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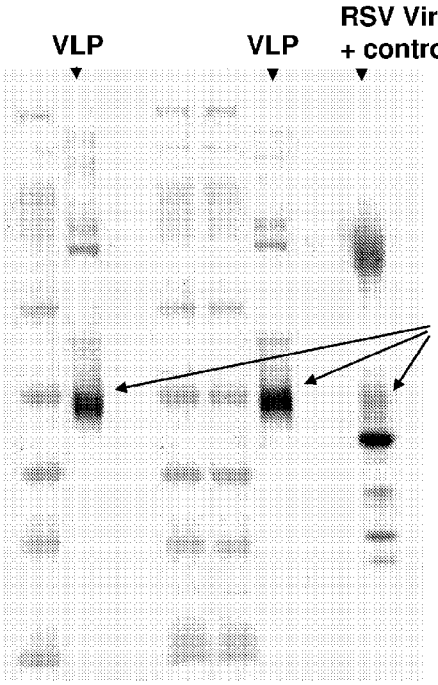
[Continued on next page]

(54) Title: CHIMERIC RSV-F POLYPEPTIDE AND LENTIVIRUS OR ALPHA-RETROVIRUS GAG-BASED VLPS

Figure 39



(57) Abstract: The present invention relates to chimeric RSV-F polypeptide and lentivirus or alpha- retrovirus GAG-based virus-like particles (VLPs). The present invention also includes methods of making and using such chimeric VLPs. In certain embodiments, the GAG polypeptide of the chimeric VLPs comprises an HIV or ALV GAG polypeptide.

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CHIMERIC RSV-F POLYPEPTIDE AND LENTIVIRUS OR ALPHA-RETROVIRUS GAG-BASED VLPS

FIELD

[0001] The present invention relates to the field of chimeric virus-like particles (VLPs) that include a respiratory syncytial virus (RSV) F polypeptide and a lentivirus or alpha-retrovirus GAG polypeptide. In preferred examples, the field includes chimeric VLPs and methods of producing chimeric VLPs. In certain embodiments, the chimeric VLPs comprise an avian leukosis virus (ALV), a rous sarcoma virus, a simian immunodeficiency virus (SIV), or a human immunodeficiency virus (HIV) Gag polypeptide and a respiratory syncytial virus F polypeptide.

BACKGROUND

[0002] Respiratory syncytial virus (RSV) is a leading cause of bronchiolitis and pneumonia among infants and children under 1 year of age (CDC National Center for Infectious Diseases (2004) Respiratory Syncytial Virus). RSV can also be a significant lower respiratory tract pathogen in immuno-compromised adults and the elderly. Individuals can be infected multiple times as natural infection with RSV does not induce protective immunity.

[0003] RSV is a negative-sense, single-stranded RNA virus that belongs to the genus Pneumovirus of the family Paramyxoviridae. The RSV genome is surrounded by a helical nucleocapsid and encodes at least ten proteins: three transmembrane structural proteins (F, G, and SH), two matrix proteins (M and M2), three nucleocapsid proteins (N, P, and L), and two nonstructural proteins (NS1 and NS2) (Collins et al (1996) Respiratory syncytial virus, pp. 1313-1351, In B.N. Fields (ed.), Fields virology. Raven Press, New York, NY). Neutralizing antibodies appear to be elicited only by the F and G proteins. RSV is divided into subgroups A and B based on the G protein, whereas F is more closely related between the subgroups. Monoclonal antibodies against the F protein have been shown to have neutralizing effects in vitro and prophylactic effects in vivo (e.g. Anderson et al. 1988. J. Virol. 62:4232-4238; Anderson et al. 1986. J. Clin. Micro.

23:475-480; Beeler and Coelingh 1989. J. Virol. 63:2941-50; Garcia-Barreno et al. 1989. J. Virol. 63:925-32; Taylor et al. 1984. Immunology 52: 137-142; and U.S. Pat. No. 6,818,216).

[0004] No safe and effective vaccine exists for RSV despite several decades of research. A formalin-inactivated virus vaccine tested in infants and children did not protect against infection and was associated with increased risk of severe symptoms during subsequent infections by wild-type RSV virus (Kapikian et al., 1969, Am. J. Epidemiol. 89:405-21; Chin et al., 1969, Am. J. Epidemiol. 89:449-63). Later attempts focused on developing live-attenuated temperature sensitive mutants also failed due to the inability to identify virus candidates at an appropriate level of attenuation and to the genetic instability of some candidates (Hodes et al. (1974) Proc. Soc. Exp. Biol. Med., 145, 1158-1164; Kim et al. (1973) Pediatrics, 52, 56-63; Wright et al (1976) J. Pediatrics, 88, 931-936).

[0005] Virus-like particles (VLPs) offer several advantages over conventional vaccine technology. An important advantage of VLPs for vaccine development is that they mimic native viruses in terms of three-dimensional structure and the ability to induce neutralizing antibody responses to both primary and conformational epitopes and therefore should prove more immunogenic than other vaccine formulations. Unlike viral vectored approaches, VLPs exhibit no problem with pre-existing immunity, thus allowing for recurrent use. VLPs containing RSV antigens have been generated by co-expression of RSV F protein with RSV matrix (M) protein or with a heterologous M protein in insect cells (US 2008/0233150). However, US 2008/02331050 does not teach actual expression of the RSV-F protein with a lentivirus or alpha-retrovirus GAG protein. In addition, the applicants in U.S. Ser. No. 61/115,780 teach expression of the RSV-F protein in the absence of an enveloped virus core forming polypeptides. However, the applicants found that the murine leukaemia virus (MLV – a gamma-retrovirus) GAG protein does not effectively form VLPs when co-expressed with the RSV-F protein. Thus, there is a need for VLPs that express RSV F protein on a core formed by a structural polypeptide other than the native RSV M protein.

SUMMARY

[0006] Various aspects of this disclosure meet this need by providing various methods and compositions as disclosed herein for methods of generating chimeric VLPs and compositions comprising chimeric VLPs. In preferred embodiments, the chimeric VLPs will comprise a lentivirus or alpha-retrovirus Gag polypeptide and a respiratory syncytial virus F polypeptide.

[0007] An aspect of the disclosed compositions includes chimeric virus-like particles comprising a lentivirus or alpha-retrovirus Gag polypeptide and a respiratory syncytial virus F polypeptide, which may have at least 80% sequence identity, at least 85% sequence identity, at least 90% sequence identity, at least 95% sequence identity, at least 97% sequence identity, or at least 99% sequence identity to any of the respiratory syncytial virus F polypeptide amino acid sequences disclosed in the examples herein. In some embodiments, the Gag polypeptide is from a human immunodeficiency virus, which may have at least 80% sequence identity, at least 85% sequence identity, at least 90% sequence identity, at least 95% sequence identity, at least 97% sequence identity, or at least 99% sequence identity to any of the human immunodeficiency virus Gag polypeptide amino acid sequences disclosed in the examples herein, or a simian immunodeficiency virus, which may have at least 80% sequence identity, at least 85% sequence identity, at least 90% sequence identity, at least 95% sequence identity, at least 97% sequence identity, or at least 99% sequence identity to the simian immunodeficiency virus Gag polypeptide amino acid sequences disclosed in the examples herein. In other embodiments, the Gag polypeptide is from an avian leukosis virus, which may have at least 80% sequence identity, at least 85% sequence identity, at least 90% sequence identity, at least 95% sequence identity, at least 97% sequence identity, or at least 99% sequence identity to any of the avian leukosis virus Gag polypeptide amino acid sequences disclosed in the examples herein. In another embodiment, the virus-like particle further comprises mammalian glycosylation.

[0008] In another embodiment that may be combined with any of the preceding embodiments or aspects, the preparation also includes an adjuvant in admixture with the virus-like particles. In another embodiment that may be combined with any of the

preceding embodiments or aspects that include an adjuvant, the adjuvant may be located outside the virus-like particle or may be located inside the virus-like particle. In another embodiment that may be combined with any of the preceding embodiments or aspects that include an adjuvant, the adjuvant may be covalently linked to the respiratory syncytial virus F polypeptide to form a covalent linkage.

[0009] In another embodiment that may be combined with any of the preceding embodiments or aspects, a neutralizing anti-RSV-F antibody may bind to the respiratory syncytial virus F polypeptide (demonstrating that the RSV F polypeptide is in substantially a native conformation). In certain embodiments that may be combined with any of the preceding embodiments or aspects that include such a neutralizing antibody, the neutralizing anti-RSV-F antibody may be Palivizumab.

[0010] In another embodiment that may be combined with any of the preceding embodiments or aspects, the chimeric virus-like particles further comprise an additional VLP-associating antigen, or VLP-associating polypeptide linked to a second antigen.

[0011] Another aspect includes methods for producing a chimeric virus-like particle, comprising: (a) providing one or more expression vectors together which express a lentivirus or alpha-retrovirus Gag polypeptide and a respiratory syncytial virus F polypeptide, which may have at least 80% sequence identity, at least 85% sequence identity, at least 90% sequence identity, at least 95% sequence identity, at least 97% sequence identity, or at least 99% sequence identity to any of the respiratory syncytial virus F polypeptide nucleic acid sequences disclosed in the examples herein; (b) introducing the one or more expression vectors into a eukaryotic cell in a media; and (c) expressing the retroviral Gag polypeptide and the respiratory syncytial virus F polypeptide to produce the chimeric virus-like particle. In certain embodiments, the eukaryotic cell is a yeast cell or a mammalian cell. In certain embodiments, the eukaryotic cell is a mammalian cell. In some embodiments, the Gag polypeptide is from a human immunodeficiency virus, which may have at least 80% sequence identity, at least 85% sequence identity, at least 90% sequence identity, at least 95% sequence identity, at least 97% sequence identity, or at least 99% sequence identity to any of the

human immunodeficiency Gag polypeptide nucleic acid sequences disclosed in the examples herein, or a simian immunodeficiency virus, which may have at least 80% sequence identity, at least 85% sequence identity, at least 90% sequence identity, at least 95% sequence identity, at least 97% sequence identity, or at least 99% sequence identity to the simian immunodeficiency virus Gag polypeptide amino acid sequences disclosed in the examples herein. In other embodiments, the Gag polypeptide is from an avian leukosis virus, which may have at least 80% sequence identity, at least 85% sequence identity, at least 90% sequence identity, at least 95% sequence identity, at least 97% sequence identity, or at least 99% sequence identity to any of the avian leukosis virus Gag polypeptide nucleic acid sequences disclosed in the examples herein. In another embodiment, the virus-like particle further comprises mammalian glycosylation.

[0012] In another embodiment which may be combined with the preceding aspect, the method further includes the step of recovering the virus-like particles from the media in which the eukaryotic cell is cultured.

[0013] In another embodiment which may be combined with the preceding embodiment and aspect, the expression vector may be a viral vector. In another embodiment which may be combined with the preceding embodiments and aspect, the viral vector may be selected from the group consisting of: an adenovirus, a herpesvirus, a poxvirus and a retrovirus. In another embodiment which may be combined with the preceding embodiments and aspect that include a viral vector, the viral vector further includes a transcriptional regulator that down-regulates expression of the respiratory syncytial virus F polypeptide when the viral vector is propagated in a helper cell or up-regulates expression of the respiratory syncytial virus F polypeptide in the eukaryotic cell. In certain embodiments, the transcriptional regulator may be a tet repressor or a metallothionine inducible enhancer. In another embodiment which may be combined with the preceding embodiment and aspect, the eukaryotic cell may be selected from the group consisting of a BHK cell, a VERO cell, an HT1080 cell, an MRC-5 cell, a WI 38 cell, an MDCK cell, an MDBK cell, a 293 cell, a 293T cell, an RD cell, a COS-7 cell, a CHO cell, a Jurkat cell, a HUT cell, a SUPT cell, a C8166 cell, a MOLT4/clone8 cell, an

MT-2 cell, an MT-4 cell, an H9 cell, a PM1 cell, a CEM cell, a myeloma cell, SB20 cell, a LtK cell, a HeLa cell, a WI-38 cell, an L2 cell, a CMT-93, and a CEMX174 cell.

[0014] In another embodiment which may be combined with the preceding embodiment and aspect, a neutralizing anti-RSV-F antibody may bind to the expressed respiratory syncytial virus F polypeptide (demonstrating that the respiratory syncytial virus F polypeptide is substantially in a native fold). In another embodiment which may be combined with the preceding embodiments and aspect including a neutralizing antibody, the neutralizing anti-RSV-F antibody is Palivizumab.

[0015] Another aspect includes methods for treating or preventing respiratory syncytial virus infection comprising administering to a subject an immunogenic amount of the preparation of any of the preceding embodiments of that aspect or the population produced by the method or any of the preceding embodiments of that aspect. Another embodiment that may be combined with any of the embodiments of the preceding aspect, the administration induces a protective immunization response in the subject. Another embodiment that may be combined with any of the embodiments of the preceding aspect, the administration may be selected from the group consisting of subcutaneous delivery, transcutaneous delivery, intradermal delivery, subdermal delivery, intramuscular delivery, peroral delivery, oral delivery, intranasal delivery, buccal delivery, sublingual delivery, intraperitoneal delivery, intravaginal delivery, anal delivery and intracranial delivery.

[0016] Another aspect includes pharmaceutical compositions comprising an immunogenic amount of the preparation of any of the preceding embodiments of that aspect or the population produced by the method or any of the preceding embodiments of that aspect. Another embodiment that may be combined with any of the embodiments of the preceding aspect, the pharmaceutical composition further includes a pharmaceutically acceptable carrier.

[0017] Another aspect includes methods for providing protection against respiratory syncytial virus infection comprising administering to a subject an immunogenic amount of the preparation of any of the preceding embodiments of that

aspect or the population produced by the method or any of the preceding embodiments of that aspect. Another embodiment that may be combined with any of the embodiments of the preceding aspect, the administration may be selected from the group consisting of subcutaneous delivery, transcutaneous delivery, intradermal delivery, subdermal delivery, intramuscular delivery, peroral delivery, oral delivery, intranasal delivery, buccal delivery, sublingual delivery, intraperitoneal delivery, intravaginal delivery, anal delivery and intracranial delivery.

[0018] The foregoing aspects and embodiments thereof may further be combined with any of the embodiments disclosed in the specification. Additional aspects of the compositions and methods disclosed herein may be found throughout the specification which may be included with any of foregoing embodiments and/or the additional embodiments disclosed in the specification.

SUMMARY OF THE FIGURES

[0019] Figure 1 shows the plasmid map of p3.1-shFv1.

[0020] Figure 2 shows the plasmid map of p3.1-shFv2.

[0021] Figure 3 shows the plasmid map for p3.1-Gag.

[0022] Figure 4 shows cytometric analysis of surface expression of RSV F on cells transfected with RSV F and Gag expression vectors. Non-transfected cells and cells transfected with p3.1-Gag alone exhibit background fluorescence levels. Cells transfected with RSV F expression vectors, with and without p3.1-Gag, show significant levels of fluorescence as a result of F detection by the 9C5 monoclonal antibody and fluorescent secondary antibody.

[0023] Figure 5 shows detection of RSV F antigenic activity in the 100,000 x g pellets from the medium of cells transfected with RSV F genes with and without co-transfection with a Gag gene.

[0024] Figure 6 shows the plasmid map of p3.1-bruGag.

[0025] Figure 7 shows the plasmid map of p3.1-F-GPI.

[0026] Figure 8 shows the HIV-1 Gag Western blot of VLPs derived from p3.1-bruGag plus p3.1-F-GPI transfection. "G" indicates bruGag only expression. "F" indicates F-GPI only expression. "1:1," "3:1," and "9:1" indicate the ratio of bruGag to F-GPI.

[0027] Figure 9 shows an RSV F Western blot of VLPs derived from p3.1-bruGag plus p3.1-F-GPI transfection. "G" indicates bruGag only expression. "F" indicates F-GPI only expression. "1:1," "3:1," and "9:1" indicate the ratio of bruGag to F-GPI.

[0028] Figure 10 shows an SDS-PAGE and Western blot showing bruGag and F-GPI products in VLPs released from transfected 293F cells. A silver-stained SDS-PAGE gel is shown in the left panel. The Western blot is shown in the right panel.

[0029] Figure 11 shows ELISA detection of F antigen in VLPs released from 293 F cells following transfection with plasmids encoding bruGag and F-GPI. Black circles indicate bruGag + F-GPI VLPs. Dark gray circles indicate the negative control. Triangles indicate the RSV virus positive control.

[0030] Figure 12 shows the plasmid map of p3.1-RSVFT.

[0031] Figure 13 shows an SDS-PAGE and Western blot showing bruGag and RSVFT products in VLPs released from transfected 293F cells. A silver-stained SDS-PAGE gel is shown in the left panel. The Western blot is shown in the right panel.

[0032] Figure 14 shows ELISA detection of F antigen in VLPs released from 293 F cells following transfection with plasmids encoding bruGag and RSVFT. Black circles indicate bruGag + F-GPI VLPs. Dark gray circles indicate the negative control. Triangles indicate the RSV virus positive control.

[0033] Figure 15 shows an electron micrograph of negative-stained, sucrose-banded VLPs derived from transfection of 293F cells with plasmids p3.1-bruGag and p3.1-RSVFT.

[0034] Figure 16 shows a plaque reduction assay demonstrating the induction of RSV-neutralizing antibody responses following VLP inoculation of mice. Columns 1-2 show RSV neutralization using control Synagis and goat anti-RSV antibodies, respectively. Columns 3-4 show lack of neutralization with sera from naïve mice. Columns 5-10 show neutralization activity detected in sera of VLP-immunized mice. Columns 11-12 show the no antibody control and lack of neutralization.

[0035] Figure 17 shows the plasmid map of p3.1-alvGag-dPR.

[0036] Figure 18 shows ELISA detection of F antigen pseudotyped onto alvGag VLPs following transfection of 293F cells with p3.1-alvGag-dPR and p3.1-RSVFT.

[0037] Figure 19 shows ELISA detection of F antigen pseudotyped onto alvGag VLPs and HIVGag VLPs following co-transfection of 293F cells with p3.1-alvGag-dPR and p3.1-RSVFT and with p3.1-bruGag and p3.1-RSVFT, respectively. Black circles indicate RSV virus positive control. Dark gray circles indicate alvGag-dPR + FT (3:1). Triangles pointing down indicate alvGag-dPR + FT (3:1). Triangles pointing up indicate HIVGag + FT (3:1).

[0038] Figure 20 shows ELISA detection of RSV F-pseudotyped VLPs produced via co-transfection of p3.1-RSVFT along with vectors encoding various Gag products. Black circles indicate MPMV-Gag + FT. Dark gray circles indicate BLV-Gag + FT. Triangles pointing down indicate EIAV-Gag + FT. Triangles pointing up indicate alvGag-dPR + FT.

[0039] Figure 21 shows plasmid map of p3.1-alvGag encoding the complete alvGag polyprotein with intact retroviral protease activity.

[0040] Figure 22 shows detection of RSV F antigenic activity in the medium of cells transfected with p3.1-RSVFT or p3.1-RSVFL in combination with p3.1-alvGag-dPR and/or p3.1-alvGag. VLPs were collected from the medium by ultracentrifugation then trapped on filter bottom ELISA plates. Black circles indicate Gag-dPR + FL (3:1). Dark gray circles indicate Gag-dPR + FT (3:1). Triangles pointing down indicate Gag + FL (3:1). Triangles pointing up indicate Gag + FT (3:1). Black squares indicate Gag-

dPR + Gag + FL (10:1:3). Grey squares indicate Gag-dPR + Gag + FT (10:1:3). Grey diamonds indicate Gag-dPR + Gag + FL (3:1:1.3). Light grey diamonds indicate Gag-dPR + Gag + FT (3:1:1.3).

[0041] Figure 23 shows a silver stained PAGE showing the proteolytic processing of ALV Gag in pelleted VLPs following transfection of cells with plasmids p3.1-alvGag-dPR and/or p3.1-alvGag. The lanes are as follows: Lane 1: alvGag-dPR + FL (3:1); Lane 2: alvGag-dPR + FT (3:1); Lane 3: alvGag + FL (3:1); Lane 4: alvGag + FT (3:1); Lane 5: alvGag-dPR + alvGag + FT (10:1:3); Lane 6: alvGag-dPR + alvGag + FL (10:1:3); Lane 7: alvGag-dPR + alvGag + FL (3:1:1.3); and Lane 8: alvGag-dPR + alvGag + FT (3:1:1.3).

[0042] Figure 24 shows an electron micrograph of negative-stained, sucrose-banded VLPs derived from transfection of 293F cells with plasmids p3.1-alvGag-dPR, p3.1-alvGag and p3.1-RSVFT at a ratio of 10:1:3.

[0043] Figure 25 shows (panel A) ELISA titers and (panel B) plaque reduction titers in various strains of mice immunized with ALV Gag VLPs pseudotyped with RSV "FT" and RSV "FL". Panel A: Antibody titers specific for RSV virus immobilized on ELISA plates. Panel B: Plaque reduction neutralizing titers.

[0044] Figure 26 shows the plasmid map of p3.1-HSVgD.

[0045] Figure 27 shows the direct ELISA of HSVgD- and alvGAG-dPR-transfected HEK 293F Culture Supernatant Fluids.

[0046] Figure 28 shows the immunoblot of HSVgD- and alvGAG-dPR-transfected HEK 293F Ultracentrifuge (UC) pelleted material. Panels (A) and (B) both have from left to right: standard (molecular weights are shown on the left); A (Transfection #314-85, see Table 1), B (Transfection #314-85, see Table 1), C (Transfection #314-85, see Table 1); standard; D (Transfection #314-91, see Table 1), E (Transfection #314-91, see Table 1), F (Transfection #314-91, see Table 1), and G (Transfection #314-91, see Table 1). Panel (A) shows the western blot using an anti-

HSVgD monoclonal antibody, and (B) shows the western blot using anti-P27 alvGAG polyclonal antibodies.

[0047] Figure 29 shows two electron micrographs of sample C: p3.1-alvGAG-dPR only transfected HEK 293F Ultracentrifuge (UC) pelleted material. Both micrographs have a 500 nm scale bar.

[0048] Figure 30 shows five electron micrographs of Sample D: p3.1-HSVgD only transfected HEK 293F Ultracentrifuge (UC) pelleted material. All five micrographs have a 1000 nm scale bar. The solid line arrows point to large triangular or folded particles ~150 – 200 nm. The dashed line arrows point to smaller oval to round particles ~ 90 – 120 nm.

[0049] Figure 31 shows five electron micrographs of Sample F: p3.1-HSVgD and p3.1-alvGAG-dPR (2.3:1) transfected HEK 293F Ultracentrifuge (UC) pelleted material. Top two micrographs have a 1000 scale bar.

[0050] Figure 32 shows the map of p3.1-SIVagmGag.

[0051] Figure 33 shows ELISA detection of F antigen in VLPs released from 293 F cells following transfection with plasmids encoding SIVagmGag and RSVFT.

