LENTIVIRAL VECTORS PSEUDOTYPED WITH A SINDBIS VIRUS ENVELOPE GLYCOPROTEIN

TECHNICAL FIELD

[0001] This patent application relates generally to targeted gene delivery, and more particularly to the use of a pseudotyped lentivirus comprising an envelope that targets dendritic cells and can thus be used for dendritic cell vaccination.

BACKGROUND

[0002] Dendritic cells (DCs) are essential antigen presenting cells for the initiation and control of immune responses. DCs can capture and process antigens, migrate from the periphery to a lymphoid organ, and present the antigens to resting T cells in a major histocompatibility complex (MHC)-restricted fashion. These cells are derived from bone marrow (BM) and display dendritic morphology and high mobility. The discovery of DCs as specialized antigen-presenting cells (APCs) has fueled attempts at DC-based immunization/vaccination strategies that involve loading DCs in vitro with specific antigens (Banchereau and Palucka, A. K. 2005. Nat. Rev. Immunol. 5:296-306; Figdor, et al. 2004. Nat. Med. 10:475-480). All of these attempts however, involve the labor-intensive preparation of a patient-specific therapy that includes the loading of autologous DCs ex vivo with specific antigens, which are then administered to the patient.

[0003] An alternative strategy is to utilize recombinant virus-based vectors as a mechanism to directly deliver a gene encoding a designated antigen(s) to host cells. In this instance, through induction of a desired adaptive immune response, the expressed gene product provides therapeutic benefit. There are a number of challenges however to achieving a safe and effective system. Some of these challenges include designing a vector that targets a desired set of host cells, providing a suitable delivery system, expressing a desired antigen to elicit an effective immune response and consistently

manufacturing a sufficiently high titered pharmaceutical composition of the recombinant virus vector virus so that it can be utilized broadly across a designated human subject population. The latter is a particular challenge in developing laboratory scale systems into products that can be produced by the pharmaceutical industry.

[0004] In the laboratory, many lentiviral vectors are pseudotyped with the VSV-G envelope proteins. This is widely used as a model system as the VSV envelope proteins are able to target many cell types (a "pantropic" envelope), and production systems generally provide a high titre.

[0005] The envelope glycoproteins of Sindbis virus and other alphaviruses disclosed herein incorporate into the lipid bilayer of the viral particle membrane. Typically, the viral membrane (envelope) includes multiple copies of trimers of two glycoprotein heterodimers, E1 and E2, which are produced from cleavage of a single precursor protein. The precursor protein comprises, from its N- to C-terminal, the E3, E2, 6K and E1 proteins. The small E3 glycoprotein serves as a signal sequence for translocation of the E2 protein into the membrane, and is cleaved from E2 by furin or some other Ca2+-dependent serine proteinase. The 6K protein serves as a signal sequence for translocation of the E1 protein into the membrane and is then cleaved from the precursor protein.

[0006] The E1 and E2 glycoproteins each have membrane-spanning regions; E2 has an about 33 residue cytoplasmic domain whereas the cytoplasmic tail of E1 is very short (about 2 residues). Both E1 and E2 have palmitic acids attached in or near the membrane-spanning regions.

[0007] Isolates of Sindbis virus described in the art are believed to infect cells via an interaction with heparan sulfate (HS). In WO 2008/011636 a lentiviral packaging system was described in which the E3/E2 envelope fusion protein (called SVGmu) contains a number of modifications, intended to reduce binding of the protein to HS but to retain binding to and infection of DCs, via the DC-SIGN surface molecule. In WO 2008/011636, the cDNA for wild-type SVG was obtained from the laboratory of Dr. J. H. Strauss laboratory at the California

Institute of Technology and cloned into the pcDNA3 vector (Invitrogen) by PCR to generate plasmid pSVG. A ten-residue tag sequence was inserted into E2 protein between amino acids 71 and 74 by PCR mutagenesis to disrupt the HS binding site. An additional deletion was introduced to the E3 glycoprotein of SVG to remove amino acids 61-64. This modified SVG was designated as SVGmu (SEQ ID NO:11 of WO2008/011636). The cDNA for SVGmu was cloned downstream of the CMV promoter in the pcDNA3 vector (designated as pSVGmu, SEQ ID NO: 3 of WO2008/011636).

SOME EMBODIMENTS OF THE PRESENT INVENTION

[0008] Though the SVGmu pseudotyped viral particles were able to selectively transduce cells expressing the DC-SIGN antigen, several aspects of the system make it unsuitable for therapeutic use. For example, the E3/E2 fusion protein displays an antigenic epitope of influenza hemagglutinin, the virus genome integrates into the host chromosome, which can activate deleterious host genes, and the present inventors have found that titers of the virus were low compared to the titer of particles pseudotyped with a VSV-G envelope. Significantly, Sindbis virus strains with a mutation preventing correct processing of E3 from the E2 glycoprotein (so-called “pE2 mutants”), such as SVGmu, grow poorly in permissive cell lines and are severely attenuated in mouse pathogenicity.

[0009] An alignment of the SVGmu E3-E2 protein used in WO2008/011636 to pseudotype a lentiviral vector against three exemplary E protein variants of the present invention is shown in Figure 1. The numbering indicated in Figure 1 is by reference to the HR strain of Sindbis virus envelope proteins. Unless otherwise indicated, numbering used herein is by reference to this strain of Sindbis virus. The present inventors have modified the SVGmu protein to provide an improved lentiviral production system. The viral particles of the invention are produced in a significantly higher titre than those using SVGmu, and also stimulate a stronger immune response. In addition, the

pseudotyped lentiviral particles have improved titre and improved infectivity whilst retaining selectivity for DCs.

[0010] In one embodiment, the invention provides a retroviral, such as a lentiviral, vector particle comprising: (a) an envelope comprising a Sindbis virus E2 glycoprotein of SEQ ID NO:1 in which 160X is absent or a non-acidic amino acid, or a variant of SEQ ID NO:1 capable of infecting dendritic cells; wherein said E2 glycoprotein or variant thereof is not fused to E3; and (b) a lentiviral genome comprising a sequence of interest.

[0011] The variant may be capable of binding to DC-SIGN. Preferably it also has reduced binding to heparan sulfate compared to a reference protein from HR strain. The E2 protein of the HR strain is shown as SEQ ID NO: 18.

[0012] Preferably, 160X is one of the small or aliphatic amino acids, including glycine, alanine, valine, leucine or isoleucine. In one aspect, 160X is absent or is glycine, valine, leucine or isoleucine. In one embodiment, X is glycine.

[0013] A variant of SEQ ID NO:1 is defined as comprising a sequence having at least 80% sequence identity, or at least 82%, 85%, 87%, 90%, 92%, 95%, or 98% sequence identity to SEQ ID NO:1 in which 160X is retained and as defined above. The variant may have one or more of the lysines and arginines in the region spanning residues 50 to 180 independently deleted or substituted with a non-basic amino acid. In one embodiment, the non-basic amino acid is glutamic acid or aspartic acid.

[0014] In one aspect, residue X is selected from a deletion, glycine, valine, leucine or isoleucine and one or more of the lysines and arginines in the region spanning residues 50 to 180 are independently deleted or substituted with a non-basic amino acid.

[0015] In another aspect, X is selected from a deletion, glycine, alanine, valine, leucine or isoleucine and one or more of the lysines and arginines in the region spanning residues 50 to 180, preferably including at

least position 159, are independently deleted or substituted with glutamic acid or aspartic acid

[0016] Candidate positively charged amino acids which may be substituted or deleted include lysines at residues 63, 70, 76, 84, 97, 104, 129, 131, 133, 139, 148, 149 and 159 and arginine at residues 65, 92, 128, 137, 157, 170 and 172 (numbering refers to SEQ ID NO: 1). When substituted, the substitution may be independently chosen from glutamic acid or aspartic acid.

[0017] In particular embodiments, one or more of the lysine residues 70, 76 and 159 are deleted or substituted. When substituted, the substitutions may be independently chosen from glutamic acid or aspartic acid.

[0018] Since Sindbis virus has an RNA genome, variations – including substitutions, insertions or deletions – in addition to those mentioned above may be made to parts of the E2 sequence of SEQ ID NO:1, within the scope of the percentage homology to SEQ ID NO:1 defined above. For example, variants of SEQ ID NO:1 exist in which position 3 is T or V, 23 is V, 209 is R, 264 is G, and 393 is H. One or more of these changes, or other variations to SEQ ID NO:1 may be made, provided the variant retains the ability to infect DCs.

[0019] In one embodiment, the variants do not contain any insertions in the region between residues 70 and 76 of SEQ ID NO:1. In this embodiment the sequence of residues 71-75 of SEQ ID NO:1 may be unchanged, or may comprise one or two substitutions which do not affect the ability of the variant to infect DCs.

[0020] In certain cases, E2 protein is first expressed as a polyprotein in fusion with at least E3 or in fusion with a leader sequence. In certain embodiments, E2 is expressed as part of E3-E2-6K-E1 polyprotein. Sindbis virus naturally expresses E2 as part of a polyprotein and the junction regions for E3/E2, E2/6K, and 6K/E1 have sequences recognized and cleaved by endopeptidases. The E3/E2 polyprotein sequence is set out as SEQ ID NO:20. Normally, the E3/E2 junction is cleaved by furin or a furin-like serine endopeptidase between residues 65 and 66 of the E3/E2 polyprotein. Furin has

specificity for paired arginine residues that are separated by two amino acids. To maintain E3/E2 cleavage by furin, residues 62-66 (RSKRS; SEQ ID NO: 26) should maintain the two arginine residues with two amino acid separation and the serine residue.

[0021] In one embodiment of the invention, the polyprotein comprises an E3 sequence corresponding to residues 1-65 of SEQ ID NO:20, or a variant thereof having at least 80% sequence identity, or at least 82%, 85%, 87%, 90%, 92%, 95%, or 98% sequence identity to residues 1-65 of SEQ ID NO:20, wherein residues 62-65 are RSKR (SEQ ID NO: 27) and the variant is capable of being incorporated into a pseudotyped viral envelope. Preferably, the E2 part of the polyprotein is any of the embodiments as defined herein above.

[0022] Alternatively, a different cleavage sequence can be used in place of the E3/E2 furin cleavage sequence or any of the other cleavage sequences. Recognition and cleavage sites can be incorporated for endopeptidases, including, without limitation, aspartic endopeptidases (e.g., cathepsin D, chymosin, HIV protease), cysteine endopeptidases (bromelains, papain, calpain), metalloendopeptidases, (e.g., collagenase, thermolysin), serine endopeptidases (e.g., chymotrypsin, factor IXa, factor X, thrombin, trypsin), streptokinases. The recognition and cleavage site sequences for these enzymes are well known.

[0023] Where such a cleavage site is used, it may be introduced into an E3 polyprotein comprising at least residues 1-60, such as residues 1-61 or 1-62 of SEQ ID NO:20 or a variant thereof having at least 80% sequence identity, or at least 82%, 85%, 87%, 90%, 92%, 95%, or 98% sequence identity to the corresponding number of residues of SEQ ID NO:20, fused directly at the C-terminal to said cleavage sequence, which in turn is fused to the E2 part of the polyprotein. Preferably, the E2 part of the polyprotein is any of the embodiments as defined herein above.

[0024] E2 protein sequences of the invention include variants of SEQ ID NO:1 in which the 160X is as defined in the following Table, and protein

is as set out in SEQ ID NO:1 apart from the following residues 70, 76 and 159 and 160, which are as follows:

SEQ ID No:	70	76	159	*160X*
3	E	**K**	E	*G*
4	E	E	E	*G*
5	E	**K**	E	*Δ*
6	E	E	E	*Δ*
7	**K**	**K**	E	*G*
8	**K**	**K**	E	*Δ*
9	**K**	E	E	*G*
10	**K**	E	E	*Δ*
11	**K**	E	**K**	*G*
12	**K**	E	**K**	*Δ*
13	E	**K**	**K**	*G*
14	E	**K**	**K**	*Δ*
15	E	E	**K**	*G*
16	*E*	*E*	***K***	*Δ*

[0025] Optionally, each of the above sequences may comprise one or more further changes to SEQ ID NO:1 but have residues 71-75 of SEQ ID NO:1 that are unchanged, or may have one or two substitutions which do not affect the ability of the variant to infect DCs, but do not alter the number of amino acids in this region.

[0026] Further E2 protein sequences of the invention comprise SEQ ID NO: 3, SEQ ID NO: 4, SEQ ID NO: 7, SEQ ID NO: 9, SEQ ID NO: 11, SEQ ID NO: 13 or SEQ ID NO: 15 in which residue 160 is Ala, Ile, Leu or Val in place of Gly. Such variants may also comprise residues 71-75 of SEQ ID NO:1 that are unchanged, or may have one or two substitutions which do not affect

the ability of the variant to infect DCs, but do not alter the number of amino acids in this region.

[0027] Optionally the E2 sequence of SEQ ID NOs: 3-15, or the further variants described in the above two paragraphs, may be varied at other positions to provide an E2 sequence having at least 80% sequence identity to SEQ ID NO:1. "At least 80% sequence identity" includes any one of at least 82%, 85%, 87%, 90%, 92%, 95%, or 98% sequence identity.

[0028] In the above embodiments, the first E2 residue, corresponding to position 66 of SEQ ID NO:20, may be Ser.

[0029] As indicated above, the E2 sequences of the invention, including any of SEQ ID NOs: 3-15 and the variants thereof described in the preceding three paragraphs, may be expressed from a polyprotein comprising at least an E3/E2 sequence, and preferably a Sindbis E3/E2/6K/E1 polyprotein sequence. The E3 polyprotein sequence in each of the embodiments may be that of residues 1-65 of SEQ ID NO:20 or any of the variants thereof described above, including variants with a non-native cleavage site.

SUMMARY OF THE INVENTION

[0030] This patent application is directed to pseudotyped lentiviral vectors that comprise a genome having a sequence of interest and an envelope comprising a glycoprotein of an arbovirus. The arbovirus glycoprotein can be from Sindbis virus, Dengue virus, and Venezuelan equine encephalitis virus. In particular, when the glycoprotein is an E2 protein from Sindbis virus, the E2 protein has at least one amino acid alteration at residue 160 compared to a SEQ ID NO: 1. The amino acid alteration can be a deletion or an amino acid other than glutamic acid. The E2 glycoprotein can alternatively be a variant protein that has at least 80% sequence identity to SEQ ID NO: 1 and also have an alteration of residue 160 that is either a deletion or an amino acid other than glutamic acid. The glycoprotein facilitates infection of dendritic cells. In all cases the E2 glycoprotein is not part of a fusion protein with Sindbis virus E3. In some embodiments, the E2 glycoprotein or variant binds DC-SIGN. The

lentiviral vector also comprises a lentiviral genome that comprises a sequence of interest.

[0031] In certain embodiments, residue 160 is absent or is glycine, alanine, valine, leucine or isoleucine. In one embodiment, residue 160 is glycine. In addition, other alterations of E2 glycoprotein can occur in combination with the mentioned alterations of residue 160. One such alteration is a change of an amino acid to reduce the net positive charge of E2. One way to reduce the net positive charge is to change one of the lysines to an amino acid that is not basic. In particular embodiments, one or more of lysine 70, lysine 76 or lysine 159 is altered. In certain embodiments, one or more of these lysines is changed to a glutamic acid or an aspartic acid. In specific embodiments, the E2 glycoprotein is one of SEQ ID NOs: 3-16. Examples of combinations of alterations include, without limitation, an alteration of glutamic acid at position 160, and alteration of one or more of lysine 70, lysine 76, or lysine 159 to a non-basic residue. Other alterations may be also be made, in combination with the alteration of residue 160 and optionally any of the other alterations disclosed herein. For example, any of the previously mentioned E2 glycoproteins may optionally comprise one or more further substitutions, insertions or deletions. As one specific example, the protein cleavage site between E2 and E3 can be either the native sequence or an altered sequence that is cleaved by a different endopeptidase. In other embodiments, which can be in combination with any of the above, the sequence of residues 71-75 of SEQ ID NO:1 is unchanged or has one or two amino acid substitutions which do not affect the ability of the variant to infect DCs.

[0032] In certain embodiments, the lentiviral vector genome of any of the foregoing viral particles comprises a sequence of interest that encodes a tumor-specific antigen or a virus-derived antigen, such as an HIV or SIV antigen. In some embodiments, any of the vector particles described are produced at a titer of at least 10^5/mL IU.

[0033] In another aspect, a lentiviral vector packaging system for producing a pseudotyped lentiviral vector particle is provided, comprising: a first

nucleic acid molecule encoding a Sindbis virus E2 glycoprotein of SEQ ID NO:1 in which residue 160 is absent or an amino acid other than glutamic acid, or a variant thereof capable of infecting dendritic cells having at least sequence 80% identity to SEQ ID NO:1 and in which residue 160 is absent or is an amino acid other than glutamic acid, a second nucleic acid molecule encoding gag and pol proteins; a third nucleic acid molecule encoding rev; and a lentiviral vector genome comprising a sequence of interest. The E2 glycoprotein or variant of the packaging system has an amino acid sequence as defined in any of the embodiments above. In some embodiments, the pol protein has a non-functional integrase. In a particular embodiment, the non-functional Integrase has a D64V mutation. In some embodiments, the second nucleic acid molecule is a non-integrating lentiviral genome. In particular embodiments, the *att* site is mutated or deleted or the PPT site is mutated or deleted or both. The non-integrating lentiviral genome can be used in combination with a non-functional Integrase and in combination with any of the E2 proteins or variants. It is preferred that lentiviral vector particles are produced to a titer of at least 10^5 IU/mL. In some instances, a cell is transfected with the first and fourth nucleic acid molecules described above. The cell may already comprise the second and third nucleic acid molecules, in a stable transformation.

[0034] An isolated nucleic acid molecule is provided that encodes the glycoprotein as described above or an E3/E2 glycoprotein optionally in the form of a Sindbis E3/E2/6K/E1 polyprotein, or an E3/E2 glycoprotein wherein the E3 sequence corresponds to residues 1-65 of SEQ ID NO:20, or a variant thereof having at least 80% sequence identity to residues 1-65 of SEQ ID NO:20, wherein residues 62-65 are RSKR (SEQ ID NO: 27) and the variant is capable of being incorporated into a pseudotyped viral envelope, optionally further wherein residue 1 of the E2 polyprotein is Ser. The E2 glycoprotein can be any of the variants described above, including the combinations of alterations. In addition, an expression vector comprising the nucleic acid molecule is provided, as is a host cell comprising the expression vector.

[0035] A method of making a lentiviral vector particle of any one of the variants or combinations above is provided, comprising expressing in a cell a first nucleic acid molecule encoding a Sindbis virus E2 glycoprotein of SEQ ID NO:1 in which residue 160 is other than glutamic acid, or a variant thereof capable of infecting dendritic cells having at least sequence 80% identity to SEQ ID NO:1 and in which residue 160 is absent or is an amino acid other than glutamic acid, and; (ii) a second nucleic acid molecule wherein the second nucleic acid molecule can be transcribed and the transcript assembled into a pseudotyped lentiviral vector particle.

[0036] Any of the lentiviral vector particles can be used in a method of treatment of a human or animal subject. The treatment can be a vaccine for immunization, in which the vaccine is prophylactic or therapeutic. A vaccine comprises the lentiviral vector particle with a pharmaceutically acceptable excipient. Alternatively, lentiviral vector particles can be administered to cells in vitro, comprising mixing the cells with any of the lentiviral vector particles above.

