and 6 months, or other schedules sufficient to elicit the desired immune responses expected to confer protective immunity, or reduce disease symptoms, or reduce severity of disease.

[0067] Preferably, the DNA for vaccine preparation is frozen or lyophilized, to form a dry powder. If a solution is used in formulation, the dry ingredients for the solution may be premixed and premeasured and contained in a container such as a vial or sealed envelope.

[0068] Vaccines may be formulated for multiple routes of administration. Specifically preferred routes include intramuscular, percutaneous, subcutaneous, or intradermal injection, aerosol, oral or by a combination of these routes, at one time, or in a plurality of unit dosages. Administration of vaccines is well known and ultimately will depend upon the particular formulation and the judgment of the attending physician.

Cancer Vaccine

[0069] One aspect of the present invention provides a method for treating cancer by administering to a mammal suffering from cancer an alphavirus vector that comprises a gene encoding a cancer antigen or an anti-cancer gene. In some embodiments, the cancer being treated can be, but is not limited to, brain tumor, cervical cancer, colon cancer, endothelial cancer, malignancies (such as neuroblastoma, gliblastoma, glioma, medulloblastoma, astrocytoma, acoustic neuroma, oligodendroglioma, and meiningioma), kidney cancer, melanoma, metastatic cancer, prostate cancer, breast cancer, bladder cancer, pancreatic cancer, lung cancer (such as small cell lung and non-small cell lung cancer).

[0070] In some embodiments, the cancer antigen is a protein or peptide capable of eliciting an immune response against cancer. For example, such a protein or peptide includes but is not limited to melanosomal antigens (such as a melanocytic tissue-specific protein, gp100, MART-1,

and tyrosinase), cancer markers (such as HER2-neu, CEA and PSA). The sequence of these cancer antigens are known to persons skilled in the art, for example, they are described in Rosenberg et al., *Immunity*, 10: 281-287 (1999). Exemplary cancer antigens are shown in Table 3.

Table 3 Cancer Vaccine Gene Target

Antigen Category	Gene
Melanocyte	MART-1/MelanA
differentiation	gp100, Tyrosinase, TRP-1, TRP-2
Cancer testis	MAGE-1, MAGE-3，GAGE-1/2，BAGE，RAGE，NY-ESO-1
Tumor specific	CDK-4, β-catenin, MUM-1, Caspase-8, KIAA0205, HPVE7,
Widely expressed	SART-1, PRAME, p15

[0071] In some embodiments, the anti-cancer gene can be a suicide gene, an apoptosis-inducing gene, a tumor suppressor gene, an oncogene antagonist gene, a tumore suppressor effector gene, an antisense oligonucleotide-encoding sequence, a ribozyme-encoding sequence. In a preferred embodiment, such anti-tumor gene is an apoptosis-inducing gene.
The representative anti-cancer genes are shown in Table 4.

Table 4. Anti-cancer genes

Target	Gene
Brain tumor	IL-12, Endostatin, gp100, IL-18, HER2/neu
Cervical cancer	HPVE6-E7, HPV-CRT (carcinoembryonic antigen), HPVE7, IL2, HPVE7-VP22,
Endothelial	VEGFR-2
Glioma	B16, 203
Kidney cancer	IL-12
Melanoma	MDA/trp-2 (melanoma differentiation antigen), IL-12, MUC18/MCAM melanoma cell adhesion molecule)

Target	Gene
Metastatic	carcinoembryonic antigen (CEA), prostate-specific membrane antigen (PSMA)
Prostate cancer	prostate-specific membrane antigen (PSMA), six-transmembrane epithelial antigen of the prostate (STEAP), prostate stem cell antigen (PSCA)
Tumor	β-galactosidase, IL-12, MHC class II, P815, trp-1

[0072] In some embodiments, the gene expression system of the present invention can be administered to a patient prior to or following the detection of cancer in a subject, via suitable method known to persons skilled in the art, and as described above. Additionally, when administered according to the present invention, the artificial cancer cell antigen should be able to induce an active and protective immune response against unmodified cancer cells.