[0052] Figure 34 shows the plasmid map of pShuttle-CMV-TO.

[0053] Figure 35 shows the plasmid map of pShuttle-ALV-Gag-dPR.

[0054] Figure 36 shows the plasmid map of pShuttle-TO-FL.

[0055] Figure 37 shows the plasmid map of pShuttle-dPR-TO-FL-rev.

[0056] Figure 38 shows (a) the visible band of RSV F-pseudotyped VLPs collected between the 30% and 60% steps of a sucrose step gradient and (b) SDS-PAGE analysis of purified RSV F-pseudotyped VLPs produced via adenovirus vector transduction of Vero cells.

[0057] Figure 39 shows the Western blot of VLPs showing presence of F antigen.

[0058] Figure 40 shows an electron micrograph of RSV F-pseudotyped VLPs in the final VLP preparation derived from adenovirus vector-transduced Vero cells.

[0059] Figure 41 shows RSV neutralization titers in cotton rats immunized with RSV VLPs.

[0060] Figure 42 shows virus titers in the lungs of immunized and challenged cotton rats.

[0061] Figure 43 shows lung histopathology scores (alveolitis and interstitial pneumonia) in VLP-immunized and challenged cotton rats.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0062] Various aspects of the compositions and methods disclosed herein include, without limitation, chimeric VLPs that include at least an RSV-F polypeptide and a lentivirus or alpha-retrovirus GAG polypeptide; methods of expressing or generating such chimeric VLPs (which can be in a mammalian cell expression system); methods of further processing such VLPs into vaccine compositions and methods of using such vaccine compositions.

[0063] In certain embodiments, chimeric VLPs disclosed herein comprise a lentivirus or alpha-retrovirus Gag polypeptide and a respiratory syncytial virus F polypeptide.

[0064] Certain aspects and embodiments of the chimeric VLPs disclosed herein are based upon the surprising discovery that co-expression of an RSV-F polypeptide with a number of retroviral Gag proteins including the murine leukemia virus Gag protein, the Mason-Phizer monkey virus Gag protein, the bovine leukemia virus Gag protein, and the equine infectious anemia virus Gag protein result in markedly reduced amounts of VLPs which indicates that the RSV-F polypeptide interferes in some way with the budding function of the MLV Gag protein. This result does not depend upon interference between the cytoplasmic tail of the RSV-F polypeptide and the MLV gag, as constructs where the extracellular portion of the RSV-F polypeptide was anchored to the VLP via a GPI-

anchor tag still interfered with VLP formation. In contrast, as demonstrated in the examples herein, the RSV-F polypeptide surprisingly does not interfere with VLP formation by rous sarcoma virus Gag protein, by avian leukosis virus Gag protein, by simian immunodeficiency virus Gag protein, or by human immunodeficiency virus Gag protein.

[0065] An exemplary method of generating the chimeric VLPs is by expression in eukaryotic cells, which in particular embodiments may be yeast, insect or mammalian cells, and which may include co-expression of additional polypeptide antigens.

[0066] The practice of the disclosed methods and protocols will employ, unless otherwise indicated, conventional techniques of chemistry, molecular biology, microbiology, recombinant DNA and immunology, which are within the capabilities of a person of ordinary skill in the art. Such techniques are explained in the literature. See, for example, J. Sambrook, E. F. Fritsch, and T. Maniatis, 1989, Molecular Cloning: A Laboratory Manual, Second Edition, Books 1-3, Cold Spring Harbor Laboratory Press; Ausubel, F. M. et al. (1995 and periodic supplements; Current Protocols in Molecular Biology, ch. 9, 13, and 16, John Wiley & Sons, New York, N.Y.); B. Roe, J. Crabtree, and A. Kahn, 1996, DNA Isolation and Sequencing: Essential Techniques, John Wiley & Sons; J. M. Polak and James O'D. McGee, 1990, In Situ Hybridization: Principles and Practice; Oxford University Press; M. J. Gait (Editor), 1984, Oligonucleotide Synthesis: A Practical Approach, Irl Press; and, D. M. J. Lilley and J. E. Dahlberg, 1992, Methods of Enzymology: DNA Structure Part A: Synthesis and Physical Analysis of DNA Methods in Enzymology, Academic Press.

Definitions

[0067] A "***chimeric VLP***" as used here refers to virus-like particles that are formed using a lentivirus or alpha-retrovirus Gag polypeptide that may be expressed simultaneously with a respiratory syncytial virus F polypeptide. Examples include, without limitation, VLPs comprising a respiratory syncytial virus F polypeptide substantially lacking the cytoplasmic portion of the respiratory syncytial virus F polypeptide or a respiratory syncytial virus F polypeptide substantially lacking the

transmembrane domain and the cytoplasmic portion of respiratory syncytial virus F polypeptide and additionally linked to a GPI anchor signal.

[0068] "***Mammalian glycosylation***" refers to glycosylation patterns generated by mammalian cell expression systems. Such glycosylation patterns do not include glycosylation patterns produced by insect cells that have been modified to include mammalian glycosylation enzymes, so long as such modified insect cells only produce "mammalian-like" glycosylation rather than the glycosylation pattern that would be naturally produced by a mammal or a mammalian cell based expression system. Non-limiting examples of mammalian glycosylation patterns include glycosylation produced by expression in human (e.g., HEK 293, HeLa), Chinese hamster ovary (CHO), dog (e.g., MDCK), mouse (e.g., H9), rat (e.g., IE) and non-human primate (e.g., NCTC) cells.

[0069] A "***Gag polypeptide***" as used herein includes any retroviral Gag polypeptide that is from a lentivirus (but excluding EIAV) or alpha-retrovirus. Certain embodiments of the chimeric VLPs described herein are formed by ALV or HIV Gag polypeptides.

[0070] The genome of retroviruses codes for three major gene products: the gag gene coding for structural proteins, the pol gene coding for reverse transcriptase and associated proteolytic polypeptides, nuclease and integrase associated functions, and env whose encoded glycoprotein membrane proteins are detected on the surface of infected cells and also on the surface of mature released virus particles. The gag genes of all retroviruses have an overall structural similarity and within each group of retroviruses are conserved at the amino acid level. The gag gene gives rise to the core proteins excluding the reverse transcriptase.

[0071] For MLV the Gag precursor polyprotein is $Pr65^{Gag}$ and is cleaved into four proteins whose order on the precursor is NH_2-p15-pp12-p30-p10-COOH. These cleavages are mediated by a viral protease and may occur before or after viral release depending upon the virus. The MLV Gag protein exists in a glycosylated and a non-glycosylated form. The glycosylated forms are cleaved from $gPr80^{Gag}$ which is synthesized from a different inframe initiation codon located upstream from the AUG

codon for the non-glycosylated $Pr65^{Gag}$. Deletion mutants of MLV that do not synthesize the glycosylated Gag are still infectious and the non-glycosylated Gag can still form virus-like particles, thus raising the question over the importance of the glycosylation events. The post translational cleavage of the HIV-1 Gag precursor of $pr55^{Gag}$ by the virus coded protease yields the N-myristoylated and internally phosphorylated p17 matrix protein (p17MA), the phosphorylated p24 capsid protein (p24CA), and the nucleocapsid protein p15 (p15NC), which is further cleaved into p9 and p6.

[0072] Structurally, the prototypical Gag polyprotein is divided into three main proteins that always occur in the same order in retroviral gag genes: the matrix protein (MA) (not to be confused with influenza matrix protein M1, which shares the name matrix but is a distinct protein from MA), the capsid protein (CA), and the nucleocapsid protein (NC). Processing of the Gag polyprotein into the mature proteins is catalyzed by the retroviral encoded protease and occurs as the newly budded viral particles mature. Functionally, the Gag polyprotein is divided into three domains: the membrane binding domain, which targets the Gag polyprotein to the cellular membrane; the interaction domain which promotes Gag polymerization; and the late domain which facilitates release of nascent virions from the host cell. The form of the Gag protein that mediates assembly is the polyprotein. Thus, the assembly domains need not lie neatly within any of the cleavage products that form later. The state of the art is quite advanced regarding these important functional elements. See, *e.g.*, Hansen *et al.* J. Virol 64, 5306-5316, 1990; Will *et al.*, AIDS 5, 639-654, 1991; Wang *et al.* J. Virol. 72, 7950-7959, 1998; McDonnell *et al.*, J. Mol. Biol. 279, 921-928, 1998; Schultz and Rein, J. Virol. 63, 2370-2372, 1989; Accola *et al.*, J. Virol. 72, 2072-2078, 1998; Borsetti *et al.*, J. Virol., 72, 9313-9317, 1998; Bowzard *et al.*, J. Virol. 72, 9034-9044, 1998; Krishna *et al.*, J. Virol. 72, 564-577, 1998; Wills *et al.*, J. Virol. 68, 6605-6618, 1994; Xiang *et al.*, J. Virol. 70, 5695-5700, 1996; Garnier *et al.*, J. Virol. 73, 2309-2320, 1999.

[0073] Examples of retroviral sources for Gag polypeptides include alpha-retroviruses (such as the avian leukosis virus or the Rous sarcoma virus), or lentiviruses (human immunodeficiency virus type 1, HIV-2, simian immunodeficiency virus, feline

immunodeficiency virus, and caprine arthritis encephalitis virus (but excluding the equine infectious anemia virus)).

[0074] Alpha-retroviruses such as avian leukosis virus contain their protease domain as part of the Gag polyprotein rather than the Pol polyprotein as is the case with most other retroviruses. For use in the compositions and methods as described herein, a Gag polypeptide may be substantially lacking a C-terminal protease domain.

[0075] The "***lipid raft***" as used herein refers to the cell membrane microdomain in which the gag polypeptide may concentrate during the viral particle assembly process and therefore may be used as a means to incorporate additional antigens that either naturally associated with lipid rafts or are linked to a lipid-raft associated polypeptide.

[0076] A "***VLP-associated polypeptide***" as used herein refers to any polypeptide that is directly or indirectly associated with a VLP excluding any enveloped virus core forming polypeptide that would interfere with the lentivirus or alpha-retrovirus Gag polypeptide. The particular VLP-associated polypeptide used in the compositions and methods disclosed herein will depend on the desired use of the VLP and the role of the VLP-associated polypeptide (e.g., attaching one or more additional antigens or adjuvants to the VLP).

[0077] The VLP-associated polypeptide can be an integral membrane protein or a lipid raft-associating portion, a protein or portion thereof directly associated with the VLP via a protein modification which causes association with the membrane such as lipid modification, or a polypeptide with an indirect association with the VLP via a lipid raft-associated polypeptide.

[0078] Many proteins with lipid anchors associate with lipid rafts. Often short fragments of such proteins are sufficient for lipid attachment making such fragments ideal for lipid raft association as the fragments can be readily attached to other proteins and polypeptide that may not themselves naturally associate with lipid rafts. Lipid anchors that couple polypeptides to lipid rafts include GPI anchors, myristoylation, palmitoylation, and double acetylation.

[0079] Many different types of polypeptides are associated with lipid rafts. Lipid rafts function as platforms for numerous biological activities including signal transduction, membrane trafficking, viral entry, viral assembly, and budding of assembled particles and are therefore associated with the various polypeptides involved in these processes.

[0080] The various types of polypeptides involved in signaling cascades are associated with lipid rafts that function as signaling platforms. One type of lipid raft which functions as signaling platform is called a caveolae. It is a flask shaped invagination of the plasma-membrane which contains polypeptides from the caveolin family (e.g., caveolin and/or flottillin).

[0081] Membrane trafficking polypeptides are associated with lipid rafts which function as membrane trafficking platforms. Examples include the proteins involved in endocytosis and excocytosis, such as syntaxin-1, syntaxin-4, synapsin I, adducin, VAMP2, VAMP/synaptobrevin, synaptobrevin II, SNARE proteins, SNAP-25, SNAP-23, synaptotagmin I, synaptotagmin II, and the like.

[0082] Viral receptors, receptor-coreceptor complexes, any other components which help modulate the entry process are associated with lipid rafts which function as specialized membrane trafficking platforms for viral entry. Examples of lipid raft-associated viral receptors include the decay accelerating factor (DAF or CD55), a GPI-anchored membrane glycoprotein that is a receptor for many enteroviruses; the receptor for group A rotaviruses, a complex containing multiple components including gangliosides, Hsc70 protein, alpha2-beta1 and alpha5-beta2 integrins; glycoproteins of several enveloped viruses like HIV, MLV, measles, and Ebola; and polypeptides involved in HIV entry like CD5, CCR5, and nef. See Chazal and Gerlier, 2003, Virus Entry, Assembly, Budding, and Membrane Rafts, Microbiol. & Mol. Bio. Rev. 67(2):226-237.

[0083] Polypeptides involved in viral particle assembly are associated with lipid rafts functioning as viral assembly platforms. So long as portions that are responsible for formation of the viral nucleocapsid, capsid or core are omitted, such polypeptides or

portions thereof may be used as VLP-associated polypeptides. Examples of such polypeptides include the HA and NA influenza envelope glycoproteins, the H and mature F1-F2 fusion proteins from measles, and the gp160, gp41, and Pr55gag from HIV. See Chazal and Gerlier, 2003, Virus Entry, Assembly, Budding, and Membrane Rafts, Microbiol. And Mol. Bio. Rev. 67(2):226-237.

[0084] Polypeptides involved in budding of assembled virus are associated with lipid rafts that function as viral budding platforms. There is data suggesting that HIV-1 budding from the host cell occurs in membrane rafts. See Chazal and Gerlier, 2003, Virus Entry, Assembly, Budding, and Membrane Rafts, Microbiol. And Mol. Bio. Rev. 67(2):226-237. General information about polypeptides involved in viral budding can be found in Fields Virology (4th ed.) 2001.

[0085] Some VLP-associated polypeptides include viral polypeptides such as hemagglutinin polypeptide, neuraminidase polypeptide, fusion protein polypeptide, glycoprotein polypeptide, and envelope protein polypeptide. Each of these polypeptides can be from any type of virus; however, certain embodiments include envelope protein from HIV-1 virus, fusion protein from respiratory syncytial virus or measles virus, glycoprotein from respiratory syncytial virus, herpes simplex virus, or Ebola virus, and hemagglutinin protein from measles virus.

[0086] Certain non-viral pathogen VLP-associated polypeptides may be obtained from pathogenic protozoa, helminths, and other eukaryotic microbial pathogens including, but not limited to, Plasmodium such as Plasmodium falciparum, Plasmodium malariae, Plasmodium ovale, and Plasmodium vivax; Toxoplasma gondii; Trypanosoma brucei, Trypanosoma cruzi; Schistosoma haematobium, Schistosoma mansoni, Schistosoma japonicum; Leishmania donovani; Giardia intestinalis; Cryptosporidium parvum; and the like. Such non-viral VLP-associated polypeptides may be used without being linked to an antigen not naturally associated with a lipid-raft as the VLP-associated polypeptide itself will act as the antigen.

[0087] An example of a viral VLP-associated polypeptide that may be included with the chimeric VLPs is a hemagglutinin polypeptide. The *"**hemagglutinin***

polypeptide" as used herein is derived from the influenza virus protein that mediates binding of the virus to the cell to be infected. Hemagglutinin polypeptides may also be derived from the comparable measles virus protein. The protein is an antigenic glycoprotein found anchored to the surface of influenza viruses by a single membrane spanning domain. At least sixteen subtypes of the influenza hemagglutinin have been identified labeled H1 through H16. H1, H2, and H3, are found in human influenza viruses. Highly pathogenic avian flu viruses with H5 or H7 hemagglutinins have been found to infect humans at a low rate. It has been reported that single amino acid changes in the avian virus strain's type H5 hemagglutinin have been found in human patients that alters the receptor specificity to allow the H5 hemagglutinin to significantly alter receptor specificity of avian H5N1 viruses, providing them with an ability to bind to human receptors (109 and 110). This finding explains how an H5N1 virus that normally does not infect humans can mutate and become able to efficiently infect human cells.

[0088] Hemagglutinin is a homotrimeric integral membrane polypeptide. The membrane spanning domain naturally associates with the raft-lipid domains, which allows it to associate with the respiratory syncytial virus F polypeptides for incorporation into VLPs. It is shaped like a cylinder, and is approximately 135 Å long. The three identical monomers that constitute HA form a central coiled-coil and a spherical head that contains the sialic acid binding sites, which is exposed on the surface of the VLPs. HA monomers are synthesized as a single polypeptide precursor that is glycosylated and cleaved into two smaller polypeptides: the HA1 and HA2 subunits. The HA2 subunits form the trimeric coiled-coil that is anchored to the membrane and the HA1 subunits form the spherical head.

[0089] As used in certain VLPs disclosed herein as a VLP-associated polypeptide, the hemagglutinin polypeptide shall at a minimum include the membrane anchor domain. The hemagglutinin polypeptide may be derived from any influenza virus type, subtype, strain or substrain, which for example may be from the H1, H2, H3, H5, H7, and H9 hemagglutinins. In addition, the hemagglutinin polypeptide may be a chimera of different influenza hemagglutinins. The hemagglutinin polypeptide may include one or more additional antigens not naturally associated with a lipid raft that may

be generated by splicing the coding sequence for the one or more additional polypeptides into the hemagglutinin polypeptide coding sequence. An exemplary site for insertion of additional polypeptides into the hemagglutinin polypeptide is the N-terminus.

[0090] Another example of a viral VLP-associated polypeptide is a neuraminidase polypeptide. The *"**neuraminidase polypeptide**"* as used herein is derived from the influenza virus protein that mediates release of the influenza virus from the cell by cleavage of terminal sialic acid residues from glycoproteins. The neuraminidase glycoprotein is expressed on the viral surface. The neuraminidase proteins are tetrameric and share a common structure consisting of a globular head with a beta-pinwheel structure, a thin stalk region, and a small hydrophobic region that anchors the protein in the virus membrane by a single membrane spanning domain. The active site for sialic acid residue cleavage includes a pocket on the surface of each subunit formed by fifteen charged amino acids, which are conserved in all influenza A viruses. At least nine subtypes of the influenza neuraminidase have been identified labeled N1 through N9.

[0091] As used in certain VLPs disclosed herein, the neuraminidase polypeptide shall at a minimum include the membrane anchor domain. The state of the art regarding functional regions is quite high. See, e.g., Varghese et al., Nature 303, 35-40, 1983; Colman et al., Nature 303, 41-44, 1983; Lentz et al., Biochem, 26, 5321-5385, 1987; Webster et al., Virol. 135, 30-42, 1984. The neuraminidase polypeptide may be derived from any influenza virus type, subtype strain or substrain, which may be from the N1 and N2 neuraminidases. In addition, the neuraminidase polypeptide may be a chimera of different influenza neuraminidase. The neuraminidase polypeptide may include one or more additional antigens that are not naturally associated with a lipid raft that may be generated by splicing the coding sequence for the one or more additional polypeptides into the hemagglutinin polypeptide. An exemplary site for insertion of additional polypeptides into the neuraminidase polypeptide coding sequence is the C-terminus.

[0092] Another example of a VLP-associated peptide is an insect derived adhesion protein termed fasciclin I (FasI). The *"**fasciclin I polypeptide**"* as used herein is derived from the insect protein that is involved in embryonic development. This non-

viral protein can be expressed in an insect cell baculovirus expression system leading to lipid raft association of FasI (J. Virol. 77, 6265-6273, 2003). It therefore follows that attachment of a heterologous antigen to a fasciclin I polypeptide will lead to incorporation of the chimeric molecule into VLPs when co-expressed with respiratory syncytial F polypeptides. As used in the VLPs disclosed herein, the fasciclin I polypeptide shall at a minimum include the membrane anchor domain.

[0093] Another example of a VLP-associated peptide is a viral derived attachment protein from RSV named the G glycoprotein. The ***"G glycopolypeptide"*** as used herein is derived from the RSV G glycoprotein. Recent data has demonstrated that lipid raft domains are important for RSV particle budding as they are for influenza virus (Virol 327, 175-185, 2004; Arch. Virol. 149, 199-210, 2004; Virol. 300, 244-254, 2002). The G glycoprotein from RSV is a 32.5 kD integral membrane protein that serves as a viral attachment protein as well as a protective antigen for RSV infection. As with the hemagglutinin from influenza virus, its antigenicity may enhance the antigenicity of any non-lipid raft antigens attached to it. Any modifications to the G glycopolypeptide in the way of non-lipid raft foreign antigen attachment will result in chimeric VLPs capable of inducing significant immune responses to the foreign antigen.

Antigens

[0094] Certain aspects of the compositions and methods disclosed herein include additional antigens associated with the chimeric VLPs. Such additional antigens may be included in the same composition and may further be covalently or non-covalently associated with the VLPs. In certain embodiments, the Gag polypeptide is a readily adaptable platform for forming chimeric VLPs containing respiratory syncytial virus F polypeptide and/or other VLP-associated polypeptides. This section describes exemplary antigens for use with the disclosed VLPs.

Linkage between antigen and VLP-associated polypeptide

[0095] As a means for forming VLPs containing antigens not naturally associated with a VLP, a linkage may be formed between the respiratory syncytial virus F

polypeptide and/or another VLP-associated polypeptide and the antigen. The VLP-associated polypeptide may be linked to a single antigen or to multiple antigens to increase immunogenicity of the VLP, to confer immunogenicity to various pathogens, or to confer immunogenicity to various strains of a particular pathogen.

[0096] The linkage between the antigen and a VLP-associated polypeptide can be any type of linkage sufficient to result in the antigen being incorporated into the VLP. The bond can be a covalent bond, an ionic interaction, a hydrogen bond, an ionic bond, a van der Waals force, a metal-ligand interaction, or an antibody-antigen interaction. In certain embodiments, the linkage is a covalent bond, such as a peptide bond, carbon-oxygen bond, a carbon-sulfur bond, a carbon-nitrogen bond, a carbon-carbon bond, or a disulfide bond.

[0097] The antigen may be produced recombinantly with an existing linkage to the VLP-associated polypeptide or it may be produced as an isolated substance and then linked at a later time to the VLP-associated polypeptide.

Antigen types

[0098] The antigens as used herein can be any substance capable of eliciting an immune response and which does not naturally associate with a lipid raft. Antigens include, but are not limited to, proteins, polypeptides (including active proteins and individual polypeptide epitopes within proteins), glycopolypeptides, lipopolypeptides, peptides, polysaccharides, polysaccharide conjugates, peptide and non-peptide mimics of polysaccharides and other molecules, small molecules, lipids, glycolipids, and carbohydrates. If the antigen does not naturally associate either directly or indirectly with a VLP, it would not be expected to be incorporated into a VLP without linkage to a VLP-associated polypeptide. The antigen can be any antigen implicated in a disease or disorder, e.g., microbial antigens (e.g., viral antigens, bacterial antigens, fungal antigens, protozoan antigens, helminth antigens, yeast antigens, etc.), tumor antigens, allergens and the like.

Sources for Antigens

[0099] The antigens described herein may be synthesized chemically or enzymatically, produced recombinantly, isolated from a natural source, or a combination of the foregoing. The antigen may be purified, partially purified, or a crude extract.