[0037] These and other aspects of the present invention will become evident upon reference to the following detailed description and attached drawings. In addition, U.S. application number 61/228,491 filed on July 24, 2009 is incorporated by reference herein in its entirety for all purposes.

BRIEF DESCRIPTION OF THE DRAWINGS

[0038] Figure 1 is a sequence alignment of the envelope protein for four Sindbis virus envelopes, SVGmu, SIN-Var1, SIN-Var2, and SIN-Var3. The alignment is shown relative to SVGmu, a previously described Sindbis envelope. Main differences to SVGmu include the regeneration of the furin like protease cleavage site (RSKR; SEQ ID NO: 27) between E3 and E2, removal of the HA epitope tag, and a series of lysine substitutions to reduce heparin binding.

[0039] Figure 2 is a schematic of exemplary vectors used in packaging viral particles.

[0040] Figure 3 presents graphs of crude supernatant titers of lentiviral vector particle preparations in which the vector genome was pseudotyped with three different Sindbis virus envelope proteins, SVGmu and SIN-HR. Virus supernatants were generated by transient transfection using standard methods, and collected 48 hours post transfection. Titers were determined on 293T cells expressing human DC-SIGN (293T-DC-SIGN). Titers are expressed as the number of GFP-expressing units per ml of supernatant and are means of three independent transfections. Error bars represent the standard deviation from the mean.

[0041] Figures 4A, 4B, and 4C are graphs showing immunological responses of T cells in mice following administration of pseudotyped lentiviral vector particles. (A) C57BL/6 mice were immunized subcutaneously with one of two doses (indicated in ng p24) of integration-deficient lentiviral vector encoding OVA. The number and function of OVA257-specific CD8 T cells in the spleen was determined at day 9 by MHC-I/peptide multimer and intracellular cytokine staining. (B) C57BL/6 mice were immunized subcutaneously with a dose range of integration-deficient lentiviral vector encoding OVA. The percentage of OVA257-specific CD8 T cells in the spleen was determined at day 11 by MHC-I/peptide multimer staining. (C) C57BL/6 mice were immunized subcutaneously with a dose range of integration-deficient lentiviral vector encoding OVA. The percentage of OVA257-specific CD8 T cells in the spleen was determined at day 9 by intracellular cytokine staining.

[0042] Figure 5A presents drawings of exemplary lentiviral genomes. Figure 5B presents sequences of the U3 region of three vector constructs. (A) The elements contained in all lentivirus vectors are shown in the exemplary vector genome at the top. Promoters utilized include the human Ubiquitin-C promoter (UbiC), the cytomegalovirus immediate early promoter (CMV), or the Rous sarcoma virus (RSV) promoter. In addition to the standard SIN U3 region, a series of extended deletions are shown. Sequence alignments of the U3 regions from all 3 vectors are shown in (B). The sequence shown includes the polypurine tract (PPT), which is deleted in

construct 704, and the extended U3 deletion present in both 703 and 704 constructs.

[0043] Figures 6A and 6B show GFP expression from lentivirus vector following transduction of 293T cells. In Figure 6A, GFP was operatively linked to a UbiC promoter, and in Figure 6B, GFP was operatively linked to a CMV promoter. GFP expression levels were determined from integrase deficient lentivirus vectors 48 hr following transduction of 293T cells expressing DC-SIGN. GFP expression in transduced cells was determined by standard flow cytometric methods; a total of 50,000 events were collected from each tranduced cell pool to determine mean expression levels.

[0044] Figure 7 shows the number of GFP positive cells during five passages. Cells were transduced with different vector preparations and passaged every 72 hrs. Relative GFP titers were determined in 293T cell cultures transduced with different NILV constructs. Vectors were packed using either wild-type Integrase (IN+) or a D64V mutant Integrase (IN-), and used to transduce 293 cells expressing DC-SIGN. Transduced cell cultures were then passaged every 72 hours for 15 days. At each passage, the number of GFP+ cells in the culture was determined using standard flow-cytometric methods. Loss of GFP expression with passage indicates loss of vector episomes over time.

[0045] Figure 8 shows CD8 T cell response following administration of integrating (Int^{wt}) or nonintegrating (Int^{D64V}) lentivirus vector. C57BL/6 mice were immunized subcutaneously with $2.5x10^{10}$ genomes of integrating (Int^{wt}) or nonintegrating (Int^{D64V}) lentivirus vector encoding the Gag antigen from simian immunodeficiency virus (SIV). The number of antigen-specific T cells in spleen and their cytokine secretion profile was determined at day 10 by intracellular cytokine staining.

[0046] Figure 9 presents graphs showing tumor size in mice receiving either vehicle alone or viral particles encoding a tumor antigen (left graph) and percent survival (right graph). BALB/c mice were injected subcutaneously with $2x10^4$ CT26 colon carcinoma cells. One day later, mice

were treated subcutaneously with either vehicle or 3.2 μg (p24 capsid) of DC-targeting nonintegrating lentivirus vector (DC-NILV) encoding the AH1A5 peptide (SPSYAYHQF; SEQ ID NO: 25), a modified CT26 CD8 T cell epitope. The initial tumor growth and long-term survival of vaccinated versus control mice is depicted.

DETAILED DESCRIPTION

[0047] The present disclosure provides methods and compositions for targeting dendritic cells (DCs) by using a lentiviral vector particle (*e.g.*, a virion, a lentivirus particle) to deliver a sequence of interest to DCs. The lentiviral vector particle comprises an envelope glycoprotein variant derived from Sindbis virus E2, and a genome that comprises the sequence of interest, and optionally other components. The glycoprotein variant exhibits reduced binding to heparan sulfate compared to HR, a reference Sindbis virus strain. The envelope glycoprotein facilitates infection of dendritic cells by the lentiviral vector particles. "Facilitates" infection, as used herein, is the same as facilitates transduction and refers to the role of the envelope glycoprotein, acting alone or in concert with other molecules, in promoting or enhancing receptor-mediated entry of a pseudotyped retrovirus or lentivirus particle into a target cell.

[0048] In general, the lentiviral vector particles are produced by a cell line that contains one or more plasmid vectors and/or integrated elements that together encode the components necessary to generate functional vector particles. These lentiviral vector particles are typically not replication-competent, *i.e.,* they are only capable of a single round of infection. Most often, multiple plasmid vectors or individual expression cassettes integrated stably into the producer cell chromosome are utilized to separate the various genetic components that generate the lentiviral vector particles, however, a single plasmid vector having all of the lentiviral components can be used. In one exemplification, the packaging cell line is transfected with one or more plasmids containing the viral vector genome, including LTRs, a *cis*-acting packaging

sequence, and the sequence(s) of interest, at least one plasmid encoding the virus enzymatic and structural components (*e.g.,* gag and pol), and at least one plasmid encoding an Arbovirus envelope glycoprotein. Viral particles bud through the cell membrane and comprise a core that includes typically two RNA genomes containing the sequence of interest and an Arbovirus envelope glycoprotein that targets dendritic cells. When the Arbovirus glycoprotein is a Sindbis virus E2 glycoprotein, the glycoprotein is engineered to have reduced binding to heparan sulfate compared to the reference strain HR. This usually involves at least one amino acid change compared to the HR E2 glycoprotein sequence.

[0049] Without wishing to be bound by theory, it is believed that the binding of the viral particle to a cell surface induces endocytosis, bringing the virus into an endosome, triggering membrane fusion, and allowing the virus core to enter the cytosol. For certain embodiments, which utilize integrating lentiviral vector particles, following reverse transcription and migration of the product to the nucleus, the genome of the virus integrates into the target cell genome, incorporating the sequence(s) of interest into the genome of the target cell. To reduce the chance of insertional mutagenesis and to promote transient expression of a designate antigen(s), however, other embodiments utilize non-integrating lentiviral vector particles, which do not integrate into the target cell genome, but instead express the sequence(s) of interest from an episome. Either way, the infected DC then expresses the sequence(s) of interest, e.g., an antigen, a stimulatory molecule. The antigen can then be processed by dendritic cells and presented to T and B cells, generating an antigen-specific immune response. The specific pathway described above is not required so long as the dendritic cell is able to stimulate an antigen-specific immune response.

[0050] The viral particles can be administered to a subject in order to provide a prophylactic or therapeutic effect. The product of the sequence of interest is typically an antigen of a disease-causing agent or a diseased cell (e.g., tumor cell). Following infection of dendritic cells and

expression of the product, an immune response is generated to the product. The immune response may be humoral or cellular or both.

A. Viral Vector Envelope

[0051] Arthropod-borne viruses (Arboviruses) are viruses that are transmitted to a host, such as humans, horses, or birds by an infected arthropod vector such as a mosquito. Arboviruses are further divided into sub-families of viruses including alphaviruses and flaviviruses, which have a single-stranded RNA genome of positive polarity and a glycoprotein-containing envelope. For example, dengue fever virus, yellow fever virus and West Nile virus belong to the flavivirus family, and Sindbis virus, Semliki Forest virus and Venezuelan Equine Encephalitis virus, are members of the alphavirus family (Wang et al. J. Virol. 66, 4992 (1992)). The envelope of Sindbis virus includes two transmembrane glycoproteins (Mukhopadhyay et al. Nature Rev. Microbio. 3, 13 (2005)): E1, believed to be responsible for fusion, and E2, believed to be responsible for cell binding. Sindbis virus envelope glycoproteins are known to pseudotype other retroviruses, including oncoretroviruses and lentiviruses.

[0052] As discussed above, an arbovirus envelope glycoprotein can be used to pseudotype a lentiviral-based vector genome. A "pseudotyped" lentivirus is a lentiviral particle having one or more envelope glycoproteins that are encoded by a virus that is distinct from the lentiviral genome. The envelope glycoprotein may be modified, mutated or engineered as described herein.

[0053] The envelope of Sindbis virus and other alphaviruses incorporates into the lipid bilayer of the viral particle membrane, and typically includes multiple copies of two glycoproteins, E1 and E2. Each glycoprotein has membrane-spanning regions; E2 has an about 33 residue cytoplasmic domain whereas the cytoplasmic tail of E1 is very short (about 2 residues). Both E1 and E2 have palmitic acids attached in or near the membrane-spanning regions. E2 is initially synthesized as a precursor protein that is cleaved by furin or other Ca2+-dependent serine proteinase into E2 and a small glycoprotein called E3. Located between sequences encoding E2 and E1 is a

sequence encoding a protein called 6K. E3 and 6K are signal sequences which serve to translocate the E2 and E1 glycoproteins, respectively, into the membrane. In the Sindbis virus genome, the coding region for Sindbis envelope proteins includes sequence encoding E3, E2, 6K, and E1. As used herein, "envelope" of an arbovirus virus includes at least E2, and may also include E1, 6K and E3. An exemplary sequence of envelope glycoproteins of Sindbis virus, strain HR, is presented as SEQ ID No. 17. Sequences of envelope glycoproteins for other arboviruses can be found in e.g., GenBank. For example, sequence encoding Dengue virus glycoproteins can be found in Accession GQ252677 (among others in GenBank) and in the virus variation database at NCBI (GenBank accessions and virus variation database are incorporated by reference for envelope glycoprotein sequences) and sequence encoding Venezuelan equine encephalitis virus envelope glycoproteins in Accession NP 040824 (incorporated by reference for sequences of envelope glycoproteins).

[0054] Although the cellular receptor(s) on dendritic cells for alphaviruses, and Sindbis virus in particular, have not been definitively identified to date, one receptor appears to be DC-SIGN (Klimstra et al., J Virol 77: 12022, 2003). The use of the terms "attachment", "binding", "targeting" and the like are used interchangeably and are not meant to indicate a mechanism of the interaction between Sindbis virus envelope glycoprotein and a cellular component. DC-SIGN (Dendritic Cell Specific ICAM-3 (Intracellular Adhesion Molecules 3)-Grabbing Nonintegrin; also known as CD209) is a C-type lectin-like receptor capable of rapid binding and endocytosis of materials (Geijtenbeek, T. B., et al. Annu. Rev. Immunol. 22: 33-54, 2004). E2 appears to target virus to dendritic cells through DC-SIGN. As shown herein, cells expressing DC-SIGN are transduced by viral vector particles pseudotyped with Sindbis virus E2 better (at least 2-fold, at least 3-fold, at least 4-fold, at least 5-fold, at least 6-fold, at least 7-fold, at least 8-fold, at least 9-fold, or at least 10-fold better) than isogenic cells that don't express DC-SIGN. The mechanism of how E2 glycoprotein facilitates viral infection appears to involve DC-SIGN,

possibly through direct binding to DC-SIGN or causing a change in conformation or some other mechanism. Regardless of the actual mechanism, the targeting by E2 is preferential for cells expressing DC-SIGN, namely dendritic cells.

[0055] Sindbis virus also appears to bind to cells via heparan sulfate (Klimstra et al., J Virol 72: 7357, 1998; Burmes and Griffin, J Virol 72: 7349, 1998). Because heparan sulfate and other cell surface glycosaminoglycans are found on the surface of most cell types, it is desirable to reduce interaction between heparan sulfate and Sindbis envelope glycoproteins. This can be accomplished by diminishing the binding of Sindbis virus envelope to heparan sulfate or increasing the binding, e.g., increasing avidity, of Sindbis virus envelope to dendritic cells or both. As a result, nonspecific binding to other molecules, which may be expressed by other cell types and which may occur even if the envelope is specific for DC-SIGN, is reduced, and the improved specificity may serve to avoid undesired side effects, such as side effects that may reduce the desired immune response, or side effects associated with off-target transduction of other cell types. Alternatively or in addition to the advantages of relatively specific transduction of cells expressing DC-SIGN, viral particles pseudo-typed with Sindbis virus envelope E2 glycoprotein may offer other advantages over viral particles pseudo-typed with glycoproteins such as VSVG. Examples of such advantages include reduced complement-mediated lysis and/or reduced neuronal cell targeting, both of which are believed to associate with administration of VSV-G pseudo-typed viral particles.

[0056] In various exemplifications, the lentiviral vector particles specifically bind to cells expressing DC-SIGN and have reduced or abrogated binding to heparan sulfate. That is, a Sindbis virus envelope E2 glycoprotein may be modified to preferentially direct the virus to dendritic cells that express DC-SIGN relative to other cell types. Based on information obtained from structural studies and molecular modeling among other studies, variant sequences of envelope proteins, especially E2 and E1 glycoproteins, are

designed and generated such that the glycoproteins maintain their functions as envelope proteins, but have the desired binding specificity, avidity, or level of binding. Candidate variant sequences may be created for each glycoprotein and assayed using the methods described below, or other methods known in the art, to identify envelope glycoproteins with the most desirable characteristics.

[0057] Certain variant sequences of Sindbis E2 have at least one amino acid alteration at residue 160 as compared to SEQ ID NO: 1. Residue 160 is deleted or changed to an amino acid other than glutamic acid. An alteration is most commonly a substitution of at least one amino acid, but alternatively can be an addition or deletion of one or more amino acids. Preferably, any additional amino acids are few in number and do not comprise an antigenic epitope (e.g., hemagglutinin tag sequence), which may compromise safety. When there are two or more alterations, they can both be of the same type (e.g., substitution) or differing types (e.g., a substitution and a deletion). Multiple alterations can be scattered or located contiguously in the protein sequence.

[0058] In the first instance, variant sequences comprise at least one amino acid alteration in the region of about residue 50 to about residue 180. Within this region are amino acids that are involved with binding to heparan sulfate. By reducing the net positive charge of E2, electrostatic interaction with heparan sulfate can be reduced, resulting in decreased binding to heparan sulfate. Candidate positively charged amino acids in this region include lysines at residues 63, 70, 76, 84, 97, 104, 129, 131, 133, 139, 148, 149, 159 and arginine at residues 65, 92, 128, 137, 157, 170, 172 (Bear et al., Virology 347: 183-190, 2006). At least several of these amino acids are directly implicated in E2 binding to heparan sulfate. Net positive charge can be reduced by deletion of lysine or arginine or substitution of lysine or arginine with a neutral or negatively charged amino acid. For example, one or more of these lysines and arginines may be replaced with glutamic or aspartic acid. Certain embodiments have at least one substitution of lysine 70, 76 or 159. In cases

where E2 is expressed as a polyprotein with E3, the lysine located adjacent to the natural E3/E2 cleavage site is maintained – that is, the recognition sequence and cleavage site is unaltered. Alternatively, the native endopeptidase cleavage site sequence is replaced with a recognition sequence for a different endopeptidase.

[0059] Certain variants of E2 are also modified in a way that positively impacts binding to dendritic cells. Alteration of the glutamic acid found at residue 160 in the reference HR sequence can improve binding to dendritic cells (see Gardner et al., J Virol 74, 11849, 2000, which is incorporated in its entirety). Alterations, such as a deletion of residue 160 or substitution of residue 160 are found in certain variants. In particular variants, a non-charged amino acid is substituted for Glu, in other variants, a non-acidic amino acid is substituted for Glu. Typically, Glu160 is replaced with one of the small or aliphatic amino acids, including glycine, alanine, valine, leucine or isoleucine.

[0060] Other variants comprise two or more amino acid alterations. Typically in these variants one of the alterations is Glu160 and the remaining alteration(s) are changes of one or more of the lysines and arginines in the region spanning residue about 50 to about 180. Certain of the variants comprise an alteration of Glu160 to a non-acidic residue or deletion and one or more alterations of lysine 70, lysine 76, or lysine 159 with a non-basic amino acid. Some specific variants comprise a Glu160 to Gly, Lys 70 to Glu, and Lys 159 to Glu; a Glu 160 to Gly, Lys 70, 76 and 159 to Glu; a deletion of Glu 160 and Lys 70 and 159 to Glu; and a deletion of Glu 160 and Lys 70, 76, and 159 to Glu.

[0061] In certain cases, E2 protein is first expressed as a polyprotein in fusion with at least E3 or in fusion with a leader sequence. Regardless of whether the leader sequence is E3 or another sequence, E2 in the viral envelope should be free of the E3 or other leader sequence. In other words, E2 is preferably not an E3/E2 fusion protein (e.g., the E3/E2 fusion protein called SVGmu). In certain embodiments, E2 is expressed as part of E3-

E2-6K-E1 polyprotein. Sindbis virus naturally expresses E2 as part of a polyprotein and the junction regions for E3/E2, E2/6K, and 6K/E1 have sequences recognized and cleaved by endopeptidases. Normally, the E3/E2 junction is cleaved by furin or a furin-like serine endopeptidase between residues 65 and 66. Furin has specificity for paired arginine residues that are separated by two amino acids. To maintain E3/E2 cleavage by furin, residues 62-66 (RSKRS; SEQ ID NO: 26) should maintain the two arginine residues with two amino acid separation and the serine residue. Alternatively, a different cleavage sequence can be used in place of the E3/E2 furin cleavage sequence or any of the other cleavage sequences. Recognition and cleavage sites can be incorporated for endopeptidases, including, without limitation, aspartic endopeptidases (e.g., cathepsin D, chymosin, HIV protease), cysteine endopeptidases (bromelains, papain, calpain), metalloendopeptidases, (e.g., collagenase, thermolysin), serine endopeptidases (e.g., chymotrypsin, factor IXa, factor X, thrombin, trypsin), streptokinases. The recognition and cleavage site sequences for these enzymes are well known.