[0073] Vaccines comprising the gene expression system may be formulated for multiple routes of administration. Specifically preferred routes include intramuscular, percutaneous, subcutaneous, or intradermal injection, aerosol, oral or by a combination of these routes, at one time, or in a plurality of unit dosages. Administration of vaccines is well known and ultimately will depend upon the particular formulation and the judgment of the attending physician. The vaccines may further comprise an adjuvant or excipient known to persons skilled in the art, and as described above.

Dendritic Cell Vaccine

[0074] In another aspect, the present invention provides a method for immune cell stimulation, such as a dendritic cell stimulation to generate a strong anti-tumor immune response. In some embodiments, the present invention provides a methods for transfecting antigens with dendritic cells so that the antigens are displayed at the surface of dendritic cells to elicit an immune response against the antigen of interest.

[0075] In some embodiments, the antigens for use in dendritic cell stimulation by the present invention are tumor antigens that include, but are not limited to melanoma tumor antigens (Kawakami et al., *Proc. Natl. Acad. Sci. USA* 91:3515-3519 (1994); Kawakami et al., *J. Exp.*

Med., 180:347-352 (1994); Kawakami et al. *Cancer Res.* 54:3124-3126 (1994), including MART-1 (Coulie et al., *J. Exp. Med.* 180:35-42 (1991), gp100 (Wick et al., *J. Cutan. Pathol.* 4:201-207 (1988) and MAGE antigen, MAGE-1, MAGE-2 and MAGE-3 (Van der Bruggen et al., *Science*, 254:1643-1647 (1991)); CEA, TRP-1, P-15 and tyrosinase (Brichard et al., *J. Exp. Med.* 178:489 (1993)); HER-2/neu gene product (U.S. Pat. 4,968,603); estrogen receptor, milk fat globulin, p53 tumor suppressor protein (Levine, Ann. Rev. Biochem. 62:623 (1993)); mucin antigens (Taylor-Papdimitriou, International Pub. WO90/05142)); telomerases; nuclear matrix proteins; prostatic acid phosphatase; papilloma virus antigens; and antigens associated with the following cancers: melanomas, metastases, adenocarcinoma, thymoma, lymphoma, sarcoma, lung cancer, liver cancer, colon cancer, non-Hodgkins lymphoma, Hodgkins lymphoma, leukemias, uterine cancer, breast cancer, prostate cancer, ovarian cancer, cervical cancer, bladder cancer, kidney cancer, pancreatic cancer and others (e.g., Rosenberg, *Ann. Rev. Med.* 47:481-91 (1996)).

[0076] In a preferred embodiment, the tumor antigen for use in the dendritic cell vaccine of the present invention is tyrosinase, tyrosinase related protein 1 (TRP-1), or tyrosinase related protein 2 (TRP-2). Tyrosinase, TRP-1 and TRP-2 are members of the tyrosinase related gene family.

[0077] One aspect of the invention relates to gene expression of cancer peptides encoded by the tyrosinase, TRP-1 gene, TRP-2 gene or variants thereof, in the dendritic cell. Tyrosinase gene, TRP-1 antigen, TRP-2 antigen, a fragment thereof, alone or in combination with one or more co-immunostimulatory molecules can be used. In one aspect, the present invention contemplates both preventing and treating melanoma by expressing tyrosinase gene, TRP-1 antigen, TRP-2 antigen in dendritic cells.

[0078] In some embodiments, the gene expression system expressing the tumor antigens stated above are inserted *ex vivo* into dendritic cells, such that one or more selected antigens are presented in effective amounts on the surface of the dendritic cells. By "effective amount" it is meant that presentation is sufficient to enable the dendritic cells to provoke an immune response. Techniques for nucleic acid manipulation are well known. Reagents useful in applying such techniques, such as restriction enzymes and the like, are widely known in the art and commercially available from a number of vendors.