[0100] Polypeptide antigens may be isolated from natural sources using standard methods of protein purification known in the art, including, but not limited to, liquid chromatography (e.g., high performance liquid chromatography, fast protein liquid chromatography, etc.), size exclusion chromatography, gel electrophoresis (including one-dimensional gel electrophoresis, two-dimensional gel electrophoresis), affinity chromatography, or other purification technique. In many embodiments, the antigen is a purified antigen, e.g., from about 50% to about 75% pure, from about 75% to about 85% pure, from about 85% to about 90% pure, from about 90% to about 95% pure, from about 95% to about 98% pure, from about 98% to about 99% pure, or greater than 99% pure.

[0101] One may employ solid phase peptide synthesis techniques, where such techniques are known to those of skill in the art. See Jones, The Chemical Synthesis of Peptides (Clarendon Press, Oxford) (1994). Generally, in such methods a peptide is produced through the sequential additional of activated monomeric units to a solid phase bound growing peptide chain.

[0102] Well-established recombinant DNA techniques can be employed for production of polypeptides either in the same vector as the lipid-raft associated polypeptide, where, e.g., an expression construct comprising a nucleotide sequence encoding a polypeptide is introduced into an appropriate host cell (e.g., a eukaryotic host cell grown as a unicellular entity in *in vitro* cell culture, e.g., a yeast cell, an insect cell, a mammalian cell, etc.) or a prokaryotic cell (e.g., grown in *in vitro* cell culture), generating a genetically modified host cell; under appropriate culture conditions, the protein is produced by the genetically modified host cell.

Viral Antigens

[0103] Suitable viral antigens include those associated with (e.g., synthesized by) viruses of one or more of the following groups: Retroviridae (e.g. human immunodeficiency viruses, such as HIV-1 (also referred to as HTLV-III, LAV or HTLV-III/LAV, or HIV-III); and other isolates, such as HIV-LP; Picomaviridae (e.g. polio viruses, hepatitis A virus; enteroviruses, human Coxsackie viruses, rhinoviruses, echoviruses); Calciviridae (e.g. strains that cause gastroenteritis, including Norwalk and related viruses); Togaviridae (e.g. equine encephalitis viruses, rubella viruses); Flaviridae (e.g. dengue viruses, encephalitis viruses, yellow fever viruses); Coronoviridae (e.g. coronaviruses); Rhabdoviradae (e.g. vesicular stomatitis viruses, rabies viruses); Coronaviridae (e.g. coronaviruses); Rhabdoviridae (e.g. vesicular stomatitis viruses, rabies viruses); Filoviridae (e.g. ebola viruses); Paramyxoviridae (e.g. parainfluenza viruses, mumps virus, measles virus, respiratory syncytial virus); Orthomyxoviridae (e.g. influenza viruses); Bungaviridae (e.g. Hantaan viruses, bunga viruses, phleboviruses and Nairo viruses); Arena viridae (hemorrhagic fever viruses); Reoviridae (e.g. reoviruses, orbiviurses and rotaviruses); Bimaviridae; Hepadnaviridae (Hepatitis B virus); Parvovirida (parvoviruses); Papovaviridae (papilloma viruses, polyoma viruses); Adenoviridae (most adenoviruses); Herpesviridae (herpes simplex virus (HSV) 1 and 2, varicella zoster virus, cytomegalovirus (CMV), herpes virus; Poxyiridae (variola viruses, vaccinia viruses, pox viruses); and Iridoviridae (e.g. African swine fever virus); and unclassified viruses (e.g. the etiological agents of Spongiform encephalopathies, the agent of delta hepatitis (thought to be a defective satellite of hepatitis B virus), the agents of non-A, non-B hepatitis (class 1=internally transmitted; class 2=parenterally transmitted (i.e. Hepatitis C); and astroviruses.

Norvirus Antigens

[0104] The VLPs disclosed herein may include various antigens from the Norovirus family. Noroviruses, also called "Norwalk-like viruses" represent one of four genera within the Caliciviridae virus family. Within the Norovirus genus there are two major genetic groups that have been designated Genogroup I and Genogroup II. Genogroup I Norovirus strains include Norwalk virus, Southampton virus, Desert Shield

virus, and Chiba virus. Genogroup II Norovirus strains include Houston virus, Hawaii virus, Lordsdale virus, Grimsby virus, Mexico virus, and the Snow Mountain agent (Parker, T.D., et al. J Virol. (2005) 79(12):7402-9; Hale, A.D., et al. J Clin. Micro. (2000) 38(4):1656-1660). Norwalk virus (NV) is the prototype strain of a group of human caliciviruses responsible for the majority of epidemic outbreaks of acute viral gastroenteritis worldwide. The Norwalk virus capsid protein has two domains: the shell domain (S) and the protruding domain (P). The P domain (aa 226–530, Norwalk strain numbering) is divided into two subdomains, P1 and P2. The P2 domain is a 127 aa insertion (aa 279–405) in the P1 domain and is located at the most distal surface of the folded monomer. The P2 domain is the least conserved region of VP1 among norovirus strains, and the hypervariable region within P2 is thought to play an important role in receptor binding and immune reactivity. Given the external location of the P domain, it is an exemplary antigen or source of polypeptide epitopes for use as antigens for the VLP vaccines disclosed herein. The P2 domain is an exemplary antigen for Genogroup I or Genogroup II Norovirus strains. Yet another example is the mAb 61.21 epitope recently identified as lying in a region of the P2 domain conserved across a range of norovirus strains, as well as the mAb 54.6 epitope (Lochridge, V.P., et al. J Gen. Virol. (2005) 86:2799-2806).

Influenza antigens

[0105] The VLPs disclosed herein may include various antigens from influenza including, without limitation, hemagglutinin, neuraminidase, or an additional influenza antigen. An additional influenza antigen is the M2 polypeptide. The M2 polypeptide of influenza virus is a small 97 amino acid class III integral membrane protein encoded by RNA segment 7 (matrix segment) following a splicing event (80, 81). Very little M2 exists on virus particles but it can be found more abundantly on infected cells. M2 serves as a proton-selective ion channel that is necessary for viral entry (82, 83). It is minimally immunogenic during infection or conventional vaccination, explaining its conservation, but when presented in an alternative format it is more immunogenic and protective (84-86). This is consistent with observations that passive transfer of an M2 monoclonal antibody in vivo accelerates viral clearance and results in protection (87). When the M2

external domain epitope is linked to HBV core particles as a fusion protein it is protective in mice via both parenteral and intranasal inoculation and is most immunogenic when three tandem copies are fused to the N-terminus of the core protein (88-90). This is consistent with other carrier-hapten data showing that increased epitope density increases immunogenicity (91).

[0106] For intranasal delivery of an M2 vaccine an adjuvant is required to achieve good protection and good results have been achieved with LTR192G (88, 90) and CTA1-DD (89). The peptide can also be chemically conjugated to a carrier such as KLH, or the outer membrane protein complex of N. meningitides, or human papilloma virus VLPs and is protective as a vaccine in mice and other animals (92, 93).

[0107] Insofar as the M2 protein is highly conserved it is not completely without sequence divergence. The M2 ectodomain epitopes of common strains A/PR/8/34 (H1N1) and A/Aichi/68 (H3N2) were shown to be immunologically cross reactive with all other modern sequenced human strains except for A/Hong Kong/156/97 (H5N1)(92). Examination of influenza database sequences also shows similar divergence in the M2 sequence of other more recent pathogenic H5N1 human isolates such as A/Vietnam/1203/04. This finding demonstrates that a successful H5-specific pandemic vaccine incorporating M2 epitopes will need to reflect the M2 sequences that are unique to the pathogenic avian strains rather than M2 sequences currently circulating in human H1 and H3 isolates.

[0108] Additional proteins from influenza virus (other than HA, NA and M2) may be included in the VLP vaccine either by co-expression or via linkage of all or part of the additional antigen to the respiratory syncytial virus F polypeptide or other VLP-associated polypeptides. These additional antigens include PB2, PB1, PA, nucleoprotein, matrix (M1), NS1, and NS2. These latter antigens are not generally targets of neutralizing antibody responses but may contain important epitopes recognized by T cells. T cell responses induced by a VLP vaccine to such epitopes may prove beneficial in boosting protective immunity.

Other Pathogenic Antigens

[0109] Suitable bacterial antigens include antigens associated with (e.g., synthesized by and endogenous to) any of a variety of pathogenic bacteria, including, e.g., pathogenic gram positive bacteria such as pathogenic Pasteurella species, Staphylococci species, and Streptococcus species; and gram-negative pathogens such as those of the genera Neisseria, Escherichia, Bordetella, Campylobacter, Legionella, Pseudomonas, Shigella, Vibrio, Yersinia, Salmonella, Haemophilus, Brucella, Francisella and Bacterioides. See, e.g., Schaechter, M, H. Medoff, D. Schlesinger, Mechanisms of Microbial Disease. Williams and Wilkins, Baltimore (1989).

[0110] Suitable antigens associated with (e.g., synthesized by and endogenous to) infectious pathogenic fungi include antigens associated with infectious fungi including but not limited to: Cryptococcus neoformans, Histoplasma capsulatum, Coccidioides immitis, Blastomyces dermatitidis, and Candida albicans, Candida glabrata, Aspergillus fumigata, Aspergillus flavus, and Sporothrix schenckii.

[0111] Suitable antigens associated with (e.g., synthesized by and endogenous to) pathogenic protozoa, helminths, and other eukaryotic microbial pathogens include antigens associated with protozoa, helminths, and other eukaryotic microbial pathogens including, but not limited to, Plasmodium such as Plasmodium falciparum, Plasmodium malariae, Plasmodium ovale, and Plasmodium vivax; Toxoplasma gondii; Trypanosoma brucei, Trypanosoma cruzi; Schistosoma haematobium, Schistosoma mansoni, Schistosoma japonicum; Leishmania donovani; Giardia intestinalis; Cryptosporidium parvum; and the like.

[0112] Suitable antigens include antigens associated with (e.g., synthesized by and endogenous to) pathogenic microorganisms such as: Helicobacter pyloris, Borelia burgdorferi, Legionella pneumophila, Mycobacteria sps (e.g. M. tuberculosis, M. avium, M. intracellulare, M. kansaii, M. gordonae), Staphylococcus aureus, Neisseria gonorrhoeae, Neisseria meningitidis, Listeria monocytogenes, Chlamydia trachomatis, Streptococcus pyogenes (Group A Streptococcus), Streptococcus agalactiae (Group B Streptococcus), Streptococcus (viridans group), Streptococcus faecalis, Streptococcus

bovis, Streptococcus (anaerobic sps.), Streptococcus pneumoniae, pathogenic Campylobacter sp., Enterococcus sp., Haemophilus influenzae, Bacillus anthracis, Corynebacterium diphtheriae, corynebacterium sp., Erysipelothrix rhusiopathiae, Clostridium perfringens, Clostridium tetani, Enterobacter aerogenes, Klebsiella pneumoniae, Pasturella multocida, Bacteroides sp., Fusobacterium nucleatum, Streptobacillus moniliformis, Treponema pallidium, Treponema pertenue, Leptospira, Rickettsia, and Actinomyces israeli. Non-limiting examples of pathogenic E. coli strains are: ATCC No. 31618, 23505, 43886, 43892, 35401, 43896, 33985, 31619 and 31617.

[0113] Any of a variety of polypeptides or other antigens associated with intracellular pathogens may be included in the VLPs. Polypeptides and peptide epitopes associated with intracellular pathogens are any polypeptide associated with (e.g., encoded by) an intracellular pathogen, fragments of which are displayed together with MHC Class I molecule on the surface of the infected cell such that they are recognized by, e.g., bound by a T-cell antigen receptor on the surface of, a $CD8^+$ lymphocyte. Polypeptides and peptide epitopes associated with intracellular pathogens are known in the art and include, but are not limited to, antigens associated with human immunodeficiency virus, e.g., HIV gp120, or an antigenic fragment thereof; cytomegalovirus antigens; Mycobacterium antigens (e.g., Mycobacterium avium, Mycobacterium tuberculosis, and the like); Pneumocystic carinii (PCP) antigens; malarial antigens, including, but not limited to, antigens associated with Plasmodium falciparum or any other malarial species, such as 41-3, AMA-1, CSP, PFEMP-1, GBP-130, MSP-1, PFS-16, SERP, etc.; fungal antigens; yeast antigens (e.g., an antigen of a Candida spp.); toxoplasma antigens, including, but not limited to, antigens associated with Toxoplasma gondii, Toxoplasma encephalitis, or any other Toxoplasma species; Epstein-Barr virus (EBV) antigens; Plasmodium antigens (e.g., gp190/MSP1, and the like); etc.

[0114] Another VLP vaccine may be directed against *Bacillus anthracis*. *Bacillus anthracis* are aerobic or facultative anaerobic Gram-positive, nonmotile rods measuring 1.0 μm wide by 3.0–5.0 μm long. Under adverse conditions, *B. anthracis* form highly resistant endospores, which can be found in soil at sites where infected animals previously died. An antigen for use in a VLP vaccine as disclosed herein is the

protective antigen (PA), an 83 kDa protein that binds to receptors on mammalian cells and is critical to the ability of *B. anthracis* to cause disease. Another antigen is the C-terminal 140 amino acid fragment of *Bacillus anthracis* PA which may be used to induce protective immunity in a subject against *Bacillus anthracis*. Other exemplary antigens for use in a VLP vaccine against anthrax are antigens from the anthrax spore (e.g., BclA), antigens from the vegetative stage of the bacterium (e.g., a cell wall antigen, capsule antigen (e.g., poly-gamma-D-glutamic acid or PGA), secreted antigen (e.g., exotoxin such as protective antigen, lethal factor, or edema factor). Another antigen for use in a VLP vaccine is the tetra-saccharide containing anthrose, which is unique to *B. anthracis* (Daubenspeck J.M., et al. J. Biol. Chem. (2004), 279:30945). The tetra-saccharide may be coupled to a VLP-associated polypeptide allowing association of the antigen with the VLP vaccine.

Tumor-Associated Antigens

[0115] Any of a variety of known tumor-specific antigens or tumor-associated antigens (TAA) can be included in the VLPs. The entire TAA may be, but need not be, used. Instead, a portion of a TAA, e.g., an epitope, may be used. Tumor-associated antigens (or epitope-containing fragments thereof) which may be used in VLPs include, but are not limited to, MAGE-2, MAGE-3, MUC-1, MUC-2, HER-2, high molecular weight melanoma-associated antigen MAA, GD2, carcinoembryonic antigen (CEA), TAG-72, ovarian-associated antigens OV-TL3 and MOV18, TUAN, alpha-feto protein (AFP), OFP, CA-125, CA-50, CA-19-9, renal tumor-associated antigen G250, EGP-40 (also known as EpCAM), S100 (malignant melanoma-associated antigen), p53, and p21ras. A synthetic analog of any TAA (or epitope thereof), including any of the foregoing, may be used. Furthermore, combinations of one or more TAAs (or epitopes thereof) may be included in the composition.

Allergens

[0116] In one aspect, the antigen that is part of the VLP vaccine may be any of a variety of allergens. Allergen based vaccines may be used to induce tolerance in a

subject to the allergen. Examples of an allergen vaccine involving co-precipitation with tyrosine may be found in U.S. Patent No. 3,792,159, 4,070,455, and 6,440,426.

[0117] Any of a variety of allergens can be included in VLPs. Allergens include but are not limited to environmental aeroallergens; plant pollens such as ragweed/hayfever; weed pollen allergens; grass pollen allergens; Johnson grass; tree pollen allergens; ryegrass; arachnid allergens, such as house dust mite allergens (e.g., Der p I, Der f I, etc.); storage mite allergens; Japanese cedar pollen/hay fever; mold spore allergens; animal allergens (e.g., dog, guinea pig, hamster, gerbil, rat, mouse, etc., allergens); food allergens (e.g., allergens of crustaceans; nuts, such as peanuts; citrus fruits); insect allergens; venoms: (Hymenoptera, yellow jacket, honey bee, wasp, hornet, fire ant); other environmental insect allergens from cockroaches, fleas, mosquitoes, etc.; bacterial allergens such as streptococcal antigens; parasite allergens such as Ascaris antigen; viral antigens; fungal spores; drug allergens; antibiotics; penicillins and related compounds; other antibiotics; whole proteins such as hormones (insulin), enzymes (streptokinase); all drugs and their metabolites capable of acting as incomplete antigens or haptens; industrial chemicals and metabolites capable of acting as haptens and functioning as allergens (e.g., the acid anhydrides (such as trimellitic anhydride) and the isocyanates (such as toluene diisocyanate)); occupational allergens such as flour (e.g., allergens causing Baker's asthma), castor bean, coffee bean, and industrial chemicals described above; flea allergens; and human proteins in non-human animals.

[0118] Allergens include but are not limited to cells, cell extracts, proteins, polypeptides, peptides, polysaccharides, polysaccharide conjugates, peptide and non-peptide mimics of polysaccharides and other molecules, small molecules, lipids, glycolipids, and carbohydrates.

[0119] Examples of specific natural, animal and plant allergens include but are not limited to proteins specific to the following genera: Canine (Canis familiaris); Dermatophagoides (e.g. Dermatophagoides farinae); Felis (Felis domesticus); Ambrosia (Ambrosia artemiisfolia; Lolium (e.g. Lolium perenne or Lolium multiflorum); Cryptomeria (Cryptomeria japonica); Altemaria (Altemaria altemata); Alder; Alnus

(Alnus gultinoas); Betula (Betula verrucosa); Quercus (Quercus alba); Olea (Olea europa); Artemisia (Artemisia vulgaris); Plantago (e.g. Plantago lanceolata); Parietaria (e.g. Parietaria officinalis or Parietaria judaica); Blattella (e.g. Blattella germanica); Apis (e.g. Apis multiflorum); Cupressus (e.g. Cupressus sempervirens, Cupressus arizonica and Cupressus macrocarpa); Juniperus (e.g. Juniperus sabinoides, Juniperus virginiana, Juniperus communis and Juniperus ashei); Thuya (e.g. Thuya orientalis); Chamaecyparis (e.g. Chamaecyparis obtusa); Periplaneta (e.g. Periplaneta americana); Agropyron (e.g. Agropyron repens); Secale (e.g. Secale cereale); Triticum (e.g. Triticum aestivum); Dactylis (e.g. Dactylis glomerata); Festuca (e.g. Festuca elatior); Poa (e.g. Poapratensis or Poa compressa); Avena (e.g. Avena sativa); Holcus (e.g. Holcus lanatus); Anthoxanthum (e.g. Anthoxanthum odoratum); Arrhenatherum (e.g. Arrhenatherun elatius); Agrostis (e.g. Agrostis alba); Phleum (e.g. Phleum pratense); Phalaris (e.g. Phalaris arundinacea); Paspalum (e.g. Paspalum notatum); Sorghum (e.g. Sorghum halepensis); and Bromus (e.g. Bromus inermis).

Exemplary Methods of Making Chimeric VLPs from Mammalian Cells

[0120] Chimeric VLPs may be made by any method available to one of skill in the art. Chimeric VLPs include a lentivirus or alpha-retrovirus Gag polypeptide which is responsible for the formation of the VLP with the RSV-F polypeptide. In addition, the chimeric VLP may include one or more additional polypeptides such as a membrane (including lipid-raft)-associated polypeptide to provide additional antigens (other than those present naturally or artificially as a part of the one or more polypeptides responsible for the formation of the VLP or the RSV-F polypeptide). In certain embodiments, the polypeptides may be co-expressed in any available protein expression system including, for example, a mammalian cell-based system that includes lipid raft domains in the plasma membrane.

[0121] Recombinant expression of the polypeptides for the VLPs involves expression vectors containing polynucleotides that encode one or more of the polypeptides. Once a polynucleotide encoding one or more of the polypeptides has been obtained, the vector for the production of the polypeptide may be produced by recombinant DNA technology using techniques well known in the art. Thus, methods for

preparing a protein by expressing a polynucleotide containing any of the VLP polypeptide-encoding nucleotide sequences are described herein. Methods which are well known to those skilled in the art can be used to construct expression vectors containing the VLP polypeptide coding sequences and appropriate transcriptional and translational control signals. These methods include, for example, in vitro recombinant DNA techniques, synthetic techniques, and in vivo genetic recombination. The methods and compositions disclosed herein, thus, provides replicable vectors comprising a nucleotide sequence encoding a lentivirus or alpha-retrovirus Gag polypeptide and a nucleotide sequence encoding respiratory syncytial virus F polypeptide and optionally one or more additional VLP-associated polypeptides, all operably linked to one or more promoters.

[0122] Non-limiting examples of vectors that can be used to express sequences that assemble into VLPs as described herein include viral-based vectors (e.g., retrovirus, adenovirus, adeno-associated virus, lentivirus, pox viruses and baculovirus), plasmid vectors, non-viral vectors, mammalian vectors, mammalian artificial chromosomes (e.g., liposomes, particulate carriers, etc.) and combinations thereof.

[0123] The expression vector(s) typically contain(s) coding sequences and expression control elements which allow expression of the coding regions in a suitable host. The control elements generally include a promoter, enhancer, exon, intron, splicing sites translation initiation codon, and translation and transcription termination sequences, and an insertion site for introducing the insert into the vector. Translational control elements have been reviewed by M. Kozak (e.g., Kozak, M., Mamm. Genome 7(8):563-574, 1996; Kozak, M., Biochimie 76(9):815-821, 1994; Kozak, M., J Cell Biol 108(2):229-241, 1989; Kozak, M., and Shatkin, A. J., Methods Enzymol 60:360-375, 1979).

[0124] For example, typical promoters used for mammalian cell expression include the SV40 early promoter, a CMV promoter such as the CMV immediate early promoter (a CMV promoter can include intron A), RSV, HIV-LTR, the mouse mammary tumor virus LTR promoter (MMLV-LTR), FIV-LTR, the adenovirus major late promoter

(Ad MLP), and the herpes simplex virus promoter, among others. Other nonviral promoters, such as a promoter derived from the murine metallothionein gene, will also find use for mammalian expression. Typically, transcription termination and polyadenylation sequences will also be present, located 3' to the translation stop codon. A sequence for optimization of initiation of translation, located 5' to the coding sequence, may also be present. Examples of transcription terminator/polyadenylation signals include those derived from SV40, as described in Sambrook, et al., supra, as well as a bovine growth hormone terminator sequence. Introns, containing splice donor and acceptor sites, may also be designed into the constructs as described herein (Chapman et al., Nuc. Acids Res. (1991) 19:3979-3986).

[0125] Enhancer elements may also be used herein to increase expression levels of the constructs, for example in mammalian host cells. Examples include the SV40 early gene enhancer, as described in Dijkema et al., EMBO J. (1985) 4:761, the enhancer/promoter derived from the long terminal repeat (LTR) of the Rous Sarcoma Virus, as described in Gorman et al., Proc. Natl. Acad. Sci. USA (1982b) 79:6777 and elements derived from human CMV, as described in Boshart et al., Cell (1985) 41:521, such as elements included in the CMV intron A sequence (Chapman et al., Nuc. Acids Res. (1991) 19:3979-3986).