[0062] Amino acids in E2, other than those already mentioned, may also be altered. Generally, a variant E2 sequence will have at least 80% sequence amino acid identity to the reference E2 sequence, or it may have at least 82%, at least 85%, at least 87%, at least 90%, at least 92%, at least 95%, or at least 98% sequence identity. The variant glycoprotein should exhibit biological function, such as the ability to facilitate infection of dendritic cells by a viral particle having an envelope comprising E2. Experiments have identified regions of envelope glycoproteins that appear to have an important role in various aspects of viral assembly, attachment to cell surface, and infection. When making variants, the following information can be used as guidelines. The cytoplasmic tail of E2 – approximately residues 408 to 415 – is important for virus assembly (West et al. J Virol 80: 4458-4468, 2006; incorporated in its entirety). Other regions are involved in forming secondary structure (approximately residues 33-53); and involved in transport and protein stability (approximately residues 86-119) (Navaratmarajah et al., J Virol 363: 124-147,

2007; incorporated in its entirety). The variant may retain hydrophobic character of a region that spans the membrane, approximately residues 370-380. The variant may retain one or both N-linked glycosylation sites residues NIT (residues 196-198) and NFT (residues 318-320) and may retain one or more of the sites that are palmitoylated (C-396, C416 and C417) (Strauss and Strauss Microbiol Rev 58, 491-562, 1994; pp. 499-509 incorporated). On the other hand, many regions of E2 may be altered without deleterious event. For example, insertions of transposons at many different locations in E2 still resulted in viable virus (Navaratmarajah, ibid).

[0063] In certain embodiments, a tag peptide may be incorporated into E3, 6K, or E1 proteins. For some purposes, a tag may be incorporated into E2, but a tag is not desirable for use in a product for administration to human patients. A tag peptide, which is a short sequence (e.g., 5-30 amino acids), can be used to facilitate detection of envelope expression and its presence in viral particles. . For detection purposes, a tag sequence will typically be detectable by antibodies or chemicals. Another use for a tag is to facilitate purification of viral particles A substrate containing a binding partner for the tag can be used to absorb virus. Elution of the virus can be accomplished by treatment with a moiety that displaces the tag from the binding partner or when the tag sequence is in linkage with a cleavable sequence, treatment with the appropriate endopeptidase will conveniently allow release of virus. (See, for example, Qiagen catalog, Factor Xa Protease System). Removal of the tag peptide is generally desirable for safety purposes of the virus particles use in animal subjects. If the tag is not removed, an immune response to the tag may occur.

[0064] Suitable tags include, without limitation, FLAG (DYKDDDDK) (U.S. Patent No. 4,703,004, incorporated in its entirety), for which antibodies are commercially available, chitin binding protein, maltose binding protein, glutathione-S-transferase, poly(His) (U.S. Patent No. 4,569,794, incorporated in its entirety), thioredoxiin, HA (hemagglutinin)-tag,

among others. Poly(His) can be adsorbed onto affinity media containing bound metal ions, e.g., nickel or cobalt, and eluted with a low pH medium.

[0065] The viral particles may be evaluated to determine the specificity of the envelope glycoprotein incorporated into the virus that targets dendritic cells. For example, a mixed population of bone marrow cells can be obtained from a subject and cultured in vitro. Alternatively, isogenic cells lines that express or don't express DC-SIGN can be obtained and used. The recombinant virus can be administered to the mixed population of bone marrow cells or isogenic cell lines, and expression of a reporter gene incorporated into the virus can be assayed in the cultured cells. Certain embodiments may employ a limiting dilution analysis, in which the mixed population of cells is split into separate parts, which are then separately incubated with decreasing amounts of virus (*e.g.,* 2-fold, 5-fold, 10-fold less virus in each part). In some embodiments, at least about 50%, more preferably at least about 60%, 70%, 80% or 90%, still more preferably at least about 95% of infected cells in the mixed cell population are dendritic cells that express DC-SIGN. In certain embodiments, the ratio of infected dendritic cells to infected non-dendritic cells (or non DC-SIGN expressing cells) is at least about 2:1, at least about 3:1, at least about 4:1, at least about 5:1, at least about 6:1, at least about 7:1, at least about 8:1, at least about 9:1, at least about 10:1, at least about 20:1, at least about 30:1, at least about 40:1, at least about 50:1, at least about 100:1, at least about 200:1, at least about 500:1, at least about 1000:1, at least about 5000:1, at least about 10,000:1, or more. For limiting dilution, greater selectivity is typically seen at higher dilutions (i.e., lower amounts) of input virus.

[0066] Activity of pseudotyped viral particles can be determined by any of a variety of techniques. For example, a preferred method to measure infectivity efficiency (IU, infectious units) is by administering viral particles to cells and measuring expression of a product encoded in the vector genome. Any product that can be assayed may be used. One convenient type of product is a fluorescent protein, such as green fluorescent protein (GFP). GFP and assay is exemplified in the Examples, such as Example 3. Other products that

can be used include proteins expressed on a cell surface (e.g., detection by antibody binding), enzymes, and the like. If the product is an antigen and cells are dendritic cells, infectivity / activity can be assessed by determining an immune response. Furthermore, it is possible to ascertain side effects in a mammal. The ability to specifically target dendritic cells can also be tested directly, for example, in cell culture as described below.

[0067] Viral particles can also be prepared and tested for their selectivity and/or their ability to facilitate penetration of the target cell membrane. Viral particles that have an envelope with unmodified glycoproteins can be used as controls for comparison. Briefly, cells expressing a receptor for an envelope glycoprotein are infected by the virus using a standard infection assay. After a specified time, for example 48 hours post-infection, cells can be collected and the percentage of cells infected by the virus can be determined by flow cytometry, for example. Selectivity can be scored by calculating the percentage of cells infected by virus. Similarly, the effect of a variant envelope glycoprotein on viral titer can be quantified by dividing the percentage of cells infected by virus comprising a variant envelope by the percentage of cells infected by virus comprising the corresponding wild type (unmodified) envelope glycoprotein. A particularly suitable variant will have the best combination of selectivity and infectious titer. Once a variant is selected, viral concentration assays may be performed to confirm that these viruses can be concentrated without compromising activity. Viral supernatants are collected and concentrated by ultracentrifugation. The titers of viruses can be determined by limited dilution of viral stock solution and infection of cells expressing the receptor for the envelope glycoprotein, measuring the expression of a product expressed by the viruses as described above.

[0068] The entry of a lentiviral vector particle into a target cell is another type of evaluation of activity. BlaM-Vpr (beta-lactamase Vpr) fusion protein has been utilized to evaluate HIV-1 viral penetration; a fusion of BlaM and a Sindbis virus envelope glycoprotein, such as E1 or an E2/E1 fusion protein can be used to assess the efficacy of an envelope protein in facilitating

fusion and penetration into a target cell. Viral particles may be prepared, for example, by transient transfection of packaging cells with one or more vectors comprising the viral elements, BlaM-Vpr, and the variant envelope of interest (and an affinity molecule if appropriate). The resulting viruses can be used to infect cells expressing a molecule the targeting molecule (or affinity molecule) specifically binds in the absence or presence of the free inhibitor of binding (such as an antibody). Cells can then be washed with CO_2-independent medium and loaded with CCF2 dye (Aurora Bioscience). After incubation at room temperature to allow completion of the cleavage reaction, the cells can be fixed by paraformaldehyde and analyzed by flow cytometry and microscopy. The presence of blue cells indicates the penetration of viruses into the cytoplasm; fewer blue cells would be expected when blocking antibody is added (Cavrois et al. Nat Biotechnol 20: 1151-1154, 2002; incorporated in its entirety).

[0069] To investigate whether penetration is dependent upon a low pH, and to identify envelope glycoproteins with the desired pH dependence, NH_4Cl or other compound that alters pH can be added at the infection step (NH_4Cl will neutralize the acidic compartments of endosomes). In the case of NH_4Cl, the disappearance of blue cells will indicate that penetration of viruses is low pH-dependent. In addition, to confirm that the activity is pH-dependent, lysosomotropic agents, such as ammonium chloride, chloroquine, concanamycin, bafilomycin Al, monensin, nigericin, etc., may be added into the incubation buffer. These agents elevate the pH within the endosomal compartments (e.g., Drose and Altendorf, J. Exp. Biol. 200, 1-8, 1997). The inhibitory effect of these agents will reveal the role of pH for viral fusion and entry. The different entry kinetics between viruses displaying different fusogenic molecules may be compared and the most suitable selected for a particular application.

[0070] PCR-based entry assays can be utilized to monitor reverse transcription and measure kinetics of viral DNA synthesis as an indication of the kinetics of viral entry. For example, viral particles comprising a

particular envelope protein molecule are incubated with target cells, such as 293T cells, DCs, or any other cells that have been engineered to express, or which naturally express, the appropriate binding partner (receptor) for the envelope protein molecule. Either immediately, or after a time increment (to allow infection to occur), unbound viruses are removed and aliquots of the cells are analyzed for viral nucleic acids. DNA is extracted from these aliquots and subjected to amplification analysis, generally in a semi-quantitative assay, primed with LTR-specific primers. The appearance of LTR-specific DNA products indicates the success of viral entry.

B. Lentiviral Vector Genome

[0071] The viral vector particle comprises a genome, which comprises the sequence(s) of interest. Other sequences may included, such as sequences that allow the genome to be packaged into the virus particle and sequences that promote expression of the sequence(s) of interest following transduction of the target cell. The genome can be derived from any of a large number of suitable, available lentiviral genome based vectors, including those identified for human gene therapy applications, such as those described by Pfeifer and Verma (Annu. Rev. Genomics Hum. Genet. 2:177-211, 2001; which is incorporated herein by reference in its entirety). For the sake of simplicity, the genome is also referred to as "viral vector genome" or "vector genome".

1. Backbone

[0072] Suitable lentiviral vector genomes include those based on Human Immunodeficiency Virus (HIV-1), HIV-2, feline immunodeficiency virus (FIV), equine infectious anemia virus, Simian Immunodeficiency Virus (SIV) and maedi/visna virus. A desirable characteristic of lentiviruses is that they are able to infect both dividing and non-dividing cells, it is not necessary for target cells to be dividing (or to stimulate the target cells to divide). Generally, the genome and envelope glycoproteins will be based on different viruses, such that the resulting viral vector particle is pseudotyped. Safety features of the vector genome are desirably incorporated. Safety features include self-inactivating

LTR and a non-integrating genome. Exemplary vectors are discussed further in Example 5 and Figure 5 and such vectors may be used in embodiments of the invention for expression of antigens of interest.

[0073] In some exemplary embodiments, the viral vector genome comprises sequences from a lentivirus genome, such as the HIV-1 genome or the SIV genome. The viral genome construct may comprise sequences from the 5' and 3' LTRs of a lentivirus, and in particular may comprise the R and U5 sequences from the 5' LTR of a lentivirus and an inactivated or self-inactivating 3' LTR from a lentivirus. The LTR sequences may be LTR sequences from any lentivirus from any species. For example, they may be LTR sequences from HIV, SIV, FIV or BIV. Typically, the LTR sequences are HIV LTR sequences.

[0074] The vector genome may comprise an inactivated or self-inactivating 3' LTR (Zufferey et al. J Virol 72: 9873, 1998; Miyoshi et al., J Virol 72:8150, 1998; both of which are incorporated in their entirety). A self-inactivating vector generally has a deletion of the enhancer and promoter sequences from the 3' long terminal repeat (LTR), which is copied over into the 5' LTR during vector integration. In one instance, the U3 element of the 3' LTR contains a deletion of its enhancer sequence, the TATA box, Sp1 and NF-kappa B sites. As a result of the self-inactivating 3' LTR, the provirus that is generated following entry and reverse transcription will comprise an inactivated 5' LTR. The rationale is to improve safety by reducing the risk of mobilization of the vector genome and the influence of the LTR on nearby cellular promoters. The self-inactivating 3' LTR may be constructed by any method known in the art.

[0075] Optionally, the U3 sequence from the lentiviral 5' LTR may be replaced with a promoter sequence in the viral construct, such as a heterologous promoter sequence. This can increase the titer of virus recovered from the packaging cell line. An enhancer sequence may also be included. Any enhancer/promoter combination that increases expression of the viral RNA genome in the packaging cell line may be used. In one example, the CMV

enhancer/promoter sequence is used (US 5385839 and US 5168062, each of which is incorporated in its entirety).

[0076] In certain embodiments, the risk of insertional mutagenesis is minimized by constructing the lentiviral vector genome to be integration defective. A variety of approaches can be pursued to produce a non-integrating vector genome. These approaches entail engineering a mutation(s) into the integrase enzyme component of the *pol* gene, such that it encodes a protein with an inactive integrase. The vector genome itself can be modified to prevent integration by, for example, mutating or deleting one or both attachment sites, or making the 3' LTR-proximal polypurine tract (PPT) non-functional through deletion or modification. In addition, non-genetic approaches are available; these include pharmacological agents that inhibit one or more functions of integrase. The approaches are not mutually exclusive, that is, more than one of them can be used at a time. For example, both the integrase and attachment sites can be non-functional, or the integrase and PPT site can be non-functional, or the attachment sites and PPT site can be non-functional, or all of them can be non-functional.

[0077] As stated above, one approach is to make and use a non-functional integrase. Integrase is involved in cleavage of viral double-stranded blunt-ended DNA and joining the ends to 5'-phosphates in the two strands of a chromosomal target site. Integrase has three functional domains: N-terminal domain, which contains a zinc-binding motif (HHCC), the central domain core, which contains the catalytic core and a conserved DD35E motif (D64, D116, E152 in HIV-1), and a C-terminal domain, which has DNA binding properties. Point mutations introduced into integrase are sufficient to disrupt normal function. Many integrase mutations have been constructed and characterized (see, Philpott and Thrasher, Human Gene Therapy 18:483, 2007; Apolonia, Thesis submitted to University College London, April 2009, pp, 82-97; Engelman et al. J Virol 69: 2729, 1995; Nightingale et al. Mol Therapy, 13: 1121, 2006; all of which are incorporated in their entirety). The sequence encoding the integrase protein can be deleted or mutated to render the protein

inactive, preferably without significantly impairing reverse transcriptase activity or nuclear targeting, thereby only preventing integration of the provirus into the target cell genome. Acceptable mutations can reduce integrase catalysis, strand transfer, binding to *att* sites, binding to host chromosomal DNA, and other functions. For example, a single aspartic acid to asparagine substitution at residue 35 of HIV or SIV integrase completely abolishes viral DNA integration. Deletions of integrase will generally be confined to the C-terminal domain. Deletion of coding sequence for residues 235-288 result in a useful non-functional integrase (Engelman et al. J Virol 69:2729, 1995). As further examples, mutations can be generated, for example, Asp64 (residue numbers are given for HIV-1, corresponding residue numbers for integrase from other lentiviruses or retroviruses can be readily determined by one of ordinary skill) (e.g., D64E, D64V), Asp116 (e.g., D116N), Asn120 (e.g., N120K), Glu152, Gln148 (e.g., Q148A), Lys156, Lys159, Trp235 (e.g.W235E), Lys264 (e.g., K264R), Lys266 (e.g., K266R), Lys273 (e.g., K273R). Other mutations can be constructed and tested for integration, transgene expression, and any other desirable parameter. Assays for these functions are well known. Mutations can be generated by any of a variety of techniques, including site-directed mutagenesis and chemical synthesis of nucleic acid sequence. One mutation may be made or more than one of these mutations can be present in integrase. For example, an integrase may have mutations at two amino acids, three amino acids, four amino acids, and so on.

[0078] Alternatively or in combination with the use of integrase mutant(s), the attachment sites (*att*) in U3 and U5 can also be mutated. Integrase binds to these sites and the 3'-terminal dinucleotide is cleaved at both ends of the vector genome. A CA dinucleotide is located at the recessed 3' end; the CA is required for processing, mutation of the nucleotides blocks integration into the host chromosome. The A of the CA dinucleotide is the most critical nucleotide for integration, and mutations at both ends of the genome will give the best results (Brown et al J Virol 73:9011 (1999). In one exemplification, the CA at each end is changed to TG. In other

exemplifications, the CA at each end is changed to TG at one end and GT at the other end. In other exemplifications, the CA at each end is deleted; in other exemplifications, the A of the CA is deleted at each end.

[0079] Integration can also be inhibited by mutation or deletion of polypurine tract (PPT) (WO 2009/076524; incorporated in its entirety), located proximally to the 3' LTR. The PPT is a polypurine sequence of about 15 nucelotides that can serve as a primer binding site for plus-strand DNA synthesis. In this case, mutations or deletions of PPT targets the reverse transcription process. Without wishing to be held to a mechanism, by mutating or deleting PPT, production of linear DNA is radically reduced and essentially only 1-LTR DNA circles are produced. Integration requires a linear double-stranded DNA vector genome, and integration is essentially eliminated without it. As stated above, a PPT can be made non-functional by mutation or by deletion. Typically, the entire about 15 nt PPT is deleted, although in some embodiments, shorter deletions of 14 nt, 13, nt, 12 nt, 11 nt, 10 nt, 9 nt, 8 nt, 7 nt, 6 nt, 5 nt, 4 nt, 3 nt and 2 nt may be made. When mutations are made, typically multiple mutations are made, especially in the 5' half of the PPT (McWilliams et al., J Virol 77:11150, 2003), although single and double mutations in the first four bases still reduce transcription. Mutations made at the 3' end of PPT generally have a more dramatic effect (Powell and Levin J Virol 70:5288, 1996).

[0080] These different approaches to make a vector genome non-integrating can be used individually or in combination. Using more than one approach may be used to build a fail-safe vector through redundant mechanisms. Thus, PPT mutations or deletions can be combined with *att* site mutations or deletions or with Integrase mutations or PPT mutations or deletions can be combined with both *att* site mutations or deletions and Integrase mutations. Similarly, *att* site mutations or deletions and Integrase mutations may be combined with each other or with PPT mutations or deletions.

2. Regulatory elements

[0081] As discussed herein, the viral vector genome comprises a sequence of interest that is desirable to express in target cells. Typically, the sequence of interest is located between the 5' LTR and 3' LTR sequences. Further, the sequence of interest is preferably in a functional relationship with other genetic elements, for example transcription regulatory sequences including promoters or enhancers, to regulate expression of the sequence of interest in a particular manner. In certain instances, the useful transcriptional regulatory sequences are those that are highly regulated with respect to activity, both temporally and spatially. Expression control elements that may be used for regulating the expression of the components are known in the art and include, but are not limited to, inducible promoters, constitutive promoters, secretion signals, enhancers and other regulatory elements.

[0082] The sequence of interest and any other expressible sequence is typically in a functional relationship with internal promoter/enhancer regulatory sequences. An "internal" promoter/enhancer is one that is located between the 5' LTR and the 3' LTR sequences in the viral vector construct and is operably linked to the sequence of interest. The internal promoter/enhancer may be any promoter, enhancer or promoter/enhancer combination known to increase expression of a gene with which it is in a functional relationship. A "functional relationship" and "operably linked" mean, without limitation, that the sequence is in the correct location and orientation with respect to the promoter and/or enhancer that the sequence of interest will be expressed when the promoter and/or enhancer is contacted with the appropriate molecules.