[0079] The alphavirus vectors may also contain polynucleotide sequences encoding selected class I and class II MHC molecules, costimulation and other immunoregulatory molecules, ABC transporter proteins, including the TAP1 and TAP2 proteins. Thus, various combinations of polynucleotide sequences may be inserted the alphavirus vector of the present invention. The alphavirus vectors may further contain at least one positive marker that enables the selection of dendritic cells carrying the vector.

[0080] In a preferred embodiment, dendritic cells are obtained from a patient to be treated. The dendritic cells are used to activate T cells of the patient, either *in vitro* or *in vivo*, for immunotherapy.

[0081] In another embodiment, dendritic cells are obtained from a healthy individual. The relevant HLA antigens (both class I and II, e.g., HLA-A, B, C and DR), for example, on the individual's peripheral blood mononuclear cells (PBMC's), are identified and dendritic cells that match the patient, in terms of HLA antigens, are isolated and expanded as described above. For example, in certain instances, a late stage cancer patient who has been treated with radiation and/or chemotherapy agents is not able to provide sufficient or efficient dendritic cells. Thus, dendritic cells from healthy HLA-matched individuals, such as siblings, can be obtained and expanded using any of the methods described above.

[0082] The procedures for isolating dendritic cells are known to the person skilled in the art. For example, dendritic cells can be obtained from any tissue where they reside, including non-lymphoid tissues such as the epidermis of the skin (Langerhans cells) and lymphoid tissues such as the spleen, bone marrow, lymph nodes and thymus as well as the circulatory system including blood (blood dendritic cells), for example peripheral blood and cord blood, and lymph (veiled cells). For example, explants of mouse or human skin placed in organ culture permit selective migration of dendritic cells into the medium surrounding the explant. *See* Larsen et al., *J. Exp. Med.* 172:1483-1493 (1990), and Richters et al., *J. Invest. Dermatol.* (1994).

[0083] Recent studies have described methods for the isolation and expansion of human dendritic cells, including, from human peripheral blood. *See* Macatonia et al., *Immunol.* 74: 399-406 (1991); O'Doherty et al., *J. Exp. Med.* 178: 1067-1078 (1993); and Markowicz et al., *J. Clin. Invest.* 85: 955-961(1990); Romani et al., *J. Exp. Med.* 180: 83-93 (1994); Sallusto et al., *J. Exp.*

Med. 179: 1109-1118 (1994); Berhard et al., J. Exp. Med. 55: 1099-1104 (1995). Techniques for deriving dendritic cells (including Langerhans' cells) from CD34+ progenitor cells obtained from bone marrow and cord blood and from mononuclear cells from peripheral blood have also been disclosed. *See* Van Tendeloo et al., *Gene Ther.* 5: 700-707 (1998).

[0084] Dendritic cells may also be treated to induce maturation or activation, e.g., by culturing, preferably in the presence of a specific growth or stimulatory factor or factors. In the examples below, dendritic cells are modified by culturing with GM-CSF. Additional techniques relating to the preparation of dendritic cells can be found, for example, in U.S. Pat. Nos. 5,788,963, 5,962,318, and 5,851,756, the disclosures of which are herein incorporated by reference.

[0085] The procedures for transfecting dendritic cells with polynucleotides are known to persons skilled in the art. For example, a dendritic cell may be transfected by incubating with the polynucleotide in a solution for a time and at a temperature sufficient for transfection to occur. In some embodiments, dendritic cells and polynucleotides are incubated for 24 hours at 37° C. in a humidified CO_2 incubator. Expression of the polynucleotide of interest after transfection into dendritic cells may be confirmed by immunoassays or biological assays. For example, expression of introduced polynucleotides into cells may be confirmed by detecting the binding to the cells of labeled antibodies specific for the antigens of interest using assays well known in the art such as FACS (Fluorescent Activated Cell Sorting) or ELISA (enzyme-linked immunoabsorbent assay) or by simply by staining (e.g., with β-gal) and determining cell counts. T cell activation may be detected by various known methods, including measuring changes in the proliferation of T cells, killing of target cells and secretion of certain regulatory factors, such as lymphokines, expression of mRNA of certain immunoregulatory molecules, or a combination of these.