[0126] It will be apparent that a vector may contain one or more sequences as described herein. For example, a single vector may carry sequences encoding all the proteins found in the VLP. Alternatively, multiple vectors may be used (e.g., multiple constructs, each encoding a single polypeptide-encoding sequence or multiple constructs, each encoding one or more polypeptide-encoding sequences). In embodiments in which a single vector comprises multiple polypeptide-encoding sequences, the sequences may be operably linked to the same or different transcriptional control elements (e.g., promoters) within the same vector.

[0127] In addition, one or more sequences encoding non-RSV proteins may be expressed and incorporated into the VLP, including, but not limited to, sequences comprising and/or encoding immunomodulatory molecules (e.g., adjuvants described

below), for example, immunomodulating oligonucleotides (e.g., CpGs), cytokines, detoxified bacterial toxins and the like.

[0128] The expression vector may be transferred to a host cell by conventional techniques and the transfected cells are then cultured by conventional techniques to produce the VLP polypeptide(s). Thus, the compositions and methods disclosed herein include host cells containing a polynucleotide encoding one or more of the VLP polypeptides operably linked to a heterologous promoter. In certain embodiments for the generation of VLPs, vectors encoding the lentivirus or alpha-retrovirus Gag polypeptide and the respiratory syncytial virus F polypeptide and optionally an additional VLP-associating antigen or VLP-associated polypeptide linked to an additional antigen or adjuvant may be (co)expressed in the host cell for generation of the VLP, as detailed below.

[0129] The VLPs may be produced in eukaryotic cells, for example mammalian cells, following transfection, establishment of continuous cell lines (using standard protocols as known to one skilled in the art) and/or infection with DNA molecules that carry the RSV genes of interest. The level of expression of the proteins required for VLP formation is maximized by sequence optimization of the eukaryotic or viral promoters that drive transcription of the selected genes. The VLP is released into the culture medium from where the VLP may be purified and subsequently formulated as vaccine. The VLPs are not infectious vaccines and therefore vaccine inactivation is not required.

[0130] The ability of lentivirus or alpha-retrovirus Gag polypeptides expressed from sequences as described herein to self-assemble into VLPs with antigenic proteins presented on the surface allows these VLPs to be produced in any host cell by the co-introduction of the desired sequences. The sequence(s) (e.g., in one or more expression vectors) may be stably and/or transiently integrated in various combinations into a host cell.

[0131] Suitable host cells include, but are not limited to, bacterial, mammalian, insect, yeast, plant, and Xenopus cells.

[0132] For example, a number of mammalian cell lines are known in the art and include primary cells as well as immortalized cell lines available from the American Type Culture Collection (A.T.C.C.), such as, but not limited to, BHK, VERO, HT1080, MRC-5, WI 38, MDCK, MDBK, 293, 293T, RD, COS-7, CHO, Jurkat, HUT, SUPT, C8166, MOLT4/clone8, MT-2, MT-4, H9, PM1, CEM, myeloma cells (e.g., SB20 cells), LtK, HeLa, WI-38, L2, CMT-93, and CEMX174 (such cell lines are available, for example, from the A.T.C.C.).

[0133] Similarly, bacterial hosts such as E. coli, Bacillus subtilis, and Streptococcus spp. will find use with the present expression constructs.

[0134] Yeast hosts useful in the present disclosure include inter alia, Saccharomyces cerevisiae, Candida albicans, Candida maltosa, Hansenula polymorpha, Kluyveromyces fragilis, Kluyveromyces lactis, Pichia guillerimondii, Pichia pastoris, Schizosaccharomyces pombe and Yarrowia lipolytica. Fungal hosts include, for example, Aspergillus.

[0135] Insect cells for use with baculovirus expression vectors include, inter alia, Aedes aegypti, Bombyx mori, Drosophila melanogaster, Spodoptera frugiperda, and Trichoplusia ni. See, Latham & Galarza (2001) J. Virol. 75(13):6154-6165; Galarza et al. (2005) Viral. Immunol. 18(1):244-51; and U.S. Patent Publications 200550186621 and 20060263804.

[0136] Cell lines expressing one or more of the sequences described above can readily be generated given the disclosure provided herein by stably integrating one or more sequences (expression vectors) encoding the respiratory syncytial virus F polypeptide of the VLP. The promoter regulating expression of the stably integrated respiratory syncytial virus F polypeptide sequences (s) may be constitutive or inducible.

[0137] The parent cell line from which a chimeric VLP-producer cell line is derived can be selected from any cell described above, including for example, mammalian, insect, yeast, bacterial cell lines. In certain embodiments, the cell line is a mammalian cell line (e.g., 293, RD, COS-7, CHO, BHK, VERO, MRC-5, HT1080, and

myeloma cells). Production of chimeric VLPs using mammalian cells provides (i) VLP formation; (ii) correct myristylation, glycosylation and budding; (iii) absence of non-mammalian cell contaminants and (iv) ease of purification.

[0138] In addition to creating cell lines, lentivirus or alpha-retrovirus Gag- and RSV F-encoding sequences may also be transiently expressed in host cells, with or without an additional antigen or adjuvant. Suitable recombinant expression host cell systems include, but are not limited to, bacterial, mammalian, baculovirus/insect, vaccinia, Semliki Forest virus (SFV), adenovirus, Alphaviruses (such as, Sindbis, Venezuelan Equine Encephalitis (VEE)), mammalian, yeast and Xenopus expression systems, well known in the art. Exemplary expression systems are mammalian cell lines, vaccinia, Sindbis, insect and yeast systems.

[0139] Many suitable expression systems are commercially available, including, for example, the following: baculovirus expression (Reilly, P. R., et al., BACULOVIRUS EXPRESSION VECTORS: A LABORATORY MANUAL (1992); Beames, et al., Biotechniques 11:378 (1991); Pharmingen; Clontech, Palo Alto, Calif.), vaccinia expression systems (Earl, P. L., et al., "Expression of proteins in mammalian cells using vaccinia" In Current Protocols in Molecular Biology (F. M. Ausubel, et al. Eds.), Greene Publishing Associates & Wiley Interscience, New York (1991); Moss, B., et al., U.S. Pat. No. 5,135,855, issued Aug. 4, 1992), expression in bacteria (Ausubel, F. M., et al., CURRENT PROTOCOLS IN MOLECULAR BIOLOGY, John Wiley and Sons, Inc., Media Pa.; Clontech), expression in yeast (Rosenberg, S, and Tekamp-Olson, P., U.S. Pat. No. RE35, 749, issued, Mar. 17, 1998, herein incorporated by reference; Shuster, J. R., U.S. Pat. No. 5,629,203, issued May 13, 1997, herein incorporated by reference; Gellissen, G., et al., Antonie Van Leeuwenhoek, 62(1-2):79-93 (1992); Romanos, M. A., et al., Yeast 8(6):423-488 (1992); Goeddel, D. V., Methods in Enzymology 185 (1990); Guthrie, C., and G. R. Fink, Methods in Enzymology 194 (1991)), expression in mammalian cells (Clontech; Gibco-BRL, Ground Island, N.Y.; e.g., Chinese hamster ovary (CHO) cell lines (Haynes, J., et al., Nuc. Acid. Res. 11:687-706 (1983); 1983, Lau, Y. F., et al., Mol. Cell. Biol. 4:1469-1475 (1984); Kaufman, R. J., "Selection and coamplification of heterologous genes in mammalian cells," in Methods in Enzymology,

vol. 185, pp 537-566. Academic Press, Inc., San Diego Calif. (1991)), and expression in plant cells (plant cloning vectors, Clontech Laboratories, Inc., Palo-Alto, Calif., and Pharmacia LKB Biotechnology, Inc., Pistcataway, N.J.; Hood, E., et al., J. Bacteriol. 168:1291-1301 (1986); Nagel, R., et al., FEMS Microbiol. Lett. 67:325 (1990); An, et al., "Binary Vectors", and others in Plant Molecular Biology Manual A3:1-19 (1988); Miki, B. L. A., et al., pp. 249-265, and others in Plant DNA Infectious Agents (Hohn, T., et al., eds.) Springer-Verlag, Wien, Austria, (1987); Plant Molecular Biology: Essential Techniques, P. G. Jones and J. M. Sutton, New York, J. Wiley, 1997; Miglani, Gurbachan Dictionary of Plant Genetics and Molecular Biology, New York, Food Products Press, 1998; Henry, R. J., Practical Applications of Plant Molecular Biology, New York, Chapman & Hall, (1997).

[0140] When expression vectors containing the altered genes that code for the proteins required for VLP formation are introduced into host cell(s) and subsequently expressed at the necessary level, the VLP assembles and is then released from the cell surface into the culture media.

[0141] Depending on the expression system and host selected, the VLPs are produced by growing host cells transformed by an expression vector under conditions whereby the particle-forming polypeptides are expressed and VLPs can be formed. The selection of the appropriate growth conditions is within the skill of the art.

[0142] The particles are then isolated (or substantially purified) using methods that preserve the integrity thereof, such as, by density gradient centrifugation, e.g., sucrose gradients, PEG-precipitation, pelleting, and the like (see, e.g., Kimbauer et al. J. Virol. (1993) 67:6929-6936), as well as standard purification techniques including, e.g., ion exchange and gel filtration chromatography.

Exemplary Methods of Inactivation of Infectious Agents in Chimeric VLPs

[0143] An exemplary method of inactivation is through electromagnetic radiation as electromagnetic radiation is capable of inactivating the infectious agents without substantially reducing the immunogenicity of the chimeric VLP. As all three exemplary

modes of electromagnetic radiation (i.e., UV irradiation with photoreactive compounds, UV irradiation alone and gamma irradiation) have a long history of use for inactivation of pathogens in a wide variety of samples such as blood, food, vaccines, etc. there are a wide variety of commercially available apparatus for applying the inactivating electromagnetic radiation that may be used with little to no modification to practice the methods disclosed herein. Furthermore, optimizing wavelengths and dosages is routine in the art and therefore readily within the capabilities of one of ordinary skill in the art.

UV Irradiation with Photoreactive Compounds

[0144] An exemplary method of inactivation with electromagnetic radiation is a combination of ultraviolet irradiation, such as UV-A irradiation, in the presence of a photoreactive compound, such as one that will react with polynucleotides in the infectious agent.

[0145] Exemplary photoreactive compounds include: actinomycins, anthracyclinones, anthramycin, benzodipyrones, fluorenes, fluorenones, furocoumarins, mitomycin, monostral fast blue, norphillin A, phenanthridines, phenazathionium salts, phenazines, phenothiazines, phenylazides, quinolines, and thiaxanthenones. One species is furocoumarins which belong in one of two main categories. The first category is psoralens [7H-furo(3,2-g)-(1)-benzopyran-7-one, or delta-lactone of 6-hydroxy-5-benzofuranacrylic acid], which are linear and in which the two oxygen residues appended to the central aromatic moiety have a 1, 3 orientation, and further in which the furan ring moiety is linked to the 6 position of the two ring coumarin system. The second category is isopsoralens [2H-furo(2,3-h)-(1)-benzopyran-2-one, or delta-lactone of 4-hydroxy-5-benzofuranacrylic acid], which are angular and in which the two oxygen residues appended to the central aromatic moiety have a 1, 3 orientation, and further in which the furan ring moiety is linked to the 8 position of the two ring coumarin system. Psoralen derivatives may be generated by substitution of the linear furocoumarin at the 3, 4, 5, 8, 4', or 5' positions, while isopsoralen derivatives may be generated by substitution of the angular furocoumarin at the 3, 4, 5, 6, 4', or 5 positions. Psoralens can intercalate between the base pairs of double-stranded nucleic acids, forming covalent adducts to pyrimidine bases upon absorption of long wave ultraviolet light (UVA). See, e.g., G. D.

Cimino et al., Ann. Rev. Biochem. 54:1151 (1985); Hearst et al., Quart. Rev. Biophys. 17:1 (1984).

[0146] Exemplary wavelengths of UV (or in some cases visible light) radiation will depend upon the wavelength at which photoadducts are generated which is dependent upon the chemistry of the photoreactive chemical. By way of example, UV radiation in the wavelengths between 320 and 380 nm are most effective for many psoralens with 330 to 360 nm having maximum effectiveness.

UV Irradiation Alone

[0147] In addition to UV irradiation in the presence of a photoreactive compound, infectious agents may be inactivated by UV irradiation alone. In certain embodiments, the radiation is UVC radiation having a wavelength between about 180 and 320 nm, or between about 225 and 290 nm, or about 254 nm (i.e., the maximal absorbance peak of polynucleotides). UVC radiation may be used because it is less detrimental to the components of the chimeric VLPs disclosed herein for both stability and immunogenicity such as the lipid bilayer forming the envelope while retaining sufficient energy to inactivate infectious agents. However, other types of UV radiation such as, for example, UVA and UVB may also be used.

Gamma Irradiation

[0148] Gamma irradiation (i.e., ionizing radiation) may also be used in the practice of the methods disclosed herein to generate the compositions. Gamma irradiation can inactivate infectious agents by introducing strand breaks in the polynucleotides encoding the genome of the infectious agent or by generating hydroxyl radicals that attack the polynucleotides.

Exemplary Methods of Using Chimeric VLPs

Formulations

[0149] An exemplary use of the chimeric VLPs described herein is as a vaccine preparation. Typically, such vaccines are prepared as injectables either as liquid

solutions or suspensions; solid forms suitable for solution in, or suspension in, liquid prior to injection may also be prepared. Such preparations may also be emulsified or produced as a dry powder. The active immunogenic ingredient is often mixed with excipients which are pharmaceutically acceptable and compatible with the active ingredient. Suitable excipients are, for example, water, saline, dextrose, sucrose, glycerol, ethanol, or the like, and combinations thereof. In addition, if desired, the vaccine may contain auxiliary substances such as wetting or emulsifying agents, pH buffering agents, or adjuvants which enhance the effectiveness of the vaccines.

[0150] Vaccines may be conventionally administered parenterally, by injection, for example, either subcutaneously, intradermally, subdermally or intramuscularly. Additional formulations which are suitable for other modes of administration include suppositories and, in some cases, oral, intranasal, buccal, sublinqual, intraperitoneal, intravaginal, anal and intracranial formulations. For suppositories, traditional binders and carriers may include, for example, polyalkalene glycols or triglycerides; such suppositories may be formed from mixtures containing the active ingredient in the range of 0.5% to 10%, or even 1-2%. In certain embodiments, a low melting wax, such as a mixture of fatty acid glycerides or cocoa butter is first melted and the chimeric VLPs described herein are dispersed homogeneously, for example, by stirring. The molten homogeneous mixture is then poured into conveniently sized molds, allowed to cool, and to solidify.

[0151] Formulations suitable for intranasal delivery include liquids (*e.g.*, aqueous solution for administration as an aerosol or nasal drops) and dry powders (*e.g.* for rapid deposition within the nasal passage). Formulations include such normally employed excipients as, for example, pharmaceutical grades of mannitol, lactose, sucrose, trehalose, xylitol, and chitosan. Mucosadhesive agents such as chitosan can be used in either liquid or powder formulations to delay mucocilliary clearance of intranasally-administered formulations. Sugars such as mannitol and sucrose can be used as stability agents in liquid formulations and as stability, bulking, or powder flow and size agents in dry powder formulations. In addition, adjuvants such as monophosphoryl lipid A (MPL) or

CpG oligoneucleotides can be used in both liquid and dry powder formulations as an immunostimulatory adjuvant.

[0152] Formulations suitable for oral delivery include liquids, solids, semi-solids, gels, tablets, capsules, lozenges, and the like. Formulations suitable for oral delivery include tablets, lozenges, capsules, gels, liquids, food products, beverages, nutraceuticals, and the like. Formulations include such normally employed excipients as, for example, pharmaceutical grades of mannitol, lactose, starch, magnesium stearate, sodium saccharine, cellulose, magnesium carbonate, and the like. Other chimeric VLPs vaccine compositions may take the form of solutions, suspensions, pills, sustained release formulations or powders and contain 10-95% of active ingredient, or 25-70%. For oral formulations, cholera toxin is an interesting formulation partner (and also a possible conjugation partner).

[0153] The chimeric VLP vaccines when formulated for vaginal administration may be in the form of pessaries, tampons, creams, gels, pastes, foams or sprays. Any of the foregoing formulations may contain agents in addition to chimeric VLPs, such as carriers, known in the art to be appropriate.

[0154] In some embodiments, the chimeric VLP vaccine may be formulated for systemic or localized delivery. Such formulations are well known in the art. Parenteral vehicles include sodium chloride solution, Ringer's dextrose, dextrose and sodium chloride, lactated Ringer's or fixed oils. Intravenous vehicles include fluid and nutrient replenishers, electrolyte replenishers (such as those based on Ringer's dextrose), and the like. Systemic and localized routes of administration include, e.g., intradermal, topical application, intravenous, intramuscular, etc.

[0155] The chimeric VLPs may be formulated into the vaccine including neutral or salt-based formulations. Pharmaceutically acceptable salts include acid addition salts (formed with the free amino groups of the peptide) and which are formed with inorganic acids such as, for example, hydrochloric or phosphoric acids, or such organic acids as acetic, oxalic, tartaric, mandelic, and the like. Salts formed with the free carboxyl groups may also be derived from inorganic bases such as, for example, sodium, potassium,

ammonium, calcium, or ferric hydroxides, and such organic bases as isopropylamine, trimethylamine, 2-ethylamino ethanol, histidine, procaine, and the like.

[0156] The vaccines may be administered in a manner compatible with the dosage formulation, and in such amount as will be therapeutically effective and immunogenic. The quantity to be administered depends on the subject to be treated, including, e.g., the capacity of the individual's immune system to mount an immune response, and the degree of protection desired. Suitable dosage ranges are of the order of several hundred micrograms active ingredient per vaccination with an exemplary range from about 0.1 μg to 2000 μg (even though higher amounts in the 1-10 mg range are contemplated), such as in the range from about 0.5 μg to 1000 μg, or even in the range from 1 μg to 500 μg or in the range from about 10 μg to 100 μg. Suitable regimens for initial administration and booster shots are also variable but are typified by an initial administration followed by subsequent inoculations or other administrations.

[0157] The manner of application may be varied widely. Any of the conventional methods for administration of a vaccine are applicable. These include oral application on a solid physiologically acceptable base or in a physiologically acceptable dispersion, parenterally, by injection or the like. The dosage of the vaccine will depend on the route of administration and will vary according to the age of the person to be vaccinated and the formulation of the antigen.

[0158] Some of the vaccine formulations will be sufficiently immunogenic as a vaccine by themselves, but for some of the others the immune response will be enhanced if the vaccine further includes an adjuvant substance.

[0159] Delivery agents that improve mucoadhesion can also be used to improve delivery and immunogenicity especially for intranasal, oral or lung based delivery formulations. One such compound, chitosan, the N-deacetylated form of chitin, is used in many pharmaceutical formulations (32). It is an attractive mucoadhesive agent for intranasal vaccine delivery due to its ability to delay mucociliary clearance and allow more time for mucosal antigen uptake and processing (33, 34). In addition, it can transiently open tight junctions which may enhance transepithelial transport of antigen to

the NALT. In a recent human trial, a trivalent inactivated influenza vaccine administered intranasally with chitosan but without any additional adjuvant yielded seroconversion and HI titers that were only marginally lower than those obtained following intramuscular inoculation (33).

[0160] Chitosan can also be formulated with adjuvants that function well intranasally such as the genetically detoxified E. coli heat-labile enterotoxin mutant LTK63. This adds an immunostimulatory effect on top of the delivery and adhesion benefits imparted by chitosan resulting in enhanced mucosal and systemic responses (35).

[0161] Finally, it should be noted that chitosan formulations can also be prepared in a dry powder format that has been shown to improve vaccine stability and result in a further delay in mucociliary clearance over liquid formulations (42). This was seen in a recent human clinical trial involving an intranasal dry powder diphtheria toxoid vaccine formulated with chitosan in which the intranasal route was as effective as the traditional intramuscular route with the added benefit of secretory IgA responses (43). The vaccine was also very well tolerated. Intranasal dry powdered vaccines for anthrax containing chitosan and MPL induce stronger responses in rabbits than intramuscular inoculation and are also protective against aerosol spore challenge (44).

[0162] Intranasal vaccines represent an exemplary formulation as they can affect the upper and lower respiratory tracts in contrast to parenterally administered vaccines which are better at affecting the lower respiratory tract. This can be beneficial for inducing tolerance to allergen-based vaccines and inducing immunity for pathogen-based vaccines.

[0163] In addition to providing protection in both the upper and lower respiratory tracts, intranasal vaccines avoid the complications of needle inoculations and provide a means of inducing both mucosal and systemic humoral and cellular responses via interaction of particulate and/or soluble antigens with nasopharyngeal-associated lymphoid tissues (NALT) (16-19). The intranasal route has been historically less effective than parenteral inoculation, but the use of chimeric VLPs, novel delivery formulations, and adjuvants are beginning to change the paradigm. Indeed, chimeric

VLPs containing functional hemagglutinin polypeptides may be especially well suited for intranasal delivery due to the abundance of sialic acid-containing receptors in the nasal mucosa resulting in the potential for enhanced HA antigen binding and reduced mucociliary clearance.

Adjuvants

[0164] Various methods of achieving adjuvant effect for vaccines are known and may be used in conjunction with the chimeric VLPs disclosed herein. General principles and methods are detailed in "The Theory and Practical Application of Adjuvants", 1995, Duncan E. S. Stewart-Tull (ed.), John Wiley & Sons Ltd, ISBN 0-471-95170-6, and also in "Vaccines: New Generation Immunological Adjuvants", 1995, Gregoriadis G et al. (eds.), Plenum Press, New York, ISBN 0-306-45283-9.

[0165] In some embodiments, a chimeric VLP vaccine includes the chimeric VLPs in admixture with at least one adjuvant, at a weight-based ratio of from about 10:1 to about 10^{10}:1 chimeric VLP:adjuvant, e.g., from about 10:1 to about 100:1, from about 100:1 to about 10^3:1, from about 10^3:1 to about 10^4:1, from about 10^4:1 to about 10^5:1, from about 10^5:1 to about 10^6:1, from about 10^6:1 to about 10^7:1, from about 10^7:1 to about 10^8:1, from about 10^8:1 to about 10^9:1, or from about 10^9:1 to about 10^{10}:1 chimeric VLP:adjuvant. One of skill in the art can readily determine the appropriate ratio through information regarding the adjuvant and routine experimentation to determine optimal ratios.