[0083] The choice of an internal promoter/enhancer is based on the desired expression pattern of the sequence of interest and the specific properties of known promoters/enhancers. Thus, the internal promoter may be constitutively active. Non-limiting examples of constitutive promoters that may be used include the promoter for ubiquitin (US 5510474; WO 98/32869, each of which is incorporated herein by reference in its entirety), CMV (Thomsen et al., PNAS 81:659, 1984; US 5168062, each of which is incorporated herein by

reference in its entirety), beta-actin (Gunning et al. 1989 Proc. Natl. Acad. Sci. USA 84:4831-4835, which is incorporated herein by reference in its entirety) and pgk (see, for example, Adra et al. 1987 Gene 60:65-74; Singer-Sam et al. 1984 Gene 32:409-417; and Dobson et al. 1982 Nucleic Acids Res. 10:2635-2637, each of the foregoing which is incorporated herein by reference in its entirety).

[0084] Alternatively, the promoter may be a tissue specific promoter. In some preferred embodiments, the promoter is a target cell-specific promoter. For example, the promoter can be from any product expressed by dendritic cells, including CD11c, CD103, TLRs, DC-SIGN, BDCA-3, DEC-205, DCIR2, mannose receptor, Dectin-1, Clec9A, MHC classII. In addition, promoters may be selected to allow for inducible expression of the sequence of interest. A number of systems for inducible expression are known in the art, including the tetracycline responsive system, the lac operator-repressor system, as well as promoters responsive to a variety of environmental or physiological changes, including heat shock, metal ions, such as metallothionein promoter, interferons, hypoxia, steroids, such as progesterone or glucocorticoid receptor promoter, radiation, such as VEGF promoter. A combination of promoters may also be used to obtain the desired expression of the gene of interest. The artisan of ordinary skill will be able to select a promoter based on the desired expression pattern of the gene in the organism or the target cell of interest.

[0085] The viral genome may comprise at least one RNA Polymerase II or III responsive promoter. This promoter can be operably linked to the sequence of interest and can also be linked to a termination sequence. In addition, more than one RNA Polymerase II or III promoters may be incorporated. RNA polymerase II and III promoters are well known to one of skill in the art. A suitable range of RNA polymerase III promoters can be found, for example, in Paule and White, Nucleic Acids Research., Vol. 28, pp 1283-1298 (2000), which is incorporated herein by reference in its entirety. RNA polymerase II or III promoters also include any synthetic or engineered DNA

fragment that can direct RNA polymerase II or III to transcribe downstream RNA coding sequences. Further, the RNA polymerase II or III (Pol II or III) promoter or promoters used as part of the viral vector genome can be inducible. Any suitable inducible Pol II or III promoter can be used with the methods of the invention. Particularly suited Pol II or III promoters include the tetracycline responsive promoters provided in Ohkawa and Taira, Human Gene Therapy, Vol. 11, pp 577-585 (2000) and in Meissner et al. Nucleic Acids Research, Vol. 29, pp 1672-1682 (2001), each of which is incorporated herein by reference in its entirety.

[0086] An internal enhancer may also be present in the viral construct to increase expression of the gene of interest. For example, the CMV enhancer (Boshart et al. Cell, 41:521, 1985; which is incorporated herein by reference in its entirety) may be used. Many enhancers in viral genomes, such as HIV, CMV, and in mammalian genomes have been identified and characterized (see GenBank). An enhancer can be used in combination with a heterologous promoter. One of ordinary skill in the art will be able to select the appropriate enhancer based on the desired expression pattern.

[0087] A viral vector genome will usually contain a promoter that is recognized by the target cell and that is operably linked to the sequence of interest, viral components, and other sequences discussed herein. A promoter is an expression control element formed by a nucleic acid sequence that permits binding of RNA polymerase and transcription to occur. Promoters may be inducible, constitutive, temporally active or tissue specific. The activity of inducible promoters is induced by the presence or absence of biotic or abiotic factors. Inducible promoters can be a useful tool in genetic engineering because the expression of genes to which they are operably linked can be turned on or off at certain stages of development of an organism, its manufacture, or in a particular tissue. Inducible promoters can be grouped as chemically-regulated promoters, and physically-regulated promoters. Typical chemically-regulated promoters include, not are not limited to, alcohol-regulated promoters (e.g., alcohol dehydrogenase I (alcA) gene promoter), tetracycline-

regulated promoters (e.g., tetracycline-responsive promoter), steroid-regulated promoter (e.g., rat glucocorticoid receptor (GR)-based promoter, human estrogen receptor (ER)-based promoter, moth ecdysone receptor-based promoter, and the promoters based on the steroid/retinoid/thyroid receptor superfamily), metal-regulated promoters (e.g., metallothionein gene-based promoters), and pathogenesis-related promoters (e.g., *Arabidopsis* and maize pathogen-related (PR) protein-based promoters). Typical physically-regulated promoters include, but are not limited to, temperature-regulated promoters (e.g., heat shock promoters), and light-regulated promoters (e.g., soybean SSU promoter). Other exemplary promoters are described elsewhere, for example, in "Promoters used to regulate gene expression" on Patent Lens web site, accessed 18 May 2009 (incorporated herein by reference in its entirety).

[0088] One of skill in the art will be able to select an appropriate promoter based on the specific circumstances. Many different promoters are well known in the art, as are methods for operably linking the promoter to the gene to be expressed. Both native promoter sequences and many heterologous promoters may be used to direct expression in the packaging cell and target cell. Heterologous promoters are preferred, however, as they generally permit greater transcription and higher yields of the desired protein as compared to the native promoter.

[0089] The promoter may be obtained, for example, from the genomes of viruses such as polyoma virus, fowlpox virus, adenovirus, bovine papilloma virus, avian sarcoma virus, cytomegalovirus, a retrovirus, hepatitis-B virus and Simian Virus 40 (SV40). The promoter may also be, for example, a heterologous mammalian promoter, e.g., the actin promoter or an immunoglobulin promoter, a heat-shock promoter, or the promoter normally associated with the native sequence, provided such promoters are compatible with the target cell. In one embodiment, the promoter is the naturally occurring viral promoter in a viral expression system. In some embodiments, the promoter is a dendritic cell-specific promoter. The dendritic cell-specific promoter can be, for example, CD11c promoter.

[0090] Transcription may be increased by inserting an enhancer sequence into the vector(s). Enhancers are typically cis-acting elements of DNA, usually about 10 to 300 bp in length, that act on a promoter to increase its transcription. Many enhancer sequences are now known from mammalian genes (globin, elastase, albumin, alpha-fetoprotein, and insulin) and from eukaryotic cell viruses. Examples include the SV40 enhancer on the late side of the replication origin (bp 100-270), the cytomegalovirus early promoter enhancer, the polyoma enhancer on the late side of the replication origin, and adenovirus enhancers. The enhancer may be spliced into the vector at a position 5' or 3' to the antigen-specific polynucleotide sequence, but is preferably located at a site 5' from the promoter.

[0091] Expression vectors may also contain sequences necessary for the termination of transcription and for stabilizing the mRNA. These sequences are often found in the 5' and, occasionally 3', untranslated regions of eukaryotic or viral DNAs or cDNAs and are well known in the art.

[0092] The viral vector genome may also contain additional genetic elements. The types of elements that may be included in the construct are not limited in any way and may be chosen to achieve a particular result. For example, a signal that facilitates nuclear entry of the viral genome in the target cell may be included. An example of such a signal is the HIV-1 flap signal. Further, elements may be included that facilitate the characterization of the provirus integration site in the target cell. For example, a tRNA amber suppressor sequence may be included in the construct. An insulator sequence from e.g., chicken β-globin may also be included in the viral genome construct. This element reduces the chance of silencing an integrated provirus in the target cell due to methylation and heterochromatinization effects. In addition, the insulator may shield the internal enhancer, promoter and exogenous gene from positive or negative positional effects from surrounding DNA at the integration site on the chromosome. In addition, the vector genome may contain one or more genetic elements designed to enhance expression of the gene of interest. For example, a woodchuck hepatitis virus responsive element

(WRE) may be placed into the construct (Zufferey et al. 1999. J. Virol. 74:3668-3681; Deglon et al. 2000. Hum. Gene Ther. 11:179-190, each of which is incorporated herein by reference in its entirety).

[0093] The viral vector genome is typically constructed in a plasmid form that may be transfected into a packaging or producer cell line. The plasmid generally comprises sequences useful for replication of the plasmid in bacteria. Such plasmids are well known in the art. In addition, vectors that include a prokaryotic origin of replication may also include a gene whose expression confers a detectable or selectable marker such as a drug resistance. Typical bacterial drug resistance products are those that confer resistance to ampicillin or tetracycline.

[0094] Plasmids containing one or more of the components described herein are readily constructed using standard techniques well known in the art. For analysis to confirm correct sequences in plasmids constructed, the plasmid may be replicated in *E. coli,* purified, and analyzed by restriction endonuclease digestion or its DNA sequence determined by conventional methods.

[0095] Vectors constructed for transient expression in mammalian cells may also be used. Transient expression involves the use of an expression vector that is able to replicate efficiently in a host cell, such that the host cell accumulates many copies of the expression vector and, in turn, synthesizes high levels of a the polypeptide encoded by the antigen-specific polynucleotide in the expression vector. See Sambrook et al., supra, pp. 16.17-16.22. Other vectors and methods suitable for adaptation to the expression of polypeptides are well known in the art and are readily adapted to the specific circumstances.

[0096] Using the teachings provided herein, one of skill in the art will recognize that the efficacy of a particular expression system can be tested by transfecting packaging cells with a vector comprising a gene encoding a reporter protein and measuring the expression using a suitable technique, for

example, measuring fluorescence from a green fluorescent protein conjugate. Suitable reporter genes are well known in the art.

3. Types of sequences of interest

[0097] The sequence of interest is not limited in any way and includes any nucleic acid that one of ordinary skill desires to have integrated, transcribed, and expressed in the target cell. The product can be a protein or a nucleic acid. The sequence of interest can encode a protein or a nucleic acid molecule, including siRNA, microRNA, a self-complementary double stranded RNA in which the complementary region is greater than about 20 ribonucleotides in length, or an RNA that is complementary to a message RNA, where binding of said complementary (anti-sense) RNA to the message RNA blocks its ability to be translated into protein. In some instances, the sequence of interest can encode an antigen against which an immune response is desired. In particular, tumor antigens and infectious diseases antigens from agents such as HIV, HSV, HCV, HPV, malaria, or tuberculosis are desirable.

[0098] In certain cases, the sequence of interest can be a gene encoding a small inhibiting RNA (siRNA) or a microRNA (miRNA) of interest that down-regulates expression of a molecule. For example, the gene encoding an siRNA or a microRNA can be used to down-regulate expression of negative regulators in a cell, including those that inhibit activation or maturation of dendritic cells. siRNAs and microRNAs are well known in the art (Fire et al., Nature 391:806, 1998; see also "The RNA Interference Resource" of Applied Biosystems, Trang et al., Oncogene Suppl 2:S52, 2008; Taganov, K., et al. 2007. Immunity 26:133-137; Dahlberg, J. E. and E. Lund. 2007. Sci. STKE 387:pe25; Tiemann and Rossi, EMBO Mol Med 1: 142, 2009). Alternatively, the sequence of interest can encode a self-complementary double stranded RNA in which the complementary region is greater than about 20 ribonucleotides in length, or an anti-sense RNA that is greater than about 20 ribonucleotides in length. Those of ordinary skill in the art will appreciate that siRNA, miRNA, dsRNA and anti-sense RNA molecules can be expressed from

an RNA polymerase III promoter, or, alternatively, can be a component of a non-coding RNA that is transcribed from an RNA polymerase II promoter.

[0099] In addition, the sequence of interest may encode more than one product. In some configurations, the sequence to be delivered can comprise multiple genes encoding at least one protein, at least one siRNA, at least one microRNA, at least one dsRNA or at least one anti-sense RNA molecule or any combinations thereof. For example, the sequence to be delivered can include one or more genes that encode one or more antigens against which an immune response is desired. The one or more antigens can be associated with a single disease or disorder, or they can be associated with multiple diseases and/or disorders. In some instances, a gene encoding an immune regulatory protein can be included along with a gene encoding an antigen against which an immune response is desired, and the combination can elicit and regulate the immune response to the desired direction and magnitude. In other instances, a sequence encoding an siRNA, microRNA, dsRNA or anti-sense RNA molecule can be constructed with a gene encoding an antigen against which an immune response is desired, and the combination can regulate the scope of the immune response. The products may be produced as an initial fusion product in which the encoding sequence is in functional relationship with one promoter. Alternatively, the products may be separately encoded and each encoding sequence in functional relationship with a promoter. The promoters may be the same or different.

[00100] In certain configurations, vectors contain polynucleotide sequences that encode dendritic cell maturation / stimulatory factors. Exemplary stimulatory molecules include GM-CSF, IL-2, IL-4, IL-6, IL-7, IL-15, IL-21, IL-23, TNFα, B7.1, B7.2, 4-1BB, CD40 ligand (CD40L), drug-inducible CD40 (iCD40), and the like. These polynucleotides are typically under the control of one or more regulatory elements that direct the expression of the coding sequences in dendritic cells. Maturation of dendritic cells contributes to successful vaccination (Banchereau, J and Palucka, A. K. Nat. Rev. Immunol. 5:296-306 (2005); Schuler, G. et al. Curr. Opin. Immunol. 15:138-147 (2003);

Figdor, C. G. et al. Nat. Med. 10:475-480 (2004)). Maturation can transform DCs from cells actively involved in antigen capture into cells specialized for T cell priming. For example, engagement of CD40 by CD40L on CD4-helper T cells is a critical signal for DC maturation, resulting in potent activation of CD8 T cells. Such stimulatory molecules are also referred to as maturation factors or maturation stimulatory factors. Immune checkpoints represent significant barriers to activation of functional cellular immunity in cancer, and antagonistic antibodies specific for inhibitory ligands on T cells including CTLA4 and programmed death-1 (PD-1) are examples of targeted agents being evaluated in the clinics. A significant tolerance mechanism in chronic infections and cancer is the functional exhaustion of Ag-specific T cells that express high levels of PD-1. As the potency of therapeutic immunization has been shown to be significantly enhanced by combination with immune checkpoint control, as a non-limiting example, it can be appreciated by those of ordinary skill in the art that an alternative approach to inhibiting immune checkpoint is to inhibit the expression of programmed death (PD) ligands one and two (PD-L1/L2). One way to accomplish inhibition is by the expression of RNA molecules such as those described herein, which repress the expression of PD-L1/L2 in the DCs transduced with the lentivirus vector encoding one or more of the RNA molecules. Maturation of DCs or expression of particular elements such as immune checkpoints, for example PD-1 ligands, can be characterized by flow cytometry analysis of up-regulation of surface marker such as MHC II, and profile of expressed chemokines and cytokines.

[00101] A sequence encoding a detectable product, usually a protein, can be included to allow for identification of cells that are expressing the desired product. For example, a fluorescent marker protein, such as green fluorescent protein (GFP), is incorporated into the construct along with a sequence of interest (e.g., encoding an antigen). In other cases, the protein may be detectable by an antibody or the protein may be an enzyme that acts on a substrate to yield a detectable product, or a product that allows selection of a transfected or transduced target cell, for example confers drug resistance, such

as hygromycin resistance. Typical selection genes encode proteins that confer resistance to antibiotics or other toxins suitable for use in eukaryotic cells, e.g., neomycin, methotrexate, blasticidine, among others known in the art, or complement auxotrophic deficiencies, or supply critical nutrients withheld from the media. The selectable marker can optionally be present on a separate plasmid and introduced by co-transfection.

[00102] One or more multicistronic expression units may be utilized that include two or more of the elements (e.g., sequence(s) of interest, the envelope molecule, DC maturation factors) necessary for production of the desired virus in packaging cells. The use of multicistronic vectors reduces the total number of nucleic acid molecules required and thus avoids the possible difficulties associated with coordinating expression from multiple vector genomes. In a multicistronic vector the various elements to be expressed are operably linked to one or more promoters (and other expression control elements as necessary). In some configurations, a multicistronic vector comprises a sequence of interest, a sequence encoding a reporter product, and viral elements. The sequence of interest typically encodes an antigen and, optionally, a DC maturation factor. At times, the multicistronic vector comprises a gene encoding an antigen, a gene encoding a DC maturation factor and viral elements.

[00103] Each component to be expressed in a multicistronic expression vector may be separated, for example, by an internal ribosome entry site (IRES) element or a viral 2A element, to allow for separate expression of the various proteins from the same promoter. IRES elements and 2A elements are known in the art (U.S. Pat. No. 4,937,190; de Felipe et al. 2004. Traffic 5: 616-626, each of which is incorporated herein by reference in its entirety). In one embodiment, oligonucleotides encoding furin cleavage site sequences (RAKR) (Fang et al. 2005. Nat. Biotech 23: 584-590, which is incorporated herein by reference in its entirety) linked with 2A-like sequences from foot-and-mouth diseases virus (FMDV), equine rhinitis A virus (ERAV), and thosea asigna virus (TaV) (Szymczak et al. 2004. Nat. Biotechnol. 22: 589-

594, which is incorporated herein by reference in its entirety) are used to separate genetic elements in a multicistronic vector. The efficacy of a particular multicistronic vector can readily be tested by detecting expression of each of the genes using standard protocols.

[00104] In a specific exemplification, the viral vector genome comprises: a cytomegalovirus (CMV) enhancer/promoter sequence; the R and U5 sequences from the HIV 5' LTR; a packaging sequence (ψ); the HIV-1 flap signal; an internal enhancer; an internal promoter; a gene of interest; the woodchuck hepatitis virus responsive element; a tRNA amber suppressor sequence; a U3 element with a deletion of its enhancer sequence; the chicken β-globin insulator; and the R and U5 sequences of the 3' HIV LTR. In some exemplifications, the vector genome comprises an intact lentiviral 5' LTR and a self-inactivating 3' LTR. (Iwakuma et al. Virology 15:120, 1999, incorporated by reference in its entirety)

[0100] Construction of the vector genome can be accomplished using any suitable genetic engineering techniques known in the art, including, without limitation, the standard techniques of restriction endonuclease digestion, ligation, transformation, plasmid purification, and DNA sequencing, for example as described in Sambrook et al. (1989. Molecular Cloning: A Laboratory Manual. Cold Spring Harbor Laboratory Press, N.Y.), Coffin et al. (Retroviruses. Cold Spring Harbor Laboratory Press, N.Y. (1997)) and "RNA Viruses: A Practical Approach" (Alan J. Cann, Ed., Oxford University Press, (2000), each of the foregoing which is incorporated herein by reference in its entirety.

4. Production of viral particles

[0101] Any of a variety of methods already known in the art may be used to produce infectious lentiviral particles whose genome comprises an RNA copy of the viral vector genome. In one method, the viral vector genome is introduced into a packaging cell line that contains all the components necessary to package viral genomic RNA, transcribed from the viral vector genome, into viral particles. Alternatively, the viral vector genome may

comprise one or more genes encoding viral components in addition to the one or more sequences of interest. In order to prevent replication of the genome in the target cell, however, endogenous viral genes required for replication will usually be removed and provided separately in the packaging cell line.