[0086] In some embodiments, dendritic cells isolated from a patient are cultured, transfected *in vitro* and administered back to the patient to stimulate an immune response, including T cell activation. As such, the dendritic cells constitute a vaccine and/or immunotherapeutic agent. As an example, dendritic cells presenting antigen are administered, via intravenous infusion, at a dose of, for example, about 10^6 to 10^8 cells. The immune response of the patient can be

monitored. Infusion can be repeated at desired intervals based upon the patient's immune response.

[0087] Below are examples of specific embodiments for carrying out the present invention. The examples are offered for illustrative purposes only, and are not intended to limit the scope of the present invention in any way.

EXAMPLES

EXAMPLE 1 Construction of the alphavirus expression vector.

[0088] Construction of vector.

[0089] For construction of the expression vector pT7/NSP1-4/HygEGFP, an in-fusion cloning kit was used to clone different fragments into vector pTNT. Briefly, pTNT was first cut with SmaI and gel purified. Fragments for IRES,NSP1-4, HygEGFP were PCR amplified using phusion enzyme from plasmids pCITE-2a, pSmart2a and pHygEGFP. Primers used for PCR amplifications were designed using the online tool from Clontech and contain 15bp overlaps either with vector or with the adjacent fragments. Purified vector and fragments were mixed together and co-incubated with infusion enzyme mix for 15 minutes at 50 ^{o}C. The resultant reaction was used for transformation.

[0090] Primer sequences for PCR amplification:

1. Primers for first IRES fragment which is for 5'-cap independent invivo expression:
   TNT-IRES FW Primer (F1_FW) CTCTAGAGTCGACCCgttattttccaccatattgcc
   IRES-NSP RV Primer (F1_RV) TCACACATCCGCCATaaaggaaaaccacgtcccc
2. Primers for NSP1-4:
   NSP FW Primer (F2_FW) ATGGCGGATGTGTGACATA
   NSP-IRES RV Primer (F2_RV) AAATAACATTTAAATcgtagaggtgtataacagg
3. Primers for second IRES fragment which is used as an internal ribosomal entry site so the target gene and HygEGFP can both be expressed under the subgenomic promoter:
   IRES FW Primer (F3_FW) ATTTAAATgttattttccaccatattgccgtcttttggc
   IRES-Hyg RV Primer (F3_RV) TTCAGGCTTTTTCAtaaaggaaaaccacgtcccc

4. Primers for HygEGFP:

   Hyg FW Primer (F4_FW) ATGAAAAAGCCTGAACTCAC

   Hyg-TNT RV Primer (F4_RV) TTTTTGCGGCCGCCCcttgtacagctcgtccatg

[0091] Note: Upper case letters in the primer sequence indicate overlap sequence.

[0092] T7 RNA polymerase prebound to DNA for efficient gene expression

[0093] The vector pT7/NSP1-4/HygEGFP is complexed with T7 RNA polymerase in a buffer solution, such as saline, PBS or DMEM. The solution is injected into mouse tail, liver, leg muscles, cerebrospinal fluids or intravenously. After a certain time, gene expression is assessed by sacrificing the animal, and removing a portion of a specific tissue. The EGFP is used as a marker for indicating the gene expression level. The same procedure is performed with a solution containing the vector only as a control.

[0094] It is expected that the sample from mouse injected with solution containing the vector and prebound T7 RNA polymerase shows a high level of fluorescence intensity due to high level expression of the EGFP. It is also expected that the EGFP expression is detectable for an extended period of time, for example, at least one week. On the other hand, the control sample is expected to exhibit no fluorescence, due to no EGFP expression.