[0166] Exemplary examples of adjuvants may include, but are not limited to, toll-like receptor (TLR) agonists, monophosphoryl lipid A (MPL), synthetic lipid A, lipid A mimetics or analogs, aluminum salts, cytokines, saponins, muramyl dipeptide (MDP) derivatives, CpG oligos, lipopolysaccharide (LPS) of gram-negative bacteria, polyphosphazenes, emulsions, oil in water emulsions, virosomes, cochleates, poly(lactide-co-glycolides) (PLG) microparticles, poloxamer particles, microparticles, and liposomes. Preferably, the adjuvants are not bacterially-derived exotoxins. Preferred adjuvants are those which stimulate a Th1 type response such as 3DMPL, CpG oligonucleotides, or QS21.

[0167] Monophosphoryl Lipid A (MPL), a non-toxic derivative of lipid A from Salmonella, is a potent TLR-4 agonist that has been developed as a vaccine adjuvant (Evans *et al.* 2003). In pre-clinical murine studies intranasal MPL has been shown to enhance secretory, as well as systemic, humoral responses (Baldridge *et al.* 2000; Yang *et al.* 2002). It has also been proven to be safe and effective as a vaccine adjuvant in clinical studies of greater than 120,000 patients (Baldrick *et al.*, 2002; 2004). MPL stimulates the induction of innate immunity through the TLR-4 receptor and is thus capable of eliciting nonspecific immune responses against a wide range of infectious pathogens, including both gram negative and gram positive bacteria, viruses, and parasites (Baldrick *et al.* 2004; Persing *et al.* 2002). Inclusion of MPL in intranasal formulations should provide rapid induction of innate responses, eliciting nonspecific immune responses from viral challenge while enhancing the specific responses generated by the antigenic components of the vaccine.

[0168] Accordingly, in one embodiment, the present invention provides a composition comprising monophosphoryl lipid A (MPL®) or 3 De-O-acylated monophosphoryl lipid A (3D-MPL®) as an enhancer of adaptive and innate immunity. Chemically 3D-MPL® is a mixture of 3 De-O-acylated monophosphoryl lipid A with 4, 5 or 6 acylated chains. A preferred form of 3 De-O-acylated monophosphoryl lipid A is disclosed in European Patent 0 689 454 B1 (SmithKline Beecham Biologicals SA), which is incorporated herein by reference. In another embodiment, the present invention provides a composition comprising synthetic lipid A, lipid A mimetics or analogs, such as BioMira's PET Lipid A, or synthetic derivatives designed to function like TLR-4 agonists.

[0169] Exemplary examples of adjuvants are polypeptide adjuvants that may be readily added to the chimeric VLPs described herein by co-expression with the polypeptide components of the chimeric VLP or fusion with the polypeptide components to produce chimeric polypeptides. Bacterial flagellin, the major protein constituent of flagella, is an adjuvant which has received increasing attention as an adjuvant protein because of its recognition by the innate immune system by the toll-like receptor TLR5 (65). Flagellin signaling through TLR5 has effects on both innate and adaptive immune

functions by inducing DC maturation and migration as well as activation of macrophages, neutrophils, and intestinal epithelial cells resulting in production of proinflammatory mediators (66-72).

[0170] TLR5 recognizes a conserved structure within flagellin monomers that is unique to this protein and is required for flagellar function, precluding its mutation in response to immunological pressure (73). The receptor is sensitive to a 100 fM concentration but does not recognize intact filaments. Flagellar disassembly into monomers is required for binding and stimulation.

[0171] As an adjuvant, flagellin has potent activity for induction of protective responses for heterologous antigens administered either parenterally or intranasally (66, 74-77) and adjuvant effects for DNA vaccines have also been reported (78). A Th2 bias is observed when flagellin is employed which would be appropriate for a respiratory virus such as influenza but no evidence for IgE induction in mice or monkeys has been observed. In addition, no local or systemic inflammatory responses have been reported following intranasal or systemic administration in monkeys (74). The Th2 character of responses elicited following use of flagellin is somewhat surprising since flagellin signals through TLR5 in a MyD88-dependent manner and all other MyD88-dependent signals through TLRs have been shown to result in a Th1 bias (67, 79). Importantly, pre-existing antibodies to flagellin have no appreciable effect on adjuvant efficacy (74) making it attractive as a multi-use adjuvant.

[0172] A common theme in many recent intranasal vaccine trials is the use of adjuvants and/or delivery systems to improve vaccine efficacy. In one such study an influenza H3 vaccine containing a genetically detoxified E. coli heat-labile enterotoxin adjuvant (LT R192G) resulted in heterosubtypic protection against H5 challenge but only following intranasal delivery. Protection was based on the induction of cross neutralizing antibodies and demonstrated important implications for the intranasal route in development of new vaccines (22).

[0173] Cytokines, colony-stimulating factors (e.g., GM-CSF, CSF, and the like); tumor necrosis factor; interleukin-2, -7, -12, interferons and other like growth factors,

may also be used as adjuvants as they may be readily included in the chimeric VLP vaccine by admixing or fusion with the polypeptide component.

[0174] In some embodiments, the chimeric VLP vaccine compositions disclosed herein may include other adjuvants that act through a Toll-like receptor such as a nucleic acid TLR9 ligand comprising a 5'-TCG-3' sequence; an imidazoquinoline TLR7 ligand; a substituted guanine TLR7/8 ligand; other TLR7 ligands such as Loxoribine, 7-deazadeoxyguanosine, 7-thia-8-oxodeoxyguanosine, Imiquimod (R-837), and Resiquimod (R-848).

[0175] Certain adjuvants facilitate uptake of the vaccine molecules by APCs, such as dendritic cells, and activate these. Non-limiting examples are selected from the group consisting of an immune targeting adjuvant; an immune modulating adjuvant such as a toxin, a cytokine, and a mycobacterial derivative; an oil formulation; a polymer; a micelle forming adjuvant; a saponin; an immunostimulating complex matrix (ISCOM matrix); a particle; DDA; aluminum adjuvants; DNA adjuvants; MPL; and an encapsulating adjuvant.

[0176] Additional examples of adjuvants include agents such as aluminum salts such as hydroxide or phosphate (alum), commonly used as 0.05 to 0.1 percent solution in buffered saline (see, e.g., Nicklas (1992) Res. Immunol. 143:489-493), admixture with synthetic polymers of sugars (e.g. Carbopol®) used as 0.25 percent solution, aggregation of the protein in the vaccine by heat treatment with temperatures ranging between 70° to 101°C for 30 second to 2 minute periods respectively and also aggregation by means of cross-linking agents are possible. Aggregation by reactivation with pepsin treated antibodies (Fab fragments) to albumin, mixture with bacterial cells such as C. parvum or endotoxins or lipopolysaccharide components of gram-negative bacteria, emulsion in physiologically acceptable oil vehicles such as mannide mono-oleate (Aracel A) or emulsion with 20 percent solution of a perfluorocarbon (Fluosol-DA) used as a block substitute may also be employed. Admixture with oils such as squalene and IFA may als be used.

[0177] DDA (dimethyldioctadecylammonium bromide) is an interesting candidate for an adjuvant, but also Freund's complete and incomplete adjuvants as well as quillaja saponins such as QuilA and QS21 are interesting. Further possibilities include poly[di(earboxylatophenoxy)phosphazene (PCPP) derivatives of lipopolysaccharides such as monophosphoryl lipid A (MPL®), muramyl dipeptide (MDP) and threonyl muramyl dipeptide (tMDP). The lipopolysaccharide based adjuvants may also be used for producing a predominantly Th1-type response including, for example, a combination of monophosphoryl lipid A, such as 3-de-O-acylated monophosphoryl lipid A, together with an aluminum salt. MPL® adjuvants are available from GlaxoSmithKline (see, for example, U.S. Pat. Nos. 4,436,727; 4,877,611; 4,866,034 and 4,912,094).

[0178] Liposome formulations are also known to confer adjuvant effects, and therefore liposome adjuvants may be used in conjunction with the chimeric VLPs.

[0179] Immunostimulating complex matrix type (ISCOM® matrix) adjuvants may also be used with the chimeric VLPs, especially since it has been shown that this type of adjuvants are capable of up-regulating MHC Class II expression by APCs. An ISCOM matrix consists of (optionally fractionated) saponins (triterpenoids) from Quillaja saponaria, cholesterol, and phospholipid. When admixed with the immunogenic protein such as in the VLPs, the resulting particulate formulation is what is known as an ISCOM particle where the saponin may constitute 60-70% w/w, the cholesterol and phospholipid 10-15% w/w, and the protein 10-15% w/w. Details relating to composition and use of immunostimulating complexes can for example be found in the above-mentioned text-books dealing with adjuvants, but also Morein B et al., 1995, Clin. Immunother. 3: 461-475 as well as Barr I G and Mitchell G F, 1996, Immunol. and Cell Biol. 74: 8-25 provide useful instructions for the preparation of complete immunostimulating complexes.

[0180] The saponins, whether or not in the form of iscoms, that may be used in the adjuvant combinations with the chimeric VLP vaccines disclosed herein include those derived from the bark of Quillaja Saponaria Molina, termed Quil A, and fractions thereof, described in U.S. Pat. No. 5,057,540 and "Saponins as vaccine adjuvants", Kensil, C. R.,

Crit Rev Ther Drug Carrier Syst, 1996, 12 (1-2):1-55; and EP 0 362 279 B1. Exemplary fractions of Quil A are QS21, QS7, and QS17.

[0181] β-Escin is another haemolytic saponin for use in the adjuvant compositions of the chimeric VLPs. Escin is described in the Merck index (12th ed: entry 3737) as a mixture of saponins occurring in the seed of the horse chestnut tree, Lat: Aesculus hippocastanum. Its isolation is described by chromatography and purification (Fiedler, Arzneimittel-Forsch. 4, 213 (1953)), and by ion-exchange resins (Erbring et al., U.S. Pat. No. 3,238,190). Fractions of escin have been purified and shown to be biologically active (Yoshikawa M, et al. (Chem Pharm Bull (Tokyo) 1996 August;44(8):1454-1464)). β-escin is also known as aescin.

[0182] Another haemolytic saponin for use in the chimeric VLPs is Digitonin. Digitonin is described in the Merck index (12th Edition, entry 3204) as a saponin, being derived from the seeds of Digitalis purpurea and purified according to the procedure described Gisvold et al., J.Am.Pharm.Assoc., 1934, 23, 664; and Ruhenstroth-Bauer, Physiol.Chem., 1955, 301, 621. Its use is described as being a clinical reagent for cholesterol determination.

[0183] Another interesting possibility of achieving adjuvant effect is to employ the technique described in Gosselin et al., 1992. In brief, the presentation of a relevant antigen such as an antigen in a chimeric VLP disclosed herein can be enhanced by conjugating the antigen to antibodies (or antigen binding antibody fragments) against the F_C receptors on monocytes/macrophages. Especially conjugates between antigen and anti-F_CRI have been demonstrated to enhance immunogenicity for the purposes of vaccination. The antibody may be conjugated to the chimeric VLP after generation or as a part of the generation including by expressing as a fusion to any one of the polypeptide components of the chimeric VLP.

[0184] Other possibilities involve the use of the targeting and immune modulating substances (i.e. cytokines). In addition, synthetic inducers of cytokines such as poly I:C may also be used.

[0185] Suitable mycobacterial derivatives may be selected from the group consisting of muramyl dipeptide, complete Freund's adjuvant, RIBI, (Ribi ImmunoChem Research Inc., Hamilton, Mont.) and a diester of trehalose such as TDM and TDE.

[0186] Examples of suitable immune targeting adjuvants include CD40 ligand and CD40 antibodies or specifically binding fragments thereof (cf. the discussion above), mannose, a Fab fragment, and CTLA-4.

[0187] Examples of suitable polymer adjuvants include a carbohydrate such as dextran, PEG, starch, mannan, and mannose; a plastic polymer; and latex such as latex beads.

[0188] Yet another interesting way of modulating an immune response is to include the immunogen (optionally together with adjuvants and pharmaceutically acceptable carriers and vehicles) in a "virtual lymph node" (VLN) (a proprietary medical device developed by ImmunoTherapy, Inc., 360 Lexington Avenue, New York, N.Y. 10017-6501). The VLN (a thin tubular device) mimics the structure and function of a lymph node. Insertion of a VLN under the skin creates a site of sterile inflammation with an upsurge of cytokines and chemokines. T- and B-cells as well as APCs rapidly respond to the danger signals, home to the inflamed site and accumulate inside the porous matrix of the VLN. It has been shown that the necessary antigen dose required to mount an immune response to an antigen is reduced when using the VLN and that immune protection conferred by vaccination using a VLN surpassed conventional immunization using Ribi as an adjuvant. The technology is described briefly in Gelber C et al., 1998, "Elicitation of Robust Cellular and Humoral Immune Responses to Small Amounts of Immunogens Using a Novel Medical Device Designated the Virtual Lymph Node", in: "From the Laboratory to the Clinic, Book of Abstracts, Oct. 12-15, 1998, Seascape Resort, Aptos, Calif."

[0189] Oligonucleotides may be used as adjuvants in conjunction with the chimeric VLP vaccines and may contain two or more dinucleotide CpG motifs separated by at least three or more or even at least six or more nucleotides. CpG-containing oligonucleotides (in which the CpG dinucleotide is unmethylated) induce a

predominantly Th1 response. Such oligonucleotides are well known and are described, for example, in WO 96/02555, WO 99/33488 and U.S. Pat. Nos. 6,008,200 and 5,856,462.

[0190] Such oligonucleotide adjuvants may be deoxynucleotides. In certain embodiments, the nucleotide backbone in the oligonucleotide is phosphorodithioate, or a phosphorothioate bond, although phosphodiester and other nucleotide backbones such as PNA including oligonucleotides with mixed backbone linkages may also be used. Methods for producing phosphorothioate oligonucleotides or phosphorodithioate are described in U.S. Pat. No. 5,666,153, U.S. Pat. No. 5,278,302 and W095/26204.

[0191] Exemplary oligonucleotides have the following sequences. The sequences may contain phosphorothioate modified nucleotide backbones.

[0192] (SEQ ID NO:1) OLIGO 1: TCC ATG ACG TTC CTG ACG TT (CpG 1826)

[0193] (SEQ ID NO:2) OLIGO 2: TCT CCC AGC GTG CGC CAT (CpG 1758)

[0194] (SEQ ID NO:3) OLIGO 3: ACC GAT GAC GTC GCC GGT GAC GGC ACC ACG

[0195] (SEQ ID NO:4) OLIGO 4: TCG TCG TTT TGT CGT TTT GTC GTT (CpG 2006)

[0196] (SEQ ID NO:5) OLIGO 5: TCC ATG ACG TTC CTG ATG CT (CpG 1668)

[0197] Alternative CpG oligonucleotides include the above sequences with inconsequential deletions or additions thereto. The CpG oligonucleotides as adjuvants may be synthesized by any method known in the art (e.g., EP 468520). For example, such oligonucleotides may be synthesized utilizing an automated synthesizer. Such oligonucleotide adjuvants may be between 10-50 bases in length. Another adjuvant system involves the combination of a CpG-containing oligonucleotide and a saponin derivative particularly the combination of CpG and QS21 is disclosed in WO 00/09159.

[0198] Many single or multiphase emulsion systems have been described. One of skill in the art may readily adapt such emulsion systems for use with chimeric VLPs so that the emulsion does not disrupt the chimeric VLP's structure. Oil in water emulsion adjuvants per se have been suggested to be useful as adjuvant compositions (EPO 399 843B), also combinations of oil in water emulsions and other active agents have been described as adjuvants for vaccines (WO 95/17210; WO 98/56414; WO 99/12565; WO 99/11241). Other oil emulsion adjuvants have been described, such as water in oil emulsions (U.S. Pat. No. 5,422,109; EP 0 480 982 B2) and water in oil in water emulsions (U.S. Pat. No. 5,424,067; EP 0 480 981 B).

[0199] The oil emulsion adjuvants for use with the chimeric VLP vaccines described herein may be natural or synthetic, and may be mineral or organic. Examples of mineral and organic oils will be readily apparent to the man skilled in the art.

[0200] In order for any oil in water composition to be suitable for human administration, the oil phase of the emulsion system may include a metabolizable oil. The meaning of the term metabolizable oil is well known in the art. Metabolizable can be defined as "being capable of being transformed by metabolism" (Dorland's Illustrated Medical Dictionary, W.B. Sanders Company, 25th edition (1974)). The oil may be any vegetable oil, fish oil, animal oil or synthetic oil, which is not toxic to the recipient and is capable of being transformed by metabolism. Nuts (such as peanut oil), seeds, and grains are common sources of vegetable oils. Synthetic oils may also be used and can include commercially available oils such as NEOBEE® and others. Squalene (2,6,10,15,19,23-Hexamethyl-2,6,10,14,18,22-tetracosahexaene) is an unsaturated oil which is found in large quantities in shark-liver oil, and in lower quantities in olive oil, wheat germ oil, rice bran oil, and yeast, and may be used with the chimeric VLPs. Squalene is a metabolizable oil virtue of the fact that it is an intermediate in the biosynthesis of cholesterol (Merck index, 10th Edition, entry no.8619).

[0201] Exemplary oil emulsions are oil in water emulsions, and in particular squalene in water emulsions.

[0202] In addition, the oil emulsion adjuvants for use with the chimeric VLPs may include an antioxidant, such as the oil α-tocopherol (vitamin E, EP 0 382 271 B1).

[0203] WO 95/17210 and WO 99/11241 disclose emulsion adjuvants based on squalene, α-tocopherol, and TWEEN 80 (TM), optionally formulated with the immunostimulants QS21 and/or 3D-MPL. WO 99/12565 discloses an improvement to these squalene emulsions with the addition of a sterol into the oil phase. Additionally, a triglyceride, such as tricaprylin (C27H50O6), may be added to the oil phase in order to stabilize the emulsion (WO 98/56414).

[0204] The size of the oil droplets found within the stable oil in water emulsion may be less than 1 micron, may be in the range of substantially 30-600 nm, substantially around 30-500 nm in diameter, or substantially 150-500 nm in diameter, and in particular about 150 nm in diameter as measured by photon correlation spectroscopy. In this regard, 80% of the oil droplets by number may be within these ranges, more than 90% or more than 95% of the oil droplets by number are within the defined size ranges. The amounts of the components present in oil emulsions are conventionally in the range of from 2 to 10% oil, such as squalene; and when present, from 2 to 10% alpha tocopherol; and from 0.3 to 3% surfactant, such as polyoxyethylene sorbitan monooleate. The ratio of oil: alpha tocopherol may be equal or less than 1 as this provides a more stable emulsion. SPAN 85 (TM) may also be present at a level of about 1%. In some cases it may be advantageous that the chimeric VLP vaccines disclosed herein will further contain a stabilizer.

[0205] The method of producing oil in water emulsions is well known to the man skilled in the art. Commonly, the method includes the step of mixing the oil phase with a surfactant such as a PBS/TWEEN80® solution, followed by homogenization using a homogenizer, it would be clear to a man skilled in the art that a method comprising passing the mixture twice through a syringe needle would be suitable for homogenizing small volumes of liquid. Equally, the emulsification process in microfluidizer (M110S microfluidics machine, maximum of 50 passes, for a period of 2 minutes at maximum pressure input of 6 bar (output pressure of about 850 bar)) could be adapted by the man

skilled in the art to produce smaller or larger volumes of emulsion. This adaptation could be achieved by routine experimentation comprising the measurement of the resultant emulsion until a preparation was achieved with oil droplets of the required diameter.

[0206] The chimeric VLP vaccine preparations disclosed herein may be used to protect or treat a mammal or bird susceptible to, or suffering from a viral infection, by means of administering the vaccine by intranasal, intramuscular, intraperitoneal, intradermal, transdermal, intravenous, or subcutaneous administration. Methods of systemic administration of the vaccine preparations may include conventional syringes and needles, or devices designed for ballistic delivery of solid vaccines (WO 99/27961), or needleless pressure liquid jet device (U.S. Pat. No. 4,596,556; U.S. Pat. No. 5,993,412), or transdermal patches (WO 97/48440; WO 98/28037). The chimeric VLP vaccines may also be applied to the skin (transdermal or transcutaneous delivery WO 98/20734; WO 98/28037). The chimeric VLP vaccines disclosed herein therefore includes a delivery device for systemic administration, pre-filled with the chimeric VLP vaccine or adjuvant compositions. Accordingly there is provided a method for inducing an immune response in an individual such as a mammal or bird, comprising the administration of a vaccine comprising any of the chimeric VLP compositions described herein and optionally including an adjuvant and/or a carrier, to the individual, wherein the vaccine is administered via the parenteral or systemic route.

[0207] The vaccine preparations of the chimeric VLPs may be used to protect or treat a mammal or bird susceptible to, or suffering from a viral infection, by means of administering the vaccine via a mucosal route, such as the oral/alimentary or nasal route. Alternative mucosal routes are intravaginal and intra-rectal. The mucosal route of administration may be via the nasal route, termed intranasal vaccination. Methods of intranasal vaccination are well known in the art, including the administration of a droplet, spray, or dry powdered form of the vaccine into the nasopharynx of the individual to be immunized. Nebulized or aerosolized vaccine formulations are potential forms of the chimeric VLP vaccines disclosed herein. Enteric formulations such as gastro resistant capsules and granules for oral administration, suppositories for rectal or vaginal administration are also formulations of the chimeric VLP vaccines disclosed herein.

[0208] The exemplary chimeric VLP vaccine compositions disclosed herein, represent a class of mucosal vaccines suitable for application in humans to replace systemic vaccination by mucosal vaccination.

[0209] The chimeric VLP vaccines may also be administered via the oral route. In such cases the pharmaceutically acceptable excipient may also include alkaline buffers, or enteric capsules or microgranules. The chimeric VLP vaccines may also be administered by the vaginal route. In such cases, the pharmaceutically acceptable excipients may also include emulsifiers, polymers such as CARBOPOL®, and other known stabilizers of vaginal creams and suppositories. The chimeric VLP vaccines may also be administered by the rectal route. In such cases the excipients may also include waxes and polymers known in the art for forming rectal suppositories.

[0210] Alternatively the chimeric VLP vaccines formulations may be combined with vaccine vehicles composed of chitosan (as described above) or other polycationic polymers, polylactide and polylactide-coglycolide particles, poly-N-acetyl glucosamine-based polymer matrix, particles composed of polysaccharides or chemically modified polysaccharides, liposomes and lipid-based particles, particles composed of glycerol monoesters, etc. The saponins may also be formulated in the presence of cholesterol to form particulate structures such as liposomes or ISCOMs. Furthermore, the saponins may be formulated together with a polyoxyethylene ether or ester, in either a non-particulate solution or suspension, or in a particulate structure such as a paucilamelar liposome or ISCOM.

[0211] Additional illustrative adjuvants for use in the pharmaceutical and vaccine compositions using the chimeric VLPs as described herein include SAF (Chiron, Calif., United States), MF-59 (Chiron, see, e.g., Granoff et al. (1997) Infect Immun. 65 (5):1710-1715), the SBAS series of adjuvants (e.g., SB-AS2 (SmithKline Beecham adjuvant system #2; an oil-in-water emulsion containing MPL and QS21); SBAS-4 (SmithKline Beecham adjuvant system #4; contains alum and MPL), available from SmithKline Beecham, Rixensart, Belgium), Detox (Enhanzyn®) (GlaxoSmithKline), RC-512, RC-522, RC-527, RC-529, RC-544, and RC-560 (GlaxoSmithKline) and other

aminoalkyl glucosaminide 4-phosphates (AGPs), such as those described in pending U.S. patent application Ser. Nos. 08/853,826 and 09/074,720.