[0102] In general, the lentiviral vector particles are produced by a cell line that is transfected with one or more plasmid vectors containing the components necessary to generate the particles. These lentiviral vector particles are typically not replication-competent, *i.e.,* they are only capable of a single round of infection. Most often, multiple plasmid vectors are utilized to separate the various genetic components that generate the lentiviral vector particles, mainly to reduce the chance of recombination events that might otherwise generate replication competent viruses. A single plasmid vector having all of the lentiviral components can be used if desired, however. As one example of a system that employs multiple plasmid vectors, a cell line is transfected with at least one plasmid containing the viral vector genome (*i.e.,* the vector genome plasmid), including the LTRs, the cis-acting packaging sequence, and the sequence(s) of interest, which are often operably linked to a heterologous promoter, at least one plasmid encoding the virus enzymatic and structural components (*i.e.,* the packaging plasmid that encodes components such as, Gag and Pol), and at least one envelope plasmid encoding an Arbovirus envelope glycoprotein. Additional plasmids can be used to enhance retrovirus particle production, e.g., Rev-expression plasmids, as described herein and known in the art. Viral particles bud through the cell membrane and comprise a core that includes a genome containing the sequence of interest and an Arbovirus envelope glycoprotein that targets dendritic cells. When the Arbovirus glycoprotein is Sindbis virus E2 glycoprotein, the glycoprotein is engineered to have reduced binding to heparan sulfate compared to the reference strain HR.

[0103] Transfection of packaging cells with plasmid vectors of the present invention can be accomplished by well-known methods, and the method to be used is not limited in any way. A number of non-viral delivery

systems are known in the art, including for example, electroporation, lipid-based delivery systems including liposomes, delivery of "naked" DNA, and delivery using polycyclodextrin compounds, such as those described in Schatzlein AG. (2001. Non-Viral Vectors in Cancer Gene Therapy: Principles and Progresses. Anticancer Drugs, which is incorporated herein by reference in its entirety). Cationic lipid or salt treatment methods are typically employed, see, for example, Graham et al. (1973. Virol. 52:456; Wigler et al. (1979. Proc. Natl. Acad. Sci. USA 76:1373-76), each of the foregoing which is incorporated herein by reference in its entirety. The calcium phosphate precipitation method is most often used. However, other methods for introducing the vector into cells may also be used, including nuclear microinjection and bacterial protoplast fusion.

[0104] The packaging cell line provides the components, including viral regulatory and structural proteins, that are required in *trans* for the packaging of the viral genomic RNA into lentiviral vector particles. The packaging cell line may be any cell line that is capable of expressing lentiviral proteins and producing functional lentiviral vector particles. Some suitable packaging cell lines include 293 (ATCC CCL X), 293T, HeLa (ATCC CCL 2), D17 (ATCC CCL 183), MDCK (ATCC CCL 34), BHK (ATCC CCL-10) and Cf2Th (ATCC CRL 1430) cells. The packaging cell line may stably express the necessary viral proteins. Such a packaging cell line is described, for example, in U.S. Pat. No. 6,218,181, which is incorporated herein by reference in its entirety. Alternatively a packaging cell line may be transiently transfected with nucleic acid molecules encoding one or more necessary viral proteins along with the viral vector genome. The resulting viral particles are collected and used to infect a target cell. The gene(s) encoding envelope glycoprotein(s) is usually cloned into an expression vector, such as pcDNA3 (Invitrogen, CA USA). Eukaryotic cell expression vectors are well known in the art and are available from a number of commercial sources. Packaging cells, such as 293T cells are then co-transfected with the viral vector genome encoding a sequence of interest (typically encoding an antigen), at least one plasmid

encoding virus packing components, and a vector for expression of the targeting molecule. The envelope is expressed on the membrane of the packaging cell and incorporated into the viral vector.

[0105] In one scenario, one or more vectors are used to introduce polynucleotide sequences into a packaging cell line for the preparation of a lentiviral vector particle pseudotyped with a Sindbis virus envelope glycoprotein such as E2, as described herein. The vectors can contain polynucleotide sequences encoding the various components of the virus including the Sindbis virus envelope, a sequence(s) of interest (typically encoding an antigen), and any components necessary for the production of the virus that are not provided by the packaging cell.

[0106] In yet other scenarios, packaging cells are co-transfected with a viral vector genome encoding an antigen and one or more additional vectors. For example, in addition to the viral vector encoding an antigen, a second vector preferably carries the genes encoding a modified (also called a variant) Sindbis virus envelope. In some situations, the viral vector genome encoding an antigen also includes a polynucleotide sequence encoding a selected immune modulating factor, including non-limiting examples of a chemokine, a cytokine, a DC maturation factor, or a factor that regulates immune checkpoint mechanisms. In other situations, the polynucleotide sequence encoding a selected immune modulating factor is contained in a third vector that is co-transfected with the viral vector encoding an antigen and the one or more additional vectors into the packaging cells.

[0107] Production of virus is measured as described herein and expressed as IU per volume. IU is infectious unit, or alternatively transduction units (TU); IU and TU can be used interchangeably as a quantitative measure of the titer of a viral vector particle preparation. As described herein, virus is produced in which the genome can express a product that is readily measurable. A fluorescent protein, green fluorescent protein, is preferred. The lentiviral vector is typically non-integrating. The virus is then administered to target cells and the number of target cells that express GFP is determined,

such as by flow cytometry (see Example 3). The titer is then calculated. The titer is preferably as high as possible, but at least 1 x 10^5 IU / mL, at least 3 x 10^5 IU / mL, at least 1 x 10^6 IU / mL, at least 3 x 10^6 IU / mL, or at least 1 x 10^7 IU / mL of cell supernatant (before any concentration). Alternatively, the titer is at least 80%, at least 90%, at least 95%, at least 100% of the titer of the same lentiviral vector pseudotyped in the same cells with VSV-G envelope.

C. Delivery of the Virus

[0108] The virus may be delivered to a target cell in any way that allows the virus to contact the target dendritic cells (DCs) in which delivery of a polynucleotide of interest is desired. At times, a suitable amount of virus will be introduced into a human or other animal directly (in vivo), e.g., though injection into the body. Suitable animals include, without limitation, horses, dogs, cats, cattle, pigs, sheep, rabbits, chickens or other birds. Viral particles may be injected by a number of routes, such as intravenous, intra-dermal, subcutaneous, intranodal, intra-peritoneal cavity, or mucosal. The virus may be delivered using a subdermal injection device such the devices disclosed in U.S. Pat. Nos. 7,241,275, 7,115,108, 7,108,679, 7,083,599, 7,083,592, 7,047,070, 6,971,999, 6,808,506, 6,780,171, 6,776,776, 6,689,118, 6,670,349, 6,569,143, 6,494,865, 5,997,501, 5,848,991, 5,328,483, 5,279,552, 4,886,499, all of which are incorporated by reference in their entirety. Other injection locations also are suitable, such as directly into organs comprising target cells. For example intra-lymph node injection, intra-spleen injection, or intra-bone marrow injection may be used to deliver virus to the lymph node, the spleen and the bone marrow, respectively. Depending on the particular circumstances and nature of the target cells, introduction can be carried out through other means including for example, inhalation, or direct contact with epithelial tissues, for example those in the eye, mouth or skin.

[0109] Alternatively, target cells are provided and contacted with the virus in vitro, such as in culture plates. The target cells are typically populations of cells comprising dendritic cells obtained from a healthy subject or

a subject in need of treatment or in whom it is desired to stimulate an immune response to an antigen. Methods to obtain cells from a subject are well known in the art and includes phlebotomy, surgical excision, and biopsy. Human DCs may also be generated by obtaining CD34α+ human hematopoietic progenitors and using an in vitro culture method as described elsewhere (e.g., Banchereau et al. Cell 106, 271-274 (2001) incorporated by reference in its entirety).

[0110] The virus may be suspended in media and added to the wells of a culture plate, tube or other container. Media containing the virus may be added prior to the plating of the cells or after the cells have been plated. Cells are typically incubated in an appropriate amount of media to provide viability and to allow for suitable concentrations of virus in the media such that transduction of the host cell occurs. The cells are preferably incubated with the virus for a sufficient amount of time to allow the virus to infect the cells. Preferably the cells are incubated with virus for at least 1 hour, at least 5 hours or at least 10 hours.

[0111] In both in vivo and in vitro delivery, an aliquot of viral particles containing sufficient number to infect the desired target cells may be used. When the target cell is to be cultured, the concentration of the viral particles is generally at least 1 IU/μL, more preferably at least 10 IU/μl, even more preferably at least 300 IU/μL, even more preferably at least $1X10^4$ IU/μL, even more preferably at least $1X10^5$ IU/μL, even more preferably at least $1X10^6$IU/μL, or even more preferably at least $1X10^7$ IU/μL

[0112] Following infection with the virus in vitro, target cells can be introduced (or re-introduced) into a human or other animal. The cells can be introduced into the dermis, under the dermis, or into the peripheral blood stream. The cells introduced into an animal are preferably cells derived from that animal, to avoid an adverse immune response. Cells derived from a donor having a similar immune background may also be used. Other cells that also can be used include those designed to avoid an adverse immunologic response.

[0113] Target cells may be analyzed for integration, transcription and/or expression of the sequence or gene(s) of interest, the number of copies of the gene integrated, and the location of the integration, for examples. Such analysis may be carried out at any time and may be carried out by any method known in the art.

[0114] Subjects in which a virus or virus-infected dendritic cells are administered can be analyzed for location of infected cells, expression of the virus-delivered polynucleotide or gene of interest, stimulation of an immune response, and monitored for symptoms associated with a disease or disorder by any methods known in the art.

[0115] The methods of infecting cells disclosed above do not depend upon individual-specific characteristics of the cells. As a result, they are readily extended to a variety of animal species. In some instances, viral particles are delivered to a human or to human dendritic cells, and in other instances they are delivered to an animal such as a mouse, horse, dog, cat, or mouse or to birds. As discussed herein, the viral vector genome is pseudotyped to confer upon it a broad host range as well as target cell specificity. One of skill in the art would also be aware of appropriate internal promoters and other elements to achieve the desired expression of a sequence of interest in a particular animal species. Thus, one of skill in the art will be able to modify the method of infecting dendritic cells from any species.

D. Therapeutic and prophylactic immunizations

[0116] Dendritic cells may be infected with a lentivirus vector particle as described herein for the prevention of or treatment of a disease or disorder, particularly those for which activation of an immune response in a patient would be beneficial. Many such diseases are well known. For example, diseases or disorders that are amenable to treatment or prevention by the methods of the present invention include, without limitation, cancers, autoimmune diseases, and infections, including viral, bacterial, fungal and parasitic infections. In one method, a disease is treated by viral particles

described herein in order to deliver a sequence of interest to dendritic cells, wherein expression of the sequence of interest produces a disease-specific antigen and leads to stimulation of antigen-specific cellular immune responses and humoral immune responses. Generally, the sequence of interest encodes an antigen against which an immune response is desired, but is not normally expressed in a dendritic cell. The antigen is expressed and presented by the dendritic cell. The viral vector genome may further encode a DC maturation factor.

[0117] In a typical usage, viral particles deliver to dendritic cells sequences encoding an antigen against which an immune response is desired. The delivery can be achieved by contacting dendritic cells with the virus in vitro, whereupon the infected dendritic cells are provided to a patient. Other times, delivery can be achieved by delivering the virus to a subject for infecting dendritic cells in vivo. The dendritic cells then stimulate antigen-specific T cells or B cells in a patient to induce cellular and humoral immune responses to the expressed antigen. In such ways, a patient that is suffering from a disease or disorder is treated by generating immune cells with a desired specificity.

[0118] Any antigen that is associated with a disease or disorder can be delivered to dendritic cells using the viral particles as described herein. An antigen that is associated with the disease or disorder is identified for preparation of a viral particle that targets dendritic cells. Antigens associated with many diseases and disorders are well known in the art. An antigen may be previously known to be associated with the disease or disorder, or may be identified by any method known in the art. For example, an antigen to a type of cancer from which a patient is suffering may be known, such as a tumor-associated antigen or may be identified from the tumor itself by any of a variety of methods known in the art.

[0119] Tumor-associated antigens are known for a variety of cancers including, for example, renal cell carcinoma, prostate cancer, melanoma, and breast cancer. In some breast cancers, for example, the Her-2 receptor is overexpressed on the surface of cancerous cells. Exemplary tumor

antigens include, but are not limited to, MAGE, BAGE, RAGE, and NY-ESO-1, which are unmutated antigens expressed in the immune-privileged areas of the testes and in a variety of tumor cells; lineage-specific tumor antigens such as the melanocyte-melanoma lineage antigens MART-1/Melan-A, gp100, gp75, mda-7, tyrosinase and tyrosinase-related protein, renal cell carcinoma – 5T4, SM22-alpha, carbonic anhydrases I and IX (also known as G250), hypoxia-inducible factors (e.g., HIF-1alpha and HIF-2alpha), VEGF or prostate specific membrane antigen (PSMA), prostate-specific antigen (PSA), prostatic acid phosphates, and six-transmembrane epoithelial antigen of the prostate (STEAP), NKX3.1, which are antigens expressed in normal and neoplastic cells derived from the same tissue; epitope proteins/peptides derived from genes mutated in tumor cells or genes transcribed at different levels in tumor compared to normal cells, such as telomerase enzyme, survivin, mesothelin, mutated ras, bcr/abl rearrangement, Her2/neu, mutated or wild-type p53, cytochrome P450 1B1, and abnormally expressed intron sequences such as N-acetylglucosaminyltransferase-V; clonal rearrangements of immunoglobulin genes generating unique idiotypes in myeloma and B-cell lymphomas; epitope proteins/peptides derived from oncoviral processes, such as human papilloma virus proteins E6 and E7; nonmutated oncofetal proteins with a tumor-selective expression, such as carcinoembryonic antigen and alpha-fetoprotein. A number of tumor associated antigens have been reviewed (see, for example, "Tumor-Antigens Recognized By T-Lymphocytes," Boon T, Cerottini J C, Vandeneynde B, Vanderbruggen P, Vanpel A, Annual Review Of Immunology 12: 337-365, 1994; "A listing of human tumor antigens recognized by T cells," Renkvist N, Castelli C, Robbins P F, Parmiani G. Cancer Immunology Immunotherapy 50: (1) 3-15 MAR 2001, each of which is incorporated herein by reference in its entirety.)

[0120] The antigen can also be an antigen associated with an infectious disease, such as, for example, HIV/AIDS. The antigen can be, for example, gp120 (Klimstra, W. B., et al. 2003. J Virol 77:12022-12032; Bernard, K. A., et al. 2000. Virology 276:93-103; Byrnes, A. P., et al. 1998. J Virol 72:

7349-7356, each of which is incorporated herein by reference in its entirety). Other exemplary antigens include, but are not limited to: gag, pol, env, tat, nef and rev (Lieberman, J. et al. 1997. AIDS Res Hum Retroviruses 13(5): 383-392; Menendez-Arias, L. et al. 1998. Viral Immunol 11(4): 167-181, each of which is incorporated herein by reference in its entirety).

[0121] Examples of viral antigens include, but are not limited to, adenovirus polypeptides, alphavirus polypeptides, calicivirus polypeptides, e.g., a calicivirus capsid antigen, coronavirus polypeptides, distemper virus polypeptides, Ebola virus polypeptides, enterovirus polypeptides, flavivirus polypeptides, hepatitis virus (AE) polypeptides, e.g., a hepatitis B core or surface antigen, or a hepatitis C virus E1 or E2 glycoproteins, core, or non-structural proteins, herpesvirus polypeptides, e.g., a herpes simplex virus or varicella zoster virus glycoprotein, immunodeficiency virus polypeptides, e.g., the human immunodeficiency virus envelope or protease, infectious peritonitis virus polypeptides, influenza virus polypeptides, e.g., an influenza A hemagglutinin, neuraminidase, or nucleoprotein, leukemia virus polypeptides, Marburg virus polypeptides, orthomyxovirus polypeptides, papilloma virus polypeptides, parainfluenza virus polypeptides, e.g., the hemagglutinin/neuraminidase, paramyxovirus polypeptides, parvovirus polypeptides, pestivirus polypeptides, picorna virus polypeptides, e.g., a poliovirus capsid polypeptide, pox virus polypeptides, e.g., a vaccinia virus polypeptide, rabies virus polypeptides, e.g., a rabies virus glycoprotein G, reovirus polypeptides, retrovirus polypeptides, and rotavirus polypeptides.

[0122] Examples of bacterial antigens include, but are not limited to, Actinomyces polypeptides, Bacillus polypeptides, Bacteroides polypeptides, Bordetella polypeptides, Bartonella polypeptides, Borrelia polypeptides, e.g., B. burgdorferi OspA, Brucella polypeptides, Campylobacter polypeptides, Capnocytophaga polypeptides, Chlamydia polypeptides, Clostridium polypeptides, Corynebacterium polypeptides, Coxiella polypeptides, Dermatophilus polypeptides, Enterococcus polypeptides, Ehrlichia polypeptides, Escherichia polypeptides, Francisella polypeptides,

Fusobacterium polypeptides, Haemobartonella polypeptides, Haemophilus polypeptides, e.g., H. influenzae type b outer membrane protein, Helicobacter polypeptides, Klebsiella polypeptides, L-form bacteria polypeptides, Leptospira polypeptides, Listeria polypeptides, Mycobacteria polypeptides, Mycoplasma polypeptides, Neisseria polypeptides, Neorickettsia polypeptides, Nocardia polypeptides, Pasteurella polypeptides, Peptococcus polypeptides, Peptostreptococcus polypeptides, Pneumococcus polypeptides, Proteus polypeptides, Pseudomonas polypeptides, Rickettsia polypeptides, Rochalimaea polypeptides, Salmonella polypeptides, Shigella polypeptides, Staphylococcus polypeptides, Streptococcus polypeptides, e.g., S. pyogenes M proteins, Treponema polypeptides, and Yersinia polypeptides, e.g., Y. pestis F1 and V antigens.

[0123] Examples of fungal antigens include, but are not limited to, Absidia polypeptides, Acremonium polypeptides, Alternaria polypeptides, Aspergillus polypeptides, Basidiobolus polypeptides, Bipolaris polypeptides, Blastomyces polypeptides, Candida polypeptides, Coccidioides polypeptides, Conidiobolus polypeptides, Cryptococcus polypeptides, Curvalaria polypeptides, Epidermophyton polypeptides, Exophiala polypeptides, Geotrichum polypeptides, Histoplasma polypeptides, Madurella polypeptides, Malassezia polypeptides, Microsporum polypeptides, Moniliella polypeptides, Mortierella polypeptides, Mucor polypeptides, Paecilomyces polypeptides, Penicillium polypeptides, Phialemonium polypeptides, Phialophora polypeptides, Prototheca polypeptides, Pseudallescheria polypeptides, Pseudomicrodochium polypeptides, Pythium polypeptides, Rhinosporidium polypeptides, Rhizopus polypeptides, Scolecobasidium polypeptides, Sporothrix polypeptides, Stemphylium polypeptides, Trichophyton polypeptides, Trichosporon polypeptides, and Xylohypha polypeptides.

[0124] Examples of protozoan parasite antigens include, but are not limited to, Babesia polypeptides, Balantidium polypeptides, Besnoitia polypeptides, Cryptosporidium polypeptides, Eimeria polypeptides, Encephalitozoon polypeptides, Entamoeba polypeptides, Giardia polypeptides,

Hammondia polypeptides, Hepatozoon polypeptides, Isospora polypeptides, Leishmania polypeptides, Microsporidia polypeptides, Neospora polypeptides, Nosema polypeptides, Pentatrichomonas polypeptides, Plasmodium polypeptides, e.g., P. falciparum circumsporozoite (PfCSP), sporozoite surface protein 2 (PfSSP2), carboxyl terminus of liver state antigen 1 (PfLSA1 c-term), and exported protein 1 (PfExp-1), Pneumocystis polypeptides, Sarcocystis polypeptides, Schistosoma polypeptides, Theileria polypeptides, Toxoplasma polypeptides, and Trypanosoma polypeptides.