EXAMPLE 3 Establishment of human iPS cells using the gene expression system

[0095] Four human genes encoding reprograming factors Klf4, Oct 3/4, Sox2, and c-Myc are cloned into the vector, and introduced into the cells with a prebound RNA polymerase. On day 7 after infection, cells are collected and then are reseeded on feeder cells, for example, 5×10^5 cells/100-mm dish. As feeder cells, SNL cells (McMahon, A. P. & Bradley, A. *Cell* 62, 1073-1085 (1990)) treated with mitomycin C to cease cell division are used. From day 10 after infection, cells are cultured in medium prepared by adding recombinant human bFGF (WAKO, Japan) to medium for primate ES cell culture (ReproCELL, Japan). The transfection is further confirmed by using a marker gene.

[0096] The clones are inserted into the testis of a Scid mouse to examine its pluripotency. Specifically, human iPS cell clone is cultured in a medium for primate ES cell culture (ReproCELL, COSMO BIO, both Japan) containing recombinant human bFGF and an Rho

kinase inhibitor Y-27632. One hour later, cells are treated with collagen IV and then collected. Cells are then centrifuged, collected, and suspended in DMEM/F12 containing Y-27632. Confluent cells (100-mm dish) are injected into the testis of a Scid mouse. Two to three months later, tumors are cut into pieces and then fixed with a PBS buffer containing 4% formaldehyde. Paraffin-embedded tissues are sliced and then stained with hematoxylin-eosin. The tumor is expected to be composed of a plurality of types of cells and show differentiation into multiple germ layers, for example neural tube tissue, cartilage tissue, and intestine-like epithelial structure. Thus, the pluripotency of iPS cells is expected to be observed.

EXAMPLE 4 Influenza virus vaccine activity *in vitro*

[0097] DNA encoding influenza virus antigen hemagglutinin (HA) is cloned into the vector pT7/NSP1-4/Hyg vector. The influenza virus genes may be generated in a similar manner by one of skill in the art.

[0098] To demonstrate stimulation of flu antigen-specific immune response, a solution containing the vector with influenza antigen HA prebound with T7 RNA polymerase is used to immunize BALB/c mice in parallel with commercial subunit FLU vaccine antigen. The solution is administered intramuscularly twice and HA specific serum antibody responses are determined by standard ELISA assay following each immunization. An example ELISA assay is as follows: flat-bottom plates are coated overnight at 4 °C with a PBS solution containing 2.5 µg/ml monovalent subunit influenza vaccine preparation or the solution containing the vector and prebound T7 RNA polymerase. Plates are then washed three times with PBS (pH7.2) supplemented with 0.05% Tween-20 (PBS-T). After washing wells are blocked against non-specific binding using 5 % (w/v) dry milk in PBS-T for 1 hour at 37 °C. Sample sera are serially diluted in PBS-T by three fold starting from 1:50. After incubation with diluted sera at for 90 minutes at 37 °C, plates are rinsed three times with PBS-T.

[0099] Plates are further incubated with alkaline phosphatase conjugated goat anti-mouse Ig, IgG1, or IgG2a diluted in PBS-T for 1 hour at 37 °C. After extensive washing with PBS-T, 100 µl of a chromogen-substrate solution, paranitrophenylphosphate 1 mg/ml in diethanolamine, are added to each well. Then, the plate is read after 20 min at 405 nm using SpectraMax®

(Molecular Devices, CA). For calculation of titers, a cut-off value is defined as the optical density (OD) value of average of PBS controls plus 3 x their standard deviation. Antibody titers are then calculated as dilutions of which the samples generate OD of the cut-off value.
It is expected that the sample with the vector and prebound T7 RNA polymerase is highly potent at both doses tested and of greater immunogenicity than the commercial subunit influenza vaccine.