[0212] Other examples of adjuvants include, but are not limited to, Hunter's TiterMax® adjuvants (CytRx Corp., Norcross, Ga.); Gerbu adjuvants (Gerbu Biotechnik GmbH, Gaiberg, Germany); nitrocellulose (Nilsson and Larsson (1992) Res. Immunol. 143:553-557); alum (e.g., aluminum hydroxide, aluminum phosphate) emulsion based formulations including mineral oil, non-mineral oil, water-in-oil or oil-in-water emulsions, such as the Seppic ISA series of Montamide adjuvants (e.g., ISA-51, ISA-57, ISA-720, ISA-151, etc.; Seppic, Paris, France); and PROVAX® (IDEC Pharmaceuticals); OM-174 (a glucosamine disaccharide related to lipid A); Leishmania elongation factor; non-ionic block copolymers that form micelles such as CRL 1005; and Syntex Adjuvant Formulation. See, e.g., O'Hagan et al. (2001) Biomol Eng. 18(3):69-85; and "Vaccine Adjuvants: Preparation Methods and Research Protocols" D. O'Hagan, ed. (2000) Humana Press.

[0213] Other exemplary adjuvants include adjuvant molecules of the general formula

[0214] $HO(CH_2CH_2O)_n$-A-R, (I)

[0215] wherein, n is 1-50, A is a bond or --C(O)--, R is C_{1-50} alkyl or Phenyl C_{1-50} alkyl.

[0216] One embodiment consists of a vaccine formulation comprising a polyoxyethylene ether of general formula (I), wherein n is between 1 and 50, 4-24, or 9; the R component is C_{1-50}, C_4-C_{20} alkyl, or C_{12} alkyl, and A is a bond. The concentration of the polyoxyethylene ethers should be in the range 0.1-20%, from 0.1-10%, or in the range 0.1-1%. Exemplary polyoxyethylene ethers are selected from the following group: polyoxyethylene-9-lauryl ether, polyoxyethylene-9-steoryl ether, polyoxyethylene-8-steoryl ether, polyoxyethylene-4-lauryl ether, polyoxyethylene-35-lauryl ether, and polyoxyethylene-23-lauryl ether. Polyoxyethylene ethers such as polyoxyethylene lauryl

ether are described in the Merck index (12th edition: entry 7717). These adjuvant molecules are described in WO 99/52549.

[0217] The polyoxyethylene ether according to the general formula (I) above may, if desired, be combined with another adjuvant. For example, an adjuvant combination may include the CpG as described above.

[0218] Further examples of suitable pharmaceutically acceptable excipients for use with the chimeric VLP vaccines disclosed herein include water, phosphate buffered saline, isotonic buffer solutions.

[0219] The disclosed compositions and methods will be better understood by reference to the following non-limiting Examples. As described herein, the invention includes chimeric VLPs which optionally comprise an additional VLP-associated polypeptide linked to an antigen or adjuvant. The following Examples describe a representative embodiment of the invention which includes chimeric VLPs.

Example 1 – Attempted Pseudotyped MLV gag + RSV F VLPs

[0220] This example demonstrates that mammalian cell expression of a truncated version of the RSV fusion (F) glycoprotein lacking the cytoplasmic tail region or hybrid F proteins containing transmembrane and cytoplasmic tail regions derived from influenza hemagglutinin results in the formation of enveloped virus-like particles (VLPs) containing RSV F.

[0221] This example was designed such that the RSV F glycoprotein was expressed in mammalian cells with and without co-expression of the murine leukemia virus Gag gene product. The expectation was that the RSV F would be incorporated into enveloped Gag VLPs budding from the cells.

[0222] Plasmid p3.1-RSVFT encoded a truncated version of F (RSVFT) devoid of its cytoplasmic tail but containing the native transmembrane domain. A map of p3.1-RSVFT is shown in Figure 16 and the coding sequence for RSVFT as follows:

atggaactgctgatcctgaaggctaacgctatcaccaccatcctgaccgctgtc
accttctgcttcgcctccggccagaacatcaccgaggaattctaccagtccacc
tgctccgctgtctccaagggttacctgtccgctctgcgcaccggctggtacacc
tccgtcatcaccatcgagctgtccaacatcaaggaaaacaagtgcaacggcacc
gacgctaaggtcaagctgatcaagcaggaactggacaagtacaagaacgctgtc
accgagctgcagctgctgatgcagtccacccccgctaccaacaaccgcgctcgc
cgtgagctgccccgcttcatgaactacaccctgaacaacgccaagaaaaccaac
gtcaccctgtccaagaagcgcaagcgccgcttcctgggtttcctgctgggtgtc
ggttccgctatcgcttccggtgtcgctgtctctaaggtcctgcacctggaaggc
gaggtcaacaagatcaagtccgccctgctgtccaccaacaaggctgtcgtgtcc
ctgtccaacggtgtctccgtcctgacctccaaggtgctggacctgaagaactac
atcgacaagcagctgctgcccatcgtcaacaagcagtcctgctccatctccaac
atcgagactgtcatcgagttccagcagaagaacaaccgcctgctggaaatcacc
cgcgagttctccgtcaacgctggtgtcaccacccctgtctccacctacatgctg
accaactccgagctgctgtccctgatcaacgacatgcccatcaccaacgaccaa
aagaaactgatgtccaacaacgtccagatcgtccgccagcagtcctactctatc
atgagcatcatcaaggaagaggtcctggcttacgtcgtccagctgcccctgtac
ggtgtcatcgacacccccctgctggaagctgcacacctccccccctgtgcaccacc
aacaccaaggaaggttccaacatctgcctgacccgcaccgaccgcggctggttc
tgcgacaacgctggctctgtctccttcttcccccaagctgagacttgcaaggtc
cagtccaaccgcgtgttctgcgacaccatgaactccctgaccctgccctccgag
gtcaacctgtgcaacgtcgacatcttcaaccccaagtacgactgcaagatcatg
acctctaagaccgacgtgtcctcctctgtcatcacctccctgggtgctatcgtg
tcctgctacggcaagaccaagtgcaccgcttccaacaagaaccgcggtatcatc
aagaccttctccaacggttgcgactacgtgtccaacaagggcgtcgacaccgtg
tccgtcggcaacaccctgtactacgtgaacaagcaggaaggcaagtccctgtac
gtcaagggcgagcccatcatcaacttctacgacccctggtgttcccctccgac
gagttcgacgcttccatcagccaggtcaacgagaagatcaaccagtccctggct
ttcatccgcaagtccgacgagctgctgcacaacgtgaacgctggcaagtctacc
accaacatcatgatcaccactatcatcatcgtgatcatcgtcatcctgctgtct
ctgatcgctgtcggtctgctgctgtactaa (SEQ ID NO:6)

[0223] The RSVFT coding sequence was synthesized as a custom synthetic DNA fragment and was not cloned from virus since the natural RSV F gene is from a paramyxovirus which replicates in the cytoplasm of cells and would therefore not be expected to be appropriately expression in the nucleus of a cell. The encoded amino acid sequence of RSVFT is as follows (with the signal peptide and transmembrane domains in capital letters):

MELLILKANAITTILTAVTFCfasgqniteefyqstcsavskgylsalrtgwyt
svitielsnikenkcngtdakvklikqeldkyknavtelqllmqstpatnnrar
relprfmnytlnnakktnvtlskkrkrrflgfllgvgsaiasgvavskvlhleg
evnkiksallstnkavvslsngvsvltskvldlknyidkqllpivnkqscsisn
ietviefqqknnrlleitrefsvnagvttpvstymltnsellslindmpitndq
kklmsnnvqivrqqsysimsiikeevlayvvqlplygvidtpcwklhtsplctt
ntkegsnicltrtdrgwfcdnagsvsffpqaetckvqsnrvfcdtmnsltlpse
vnlcnvdifnpkydckimtsktdvsssvitslgaivscygktkctasnknrgii
ktfsngcdyvsnkgvdtvsvgntlyyvnkqegkslyvkgepiinfydplvfpsd
efdasisqvnekinqslafirksdellhnvnagksttnIMITTIIIVIIVILLS
LIAVGLLLY (SEQ ID NO:7)

[0224] Plasmid p3.1-shFv1 encoded a hybrid protein consisting of the ectodomain of RSV F fused to the transmembrane domain and cytoplasmic tail of an H5 hemagglutinin from influenza A. Figure 1 shows a map of p3.1-shFv1 and the coding sequence for shFv1 is as follows:

atggaactgctgatcctgaaggctaacgctatcaccaccatcctgaccgctgtg
accttctgcttcgcttccggccagaacatcaccgaggaattctaccagtccacc
tgctccgctgtgtccaagggttacctgtccgctctgcgtaccggttggtacacc
tccgtgatcaccatcgagctgtccaacatcaaagagaacaagtgcaacggcacc
gacgctaaggtcaagctgatcaagcaggaactggacaagtacaagaacgctgtg
accgagctgcagctgctgatgcagtccacccccgctaccaacaaccgtgctcgt
cgtgagctgccccgtttcatgaactacaccctgaacaacgccaagaaaaccaac
gtcaccctgtccaagaagcgtaagcgtcgtttcctgggtttcctgctgggtgtg

ggtagcgctatcgcctccggtgtcgctgtctccaaggtgctgcacctcgagggc
gaggtgaacaagatcaagtccgccctgctgtccaccaacaaggctgtggtgtcc
ctgtccaacggtgtctccgttctgaccagcaaggtcttggacctgaagaactac
atcgacaagcagctgctgcccatcgtgaacaagcagtcctgctccatctccaac
atcgagactgtgatcgagttccagcagaagaacaaccgtctgctcgagatcacc
cgtgagttctccgtgaacgctggtgtcaccacccccgtgtccacctacatgctg
accaactccgagctgctgtccctgatcaacgacatgcccatcaccaacgaccag
aaaaagctgatgtccaacaacgtgcagatcgtgcgtcagcagtcctactctatc
atgagcatcatcaaagaggaagtcctggcttacgtggtgcagctgcccctgtac
ggtgtcatcgacacccccctgctggaagctgcacacctccccccctgtgcaccacc
aacaccaaagagggttccaacatctgcctgacccgtaccgatcgtggttggttc
tgtgacaacgctggttccgtgtccttcttcccccaagctgagacttgcaaggtg
cagtccaaccgtgtgttctgcgacaccatgaactccctgaccctgccctccgag
gtgaacctgtgcaacgtggacatcttcaaccccaagtacgactgcaagatcatg
acctctaagaccgacgtgtcctcctccgtcatcacctccctgggtgctatcgtg
tcctgctacggcaagaccaagtgcaccgcttccaacaagaaccgcggtatcatc
aagaccttctccaacggttgcgactacgtgtccaacaagggtgtcgataccgtg
tccgtcggtaacaccctgtactacgtcaacaagcaggaaggcaagtctctgtac
gtgaagggcgagcccatcatcaacttctacgacccccctggtgttcccctccgac
gagttcgacgcttccatcagccaggtcaacgagaagatcaaccagtccctggct
ttcatccgtaagtccgacgagctgctgcacaacgtcaacgctggcaagtccacc
accaacatcctgtccatctactccaccgtggcttcctccctggctctggctatc
atgatggctggtctgtccctgtggatgtgctccaacggctccctgcagtgccgt
atctgcatctaataa (SEQ ID NO:8)

[0225] The amino acid sequence of shFv1 is as follows (with the signal peptide coding sequence and the HA transmembrane and cytoplasmic tail sequences shown in capital letters):

MELLILKANAITTILTAVTFcfasgqniteefyqstcsavskgylsalrtgwyt
svitielsnikenkcngtdakvklikqeldkyknavtelqllmqstpatnnrar
relprfmnytlnnakktnvtlskkrkrrflgfllgvgsaiasgvavskvlhleg

evnkiksallstnkavvslsngvsvltskvldlknyidkqllpivnkqscsisn
ietviefqqknnrlleitrefsvnagvttpvstymltnsellslindmpitndq
kklmsnnvqivrqqsysimsiikeevlayvvqlplygvidtpcwklhtsplctt
ntkegsnicltrtdrgwfcdnagsvsffpqaetckvqsnrvfcdtmnsltlpse
vnlcnvdifnpkydckimtsktdvsssvitslgaivscygktkctasnknrgii
ktfsngcdyvsnkgvdtvsvgntlyyvnkqegkslyvkgepiinfydplvfpsd
efdasisqvnekinqslafirksdellhnvnagksttnILSIYSTVASSLALAI
MMAGLSLWMCSNGSLQCRICI (SEQ ID NO:9)

[0226] As with RSVFT, the shFv1 coding sequence was generated by DNA synthesis.

[0227] Plasmid p3.1-shFv2 encoded a hybrid protein consisting of the ectodomain of RSV F fused to the transmembrane domain and cytoplasmic tail of an H5 hemagglutinin from influenza A. shFv2 differed from shFv1 in that the influenza HA-derived transmembrane and tail region is four amino acids longer. Figure 2 shows a plasmid map of p3.1-shFv2. The coding sequence for shFv2 is as follows:

atggaactgctgatcctgaaggctaacgctatcaccaccatcctgaccgctgtg
accttctgcttcgcttccggccagaacatcaccgaggaattctaccagtccacc
tgctccgctgtgtccaagggttacctgtccgctctgcgtaccggttggtacacc
tccgtgatcaccatcgagctgtccaacatcaaagagaacaagtgcaacggcacc
gacgctaaggtcaagctgatcaagcaggaactggacaagtacaagaacgctgtg
accgagctgcagctgctgatgcagtccacccccgctaccaacaaccgtgctcgt
cgtgagctgccccgtttcatgaactacaccctgaacaacgccaagaaaaccaac
gtcaccctgtccaagaagcgtaagcgtcgtttcctgggtttcctgctgggtgtg
ggtagcgctatcgcctccggtgtcgctgtctccaaggtgctgcacctcgagggc
gaggtgaacaagatcaagtccgccctgctgtccaccaacaaggctgtggtgtcc
ctgtccaacggtgtctccgttctgaccagcaaggtcttggacctgaagaactac
atcgacaagcagctgctgcccatcgtgaacaagcagtcctgctccatctccaac
atcgagactgtgatcgagttccagcagaagaacaaccgtctgctcgagatcacc
cgtgagttctccgtgaacgctggtgtcaccacccccgtgtccacctacatgctg

accaactccgagctgctgtccctgatcaacgacatgcccatcaccaacgaccag
aaaaagctgatgtccaacaacgtgcagatcgtgcgtcagcagtcctactctatc
atgagcatcatcaaagaggaagtcctggcttacgtggtgcagctgcccctgtac
ggtgtcatcgacacccccctgctggaagctgcacacctccccccctgtgcaccacc
aacaccaaagagggttccaacatctgcctgacccgtaccgatcgtggttggttc
tgtgacaacgctggttccgtgtccttcttcccccaagctgagacttgcaaggtg
cagtccaaccgtgtgttctgcgacaccatgaactccctgaccctgccctccgag
gtgaacctgtgcaacgtggacatcttcaaccccaagtacgactgcaagatcatg
acctctaagaccgacgtgtcctcctccgtcatcacctccctgggtgctatcgtg
tcctgctacggcaagaccaagtgcaccgcttccaacaagaaccgcggtatcatc
aagaccttctccaacggttgcgactacgtgtccaacaagggtgtcgataccgtg
tccgtcggtaacaccctgtactacgtcaacaagcaggaaggcaagtctctgtac
gtgaagggcgagcccatcatcaacttctacgacccccctggtgttcccctccgac
gagttcgacgcttccatcagccaggtcaacgagaagatcaaccagtccctggct
ttcatccgtaagtccgacgagctgctgcacaacgtcaacgctggcaagtccacc
accaacggcacctaccagatcctgtccatctactccaccgtggcttcctccctg
gctctggctatcatgatggctggtctgtccctgtggatgtgctccaacggctcc
ctgcagtgccgtatctgcatctaataa (SEQ ID NO:10)

[0228] The amino acid sequence of shFv2 is as follows (with the signal peptide coding sequence and the HA transmembrane and cytoplasmic tail sequences shown in capital letters):

MELLILKANAITTILTAVTFcfasgqniteefyqstcsavskgylsalrtgwyt
svitielsnikenkcngtdakvklikqeldkyknavtelqllmqstpatnnrar
relprfmnytlnnakktnvtlskkrkrrflgfllgvgsaiasgvavskvlhleg
evnkiksallstnkavvslsngvsvltskvldlknyidkqllpivnkqscsisn
ietviefqqknnrlleitrefsvnagvttpvstymltnsellslindmpitndq
kklmsnnvqivrqqsysimsiikeevlayvvqlplygvidtpcwklhtsplctt
ntkegsnicltrtdrgwfcdnagsvsffpqaetckvqsnrvfcdtmnsltlpse
vnlcnvdifnpkydckimtsktdvsssvitslgaivscygktkctasnknrgii
ktfsngcdyvsnkgvdtvsvgntlyyvnkqegkslyvkgepiinfydplvfpsd

efdasisqvnekinqslafirksdellhnvnagksttnGTYQILSIYSTVASSL
ALAIMMAGLSLWMCSNGSLQCRICI (SEQ ID NO:11)

[0229] The shFv2 coding sequence was generated by DNA synthesis.

[0230] Plasmid p3.1-Gag encoded the Gag gene product from murine leukemia virus. Figure 3 shows a plasmid map of p3.1 Gag. The coding sequence for Gag from plasmid p3.1-Gag is as follows:

atgggccagactgttaccactcccttaagtttgaccttaggtcactggaaagat
gtcgagcggatcgctcacaaccagtcggtagatgtcaagaagagacgttgggtt
accttctgctctgcagaatggccaacctttaacgtcggatggccgcgagacggc
acctttaaccgagacctcatcacccaggttaagatcaaggtcttttcacctggc
ccgcatggacacccagaccaggtcccctacatcgtgacctgggaagccttggct
tttgacccccctccctgggtcaagccctttgtacaccctaagcctccgcctcct
cttcctccatccgccccgtctctccccccttgaacctcctcgttcgaccccgcct
cgatcctccctttatccagccctcactccttctctaggcgccaaacctaaacct
caagttctttctgacagtgggggccgctcatcgacctacttacagaagacccc
ccgccttatagggacccaagaccacccccttccgacagggacggaaatggtgga
gaagcgacccctgcgggagaggcaccggacccctccccaatggcatctcgccta
cgtgggagacgggagccccctgtggccgactccactacctcgcaggcattcccc
ctccgcgcaggaggaaacggacagcttcaatactggccgttctcctcttctgac
ctttacaactggaaaaataataacccttctttttctgaagatccaggtaaactg
acagctctgatcgagtctgttctcatcacccatcagcccacctgggacgactgt
cagcagctgttggggactctgctgaccggagaagaaaaacaacgggtgctctta
gaggctagaaaggcggtgcggggcgatgatgggcgccccactcaactgcccaat
gaagtcgatgccgcttttcccctcgagcgcccagactgggattacaccacccag
gcaggtaggaaccacctagtccactatcgccagttgctcctagcgggtctccaa
aacgcgggcagaagccccaccaatttggccaaggtaaaaggaataacacaaggg
cccaatgagtctccctcggccttcctagagagacttaaggaagcctatcgcagg
tacactccttatgaccctgaggacccagggcaagaaactaatgtgtctatgtct
ttcatttggcagtctgccccagacattgggagaaagttagagaggttagaagat

ttaaaaaacaagacgcttggagatttggttagagaggcagaaaagatctttaat
aaacgagaaaccccggaagaaagagaggaacgtatcaggagagaaacagaggaa
aaagaagaacgccgtaggacagaggatgagcagaaagagaaagaaagagatcgt
aggagacatagagagatgagcaagctattggccactgtcgttagtggacagaaa
caggatagacagggaggagaacgaaggaggtcccaactcgatcgcgaccagtgt
gcctactgcaaagaaaaggggcactgggctaaagattgtcccaagaaaccacga
ggacctcggggaccaagaccccagacctccctcctgaccctagatgactagtag
(SEQ ID NO:12)

[0231] The amino acid sequence for MLV Gag is as follows:

Mgqtvttplsltlghwkdveriahnqsvdvkkrrwvtfcsaewptfnvgwprdg
tfnrdlitqvkikvfspgphghpdqvpyivtwealafdpppwvkpfvhpkpppp
lppsapslplepprstpprsslypaltpslgakpkpqvlsdsggplidlltedp
ppyrdprpppsdrdgnggeatpageapdpspmasrlrgrreppvadsttsqafp
lraggngqlqywpfsssdlynwknnnpsfsedpgkltaliesvlithqptwddc
qqllgtlltgeekqrvllearkavrgddgrptqlpnevdaafplerpdwdyttq
agrnhlvhyrqlllaglqnagrsptnlakvkgitqgpnespsaflerlkeayrr
ytpydpedpgqetnvsmsfiwqsapdigrklerledlknktlgdlvreaekifn
kretpeereerirreteekeerrrtedeqkekerdrrrhremskllatvvsgqk
qdrqggerrrsqldrdqcayckekghwakdcpkkprgprgprpqtsllt1dd
(SEQ ID NO:13)

[0232] The Gag gene represented a natural clone from the genome of MLV found in plasmid pAMS (ATCC).

[0233] Eight 10 cm^2 tissue culture dishes were seeded with 293-F cells cultured in Dulbecco's Modified Eagle's medium supplemented with 10% fetal bovine serum. When the cells reached approximately 95% confluence (monolayer culture), each well was transfected with a total of 4 μg of plasmid DNA as follows:

1. No DNA

2. 4 μg p3.1-Gag

3. 4 μg p3.1-RSVFT

4. 4 μg p3.1-shFv1

5. 4 μg p3.1-shFv2

6. 2 μg p3.1-RSVFT + 2 μg p3.1-Gag

7. 2 μg p3.1-shFv1 + 2 μg p3.1-Gag

8. 2 μg p3.1-shFv2 + 2 μg p3.1-Gag

[0234] Plasmid DNA was transfected using LIPOFECTAMINE (TM) 2000 (Invitrogen) according to the manufacture's recommendations. Eight hours post-transfection, the transfection medium was replaced with CD293 serum-free medium and culture was continued. At forty-eight hours post-transfection all dishes containing cells transfected with any of the RSV F expression vectors exhibited significant levels of syncytia (fused cells) consistent with surface expression of correctly folded F. At forty-eight hours post-transfection cells were detached by pipetting and cells and medium were harvested. The expression of RSV F antigenic activity on the surface of cells was further demonstrated by flow cytometry after staining cells with a mouse monoclonal antibody (9C5) that recognizes the correctly folded F antigen in its membrane integrated state. Cells were further reacted with a goat-anti-mouse secondary antibody conjugated to phycoerythrin for fluorescent detection of F-positive cells. Figure 4 shows the histograms from the flow cytometric runs demonstrating significant levels of surface expression of F on cells transfected with any of the F expression vectors with and without the Gag vector. These data are consistent with the presence of syncytia in transfected cell populations and demonstrate the presence of correctly folded F antigen on the cell surface.