[0100] Examples of helminth parasite antigens include, but are not limited to, Acanthocheilonema polypeptides, Aelurostrongylus polypeptides, Ancylostoma polypeptides, Angiostrongylus polypeptides, Ascaris polypeptides, Brugia polypeptides, Bunostomum polypeptides, Capillaria polypeptides, Chabertia polypeptides, Cooperia polypeptides, Crenosoma polypeptides, Dictyocaulus polypeptides, Dioctophyme polypeptides, Dipetalonema polypeptides, Diphyllobothrium polypeptides, Diplydium polypeptides, Dirofilaria polypeptides, Dracunculus polypeptides, Enterobius polypeptides, Filaroides polypeptides, Haemonchus polypeptides, Lagochilascaris polypeptides, Loa polypeptides, Mansonella polypeptides, Muellerius polypeptides, Nanophyetus polypeptides, Necator polypeptides, Nematodirus polypeptides, Oesophagostomum polypeptides, Onchocerca polypeptides, Opisthorchis polypeptides, Ostertagia polypeptides, Parafilaria polypeptides, Paragonimus polypeptides, Parascaris polypeptides, Physaloptera polypeptides, Protostrongylus polypeptides, Setaria polypeptides, Spirocerca polypeptides Spirometra polypeptides, Stephanofilaria polypeptides, Strongyloides polypeptides, Strongylus polypeptides, Thelazia polypeptides, Toxascaris polypeptides, Toxocara polypeptides, Trichinella polypeptides, Trichostrongylus polypeptides, Trichuris polypeptides, Uncinaria polypeptides, and Wuchereria polypeptides.

[0101] Examples of ectoparasite antigens include, but are not limited to, polypeptides (including protective antigens as well as allergens) from fleas; ticks, including hard ticks and soft ticks; flies, such as midges,

mosquitoes, sand flies, black flies, horse flies, horn flies, deer flies, tsetse flies, stable flies, myiasis-causing flies and biting gnats; ants; spiders, lice; mites; and true bugs, such as bed bugs and kissing bugs.

[0102] Once an antigen has been identified and selected, a sequence that encodes the desired antigen is identified. Preferably the sequence comprises a cDNA. Following viral infection, the sequence of interest (e.g., one encoding the antigen) is expressed by the target dendritic cells. If contacted ex vivo, the target dendritic cells are then transferred back to the patient, for example by injection, where they interact with immune cells that are capable of generating an immune response against the desired antigen. In preferred embodiments, the recombinant virus is injected into the patient where it transduces the targeted dendritic cells in situ. The dendritic cells then express the particular antigen associated with a disease or disorder to be treated, and the patient is able to mount an effective immune response against the disease or disorder.

[0103] The viral vector genome may contain a polynucleotide sequence encoding more than one antigen, and upon transduction of a target dendritic cell, generates immune responses to the multitude of antigens delivered to the cell. In some embodiments, the antigens are related to a single disease or disorder. In other embodiments, the antigens are related to multiple diseases or disorders.

[0104] In some of the viruses, DC maturation factors that activate and/or stimulate maturation of the DCs are delivered in conjunction with the sequence of interest. In alternatives, the DCs are activated by delivery of DC maturation factors prior to, simultaneously with, or after delivery of the virus. DC maturation factors may be provided separately from administration of the virus.

[0105] As described herein, one or more immune modulation or DC maturation factors can be encoded by one or more sequences that are contained in the viral genome and expressed after the virus infects a dendritic cell. The sequences encoding immune modulation factors can also be provided

in a separate vector that is co-transfected with the viral vector encoding one or more antigens in a packaging cell line.

[0106] The methods described herein can be used for adoptive immunotherapy in a patient. As described above, an antigen against which an immune response is desired is identified. A polynucleotide encoding the desired antigen is obtained and packaged into a recombinant virus. Target dendritic cells are obtained from the patient and transduced with a recombinant virus containing a polynucleotide that encodes the desired antigen. The dendritic cells are then transferred back into the patient.

[0107] The viral particles may be injected in vivo, where they infect DCs and deliver a sequence of interest, typically encoding an antigen. The amount of viral particles is at least $3X10^6$ IU, and can be at least $1X10^7$ IU, at least $3X10^7$IU, at least $1X10^8$ IU, at least $3X10^8$ IU, at least $1X10^9$ IU, or at least $3X10^9$ IU. At selected intervals, DCs from the recipient's lymphoid organs may be used to measure expression, for example, by observing marker expression, such as GFP or luciferase. Nucleic acid monitoring techniques and measurements of reverse transcriptase (RT) activity can also be used to analyze the biodistribution of viral particles. T cells from peripheral blood mononuclear cells, lymph nodes, spleens, or malignant or target pathogen-infected tissue of lentiviral vector particle-treated recipients may be measured from the magnitude and durability of response to antigen stimulation. Tissue cells other than DCs, such as epithelial cells and lymphoid cells, may be analyzed for the specificity of in vivo gene delivery.

[0108] It is widely agreed that the most effective potential method to end the AIDS epidemic (and other viral diseases) is an effective preventative vaccine. To date, no vaccination method against HIV has successfully passed a phase III trial. Thus, there is an urgent need for new, effective vaccination strategies. One strategy is vaccination of DCs. In this implementation, a sequence encoding a viral protein, such as those described above, is cloned into a viral vector. Patients are infected with viruses constructed as described herein. In an animal model, molecularly cloned HIV reporter viruses (NFNSZ-r-

HSAS, NL-r-HSAS) and clinical isolates may be used to challenge the animals by tail vein injection. Evidence of infection may be monitored over time in splenocytes, lymph nodes, and peripheral blood. PCR amplification for HIV-gag protein and flow cytometry for HAS in the reporter viruses may be used to test for viral integration and replication. Productive in situ DC vaccination may increase resistance to a HIV challenge.

[0109] Vaccines often include an adjuvant. The lentiviral vector particles described herein may also be administered along with an adjuvant. The adjuvant may be administered with the recombinant virus particles, before the recombinant virus particles, or after the recombinant virus particles. If administered with the virus particles, desirable adjuvants do not significantly disrupt the integrity of the virus particle, such as disrupting the viral membrane containing the envelope glycoproteins.

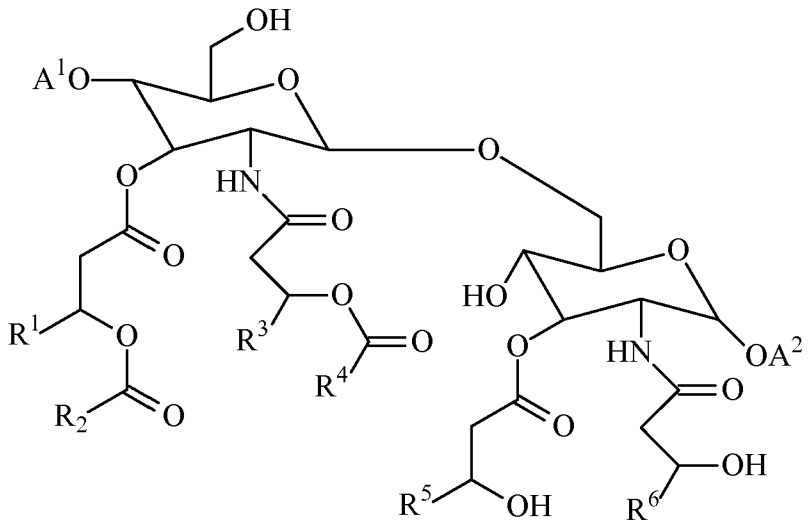
[0110] A variety of adjuvants can be used in combination with the virus to elicit an immune response to the antigen encoded in the viral vector genome. Preferred adjuvants augment the intrinsic response to an antigen without causing conformational changes in the antigen that affect the qualitative form of the response. Preferred adjuvants include alum, 3 De-O-acylated monophosphoryl lipid A (MPL) (see GB 2220211). QS21 is a triterpene glycoside or saponin isolated from the bark of the Quillaja Saponaria Molina tree found in South America (see Kensil et al., in Vaccine Design: The Subunit and Adjuvant Approach (eds. Powell and Newman, Plenum Press, NY, 1995); U.S. Pat. No. 5,057,540). Other adjuvants are oil in water emulsions (such as squalene or peanut oil), optionally in combination with immune stimulants, such as monophosphoryl lipid A (see Stoute et al., N. Engl. J. Med. 336, 86-91 (1997)). Another adjuvant is CpG (Bioworld Today, Nov. 15, 1998). Alternatively, Aβ can be coupled to an adjuvant. For example, a lipopeptide version of Aβ can be prepared by coupling palmitic acid or other lipids directly to the N-terminus of Aβ as described for hepatitis B antigen vaccination (Livingston, J. Immunol. 159, 1383-1392 (1997)). However, such coupling should not substantially change the conformation of Aβ so as to affect the

nature of the immune response thereto. Adjuvants can be administered as a component of a therapeutic composition with an active agent or can be administered separately, before, concurrently with, or after administration of the therapeutic agent.

[0111] One class of adjuvants is aluminum salts (alum), such as aluminum hydroxide, aluminum phosphate, aluminum sulfate. Such adjuvants can be used with or without other specific immunostimulating agents such as MPL or 3-DMP, QS21, polymeric or monomeric amino acids such as polyglutamic acid or polylysine. Another class of adjuvants is oil-in-water emulsion formulations. Such adjuvants can be used with or without other specific immunostimulating agents such as muramyl peptides (e.g., N-acetylmuramyl-L-threonyl-D-isoglutamine (thr-MDP), N-acetyl-normuramyl-L-alanyl-D-isoglutamine (nor-MDP), N-acetylmuramyl-L-alanyl-D-isoglutaminyl-L-alanine-2-(1'-2'dipalmitoyl-sn- -glycero-3-hydroxyphosphoryloxy)-ethylamine (MTP-PE), N-acetylglucsaminyl-N-acetylmuramyl-L-Al-D-isoglu-L-Ala-dipalmitoxy propylamide (DTP-DPP) theramide.TM.), or other bacterial cell wall components. Oil-in-water emulsions include (a) MF59 (WO 90/14837), containing 5% Squalene, 0.5% Tween 80, and 0.5% Span 85 (optionally containing various amounts of MTP-PE) formulated into submicron particles using a microfluidizer such as Model 110Y microfluidizer (Microfluidics, Newton Mass.), (b) SAF, containing 10% Squalane, 0.4% Tween 80, 5% pluronic-blocked polymer L121, and thr-MDP, either microfluidized into a submicron emulsion or vortexed to generate a larger particle size emulsion, and (c) Ribi adjuvant system (RAS), (Ribi Immunochem, Hamilton, Mont.) containing 2% squalene, 0.2% Tween 80, and one or more bacterial cell wall components from the group consisting of monophosphorylipid A (MPL), trehalose dimycolate (TDM), and cell wall skeleton (CWS), preferably MPL+CWS (Detox™). Another class of preferred adjuvants is saponin adjuvants, such as Stimulon.TM. (QS21, Aquila, Worcester, Mass.) or particles generated there from such as ISCOMs (immunostimulating complexes) and ISCOMATRIX. Other adjuvants include Complete Freund's Adjuvant (CFA) and Incomplete Freund's Adjuvant (IFA).

Other adjuvants include cytokines, such as interleukins (IL-1, IL-2, and IL-12), macrophage colony stimulating factor (M-CSF), tumor necrosis factor (TNF).

[0112] Another adjuvant that can be used with the compositions herein is identified by chemical formula (I):



(I)

wherein the moieties A1 and A2 are independently selected from the group of hydrogen, phosphate, and phosphate salts. Sodium and potassium are exemplary counterions for the phosphate salts. The moieties R^1, R^2, R^3, R^4, R^5, and R^6 are independently selected from the group of hydrocarbyl having 3 to 23 carbons, represented by C_3-C_{23}. For added clarity it will be explained that when a moiety is "independently selected from" a specified group having multiple members, it should be understood that the member chosen for the first moiety does not in any way impact or limit the choice of the member selected for the second moiety. The carbon atoms to which R^1, R^3, R^5 and R^6 are joined are asymmetric, and thus may exist in either the R or S stereochemistry. In one embodiment all of those carbon atoms are in the R stereochemistry, while in another embodiment all of those carbon atoms are in the S stereochemistry.

[0113] "Hydrocarbyl" refers to a chemical moiety formed entirely from hydrogen and carbon, where the arrangement of the carbon atoms may be straight chain or branched, noncyclic or cyclic, and the bonding between adjacent carbon atoms maybe entirely single bonds, i.e., to provide a saturated

hydrocarbyl, or there may be double or triple bonds present between any two adjacent carbon atoms, i.e., to provide an unsaturated hydrocarbyl, and the number of carbon atoms in the hydrocarbyl group is between 3 and 24 carbon atoms. The hydrocarbyl may be an alkyl, where representative straight chain alkyls include methyl, ethyl, n-propyl, n-butyl, n-pentyl, n-hexyl, and the like, including undecyl, dodecyl, tridecyl, tetradecyl, pentadecyl, hexadecyl, heptadecyl, octadecyl, etc.; while branched alkyls include isopropyl, sec-butyl, isobutyl, tert-butyl, isopentyl, and the like. Representative saturated cyclic hydrocarbyls include cyclopropyl, cyclobutyl, cyclopentyl, cyclohexyl, and the like; while unsaturated cyclic hydrocarbyls include cyclopentenyl and cyclohexenyl, and the like. Unsaturated hydrocarbyls contain at least one double or triple bond between adjacent carbon atoms (referred to as an "alkenyl" or "alkynyl", respectively, if the hydrocarbyl is non-cyclic, and cycloalkeny and cycloalkynyl, respectively, if the hydrocarbyl is at least partially cyclic). Representative straight chain and branched alkenyls include ethylenyl, propylenyl, 1-butenyl, 2-butenyl, isobutylenyl, 1-pentenyl, 2-pentenyl, 3-methyl-1-butenyl, 2-methyl-2-butenyl, 2,3-dimethyl-2-butenyl, and the like; while representative straight chain and branched alkynyls include acetylenyl, propynyl, 1-butynyl, 2-butynyl, 1-pentynyl, 2-pentynyl, 3-methyl-1-butynyl, and the like.

[0114] The adjuvant of formula (I) may be obtained by synthetic methods known in the art, for example, the synthetic methodology disclosed in PCT International Publication No. WO 2009/035528, which is incorporated herein by reference, as well as the publications identified in WO 2009/035528, where each of those publications is also incorporated herein by reference. Certain of the adjuvants may also be obtained commercially. A preferred adjuvant is Product No. 699800 as identified in the catalog of Avanti Polar Lipids, Alabaster AL, see E1 in combination with E10, below.

[0115] In various embodiments of the invention, the adjuvant has the chemical structure of formula (I) but the moieties A1, A2, R1, R2, R3, R4,

R5, and R6 are selected from subsets of the options previously provided for these moieties, where these subsets are identified below by E1, E2, etc.

E1: A_1 is phosphate or phosphate salt and A_2 is hydrogen.

E2: R^1, R^3, R^5 and R^6 are C_3-C_{21} alkyl; and R^2 and R^4 are C_5-C_{23} hydrocarbyl.

E3: R^1, R^3, R^5 and R^6 are C_5-C_{17} alkyl; and R^2 and R^4 are C_7-C_{19} hydrocarbyl.

E4: R^1, R^3, R^5 and R^6 are C_7-C_{15} alkyl; and R^2 and R^4 are C_9-C_{17} hydrocarbyl.

E5: R^1, R^3, R^5 and R^6 are C_9-C_{13} alkyl; and R^2 and R^4 are C_{11}-C_{15} hydrocarbyl.

E6: R^1, R^3, R^5 and R^6 are C_9-C_{15} alkyl; and R^2 and R^4 are C_{11}-C_{17} hydrocarbyl.

E7: R^1, R^3, R^5 and R^6 are C_7-C_{13} alkyl; and R^2 and R^4 are C_9-C_{15} hydrocarbyl.

E8: R^1, R^3, R^5 and R^6 are C_{11}-C_{20} alkyl; and R^2 and R^4 are C_{12}-C_{20} hydrocarbyl.

E9: R^1, R^3, R^5 and R^6 are C_{11} alkyl; and R^2 and R^4 are C_{13} hydrocarbyl.

E10: R^1, R^3, R^5 and R^6 are undecyl and R^2 and R^4 are tridecyl.

[0116] In certain options, each of E2 through E10 is combined with embodiment E1, and/or the hydrocarbyl groups of E2 through E9 are alkyl groups, preferably straight chain alkyl groups.

[0117] The adjuvant of formula (I) may be formulated into a pharmaceutical composition, optionally with a co-adjuvant, each as discussed below. In this regard reference is made to US Patent Publication No. 2008/0131466 which provides formulations, e.g., aqueous formulation (AF) and stable emulsion formulations (SE) for GLA adjuvant, where these formulations may be utilized for any of the adjuvants of formula (I).

[0118] An adjuvant can be administered with the virus of the invention as a single composition, or can be administered before, concurrent

with or after administration of the recombinant virus of the invention. Immunogen and adjuvant can be packaged and supplied in the same vial or can be packaged in separate vials and mixed before use. Immunogen and adjuvant are typically packaged with a label indicating the intended therapeutic application. If immunogen and adjuvant are packaged separately, the packaging typically includes instructions for mixing before use. The choice of an adjuvant and/or carrier depends on the stability of the vaccine containing the adjuvant, the route of administration, the dosing schedule, the efficacy of the adjuvant for the species being vaccinated, and, in humans, a pharmaceutically acceptable adjuvant is one that has been approved or is approvable for human administration by pertinent regulatory bodies. For example, Complete Freund's adjuvant is not suitable for human administration. Alum, MPL and QS21 are preferred. Optionally, two or more different adjuvants can be used simultaneously, such as alum with MPL, alum with QS21, MPL with QS21, and alum, QS21 and MPL together. Also, Incomplete Freund's adjuvant can be used (Chang et al., Advanced Drug Delivery Reviews 32, 173-186 (1998)), optionally in combination with any of alum, QS21, and MPL and all combinations thereof.

E. Pharmaceutical Compositions and Kits

[0119] Also contemplated herein are pharmaceutical compositions and kits containing a virus provided herein and one or more components. Pharmaceutical compositions can include viral vector particles as provided herein and a pharmaceutical carrier. Kits can include the pharmaceutical compositions and/or combinations provided herein, and one or more components, such as instructions for use, a device for administering a compound to a subject, and a device for administering a compound to a subject.

[0120] Provided herein are pharmaceutical compositions containing viral particles as provided herein and a suitable pharmaceutical carrier. Pharmaceutical compositions provided herein can be in various forms,

e.g., in solid, liquid, powder, aqueous, or lyophilized form. Examples of suitable pharmaceutical carriers are known in the art. Such carriers and/or additives can be formulated by conventional methods and can be administered to the subject at a suitable dose. Stabilizing agents such as lipids, nuclease inhibitors, polymers, and chelating agents can preserve the compositions from degradation within the body.

[0121] The viral vector particles provided herein can be packaged as kits. Kits can optionally include one or more components such as instructions for use, devices, and additional reagents, and components, such as tubes, containers and syringes for practice of the methods. Exemplary kits can include the viruses provided herein, and can optionally include instructions for use, a device for detecting a virus in a subject, a device for administering the virus to a subject, and a device for administering a compound to a subject.