EXAMPLE 5 Influenza virus vaccine activity *in vivo*

[0100] Protection from influenza virus is tested in animal models challenged with the vector expressing influenza antigen HA, and prebound to T7 RNA polymerase. Balb/c mice are divided into two groups with 10 mice in each group. Either a solution containing the vector expressing influenza antigen HA prebound with T7 RNA polymerase or commercially available subunit influenza vaccine is used to challenge the mice of each group. Mice are immunized twice with an interval of 3 weeks. Two weeks after the second immunization, mice are challenged with live influenza viruses by administration intranasally in the upper respiratory tract.
[0101] Animals are monitored for mortality for 2 weeks from the day of challenge. The mice injected with the solution contain the vector with prebound T7 RNA polymerase are expected to exhibit higher degree of protection from intransal influenza challenge compared to mice immunized with commercially available subunit vaccine.

EXAMPLE 6 Immunization of rats with the gene expression system expressing PAP elicits T cell immune response

[0102] The DNA with sequence encoding tyrosinase, tyrosinase-related protein 1(TRP-1), or tyrosinase-related protein 2 (TRP-2) is cloned into the vector, and expression of the gene of interest is confirmed by *in vitro* expression assays, such as ELISA. Dendritic cells can be prepared according to suitable procedures known in the art. An example is included here for demonstration. Peripheral blood is obtained from volunteer donors by venipuncture and diluted 1 :2 with phosphate buffered saline (PBS). Peripheral blood mononuclear cells (PBMCs) are isolated by centrifugation over lymphocyte separation medium (ICN Biomedicals, Aurora, OH),

washed twice with PBS, and resuspended in serum-free AIM-V media (Invitrogen, Carlsbad, CA). Monocytes are enriched by culturing 10^7 PBMCs/well in 6-well tissue culture plates for 2 hours. Nonadherent PBMCs are removed and cryopreserved in 90% fetal bovine serum/10% DMSO

[0103] The vectors encoding tyrosinase, TRP-1, or TRP-2 is used to transfect dendritic cells. The ability of transfected dendritic cells activate specific CD4 and CD8 T cells is tested. It is expected that the transfected dendritic cells show a strong T cell activation.

[0104] Murine bone marrow DC culture and transfection

[0105] The tibias and femurs of C57BL/6 mice were flushed with ice cold PBS through a 70 μm-wide cut-off cell strainer. RBCs were lysed with ammonium chloride Tris buffer for 3 min at 37°C. Cells were centrifuged for 5 minutes at 1400 rpm and the cells were suspended in DC-media (RPMI supplemented with 5% FCS, 1x nonessential amino acids, 2mM L glutamine, 500nM 2-ME, 100U/ml penicillin/streptomycin, 20μg/ml gentamycin), 150 U/ml GM-CSF and 75 U/ml IL-4. $3x10^6$ cells were placed in 6-well plates containing 5 ml DC-media and cultured for 6 days. At day7, the nonadherent cells were harvested (immature day 7 DCs), washed, and transfected with plasmids using lipofectamine or nucleofection. Transfected cells were suspended in DC medium supplemented with 10 ng/mL tumor necrosis factor–α (TNF-α) and cultured for 2-3 day for further maturation.

[0106] CTL Priming in Mice

[0107] Naive, C57BL/6 mice were immunized i.v. with 5 x 105 transfected DC/mouse in 200 μ l of PBS, two times at 14-day intervals. Splenocytes were harvested 12–14 days after the final immunization and depleted of RBCs with ammonium chloride Tris buffer. Splenocytes (10^7) were cultured with 5 x 10^5 stimulator B16/F0 cells pretreated with IFN-Y and irradiated at 7500 rads in 5 ml of Iscove's modified Dulbecco's medium with 10% FCS, 1 mM sodium pyruvate, 100 IU/ml penicillin, 100 mg/ml streptomycin, and 5 x 10^{-5} M β -mercaptoethanol/well in a six-well tissue culture plate. Cells were cultured for 5 days at 37°C and 5% CO2. Effector splenocytes were harvested on day 5 on Histopaque 1083 gradient prior to use in a CTL assay.