[0235] The growth medium harvested from the transfected cells was centrifuged at 2000 rpm for 5 minutes to remove syncytia and any cellular debris and the supernatant from this step was centrifuged over a 30% sucrose cushion in tris-buffered saline at

100,000 x g for 1 hour to collect any VLPs that may have been released into the medium as a result of Gag and/or F gene expression. 100,000 x g pellets from this step were resuspended in tris-buffered saline for additional analyses.

[0236] Resuspended pellets from the ultracentrifuge step were subjected to Western blot analysis to detect the presence of the Gag product as an indication of VLP formation. Unexpectedly, a significant amount of the Gag product was detected in the sample from cells transfected with the p3.1-Gag vector alone, but markedly reduced amounts of Gag were found in pellets from cells transfected with p3.1-Gag in combination with any of the F gene vectors. The results are consistent with expression of the F gene product interfering in some manner with the budding functions of the Gag product.

[0237] The presence of the F antigen in resuspended ultracentrifuge pellets was subsequently examined by ELISA as follows: Each resuspended ultracentrifuge pellet sample was loaded into a single well in row A of a Nunc MAXISORP(TM) flat bottom 96-well ELISA plate and each sample was serially diluted two-fold down each column of the plate. After coating overnight at 4o C, the plate was washed 3 times with PBS containing 0.05% TWEEN 20 (TM) (PBS-T) and then blocked with STARTING BLOCK (TM) (PBS) (Pierce, Biotechnology). After blocking, 100 µl of 1:1000 diluted monoclonal antibody 9C5 in STARTING BLOCK T20 (TM) (Pierce) was loaded into each well and the plate was incubated at room temperature for 3 hours. The plate was washed again and 100 µl of goat anti-mouse HRP conjugate antibody (Southern Biotech) diluted 1:1000 in STARTING BLOCK T20 (TM) was added to each well and incubated at room temperature for 1.5 hours. Following a final wash (3x) with PBS-T, the plate was developed by the addition of 100 µl ABTS reagent (Pierce) and incubated at room temperature for 45 minutes.

[0238] Figure 5 shows the results of this ELISA in which it can be observed that significant levels of RSV F antigen were detected in the 100,000 x g pellets from both F gene alone and F gene + Gag gene transfections. Importantly and unexpectedly, greater amounts of RSV F antigenic activity were observed in the pellets from cells transfected with the RSV F genes alone. These data demonstrates that expression of the F gene

alone, in the absence of Gag expression, results in the formation of VLPs carrying the F antigen. This is also consistent with the above observation that co-expression of F and Gag results in a suppression of Gag budding, possibly due to interference of Gag budding by F.

Example 2 – Pseudotyped HIV-1 Gag + RSV F VLPs

[0239] This example demonstrates the production of HIV-1 Gag VLPs pseudotyped with the GPI-anchored version of the RSV F glycoprotein.

Materials and Methods

[0240] Plasmid p3.1-bruGag contains a synthetic sequence that encodes the HIV-Gag product from the bru strain of HIV-1. This plasmid employs the CMV immediate early promoter and is suitable for transient transfection expression studies. Figure 6 shows the map of p3.1-bruGag. The coding sequence for the bruGag is as follows:

atgggagccagagccagcgtgctgtctggcggcgagctggacagatgggagaag
atccggctgcggccaggcggcaagaagaagtacaagctgaagcacatcgtgtgg
gctagccgggagctggaaagattcgccgtgaaccccggactgctggaaaccagc
gagggctgcagacagatcctgggccagctgcagccatctctgcagaccggcagc
gaggaactgcggagcctgtacaacaccgtggccaccctgtactgcgtgcaccag
cggatcgagatcaaggacaccaaagaggccctggacaagatcgaggaagaacag
aacaagtccaagaagaaggcccagcaggccgctgccgataccggccacagcagc
caggtgtcccagaactaccccatcgtgcagaacatccagggccagatggtgcac
caggccatctctcccagaaccctgaacgcctgggtgaaagtggtggaggaaaag
gccttcagccccgaagtgatccccatgttcagcgccctgagcgaaggcgccacc
ccccaggacctgaacaccatgctgaacaccgtgggaggacaccaggccgccatg
cagatgctgaaagagacaatcaacgaagaggccgccgagtgggacagagtgcac
cctgtgcacgccggacctatcgcccctggccagatgagagagcccagaggcagc
gatatcgccggcaccacaagcaccctgcaggaacagatcggctggatgacaaac
aaccccccatccccgtgggcgagatctacaagcggtggatcatcctgggcctg
aacaagatcgtgcggatgtacagccccacctccatcctggacatccggcagggc

cccaaagagcccttccgggactacgtggaccggttctacaagaccctgcgggcc
gagcaggccagccaggaagtgaagaactggatgaccgagacactgctggtgcag
aacgccaaccccgactgcaagaccatcctgaaggccctgggaccagccgccacc
ctggaagagatgatgaccgcctgtcagggcgtgggcggacctggacacaaagcc
agagtgctggccgaggccatgagccaggtgaccaacagcgccaccatcatgatg
cagcggggcaacttccggaaccagcggaagatcgtgaagtgcttcaactgcggc
aaggaaggccacattgcccggaactgcagagcccccagaaagaaaggctgctgg
aagtgcgggaaagaggggcaccagatgaaggactgcaccgagcggcaggccaac
ttcctcggcaaaatctggcccagctacaagggcagacccggcaacttcctgcag
agcagacccgagcctaccgcccctcccttcctgcagtccaggcctgaacctacc
gctccccccgaggaaagcttcagatccggcgtggagacaaccacccctagccag
aagcaggaacccatcgacaaagagctgtacccccctgaccagcctgagaagcctg
ttcggcaacgaccccagcagccagtga (SEQ ID NO:14)

[0241] The amino acid sequence encoded by p3.1-bruGag is as follows:

mgarasvlsggeldrwekirlrpggkkkyklkhivwasrelerfavnpgllets
egcrqilgqlqpslqtgseelrslyntvatlycvhqrieikdtkealdkieeeq
nkskkkaqqaaadtghssqvsqnypivqniqgqmvhqaisprtlnawvkvveek
afspevipmfsalsegatpqdlntmlntvgghqaamqmlketineeaaewdrvh
pvhagpiapgqmreprgsdiagttstlqeqigwmtnnppipvgeiykrwiilgl
nkivrmysptsildirqgpkepfrdyvdrfyktlraeqasqevknwmtetllvq
nanpdcktilkalgpaatleemmtacqgvggpghkarvlaeamsqvtnsatimm
qrgnfrnqrkivkcfncgkeghiarncraprkkgcwkcgkeghqmkdcterqan
flgkiwpsykgrpgnflqsrpeptappflqsrpeptappeesfrsgvetttpsq
kqepidkelypltslrslfgndpssq* (SEQ ID NO:15)

[0242] Plasmid p3.1-F-GPI contains a synthetic sequence that encodes a GPI-anchored version of the RSV F glycoprotein from RSV strain A2. This plasmid was constructed by deleting the F gene sequences encoding the transmembrane and cytoplasmic tail domains and replacing them with sequences encoding the GPI anchor

signal from human carboxypeptidase M. Figure 7 shows a map of p3.1-F-GPI. The F-GPI coding sequence is as follows:

atggagctgctgatcctgaaggccaacgccatcaccaccatcctgaccgccgtg
accttctgcttcgcctccggccagaacatcaccgaggagttctaccagtccacc
tgctccgccgtgtccaagggctacctgtccgccctgcggaccggctggtacacc
tccgtgatcaccatcgagctgtccaacatcaaagaaaacaagtgcaacggcacc
gacgccaaggtgaagctgatcaagcaggagctggacaagtacaagaacgccgtg
accgagctgcagctgctgatgcagtccacccctgccaccaacaaccgggccagg
cgggagctgcctcggttcatgaactacaccctgaacaacgccaagaaaaccaac
gtcaccctgtccaagaagcggaagcggcggttcctgggcttcctgctgggcgtg
ggctccgctatcgcctctggcgtggccgtgtctaaggtgctgcacctggagggc
gaggtgaacaagatcaagtctgccctgctgtccaccaacaaggccgtggtgtcc
ctgtccaacggcgtgtccgtgctgacctccaaggtgctggatctgaagaactac
atcgacaagcagctgctgcctatcgtgaacaagcagtcctgctccatctccaac
atcgagacagtgatcgagttccagcagaagaacaaccggctgctggaaatcaca
agagagttctccgtcaacgctggtgtgaccactcctgtctctacttatatgctg
accaactccgagctgctgtccctgatcaacgacatgcctatcaccaacgaccag
aaaaagctgatgtccaacaacgtgcagatcgtgcggcagcagtcctactctatc
atgagcatcatcaaggaggaggtcctggcctacgtggtgcagctgcctctgtac
ggcgtgatcgacacccctgctggaagctgcacacctccccctgtgcaccacc
aacaccaaggagggctccaacatctgcctgacccggaccgaccggggctggttc
tgcgacaacgccggctccgtgtccttctttccacaggccgagacatgcaaggtg
cagtccaaccgggtgttctgcgataccatgaactccctgaccctgccttccgag
gtgaacctgtgcaacgtggacatcttcaaccctaagtacgactgcaagatcatg
acctctaagaccgacgtgtcctcctctgtgatcacctccctgggcgccatcgtg
tcctgctacggcaagaccaagtgcaccgcctccaacaagaaccggggaatcatc
aagaccttctccaacggctgcgactacgtgtccaataagggcgtggacaccgtg
tccgtgggcaacacactgtactacgtgaataagcaggagggcaagtctctgtac
gtgaagggcgagcctatcatcaacttctacgaccctctggtgttcccttccgac
gagttcgacgcctccatcagccaggtgaacgagaagatcaaccagtccctggcc
ttcatccggaagtccgacgagctgctgcacaacgtgaacgctggcaagtctacc

accaaccccgaccactccgccgccaccaagccctccctgttcctgttcctggtg
tccctgctgcacatcttcttcaagtgataa (SEQ ID NO:16)

[0243] The amino acid sequence encoded by p3.1-F-GPI is as follows:

mellilkanaittiltavtfcfasgqniteefyqstcsavskgylsalrtgwyt
svitielsnikenkcngtdakvklikqeldkyknavtelqllmqstpatnnrar
relprfmnytlnnakktnvtlskkrkrrflgfllgvgsaiasgvavskvlhleg
evnkiksallstnkavvslsngvsvltskvldlknyidkqllpivnkqscsisn
ietviefqqknnrlleitrefsvnagvttpvstymltnsellslindmpitndq
kklmsnnvqivrqqsysimsiikeevlayvvqlplygvidtpcwklhtsplctt
ntkegsnicltrtdrgwfcdnagsvsffpqaetckvqsnrvfcdtmnsltlpse
vnlcnvdifnpkydckimtsktdvsssvitslgaivscygktkctasnknrgii
ktfsngcdyvsnkgvdtvsvgntlyyvnkqegkslyvkgepiinfydplvfpsd
efdasisqvnekinqslafirksdellhnvnagksttnpdhsaatkpslflflv
sllhiffk* (SEQ ID NO:17)

[0244] Plasmids p3.1-bruGag and p3.1-F-GPI were transfected into 293F cells either alone or in combination with one another at various ratios (1:1, 3:1, and 9:1 Gag-to-F). Each transfection employed a T75 culture flask of 293F cells growing as a monolayer. Transfections employed LIPOFECTAMINE (TM) 2000 as described by the manufacturer. Approximately 6 hours post-transfection, the DMEM + 10% FBS growth medium was replaced with serum-free CD293 medium. At forty-eight hours post-transfection, the growth medium was harvested and clarified of debris by low speed centrifugation, after which, VLPs in the medium were collected by centrifugation at 100,000 x g through a 20% sucrose cushion in tris-buffered saline (TBS). Pelleted material was resuspended in TBS and subjected to Western blot analysis using antibodies specific for HIV-1 Gag and RSV antigens.

Results

[0245] Figure 8 shows the Gag Western blot and Figure 9 shows the RSV Western blot. The Gag Western blot (Figure 8) shows that abundant amounts of the Gag product were present in all cultures whether transfected with the Gag vector alone or in combination with the F vector. There was some reduction in the yield of the Gag gene product in the 1:1 ratio culture but HIV Gag gene expression and VLP budding was not shut down by RSV F expression as was the case for MLV Gag. The RSV F antigen was detected in the pelleted samples as shown in Figure 9 and the amount of F antigen found in the samples was markedly increased in those cultures in which HIV-1 Gag was expressed along with RSV F. This increase in high molecular weight F antigen release in the presence of Gag co-expression was evidence for the pseudotyping of the F antigen onto HIV-1 Gag VLPs. It should be noted that the Gag product showed up as a background band in the RSV Western blot, and this was likely due to some low level cross-reactivity that the secondary conjugated antibody exhibited for the Gag product.

Example 3 – Scaled-up Pseudotyped HIV-1 Gag + RSV F (GPI) VLPs

[0246] This example describes larger scale production of HIV-1 Gag VLPs pseudotyped with the GPI-anchored version of the RSV F glycoprotein.

Materials and Methods

[0247] Six T175 flasks of 293F cells were transfected with p3.1-bruGag and p3.1-F-GPI at a ratio of 3:1 (Gag-to-F) using LIPOFECTAMINE (TM) 2000. Approximately 8 hours post-transfection the transfection medium (DMEM + 10% FBS) was replaced with CD293 medium. Forty-eight hours post-transfection the growth medium was collected, clarified of debris, and centrifuged at 100,000 x g for 1 hour at 10°C through a 20% sucrose cushion to pellet VLPs. The VLP pellet was resuspended in TBS, layered onto a 20-60% sucrose step gradient, and centrifuged at 100,000 x g for 1 hour at 10°C. Gradient fractions were analyzed by SDS-PAGE to identify Gag-containing fractions. Peak Gag-containing fractions were pooled, sucrose was diluted by three-fold with TBS, and VLPs were concentrated by centrifugation once again at 100,000 x g for 1 hour at 10°C. Samples were then resuspended in TBS for analysis by SDS-PAGE, Western blotting, and ELISA.

Results

[0248] Figure 10 shows a silver-stained SDS-PAGE gel (left panel) revealing a prominent bruGag band (~57 Kd) and a lighter band consistent with the GPI-anchored F (~ 61 Kd). The identity of the F band was confirmed by Western blotting (Figure 10, right panel). Further evidence for the presence of the F antigen was obtained by ELISA in which a sample of the VLPs was serially diluted on an ELISA plate and was reacted with the Synagis RSV F-specific neutralizing monoclonal antibody (MedImmune). ELISA data are shown in Figure 11 in which the sucrose-banded VLPs elicited a signal similar to that of live RSV virus in their reactivity to the Synagis antibody.

Example 4 – Scaled-up Pseudotyped HIV-1 Gag + RSV F (trunc) VLPs

[0249] This example describes larger scale production of HIV-1 Gag VLPs pseudotyped with the RSV F glycoprotein containing the cytoplasmic tail truncation.

Materials and Methods

[0250] Eight T175 flasks of 293F cells were transfected with p3.1-bruGag and p3.1-RSVFT at a ratio of 3:1 (Gag-to-F) using LIPOFECTAMINE (TM) 2000. Plasmid p3.1-FT contains a synthetic fragment that encodes a cytoplasmic tail-truncated version of the RSV F glycoprotein. Figure 12 shows a map of p3.1-RSVFT. The F coding sequence is as follows:

atggaactgctgatcctgaaggctaacgctatcaccaccatcctgaccgctgtc
accttctgcttcgcctccggccagaacatcaccgaggaattctaccagtccacc
tgctccgctgtctccaagggttacctgtccgctctgcgcaccggctggtacacc
tccgtcatcaccatcgagctgtccaacatcaaggaaaacaagtgcaacggcacc
gacgctaaggtcaagctgatcaagcaggaactggacaagtacaagaacgctgtc
accgagctgcagctgctgatgcagtccacccccgctaccaacaaccgcgctcgc
cgtgagctgccccgcttcatgaactacaccctgaacaacgccaagaaaaccaac
gtcaccctgtccaagaagcgcaagcgccgcttcctgggtttcctgctgggtgtc
ggttccgctatcgcttccggtgtcgctgtctctaaggtcctgcacctggaaggc
gaggtcaacaagatcaagtccgccctgctgtccaccaacaaggctgtcgtgtcc

ctgtccaacggtgtctccgtcctgacctccaaggtgctggacctgaagaactac
atcgacaagcagctgctgcccatcgtcaacaagcagtcctgctccatctccaac
atcgagactgtcatcgagttccagcagaagaacaaccgcctgctggaaatcacc
cgcgagttctccgtcaacgctggtgtcaccacccctgtctccacctacatgctg
accaactccgagctgctgtccctgatcaacgacatgcccatcaccaacgaccaa
aagaaactgatgtccaacaacgtccagatcgtccgccagcagtcctactctatc
atgagcatcatcaaggaagaggtcctggcttacgtcgtccagctgcccctgtac
ggtgtcatcgacacccccctgctggaagctgcacacctccccccctgtgcaccacc
aacaccaaggaaggttccaacatctgcctgacccgcaccgaccgcggctggttc
tgcgacaacgctggctctgtctccttcttcccccaagctgagacttgcaaggtc
cagtccaaccgcgtgttctgcgacaccatgaactccctgaccctgccctccgag
gtcaacctgtgcaacgtcgacatcttcaaccccaagtacgactgcaagatcatg
acctctaagaccgacgtgtcctcctctgtcatcacctccctgggtgctatcgtg
tcctgctacggcaagaccaagtgcaccgcttccaacaagaaccgcggtatcatc
aagaccttctccaacggttgcgactacgtgtccaacaagggcgtcgacaccgtg
tccgtcggcaacaccctgtactacgtgaacaagcaggaaggcaagtccctgtac
gtcaagggcgagcccatcatcaacttctacgacccctggtgttcccctccgac
gagttcgacgcttccatcagccaggtcaacgagaagatcaaccagtccctggct
ttcatccgcaagtccgacgagctgctgcacaacgtgaacgctggcaagtctacc
accaacatcatgatcaccactatcatcatcgtgatcatcgtcatcctgctgtct
ctgatcgctgtcggtctgctgctgtactaa (SEQ ID NO:18)

[0251] The encoded F amino acid sequence is as follows (the N-terminal signal peptide and the C-terminal transmembrane domain are underlined:

<u>mellilkanaittiltavtf</u>cfasgqniteefyqstcsavskgylsalrtgwyt
svitielsnikenkcngtdakvklikqeldkyknavtelqllmqstpatnnrar
relprfmnytlnnakktnvtlskkrkrrflgfllgvgsaiasgvavskvlhleg
evnkiksallstnkavvslsngvsvltskvldlknyidkqllpivnkqscsisn
ietviefqqknnrlleitrefsvnagvttpvstymltnsellslindmpitndq
kklmsnnvqivrqqsysimsiikeevlayvvqlplygvidtpcwklhtsplctt
ntkegsnicltrtdrgwfcdnagsvsffpqaetckvqsnrvfcdtmnsltlpse

vnlcnvdifnpkydckimtsktdvsssvitslgaivscygktkctasnknrgii
ktfsngcdyvsnkgvdtvsvgntlyyvnkqegkslyvkgepiinfydplvfpsd
efdasisqvnekinqslafirksdellhnvnagksttnimittiiiviivills
liavgllly* (SEQ ID NO:19)

[0252] Approximately 8 hours post-transfection, the transfection medium (DMEM + 10% FBS) was replaced with CD293 medium. Forty-eight hours post-transfection the growth medium was collected, clarified of debris, and centrifuged at 100,000 x g for 1 hour at 10°C through a 20% sucrose cushion to pellet VLPs. The VLP pellet was resuspended in TBS, layered onto a 20-60% sucrose step gradient, and centrifuged at 100,000 x g for 1 hour at 10°C. Gradient fractions were analyzed by SDS-PAGE to identify Gag-containing fractions. Peak Gag-containing fractions were pooled, sucrose was diluted by three-fold with TBS, and VLPs were concentrated by centrifugation once again at 100,000 x g for 1 hour at 10°C. The samples were then resuspended in TBS for analysis by SDS-PAGE, Western blotting, and ELISA.

Results

[0253] Figure 13 shows a silver-stained SDS-PAGE gel (left panel) revealing a prominent bruGag band (~57 Kd) and a lighter band consistent with the truncated F (~ 61 Kd). The identity of the F band was confirmed by Western blotting (Figure 13, right panel). Further evidence for the presence of the F antigen was obtained by ELISA in which a sample of the VLPs was serially diluted on an ELISA plate and was reacted with the Synagis RSV F-specific neutralizing monoclonal antibody (MedImmune). ELISA data are shown in Figure 14 in which the sucrose-banded VLPs elicited a signal similar to that of live RSV virus in their reactivity to the Synagis antibody.

[0254] A sample of the sucrose-banded VLPs was also subjected to electron microscopy via negative staining. A representative micrograph is shown in Figure 15 revealing the presence of uniform enveloped particles containing an immature (unprocessed) Gag core as would be expected from use of the HIV-1 Gag polyprotein precursor as the VLP budding engine.

Example 5 – Immunogenicity of Pseudotyped HIV-1 Gag + RSV F VLPs

[0255] This example demonstrates the induction of neutralizing antibody responses in mice by RSV F-pseudotyped HIV Gag VLPs.

Materials and Methods

[0256] RSV F-GPI pseudotyped HIV-1 Gag VLPs were prepared as described in Example 3 and used to immunize mice. Mice received two immunizations each, spaced 4 weeks apart, in which each immunization consisted of VLPs in TBS that contained approximately 0.5 μg of the F antigen. Two weeks following the second immunization serum samples were collected for use in an RSV plaque reduction (virus neutralizing) assay. Live RSV aliquots consisting of an average of 125 plaque forming units (pfu) of virus were treated with serial dilutions of RSV neutralizing control antibodies or sera from immunized mice or control mice. The antibody-treated virus inocula were then added to individual wells of a 96-well plate of Vero cells, and the plate was incubated for 48 hours at 37°C to allow non-neutralized virus to infect cells. After 48 hours plaques of RSV growth were identified by fixing the cells and allowing them to react with a goat polyclonal RSV-specific antibody.

Results

[0257] Data from this experiment are shown in Figure 16 in which columns 1 and 2 show RSV neutralizing activity exhibited by Synagis and goat anti-RSV control antibodies, respectively. Columns 3 and 4 represent negative control mouse sera in which no neutralizing activity was seen. Columns 5-10 represent VLP-immunized mouse sera in which significant neutralizing activity was observed in six of six immunized mice. Finally, columns 11 and 12 represent untreated RSV inocula in which no neutralizing activity was expected nor observed. These data demonstrated that pseudotyped VLPs containing the RSV F antigen can induce significant RSV-specific neutralizing antibody responses.