[0122] Kits comprising polynucleotides encoding a gene of interest (typically an antigen) are also contemplated herein. The kit may include at least one plasmid encoding virus packaging components and vector encoding Sindbis virus E2 glycoprotein variant. Some kits will contain at least one plasmid encoding virus packaging components, a vector encoding Sindbis virus E2 glycoprotein variant, and a vector encoding at least one DC maturation factor.

[0123] Kits comprising a viral vector encoding a sequence of interest (typically an antigen) and optionally, a polynucleotide sequence encoding a DC maturation factor are also contemplated herein. In some kits, the kit includes at least one plasmid encoding virus packaging components and a vector encoding Sindbis virus E2 glycoprotein variant.

[0124] A kit may also contain instructions. Instructions typically include a tangible expression describing the virus and, optionally, other components included in the kit, and methods for administration, including methods for determining the proper state of the subject, the proper dosage amount, and the proper administration method, for administering the virus.

Instructions can also include guidance for monitoring the subject over the duration of the treatment time.

[0125] Kits provided herein also can include a device for administering a virus to a subject. Any of a variety of devices known in the art for administering medications or vaccines can be included in the kits provided herein. Exemplary devices include, but are not limited to, a hypodermic needle, an intravenous needle, a catheter, a needle-less injection device, an inhaler, and a liquid dispenser, such as an eyedropper. Typically, the device for administering a virus of the kit will be compatible with the virus of the kit; for example, a needle-less injection device such as a high pressure injection device can be included in kits with viruses not damaged by high pressure injection, but is typically not included in kits with viruses damaged by high pressure injection.

[0126] Kits provided herein also can include a device for administering a compound, such as a DC activator or stimulator, to a subject. Any of a variety of devices known in the art for administering medications to a subject can be included in the kits provided herein. Exemplary devices include a hypodermic needle, an intravenous needle, a catheter, a needle-less injection, but are not limited to, a hypodermic needle, an intravenous needle, a catheter, a needle-less injection device, an inhaler, and a liquid dispenser such as an eyedropper. Typically the device for administering the compound of the kit will be compatible with the desired method of administration of the compound.

[0127] The following examples are offered by way of illustration, and not by way of limitation.

EXAMPLES

EXAMPLE 1

ENGINEERING OF A SINDBIS VIRUS ENVELOPE VARIANT

[0128] Sindbis virus (SV)--a member of the Alphavirus genus and the Togaviridae family--is able to infect DCs, probably through DC-SIGN (Klimstra, W. B., et al. 2003. J. Virol. 77: 12022-12032, which is incorporated herein by reference in its entirety). The canonical viral receptor for the laboratory strain of SV however, is cell-surface heparan sulfate (HS), which is found on many cell types (Strauss, J. H., et al. 1994. Arch. Virol. 9: 473-484; Byrnes, A. P., and D. E. Griffin. 1998. J. Virol. 72: 7349-7356, each of which is incorporated herein by reference in its entirety). To try to reduce heparan sulfate binding, a mutant E2 envelope (called SVGmu) was constructed by Wang et al. (US 2008/0019998, incorporated in its entirety). Part of their strategy involved deleting four amino acids at the E3/E2 pro-protein junction and a deletion of two amino acids with a subsequent addition of a 10 amino acid sequence from hemagglutinin (see Figures 1A and 1B). The resulting E2 protein is expressed as a fusion of E3 and E2 (also known as pE2) because the natural cleavage sequence was disrupted, and it also displays a foreign epitope (hemagglutinin). As shown below, SVGmu suffers from low expression levels among other problems.

[0129] Using a different strategy, the inventors have engineered the E2 glycoprotein of Sindbis virus to decrease binding to heparan sulfate, increase specificity with dendritic cells, and improve expression. A general approach to attain these characteristics is to increase infectivity of dendritic cells by changing residue 160 of E2 (residues 233 in Figure 1) to a non-acidic amino acid, especially an amino acid other than alanine, or delete it, to decrease heparin binding by reducing net positive charge of the protein, to remove the HA (hemagglutinin) epitope, and to restore a cleavage site at the N-terminus of E2, in this case a furin cleavage site. As part of a viral envelope,

these E2 glycoproteins are able to mediate infection of DCs as well as have reduced or abrogated infection of other cell types.

[0130] Following these principles, several variant sequences of E2 were designed and are shown in the following table. The bold typeface indicates a change from the HR strain Sindbis virus envelope sequence (GenBank NC 001547.1).

SEQ ID No:	**70**	**76**	**159**	**160**
3	**E**	K	**E**	**G**
4	**E**	**E**	**E**	**G**
5	**E**	K	**Δ**	**Δ**
6	**E**	**E**	**E**	**Δ**
7	K	K	**E**	**G**
8	K	K	**E**	**Δ**
9	K	**E**	**E**	**G**
10	K	**E**	**E**	**Δ**
11	K	**E**	K	**G**
12	K	**E**	K	**Δ**
13	**E**	K	K	**G**
14	**E**	K	K	**Δ**
15	**E**	**E**	K	**G**
16	**E**	**E**	K	**Δ**

[0131] Nucleic acid sequences encoding some of the variants were synthesized (see also Figure 1), including nucleic acid sequences that are codon-optimized for humans. The DNAs for the variants were cloned into an expression vector, such as pcDNA3.

EXAMPLE 2

PREPARATION OF A VIRAL VECTOR PARTICLE COMPRISING A SINDBIS VIRUS E2 ENVELOPE GLYCOPROTEIN VARIANT

[0132] A Sindbis envelope-pseudotyped virus is prepared by standard calcium phosphate-mediated transient transfection of 293T cells with a lentiviral vector, such as FUGW or its derivatives, packaging plasmids encoding gag, pol and rev, and a variant Sindbis virus envelope sequence. FUGW is a self-inactivating lentiviral vector carrying the human ubiquitin-C promoter to drive the expression of a GFP reporter gene (Lois, C., et al. 2002. Science 295: 868-872, which is incorporated herein by reference in its entirety). The lentiviral transfer vectors (FUGW and its derivatives) are third generation HIV-based lentiviral vectors (see generally, Cockrell and Kafri Mol. Biotechnol. 36: 184, 2007), in which most of the U3 region of the 3' LTR is deleted, resulting in a self-inactivating 3'-LTR.

[0133] Production of recombinant lentivirus vectors was accomplished by calcium phosphate ($CaPO_4$)-mediated transient transfection of 293T cells (293LTV cell line; CELL BIOLABS INC, LTV-100). 293T cells were transfected with four plasmids precipitated together with $CaPO_4$. The following four plasmids were used to produce lentiviral vector preparations are shown schematically in **Figure 3** and corresponded to the following: i) lentiviral vector; ii) HIV Rev encoding plasmid; iii) HIV Gag/Pol encoding plasmid; and, iv) envelope encoding plasmid. Lentiviral vectors may encode desired antigens or immunomodulatory elements, and contain particular targeted deletions to prevent integration into the host chromosome of the infected cells. Further examples of alternative plasmids that can be utilized for transient transfection include those that encode a Polymerase holoenzyme that harbors a mutation in its integrase rendering it defective, such as the D64V mutation described herein. For certain purposes, the envelope encoding plasmid may encode a non-DC targeting pantropic envelope such as VSV-G.

[0134] For the experiments described herein, $CaPO_4$ precipitations containing 120 µg vector and 60 µg each of Gag/Pol and Rev plasmids and 240 µg of envelope plasmid that were filtered through a 0.45 µm pore size filter and were added to approximately 6 x 10^7 293T cells grown in roller bottles and containing 75mL of DMEM media supplemented with 10%

fetal calf serum. At 6 hours post transfection, the media was replaced with 100 mL of fresh media and collected at 36 hours post transfection. Culture supernatants were centrifuged at low speed (1200 rpm) to pellet cell debris followed by filtration through 0.45 μm filters. The filtrate containing the lentivirus vector preparation was optionally concentrated by centrifugation at 17,700 x g for 5 hours at 20°C. The pelleted lentivirus vector was then resuspended in PBS at a desired volume. This process typically yielded $\geq 5 \times 10^5$ IU/mL using the Sindbis virus glycoprotein envelope described herein, or 5×10^7 IU total for each roller bottle culture. More typically this process yielded at least 1×10^8 IU total for each roller bottle culture.

[0135] In more detail, at day -4, 150 mL cell culture medium is added to Roller Bottles (RB) that are placed in a 37°C roller rack incubator (0.2 rpm) for ~1 hr. Into each RB is passed confluent 15 cm dishes. At day -2, medium is aspirated from RBs and replaced with 100 mL pre-warmed medium. On day -1, the cells are seeded in preparation for transfection. RBs are prewarmed with 100 mL cell culture medium for ~1hr. Medium is aspirated and 10-12 mL of PBS is added. The RBs are placed on their side and rotated twice around to coat the cells. The PBS is aspirated and 10-12 mL of trypsin solution is added. RBs are again placed on their sides and rotated twice around to coat the cells. The trypsin solution is aspirated and the RBs are placed in the incubator for 5 min. To the RBs, 10 mL of warm medium is added and the RBs are rotated vigorously once around to detach the cells. Using a 10 mL pipet, cells are pipetted up and down for e.g., 10 times to ensure a single cell suspension. Cells are removed to a new container and diluted with medium (40 mL medium per RB). Cells are counted and seeded into fresh RBs at $7x10^7$/ml and kept in the incubator overnight.

[0136] On day 0, at approximately 22 hr post-seeding, the plasmid solution was prepared as follows. For each RB, mix together a plasmid solution (120 μg vector, 60 μg Gag/Pol, 60 μg Rev, 60 μg envelope), 2.5 mL 1.25M $CaCl_2$, and filtered-sterile water to 12.5 mL final volume. Add 2.7ml 2×HBS (50 mM HEPES, 10 mM KCl, 12 mM dextrose, 280 mM NaCl, 1.5 mM Na2HPO4·7H2O, pH 7.0, sterile filtered) buffer to a 50ml tube (one tube / RB).

Add 12.7 mL water-CaCl2-DNA mix dropwise to 12.7 mL 2xHBS while vortexing at medium setting. Cap the tube and continue to vortex (max speed) for 5-10 seconds. Remove 25ml medium from RB and add precipitate (25ml) to RB. Incubate 6 hr, then aspirate off medium and add 100ml of fresh, pre-warmed cell culture medium. Place back in 37° incubator.

[0137] At 36 to 48 hr post-transfection, the supernatants from RB were collected into a 250 mL conical tube and processed as follows. Centrifuge supernatants for 10 min @ 2000 rpm. Filter supernatants through 0.45um filter. Centrifuge supernatants in 500ml tube for 5 hr @ 10,000rpm @ 20°C. Resuspend vector in PBS or HBSS to desired concentration and store at -80°C.

[0138] The resultant pseudo-typed viral vectors are hereafter referred to as FUGW/V1, FUGW/V2, and so on. Viral vector genomes enveloped with the VSV-G glycoprotein are hereafter referred to as FUGW/VSV-G.

EXAMPLE 3

PRODUCTION OF LENTIVIRAL VECTOR PARTICLES COMPRISING SINDBIS VIRUS ENVELOPE GLYCOPROTEINS

[0139] In this example, titers are determined for lentivirus vectors pseudotyped with different Sindbis virus envelopes. The E2 glycoproteins used were SIN-Var1 (SEQ ID No. 3), SIN-Var2 (SEQ ID No. 4), SIN-Var3 (SEQ ID No. 5), SVGmu (SEQ ID No. 2), HR (SEQ ID No. 18).

[0140] Sindbis virus glycoprotein pseudotyped lentiviral vector particles were generated by transfection of 293T cells as described in Example 2. Crude supernatants were harvested 48 hours post-transfection and used to transduce 293T cells expressing human DC-SIGN (293-DCSIGN) that had been plated in 6-well dishes the previous day at 2E5 cells/well. Titer was determined following a 72 hr incubation at 37°C by analyzing transduced cells on a Guava Easy-Cyte cytometer (Millipore). 25,000 total events were counted

to determine the percentage of GFP+ transduced cells, which was in turn used to calculate the GFP titer (IU, infectious unit) for each virus.

[0141] To facilitate the study of targeted transduction, cell lines expressing human DC-SIGN are constructed. The cell lines are generated by stable transduction of parental 293T cells with a VSVG-pseudotyped lentivector containing the coding sequence for human DC-SIGN. cDNA for human DC-SIGN is amplified from plasmids pUNO-hDCSIGN1Aa (InvivoGene) and cloned downstream of the human ubiquitin-C promoter in the lentiviral plasmid FUW to generate FUW-hDCSIGN. Alternatively, cell lines are generated by stable transduction of parental 293T cells with a VSVG-pseudotyped amphotrophic (non-lentiviral) vector containing the coding sequence for DC-SIGN, to better facilitate downstream nucleic acid-based analyses of transduction by lentiviral vector particles. The lentivectors or amphotrophic vectors are then pseudotyped with VSVG and used to transduce 293T cells. Alternatively, cell lines are generated by stable transduction of parental 293T cells with a plasmid encoding human DC-SIGN. The resulting cells are subjected to antibody staining (anti-human DC-SIGN antibody (BD Biosciences) and cell sorting to yield a uniform population of DC-SIGN+ cell lines.

[0142] In three independent experiments, lentiviral vector pseudotyped with SIN-Var1 envelope had titers approximately 10-fold higher titer than those pseudotyped with SVGmu or with the HR strain of Sindbis virus (Figure 3, upper graph). In a subsequent study, the productivity of three Sindbis envelope variants was compared. A representative result is shown. Sin-Var1, Sin-Var2 and SIN-Var3 envelopes generate lentivirus vector particles with similar overall titer.

[0143] The specificity of viral vector particles that comprise a Sindbis virus variant E2 glycoprotein is assessed by transduction of the 293T.hDC-SIGN or the parental 293T cells and measurement of expression of a visible marker (e.g., GFP) within the cell lines.

[0144] Target cells (293T.hDC-SIGN or 293T cells) are seeded in a 24-well culture dish ($0.2X10^6$ cells per well) and transduced with viral

supernatants (1 ml per well) by centrifuging the dishes at 2,500 rpm and 30°C for 90 min. Subsequently, the supernatants are replaced with fresh culture medium and incubated for 3 days at 37°C. The percentage of cells expressing the marker is measured by flow cytometry.

As shown in the table below, both E2 variant 1 and E2 variant 3 preferentially targeted cells (are specific for cells) expressing hDC-SIGN.

Table 1

Envelope	Cell Type	GFU/mL	Ratio
VSV-G	hDC-SIGN	1.35E+08	1.19
	293T	1.13E+08	
Sin-Var3 (Exp 1)	293-hDC-SIGN	4.2E+07	35.4
	293T	1.2E+06	
Sin-Var3 (Exp 2)	hDC-SIGN	8.12E+07	11.09
	293T	7.33E+06	
Sin-Var2	293-hDC-SIGN	1.7E+08	18.2
	293T	9.1E+06	
Sin-VAR-1	hDC-SIGN	2.93E+08	13.75
	293T	2.13E+07	
Sin-HR	293-hDC-SIGN	6.4E+06	9.4
	293T	6.8E+05	
SVGmu (Exp 1)	293-hDC-SIGN	3.4E+06	27.0
	293T	1.3E+05	
SVGmu (Exp 2)	hDC-SIGN	4.65E+06	12.24
	293T	3.80E+05	

EXAMPLE 4

IMMUNOGENICITY OF LENTIVIRAL VECTOR PARTICLES COMPRISING SINDBIS VIRUS ENVELOPE GLYCOPROTEINS

[0145] In this Example, immunogenicity is assessed for lentivirus vectors pseudotyped with different Sindbis virus envelopes. More specifically, the amount of antigen-specific CD8 T cells and their cytokine secretion profiles were determined. The E2 glycoproteins used were SIN-Var1 (SEQ ID No. 3), SIN-Var2 (SEQ ID No. 4), SIN-Var3 (SEQ ID No. 5), SVGmu (SEQ ID No. 2).

[0146] The viral genome comprises sequence encoding Ovalbumin (OVA). Lentivirus vector particles were generated by transfecting 293T cells as described in Example 2. Supernatants were collected, and the amount of p24 determined using an ELISA kit (Advanced Bioscience Labs, Kensington MD). The protein p24 is an HIV core protein found in the pseudotyped virions and a product of the gag gene. C57BL/6 mice (5 mice per group) were immunized subcutaneously with integration-deficient lentivector encoding ovalbumin OVA. The number and function of OVA257 (SIINFEKL) (SEQ ID NO 24) peptide-specific CD8 T cells and cytokine secretion profiles in the spleen was determined at day 9 by MHC-I/peptide multimer and intracellular cytokine staining.

[0147] Briefly, spleens were extracted and homogenized by pressing through a 70 μM nylon filter. Red blood cells were lysed by hypotonic shock by brief exposure to distilled water and immediately restored to an isotonic environment with addition of 10x PBS. Approximately $5x10^6$ splenocytes per sample were stained with PE-labeled H-2Kb/OVA257 pentamer (ProImmune) at 25°C in PBS with 2% FCS and 2 mM EDTA (FACS buffer). Cells were then washed twice and stained with the viability dye LIVE/DEAD Near-Infrared (L/D NIR; Invitrogen) and the following fluorochrome-labeled antibodies: CD44 FITC, CD19 PerCP-Cy5.5, and CD8 Pacific Blue (eBioscience) at 4°C. Data were collected on a BD LSR II flow cytometer (50,000 CD8+ events) and analyzed with FlowJo software (TreeStar). The gating strategy to identify CD8 T cells was as follows: lymphocytes (forward scatter lo-med, side scatter lo), single cells (side scatter area = side scatter height), live cells (L/D NIR-), CD8 T cells (CD8+ CD19-). The percentage of cells expressing IFN-γ within the CD8+ gate was determined and depicted in Figures 4A and 4B. The horizontal line depicts mean values. Non-specific IFN-γ staining was determined in spleen cells of vehicle (HBSS)-injected mice in which the cells were stimulated in vitro with peptide. IFN-γ staining was below 0.2% for all samples cultured without peptide (not shown). In addition to the

fraction of CD8 T cells producing IFN-γ, the fraction of IFN-γ+ cells also producing TNFα and/or IL-2 is also depicted, as indicated in the key.

[0148] In one set of experiments, the amount of virus used contained either 2500 ng or 125 ng of p24. Figure 4A illustrates that lentivectors pseudotyped with Sindbis variant envelopes have similar activity in vivo. As shown in the leftmost panel, the mean of antigen-specific CD8 T cells is essentially the same at two different dosing amounts. In addition, the mean percentage of IFN-γ cells is also similar. Patterns of cytokine secretion, specifically the fraction of IFN-gamma positive cells also expressing IL-2 or TNF-alpha, is also similar, with the highest percentage of I IFN-γ cells being negative for IL-2 and TNF-α.

[0149] In another set of experiments, groups of 5 mice received a serial dilution dose of virus or vehicle. The virus was pseudotyped with either SinVar1 or SVGmu. The percentage of cells with a CD44hi H-2Kb/OVA257 pentamer+ phenotype is depicted in Figure 4B. The connecting line depicts mean values. As shown in Figure 4B, SinVar1-pseudotyped LV induced substantially greater expansion of antigen-specific CD8 T cells than SVGmu. Moreover, the SinVar1-pseudotyped lentivectors induced a greater functional CD8 T cell response than SVGmu (Figure 4C). Non-specific IFN-γ staining was determined in HBSS-injected (vehicle) mice restimulated with peptide. IFN-γ staining was below 0.2% for all samples cultured without peptide (not shown).