[0108] *In Vitro* Cytotoxicity Assay (CD8)

[0109] Target cells (5-10 x 10^6 B16 F0) were labeled with europium for 20 min at 4°C. Europium-labeled targets (10^4) and serial dilutions of effector cells at varying E:T were incubated in 200 μ l of complete RPMI 1640. The plates were centrifuged at 500g for 3 min and incubated at 37°C for 4 h. Fifty μ l of the supernatant were harvested, and europium release was measured by time resolved fluorescence . Specific cytotoxic activity was determined using the formula:

% specific release = Experimental release- spontaneous release/ Total release - spontaneous release

[0110] Spontaneous release of the target cells was <25% of total release by detergent in all assays.

[0111] For comparison, splenocytes from mice primed with non-transfected DC were used.

CD4+ T-cell purification and bioassay for IL-2/IL-4 production.

For CD4+ T-cell purification, nylon wool–enriched spleen T cells were further treated by incubating with ascites containing MAbs against B cells (B220) and CD8+ T cells (2.43) plus complement at 37°C for 90 min and then washed 3 times. Phenotypic analysis with flow cytometry was used to analyze the purity of isolated CD4+ T cells.

Purified CD4+ T cells were stimulated in vitro with irradiated (3,000 rad) transfected DC or non-transfected DC cells at a T cell/DC cell ratio of 20:1 for 24 hr and the supernatants collected at the end of incubation. To limit non-specific cytokine release, CD4+ T cells were purified in FBS-free medium and APC cells prepared in serum-free medium or in the presence of 2% murine serum. Induction of cytokine was performed in FBS-free AIM-V medium. IL-2/IL-4 activity was determined by the ability to support the growth of the CTLL cell line. Because both IL-2 and IL-4 support the growth of CTLL cells, cytokine activity in the supernatants was not distinguished and, thus, was designated IL-2/IL-4. Alternatively, the quantities of IL-2 and IL-4 can be measured by ELISA.

SEQUENCE LISTING

SEQ ID NO: 1: Sequence of the plasmid pT7/NSP1-4/HygEGFP

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SEQ ID NO: 2: Poly A and T7 terminator

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SEQ ID NO:3 T7 promoter

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SEQ ID NO:4: IRES Sequence

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SEQ ID NO:5: Alphavirus RNA replicase nsp 1-4

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SEQ ID NO: 6: Subgenomic promoter sequence from SFV

ATTGAGAGGACCTGTTATACACCT

SEQ ID NO: 7: Hygromycin/EGFP fusion gene

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SEQ ID NO: 8: Sequence of the non-cytopathic plasmid pT7/NSP1-4/HygEGFP (Underlined letters at 8734 and 8940 indicate mutated nucleotides for mutation P718T and R649H respectively)

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WHAT IS CLAIMED IS:

1. A gene expression system comprising

(a) a vector that comprises a bacteriophage promoter, an alphavirus replicon operatively linked to the bacteriophage promoter, a first capping sequence, a subgenomic promoter, a second capping sequence, and a gene of interest, and

(b) an exogenous RNA polymerase which transcribes the alphavirus replicon, wherein the exogenous RNA polymerase is co-delivered with the alphavirus vector into a cell,

and wherein the gene of interest is expressed in the cytoplasm of the cell.

2. The gene expression system of claim 1, wherein the alphavirus replicon is derived from an alphavirus, wherein the alphavirus is selected from the group consisting of Sindbis virus (SIN), Semliki Forest virus (SFV), and Venezuelan equine encephalitis virus (VEE).

3. The gene expression system of claim 1, wherein the alphavirus replicon is noncytopathic.

4. The gene expression system of claim 3, wherein the alphavirus replicon has one or more mutations in the nsp2 subunit.

5. The gene expression system of claim 1, wherein the bacteriophage promoter is selected from the group consisting of T7, T3, and SP6 promoters.