EXAMPLE 5

CONSTRUCTION OF NON-INTEGRATING LENTIVIRAL VECTORS (NILV)

[0150] A variety of non-integrating lentiviral vectors were constructed. A schematic of the exemplary lentivirus vectors is shown in Figure 5A. The top drawing shows a vector in a provirus form. All vectors contain splice donor, packaging signal (psi), a Rev-responsive element (RRE), splice donor, splice acceptor, central poly-purine tract (cPPT) and WPRE element. In

addition, all vector constructs contain a promoter for expression in mammalian cells, and a sequence of interest, labeled "antigen" in the exemplary construct. Promoters utilized in the Examples include the human ubiquitin C promoter (UbiC), the cytomegalovirus immediate early promoter (CMV), and the Rous sarcoma virus promoter (RSV).

[0151] A zoom view of the U3 region is shown below as an open box with the PPT (polypurine tract) sequence immediately upstream. Below are shown three different U3 regions in schematic form; their sequences are shown in Figure 5B and SEQ ID NOs: 21-23. The constructs contain deletions in the U3 regions. The SIN construct has a deletion of about 130 nucleotides in the U3 (Miyoshi, et al. J Virol 72: 8150, 1998; Yu et al. PNAS 83: 3194, 1986), which removes the TATA box, abolishing LTR promoter activity. The deletions in constructs 703 and 704 increase expression from lentivirus vectors (Bayer et al. Mol Therapy 16: 1968, 2008, incorporated in its entirety). In addition, construct 704 contains a deletion of the 3' PPT, which decreases integration of the vector (WO 2009/076524, incorporated in its entirety). Sequences of the U3 region of all constructs are shown in figure 5B. The 3' PPT begins at position 3, and extended deletions relative to the SIN-deleted vector are shown.

EXAMPLE 6

EXPRESSION IN DENDRITIC CELLS FOLLOWING TRANSDUCTION WITH LENTIVIRAL VECTOR PARTICLES

[0152] This Example shows the GFP (green fluorescent protein) expression level in dendritic cells generated from vectors with extended U3 deletions.

[0153] A series of viruses were produced by transfection of 293T cells as described above. All viruses comprised a SIN-Var1 envelope, a vector genome containing a UbiC or CMV promoter in operative linkage with a GFP transgene, and a deficient integrase by virtue of containing a D64V mutation. Crude supernatants were harvested 48 hours post transduction, and equivalent volumes of each supernatant were used to transduce 293T-DCSIGN cells.

GFP expression was determined 72 hours post-transduction using a GUAVA Easy-Cyte flow cytometer. A total of 50,000 events were counted for each transduced cell population. Data was analyzed using FlowJo cytometric analysis software.

[0154] Similar results were obtained with both UbiC (Figure 6, panel A) and CMV (Figure 6, panel B) promoters. Lentivirus vectors containing extended U3 deletions (703 and 704) showed a higher overall transgene expression relative to SIN deleted vectors. Deletion of the PPT in construct 704 decreased expression slightly relative to construct 703.

EXAMPLE 7

VECTORS WITH LARGE DELETIONS IN U3 ARE NON-INTEGRATING

[0155] This example demonstrates the relative integration efficiency of SIN-Var1 pseudotyped vectors containing combinations of different vector deletions with deficient or wild-type integrase following transduction of 293-DC-SIGN cells.

[0156] Vector stocks were generated with a number of different combinations of Integrase genes and U3 deletions. Vectors with the U3 deletions (see Figures 5A and 5B), SIN, 703, and 704 were transfected as above with either a wild-type integrase gene or a mutant integrase gene. The vectors in these experiments contain a GFP-2A-Neo transgene that encodes both GFP and G418 resistance. The reading frames are linked via a 2A self-cleaving peptide to generate individual proteins. GFP titers for all vector stocks were determined using standard flow cytometric methods. Vector stocks were then used to infect 293-DC-SIGN cells plated the previous day in 6 well dishes at 5 X 10^5 cells/well. Following transduction, cells were treated with trypsin every 72 hours. At each passage, 2 X 10^5 cells were re-plated into 6 well dishes in 2 mL of DMEM + 10% FBS. Remaining cells were used to determine the number of GFP+ cells by flow cytometry.

[0157] In Figure 7, the relative GFP titer is presented as a fraction of the titer observed at passage one. Loss of GFP expression reflects loss of the GFP transgene, which is a consequence of lack of integration at the initial transduction step. As expected, all viruses containing a D64V mutant integrase (IN-) were found to be non-integrating. In addition, viruses containing a PPT deletion (704) were found to be integration deficient even in the presence of a wild-type IN gene. This shows that deletion of the 3' PPT provides a redundant safety mechanism in combination with an integrase mutation.

EXAMPLE 8

INTEGRATING AND NON-INTEGRATING LENTIVIRUS VECTORS ARE EQUIVALENTLY IMMUNOGENIC

[0158] In this Example, CD8 T cell responses are assessed following immunization with integrating or non-integrating viruses.

[0159] C57BL/6 mice were immunized subcutaneously with $2.5x10^{10}$ genomes of integrating (Int^{wt}) or nonintegrating (Int^{D64V}) lentivector encoding the Gag antigen from simian immunodeficiency virus (SIV). The number and function of SIV Gag-specific CD8 T cells in the spleen was determined at day 10 by intracellular cytokine staining, as described above, with the exception that the SIV Gag-derived peptide AAVKNWMTQTL was used for restimulation. Figure 8 illustrates that nonintegrating lentivectors can elicit a CD8 T cell response equivalent to integrating lentivectors. Moreover, the pattern of cytokine expression is similar.

EXAMPLE 9

IMMUNIZATION WITH DC-NILV PROVIDE THERAPEUTIC EFFECT

[0160] In this Example, mice that have received tumor cells are treated by immunization with DC-NILV expressing a tumor antigen.

[0161] BALB/c mice were injected subcutaneously with $2x10^4$ CT26 colon carcinoma cells. One day later, mice were treated subcutaneously with either vehicle or a SINvar1 pseudotyped lentivirus vector particle preparation containing 3.2 μg of p24 capsid protein. The viral vector envelope comprises a variant of Sindbis virus E2 as described above, and the vector is non-integrating and encodes the AH1A5 peptide (SPSYAYHQF;SEQ ID NO. 25), a modified MMTV gp70 CD8 T cell epitope that is a rejection antigen relevant to CT26 tumor cells. The initial tumor growth as well as long-term survival of immunized versus control mice is depicted. Figure 9 shows that the tumor grew more slowly in mice receiving DC-NILV and furthermore, the survival rate (measured out 75 days) was substantially better (60% survival compared to 20%). Therefore, DC-targeting non-integrating lentivectors (DC-NILV) are effective in the therapeutic treatment of tumors.

Embodiments of the invention include, but are not limited to, the following.

1. A retroviral, e.g., a lentiviral, vector particle comprising:

(a) an envelope comprising a Sindbis virus E2 glycoprotein of SEQ ID NO:1 in which 160X is absent or is an amino acid other than glutamic acid, or a variant of SEQ ID NO:1 thereof capable of infecting dendritic cells having at least sequence 80% identity to SEQ ID NO:1; wherein said E2 glycoprotein or variant thereof is not fused to E3; and

(b) a lentiviral genome comprising a sequence of interest.

2. The retroviral vector particle of embodiment 1, wherein the E2 glycoprotein or variant binds to DC-SIGN.

3. The retroviral vector particle of embodiment 1 or embodiment 2, wherein the 160X is absent or is glycine, alanine, valine, leucine or isoleucine, such as selected from glycine, valine, leucine or isoleucine.

4. The retroviral vector particle of embodiment 1 or embodiment 2, wherein 160X is glycine.

5. The retroviral vector particle of embodiment 1, 2, 3 or 4, wherein the E2 glycoprotein variant has at least one amino acid altered to reduce its net positive charge.

6. The retroviral vector particle of embodiment 5, wherein the altered amino acids are chosen from the group consisting of lysine 70, lysine 76, or lysine 159 of SEQ ID NO:1, and the substitutions are optionally independently chosen from glutamic acid or aspartic acid.

7. The retroviral vector particle of embodiment 1, 2, 3, 4, 5 or 6, wherein the E2 variant sequence is SEQ ID No. 2, 3, or 4; (variants 1, 2, and 3), optionally comprising one or more further substitutions, insertions or deletions.

8. The retroviral vector particle of embodiment 1, 2, 3, 4, 5, 6 or 7, which is a variant in which the sequence of residues 71-75 of SEQ ID NO:1 is unchanged or has one or two substitutions which do not affect the ability of the variant to infect DCs, but do not alter the number of amino acids in this region.

Any combination of the above embodiments are contemplated by the invention, as set out in the non-limiting following combinations, where ">" indicates a reference to the earlier numbered embodiment: 4>2>1; 5>4>1; 5>4>2>1; 5>3>1; 5>3>2>1; 6>5>4>1; 6>5>4>2>1; 6>5>3>2>1; 6>4>2>1; 6>3>2>1; 6>5>3>1; 7>6>5>4>1; 7>6>5>4>2>1; 7>6>5>3>1; 7>6>5>3>2>1; 7>6>4>2>1; 7>5>4>1; 7>5>4>2>1; 7>5>3>1; 7>5>3>2>1; 7>4>2>1; 7>3>2>1; 7>6>4>1; 7>6>4>2>1; 7>6>3>1; 7>6>3>2>1; 7>6>2>1; 8>4>2>1; 8>5>4>1; 8>5>4>2>1; 8>5>3>1; 8>5>3>2>1; 8>6>5>4>1; 8>6>5>4>2>1; 8>6>5>3>2>1; 8>6>4>2>1; 8>6>3>2>1; 8>6>5>3>1; 8>7>6>5>4>1; 8>7>6>5>4>2>1; 8>7>6>5>3>1; 8>7>6>5>3>2>1; 8>7>6>4>2>1; 8>7>5>4>1; 8>7>5>4>2>1;

8>7>5>3>1; 8>7>5>3>2>1; 8>7>4>2>1; 8>7>3>2>1; 8>7>6>4>1; 8>7>6>3>1; 8>7>6>3>2>1; 8>7>6>2>1.

Further embodiments of the invention include:

9. The retroviral vector particle of any of the above embodiments, wherein the sequence of interest encodes a tumor-specific antigen or a virus-derived antigen, such as an HIV or SIV antigen.

10. A retroviral, e.g., a lentiviral, vector genome pseudotyped in an envelope comprising a Sindbis virus E2 glycoprotein variant, the genome comprising a sequence of interest,

wherein the E2 glycoprotein variant facilitates infection of dendritic cells by the retroviral vector particle; and wherein the E2 glycoprotein variant has an amino acid sequence as defined in any one of embodiments 1 to 9 above.

11. A retroviral vector packaging system for producing a pseudotyped retroviral vector particle, comprising:

(i) a first nucleic acid molecule encoding a Sindbis virus E2 glycoprotein of SEQ ID NO:1 in which 160X is absent or an amino acid other than glutamic acid, or a variant thereof capable of infecting dendritic cells having at least sequence 80% identity to SEQ ID NO:1, and;

(ii) a second nucleic acid molecule wherein the second nucleic acid molecule can be transcribed and the transcript assembled into a pseudotyped retroviral vector particle.

12. The packaging system of embodiment 11, wherein the E2 glycoprotein has an amino acid sequence as defined in any one of embodiments 1 to 9 above.

13. The packaging system of embodiment 11 or 12, wherein the first nucleic acid molecule encodes an E3/E2 glycoprotein, optionally in the form of a Sindbis virus E3/E2/6K/E1 polyprotein.

14. The packaging system of embodiment 13, wherein the E3 sequence corresponds to residues 1-65 of SEQ ID NO:20, or a variant thereof having at least 80% sequence identity to residues 1-65 of SEQ ID NO:20, wherein residues 62-65 are RSKR (SEQ ID NO: 27) and the variant is capable of being incorporated into a pseudotyped viral envelope, optionally further wherein residue 1 of the E2 polyprotein is Ser.

15. The packaging system of embodiment 11, 12, 13 or 14, further comprising a third nucleic acid molecule encoding gag and pol proteins.

16. The packaging system of any one of embodiments 11 to 15, wherein the second nucleic acid molecule comprises a sequence of interest.

17. A cell transfected with the first and second nucleic acid molecules of any one of embodiments 11 to 16.

18. An isolated nucleic acid molecule encoding the protein of any one of embodiments 1 to 9, or the E3/E2 glycoprotein defined in embodiments 13 or 14.

19. An expression vector comprising the nucleic acid molecule of embodiment 18.

20. A host cell comprising the expression vector of embodiment 19.

21. A method of making a retroviral vector particle of any one of embodiments 1 to 10, comprising expressing in a cell

(i) a first nucleic acid molecule encoding a Sindbis virus E2 glycoprotein of SEQ ID NO:1 in which 160X is other than glutamic acid, or a variant thereof capable of infecting dendritic cells having at least sequence 80% identity to SEQ ID NO:1, and;

(ii) a second nucleic acid molecule wherein the second nucleic acid molecule can be transcribed and the transcript assembled into a pseudotyped retroviral vector particle.

22. A retroviral vector particle according to any one of embodiments 1 to 10 for use in a method of treatment of a human or animal subject.

23. A method of delivering retroviral vector particles to cells in vitro, comprising mixing the cells with the retroviral vector particles of any one of embodiments 1 to 10.

24. A therapeutic vaccine comprising the retroviral vector particles of any one of embodiments 1 to 10 and a pharmaceutically acceptable excipient.

CLAIMS

We claim:

1. A lentiviral vector particle comprising:

(a) an envelope comprising a Sindbis virus E2 glycoprotein of SEQ ID NO: 1 in which 160X is absent or is an amino acid other than glutamic acid, or a variant of SEQ ID NO: 1 thereof having at least 80% identity to SEQ ID NO: 1 and in which 160X is absent or is an amino acid other than glutamic acid, capable of infecting dendritic cells; wherein E2 is not part of a fusion protein with Sindbis virus E3; and

(b) a lentiviral vector genome comprising a sequence of interest;

2. The lentiviral vector particle of claim 1, wherein the E2 glycoprotein or variant binds to DC-SIGN.

3. The lentiviral vector particle of claim 1 or claim 2, wherein the 160X is absent or is glycine, alanine, valine, leucine or isoleucine, such as selected from glycine, valine, leucine or isoleucine.

4. The lentiviral vector particle of claim 1 or claim 2, wherein 160X is glycine.

5. The lentiviral vector particle of claim 1, 2, 3 or 4, wherein the E2 glycoprotein variant has at least one amino acid altered to reduce its net positive charge.

6. The lentiviral vector particle of claim 5, wherein the altered amino acids are chosen from the group consisting of lysine 70, lysine 76, or lysine 159 of SEQ ID NO:1, and the substitutions are optionally independently chosen from glutamic acid or aspartic acid.

7. The lentiviral vector particle of claim 1, 2, 3, 4, 5 or 6, wherein the E2 variant sequence is SEQ ID No. 2, 3, or 4; (variants 1, 2, and 3), optionally comprising one or more further substitutions, insertions or deletions.

8. The lentiviral vector particle of claim 1, 2, 3, 4, 5, 6 or 7, which is a variant in which the sequence of residues 71-75 of SEQ ID NO:1 is unchanged or has one or two substitutions which do not affect the ability of the variant to infect DCs, but do not alter the number of amino acids in this region.

9. The lentiviral vector particle of any of the foregoing claims, wherein the sequence of interest encodes a tumor-specific antigen or a virus-derived antigen, such as an HIV or SIV antigen.

10. The lentiviral vector particle of any of the foregoing claims, wherein the particles have an IU of at least 10^5/mL.

11. A lentiviral vector genome pseudotyped in an envelope comprising a Sindbis virus E2 glycoprotein variant, the genome comprising a sequence of interest,

wherein the E2 glycoprotein variant facilitates infection of dendritic cells by the lentiviral vector particle; and wherein the E2 glycoprotein variant has an amino acid sequence as defined in any one of claims 1 to 10 above.

12. A lentiviral vector packaging system for producing a pseudotyped lentiviral vector particle, comprising:

(i) a first nucleic acid molecule encoding a Sindbis virus E2 glycoprotein of SEQ ID NO:1 in which 160X is absent or an amino acid other than glutamic acid, or a variant thereof capable of infecting dendritic cells having at least sequence 80% identity to SEQ ID NO:1 and in which 160X is absent or is an amino acid other than glutamic acid, and;

(ii) a second nucleic acid molecule encoding gag and pol proteins;

(iii) a third nucleic acid molecule encoding rev; and

(iv) a lentiviral vector genome comprising a sequence of interest;

13. The packaging system of claim 12, wherein the E2 glycoprotein has an amino acid sequence as defined in any one of claims 1 to 9 above.

14. The packaging system of claims 12 or 13, wherein the pol protein has a non-functional integrase.

15. The packaging system of claim 14, wherein the non-functional Integrase has a D64V mutation.

16. The packaging system of claims 12, 13, 14 or 15, wherein the fourth nucleic acid molecule is a non-integrating lentiviral genome.

17. The packaging system of claims 12, 13, 14, 15 or 16, wherein the lentiviral vector particles are produced to a titer of at least 10^5 IU/mL.

18. A cell transfected with the first and fourth nucleic acid molecules of any one of claims 12, 13, 14, 15, 16, or 17.

19. An isolated nucleic acid molecule encoding the protein of any one of claims 1, 2, 3, 4, 5, 6, 7, 8, 9 or 10, or an E3/E2 glycoprotein optionally in the form of a Sindbis E3/E2/6K/E1 polyprotein, or an E3/E2 glycoprotein wherein the E3 sequence corresponds to residues 1-65 of SEQ ID NO:20, or a variant thereof having at least 80% sequence identity to residues 1-65 of SEQ ID NO:20, wherein residues 62-65 are RSKR (SEQ ID NO: 27) and the variant is capable of being incorporated into a pseudotyped viral envelope, optionally further wherein residue 1 of the E2 polyprotein is Ser.

20. An expression vector comprising the nucleic acid molecule of claim 19.

21. A host cell comprising the expression vector of claim 20.

22. A method of making a lentiviral vector particle of any one of claims 1 to 11, comprising expressing in a cell

(i) a first nucleic acid molecule encoding a Sindbis virus E2 glycoprotein of SEQ ID NO:1 in which 160X is other than glutamic acid, or a variant thereof capable of infecting dendritic cells having at least sequence 80% identity to SEQ ID NO:1 and in which 160X is absent or is an amino acid other than glutamic acid, and;

(ii) a second nucleic acid molecule wherein the second nucleic acid molecule can be transcribed and the transcript assembled into a pseudotyped lentiviral vector particle.

23. A lentiviral vector particle according to any one of claims 1, 2, 3, 4, 5, 6, 7, 8, 9, 10 or 11 for use in a method of treatment of a human or animal subject.

24. A method of delivering lentiviral vector particles to cells in vitro, comprising mixing the cells with the lentiviral vector particles of any one of claims 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, or 11.

25. A therapeutic or prophylactic vaccine comprising the lentiviral vector particles of any one of claims 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, or 11 and a pharmaceutically acceptable excipient.