6. The gene expression system of claim 1, wherein both the first and second capping sequences are the internal ribosome entry site sequence derived from encephalomyocarditis virus.

7. The gene expression system of claim 1, wherein the gene of interest encodes for an antigen.

8. The gene expression system of claim 7, wherein the antigen is selected from the group consisting of a viral antigen, a bacterial antigen, and a cancer antigen.

9. The gene expression system of claim 1, wherein the subgenomic promoter is derived from an alphavirus.

10. The gene expression system of claim 1, wherein the bacteriophage promoter is T7 promoter and the exogenous RNA polymerase is T7 RNA polymerase.

11. An vector comprising a bacteriophage promoter, an alphavirus replicon operatively linked to the bacteriophage promoter, a first capping sequence, a subgenomic promoter, a second capping sequence, and a gene of interest.

12. The vector of claim 11, wherein the bacteriophage promoter is T7 promoter.

13. The vector of claim 11, wherein both the first and second capping sequences are the internal ribosome entry site sequence derived from encephalomyocarditis virus.

14. The vector of claim 11, wherein the gene of interest encodes an antigen.

15. The vector of claim 14, wherein the antigen is selected from the group consisting of a viral antigen, a bacterial antigen, and a cancer antigen.

16. The vector of claim 15, wherein the antigen is influenza hemagglutinin (HA).

17. A method for producing an induced pluripotent stem cell, comprising

(a) introducing into a mammalian somatic cell a gene expression system comprising a vector, wherein the vector comprises a sequence that encodes one or more mammal-derived reprogramming factor, and an exogenous RNA polymerase co-delivered with the alphavirus vector, and

(b) culturing the transduced somatic cell in the presence of a cytokine on a fibroblast feeder layer or an extracellular matrix under a condition for maintaining pluripotency and self-renewal.

18. The method of claim 17, wherein the sequence encodes reprogramming factors Oct 4, Sox3/4, Klf4, and c-Myc, wherein the four reprogramming factors are expressed simultaneously.

19. The method of claim 17, wherein the method is carried out in the presence of a substance for improving the efficiency of establishing the pluripotent stem cell.

20. The method of claim 19, wherein the substance for improving the efficiency of establishing the pluripotent stem cell is selected from the group consisting of a histone deacetylase (HDAC) inhibitor, a histone methyltransferase (G9a) inhibitor, and a DNA methylase (Dnmt) inhibitor.

21. A vaccine comprising the gene expression system of claim 1, wherein the gene of interest encodes an antigen.

22. The vaccine of claim 21, wherein the antigen is selected from the group consisting of a viral antigen, a bacterial antigen, and a cancer antigen.

23. The vaccine of claim 22, wherein the antigen is influenza hemagglutinin (HA).

24. A method for eliciting an immune response in a subject, comprising:

(a) delivering into the subject the gene expression system of claim 1, wherein the gene of interest encodes an antigen;

(b) inducing in the subject an immune response to the antigen in the subject.

25. A therapeutic composition, comprising a dendritic cell transfected with the gene expression system of claim 1, wherein the gene of interest encodes an antigen capable of being displayed on the surface of the dendritic cell, wherein the therapeutic composition is capable of producing an immune response in a subject.

26. The therapeutic composition of claim 25, wherein the antigen is a tumor antigen.

27. The therapeutic composition of claim 26, wherein the tumor antigen is one or more proteins selected from the group consisting of tyrosinase, tyrosine-related protein 1 (TRP-1), and tyrosine-related protein 2 (TRP-2).

28. A method for treating cancer, comprising administering to a patient in need thereof a therapeutic composition of claim 25.

29. The method of claim 28, wherein the cancer is melanoma, and the antigen is tyrosinase.

30. The method of claim 28, wherein the cancer is melanoma, and the antigen is tyrosine-related protein 1 (TRP-1).

31. The method of claim 28, wherein the cancer is melanoma, and the antigen is tyrosine-related protein 2 (TRP-2).