Example 6 – Pseudotyped ALV Gag + RSV F (trunc) VLPs

[0258] This example demonstrates the production of RSV F-pseudotyped ALV Gag VLPs. In addition to HIV-1 Gag (lentivirus), a vector encoding the Gag product of avian leukosis virus (ALV, an alpharetrovirus) was also constructed. While it is recognized that HIV virions bud from lipid raft domains and that HIV-1 Gag is capable of targeting to lipid rafts, similar data regarding the ALV Gag product are lacking.

Materials and Methods

[0259] To determine if the RSV F glycoprotein could be pseudotyped onto alpharetroviral particles such as ALV Gag, a vector encoding ALV Gag was produced. Plasmid p3.1-alvGag-dPR contains a synthetic sequence encoding the ALV Gag gene product devoid of its C-terminal protease domain. Alpha retroviruses such as ALV contain their protease domain as part of the Gag polyprotein rather than the Pol polyprotein as is the case with most other retroviruses. Because the protease domain is dispensable for VLP budding, it was not included in the final vector. Figure 17 shows a map of p3.1-alvGag-dPR. The nucleotide coding sequence is as follows:

atggaagctgtgatcaaggtcatctcctccgcttgcaagacctactgcggcaag
acctccccctccaagaaagaaatcggtgctatgctgtccctgctgcagaaagag
ggcctgctgatgtccccctccgacctgtactcccccggttcctgggaccctatc
accgctgctctgtcccagcgtgctatgatcctgggcaagtccggcgaactcaag
acctggggcctggtgctgggtgctctgaaggctgctcgcgaggaacaagtgacc
tccgagcaggctaagttctggctgggtctgggtggtggtcgtgtgtccccccct
ggtcccgagtgcatcgagaagcccgctaccgagcgtcgtatcgacaagggcgag
gaagtgggcgagactaccgtgcagcgtgacgctaagatggctcccgaggaaacc
gctacccccaagaccgtgggcacctcctgctaccactgcggcaccgctatcggt
tgcaactgcgctaccgcttccgctcccccccctccttacgtgggctccggcctg
taccttccctggctggtgtcggcgagcagcaaggacagggtggagacacccct
cccggtgctgaacagtcccgtgccgagcctggtcacgctggtcaagctcccggt
cccgctctgactgactgggctcgtgtgcgtgaggaactggcttccaccggtccc
cctgtggtggctatgcccgtggtcatcaagaccgagggtcccgcttggaccccc

ctggaacccaagctgatcacccgtctggctgacaccgtgcgtaccaagggcctg
cgttccccaatcaccatggctgaggtggaggctctgatgtcctccccctgctg
cctcacgacgtgaccaacctgatgcgtgtgatcctgggtcccgctccctacgct
ctgtggatggacgcttggggcgtgcagctgcagaccgtgatcgctgctgctacc
cgtgacccccgtcaccctgctaacggacagggtcgtggcgagcgtaccaacctg
aaccgtctgaagggcctggctgacggcatggtcggcaaccctcagggacaggct
gctctgctgcgtcctggcgagctggtcgctatcaccgccagcgctctgcaggct
ttccgtgaggtggcccgtttggccgaaccagctggtccctgggctgacatcatg
cagggcccctccgagtccttcgtggacttcgctaaccgtctgatcaaggctgtg
gagggctccgacctccctccttccgctcgtgctcccgtgatcatcgactgcttc
cgtcagaagtcccagcccgacatccagcagctgatccgtaccgctccctccacc
ctgactacccctggcgagatcatcaagtacgtgctggaccgtcaaaagaccgct
cccctgaccgaccaaggtatcgctgccgctatgtcctccgctatccagcccctg
atcatggctgtcgtgaaccgcgagagggacggacagaccggttccggtggtcgt
gctcgtggcctgtgctacacttgcggttcccccggtcactaccaggctcagtgc
cccaagaagcgcaagtccggaaactcccgcgagcgctgccagctctgcaacggc
atgggtcacaacgccaagcagtgccgcaagcgcgacggaaaccagggccagcgt
cccggaaagggactgtcctccggtccttggcctggtcctgagccccctgctgtg
tcctaa (SEQ ID NO:20)

[0260] The encoded amino acid sequence is as follows:

meavikvissacktycgktspskkeigamlsllqkegllmspsdlyspgswdpi
taalsqramilgksgelktwglvlgalkaareeqvtseqakfwlglgggrvspp
gpeciekpaterridkgeevgettvqrdakmapeetatpktvgtscyhcgtaig
cncatasappppyvgsglypslagvgeqqgqgggdtppgaeqsraepghagqapg
paltdwarvreelastgppvvampvviktegpawtplepklitrladtvrtkgl
rspitmaevealmsspllphdvtnlmrvilgpapyalwmdawgvqlqtviaaat
rdprhpangqgrgertnlnrlkgladgmvgnpqgqaallrpgelvaitasalqa
frevarlaepagpwadimqgpsesfvdfanrlikavegsdlppsarapviidcf
rqksqpdiqqlirtapstlttpgeiikyvldrqktapltdqgiaaamssaiqpl

imavvnrerdgqtgsggrarglcytcgspghyqaqcpkkrksgnsrercqlcng
mghnakqcrkrdgnqgqrpgkglssgpwpgpeppavs* (SEQ ID NO:21)

[0261] Plasmids p3.1-alvGag-dPR and p3.1-RSVFT were transfected into 293F cells individually or together at ratios of 1:1, 3:1 and 9:1 (Gag-to-F). Forty-eight hours post-transfection the medium was harvested, clarified of debris, and VLPs were pelleted at 100,000 x g for 1 hour at 10°C. Resuspended pellets were analyzed for RSV F antigenic activity via an ELISA using the Synagis monoclonal antibody as described above.

Results

[0262] The data shown in Figure 18 demonstrates that the combination of p3.1-alvGag-dPR plus p3.1-RSVFT resulted in the release of considerably more Synagis-reactive VLPs than seen with the expression of p3.1-RSVFT alone. Therefore, the RSV F antigen, while demonstrating some VLP budding activity on its own can be pseudotyped onto Gag products from both lentiviruses and alpharetroviruses.

Example 7 – Comparison of RSV F pseudotyped VLP production between vectors encoding HIV-1 Gag and alvGag-dPR.

[0263] This example compares the productions of pseudotyped HIV-1 Gag + RSV F VLP with the production of alvGag-dPR + RSV F VLP.

Materials and Methods

[0264] Plasmid p3.1-alvGag-dPR was co-transfected into 293F cells along with p3.1-RSVFT at ratios of 1:1 and 3:1. In addition, plasmid p3.1-bruGag was co-transfected into 293F cells with p3.1-RSVFT at a ratio of 3:1. Seventy-two hours post-transfection the medium was harvested, clarified of debris and VLPs were pelleted at 100,000 x g for 1 hour at 10°C. Resuspended pellets were analyzed for RSV F antigenic activity via an ELISA using the Synagis monoclonal antibody as described above.

Results

[0265] These data are shown in Figure 19 which shows that similar amounts of Synagis reactive VLPs were detected in all three transfections demonstrating that the alvGag-dPR expression vector is equally effective as the HIV Gag expression vector in terms of producing RSV F-pseudotyped VLPs.

Example 8 – Attempted Pseudotyping of RSV F with MPMV-Gag, BVL-Gag, and EIAV-Gag

[0266] This example attempts to determine if Gag proteins from other retroviruses were effective for the production of RSV F-pseudotyped VLPs.

Materials and Methods

[0267] Vectors encoding the Gag products of Mason Pfizer Monkey virus (MPMV, betaretrovirus), Bovine Leukemia virus (BLV, deltaretrovirus), and Equine Infectious Anemia virus (EIAV, lentivirus) were constructed using custom synthesized Gag coding sequence fragments that were confirmed by DNA sequence analysis. These vectors were co-transfected into 293F cells along with the F-encoding vector p3.1-RSVFT at a ratio of 3:1 (Gag:F). Seventy-two hours post-transfection the medium was harvested, clarified of debris and VLPs were pelleted at 100,000 x g for 1 hour at 10°C. Resuspended pellets were analyzed for RSV F antigenic activity via an ELISA using the Synagis monoclonal antibody as described above.

Results

[0268] The data are shown in Figure 20, in which it is demonstrated that vectors encoding the three alternative Gag products do not function like alvGag in terms of the release of RSV F-pseudotyped VLPs as determined by an ELISA assay employing an F-specific monoclonal antibody. The weaker F ELISA signals obtained with vectors encoding MPMV Gag, BLV Gag, and EIAV Gag were similar to signals typically obtained following expression of RSV F alone in which F protein self-budding (Gag-independent) activity us usually detected. The inability of MPMV, BLV, and EIVA Gags

to significantly augment F particle release is similar to results with MLV Gag in which this latter Gag product was shown not form pseudotypes with RSV F and therefore does not increase the release of RSV F-containing particles when co-expressed with F. Moreover, data indicate that expression of MLV, MPMV, BLV, and EIAV Gags in the presence of RSV F expression is suppressed showing an incompatibility between VLP production by these latter Gags and RSV F expression.

Example 9 – Comparison of alvGag with intact protease to alvGag-dPR

[0269] In addition to alvGag-dPR, the complete alvGag with its C-terminal protease activity intact can also form pseudotyped VLPs with the RSV F protein. This was demonstrated in a transfection experiment comparing the release of VLPs following transfection with p3.1-alvGag-dPR (plus FL or FT) versus transfection with p3.1-alvGag (plus FL or FT) versus transfection of a mixture of p3.1-alvGag-dPR and p3.1-alvGag (plus FL or FT). Figure 21 shows a map of plasmid p3.1-alvGag encoding the complete alvGag polyprotein with intact retroviral protease activity. The nucleotide coding sequence is as follows:

atggaagccgtgatcaaagtgatcagcagcgcctgcaagacctactgcggcaag
accagccccagcaagaaagaaattggcgccatgctgtctctgctgcagaaggaa
ggcctgctgatgagccccagcgacctgtacagccccggcagctgggatcctatc
acagctgccctgagccagagagccatgatcctgggcaagagcggcgagctgaaa
acctggggcctggtgctgggagccctgaaggccgccagagaagaacaggtcacc
agcgagcaggccaagttttggctgggcctgggcggaggaagagtgtctccccct
ggccccgagtgtatcgagaagcccgccaccgagcggagaatcgacaagggcgag
gaagtgggcgagacaaccgtgcagcgggacgccaagatggcccctgaggaaacc
gccacccccaagaccgtgggcaccagctgctaccactgtggcaccgccatcggc
tgcaattgtgccaccgccagcgcccctccacctccttacgtgggcagcggcctc
tatccttcactggccggcgtgggcgaacagcagggacagggcggcgatacacct
cctggcgccgagcagagcagagccgaacctggacatgccggacaggcccctgga
cctgctctgaccgattgggccagagtgcgggaggaactggcctctaccggaccc
cctgtggtggctatgcccgtggtgattaagacagagggccctgcctggacccct
ctggaacccaagctgatcacccggctggccgatacagtgcggaccaagggcctg

agaagccccatcaccatggccgaggtggaggccctgatgagcagccccctgctg
ccccacgacgtgaccaacctgatgagagtgatcctgggacccgctccctacgcc
ctgtggatggatgcctggggcgtgcagctgcagacagtgatcgccgctgccacc
agagatcccagacaccccgccaatggccagggcagaggcgagagaaccaacctg
aaccggctgaagggcctggccgacggcatggtcggcaatcctcagggacaggcc
gctctgctgaggcctggcgaactggtggccatcacagccagcgccctgcaggcc
ttcagagaagtggctagactggccgaacctgccggcccttgggccgatatcatg
cagggccccagcgagagcttcgtggacttcgccaaccggctgatcaaggccgtg
gagggcagcgatctgcctcctagcgccagagcccccgtgatcatcgactgcttc
cggcagaagtcccagcccgacatccagcagctgatcagaaccgccccagcacc
ctgaccacccctggcgagatcatcaaatacgtgctggaccggcagaaaaccgcc
cctctgaccgatcagggcattgccgccgctatgagcagcgccatccagcccctg
attatggccgtggtgaaccgggagagggatggccagacaggaagcggcggcaga
gctagaggactgtgctacacctgtggcagccctggccactaccaggctcagtgc
cccaagaagcggaagtccggcaacagccgggagagatgccagctgtgcaacggc
atgggccacaacgccaagcagtgcagaaagagggacggcaatcagggccagagg
cccggcaaaggcctgtctagcggaccttggcctggacctgagcctcctgccgtg
agcctggccatgaccatggaacacaaggaccggcccctggtccgcgtgatcctg
accaacaccggcagccaccccgtgaagcagcggagcgtgtacatcaccgccctg
ctggactctggcgccgacatcaccatcatcagcgaagaggactggcccaccgac
tggcctgtgatggaagccgccaacccccagatccacggcatcggcggaggcatc
cccatgcggaagtccagagacatgatcgagctgggcgtgatcaaccgggacggc
agcctggaaagacccctgctgctgttcccagctgtggccatggtccggggcagc
atcctgggcagagactgtctgcagggactgggcctgcggctgaccaatctgtga
tga (SEQ ID NO:22)

[0270] The encoded amino acid sequence is as follows:

meavikvissacktycgktspskkeigamlsllqkegllmspsdlyspgswdpi
taalsqramilgksgelktwglvlgalkaareeqvtseqakfwlglgggrvspp
gpeciekpaterridkgeevgettvqrdakmapeetatpktvgtscyhcgtaig
cncatasappppyvgsglypslagvgeqqgqgggdtppgaeqsraepghagqapg

paltdwarvreelastgppvvampvviktegpawtplepklitrladtvrtkgl
rspitmaevealmsspllphdvtnlmrvilgpapyalwmdawgvqlqtviaaat
rdprhpangqgrgertnlnrlkgladgmvgnpqgqaallrpgelvaitasalqa
frevarlaepagpwadimqgpsesfvdfanrlikavegsdlppsarapviidcf
rqksqpdiqqlirtapstlttpgeiikyvldrqktapltdqgiaaamssaiqpl
imavvnrerdgqtgsggrarglcytcgspghyqaqcpkkrksgnsrercqlcng
mghnakqcrkrdgnqgqrpgkglssgpwpgpeppavslamtmehkdrplvrvil
tntgshpvkqrsvyitalldsgaditiiseedwptdwpvmeaanpqihgigggi
pmrksrdmielgvinrdgslerplllfpavamvrgsilgrdclqglglrltnl*
(SEQ ID NO:23)

[0271] Following transfection, medium supernatants were clarified of debris and VLPs were pelleted through a 30% sucrose cushion. Quantification of the amount of F antigen released on VLPs was performed by an ELISA assay using a 0.2 micron filter-bottom ELISA plate in which VLPs were trapped on the filter then reacted with an RSV-specific antibody and developed using a secondary antibody conjugated to horse radish peroxidase. Results of the assay are shown in Figure 22 in which shows that plasmids p3.1-alvGag-dPR and p3.1-alvGag performed similarly in terms the amount of high molecular weight RSV F antigenic activity released into the medium following co-transfection with F-encoding plasmids. Also, similar amounts of RSV F antigenic activity were released into the medium when 10:1 or 3:1 ratios of p3.1-alvGag-dPR and p3.1-alvGag were employed. Figure 23 shows the status of the ALV Gag protein in each of these transfections. As expected, transfection with p3.1-alvGag-dPR resulted in a prominent 61 kD band consistent with expression of the intact Gag-dPR polyprotein (lanes 1 and 2). The remaining lanes representing transfection with p3.1-alvGag or combinations of p3.1-alv-Gag and p3.1-alvGag-dPR resulted in a prominent 27 kD band consistent with Gag processing due to the presence of the retroviral protease activity.

[0272] Final confirmation of VLP production in cells co-transfected with p3.1-RSVFT along with a combination of p3.1-alvGag-dPR and p3.1-alvGag (10:1:3 alvGag-dPR-to-alvGag-to-RSVFT) is shown in Figure 24 in which VLPs from such a transfection were purified by banding between 30% and 60% sucrose layers in tris-

buffered saline at 100,000 x g for 1 hour. VLPs were applied to nitrocellulose-coated, 300 mesh copper grids and negatively stained with 2% w/v uranyl acetate for analysis by electron microscopy. The micrograph in Figure 24 shows the presence of enveloped VLPs.

Example 10 – RSV F-pseudotyped ALV Gag VLPs induce neutralizing antibody responses in mice.

[0273] ALV Gag VLPs containing RSV "FT" or "FL" were prepared from HEK293 cells following transfection of cells with p3.1-alvGag-dPR along with p3.1-RSVFT or p3.1-RSVFL. The "Gag" to "F" plasmid DNA transfection ratio was 3:1. VLPs containing F antigen were pelleted from the growth medium harvested on day 3 by centrifugation at 100,000 x g through a 30% sucrose cushion then banded on 20-60% discontinuous sucrose gradients. Aliquots of VLPs containing less that 1 μg F antigen were used for immunization of various strains of mice in which each mouse received priming and booster vaccinations spaced 21 days apart. Each vaccine inoculum contained both "FT" and "FL" VLPs. Two weeks following the booster immunization sera were collected and used to measure RSV-specific antibody responses. These data are shown in Figure 25 in which the top panel shows ELISA titer data in which sera were tested for reactivity in a traditional ELISA employing RSV virus particles immobilized on an ELISA plate. The bottom panel shows levels of virus-neutralizing antibodies measured using a plaque reduction assay as described in Example 5 above.

Example 11 – Attempted Pseudotyping of HSV gD + ALV Gag

[0274] Other enveloped viruses produce surface glycoproteins that are analogous to the F protein of RSV; these glycoproteins can function in adhesion and interaction with host cell receptors and play critical roles in viral pathogenesis. One such example from Herpes Simplex Virus (HSV) is glycoprotein D (gD), which interacts with more than one host receptor during viral entry (reviewed in J.C. Whitbeck, et al. The major neutralizing antigenic site on Herpes Simplex Virus glycoprotein D overlaps a receptor-binding domain. 1999. J Virol 73(12):9879-9890). HSV gD subunit vaccine formulations have been tested in clinical trials for the prevention of HSV infections (D.I. Bernstein, et al.,

Safety and immunogenicity of glycoprotein D-adjuvant genital herpes vaccine. 2005. Clin Inf Disease 40:1271-1281).

[0275] To compare pseudotyping of an alternative viral glycoprotein onto ALV Gag-based VLPs, the HSV gD gene was utilized in co-expression studies with p3.1-alvGag-dPR.

Materials and Methods

[0276] A human HSV type 2 gD gene (GeneBank GeneID:1487358) was synthesized and cloned into the pcDNA3.1(-) vector (Invitrogen) to construct plasmid p3.1-HSVgD. The plasmid map is shown in Figure 26. The nucleic acid coding sequence is as follows:

atgggtagactgacttccggagtgggcaccgccgctctgctggtcgtggctgtg
ggcctgcgcgtcgtgtgcgccaagtacgcactggccgatccctccctgaagatg
gccgaccctaaccgcttccgcggcaagaacctccccgtgctggaccagctgacc
gacccccctggcgtgaagcgcgtgtaccacatccagccttccctggaagatccc
ttccagcccccctccatccccatcaccgtgtactacgcagtgctggaacgcgcc
tgccgctccgtgctgctgcatgctccctccgaggcccctcagatcgtgcgcgga
gcctccgacgaggcccgcaagcacacctacaacctgactatcgcctggtacagg
atgggcgacaactgcgccatccctatcactgtgatggaatacaccgagtgcccc
tacaacaagtccctgggcgtgtgccccatccgcacccagccccgctggtcctac
tacgactccttctccgccgtgtccgaggacaacctgggcttcctgatgcacgcc
cctgccttcgaaaccgccggcacctacctgaggctggtcaagatcaacgactgg
accgagatcacccagttcatcctggaacaccgcgccagggcctcttgcaagtac
gctctgcccctgcgcatccccccctgccgcctgcctgacctctaaggcctaccag
cagggcgtgaccgtggactccatcggcatgctgcctcgcttcatccccgagaac
cagcgcaccgtggccctgtacagcctgaagatcgccggctggcacggccccaag
ccaccctacacctccaccctgctgccccccgagctgtccgacaccaccaacgcc
acccagcccgagctggtgcccgaggaccctgaggactccgccctgctcgaagat
cccgccggaaccgtgtcctcccagatccccccccaactggcacatcccttccatc
caggacgtggcccccccaccacgctccagccgcaccttccaacccaggcctgatc
atcggagccctggccggctccaccctggccgtcctggtcatcggcggaatcgct

ttctgggtcaggagaagggcccagatggctccaaagcgcctgcgcctgccccac atccgcgacgacgacgcccctccctctcaccagcccctgttctac (SEQ ID NO:24)

[0277] The encoded amino acid sequence is as follows:

Mgrltsgvgtaallvvavglrvvcakyaladpslkmadpnrfrgknlpvldqlt dppgvkrvyhiqpsledpfqppsipitvyyavleracrsvllhapseapqivrg asdearkhtynltiawyrmgdncaipitvmeytecpynkslgvcpirtqprwsy ydsfsavsednlgflmhapafetagtylrlvkindwteitqfilehrarascky alplrippaacltskayqqgvtvdsigmlprfipenqrtvalyslkiagwhgpk ppytstllppelsdttnatqpelvpedpedsalledpagtvssqippnwhipsi qdvaphhapaapsnpgliigalagstlavlviggiafwvrrraqmapkrlrlph irdddappshqplfy (SEQ ID NO:25)

[0278] Plasmids p3.1-HSVgD and p3.1-alvGag-dPR were transfected into 293F cells either alone or in combination ratios of 1:1, 5.6:1, and 2.3:1 HSVgD-to-ALVGag. HEK 293F monolayers in T75 flasks were transfected with the above DNAs using LIPOFECTAMINE (TM) 2000, incubated 8 hours and switched to fresh serum-free medium for 48 hours. The culture supernatants were harvested, centrifuged to pellet cells (3 min at 500 x g) and to pellet cell debris (10 min at 4000 x g) to produce clarified culture supernatant fluids. These samples were utilized directly in ELISA screening or overlaid onto a 30% sucrose-TBS cushion for ultracentrifugation (10°C, 100,000 x g, 1 hour) to pellet VLPs and multimeric protein complexes. Ultracentrifuge pelleted material (*i.e.*, UC pellet) was suspended in sterile TBS and electrophoresed on 4-12% SDS-PAGE (NuPAGE Bis-Tris Gels, Invitrogen) and transferred to polyvinylidene fluoride membranes for Western blot analysis. Expression of the HSVgD and ALV Gag proteins was tracked with specific antibody reagents: anti-HSVgD monoclonal antibody (GeneTex) and a goat anti-p27 alvGAG polyclonal antibody (Synbiotics).

Direct ELISAs

[0279] ELISAs were performed by coating Immunon II microtiter plate wells with test or control samples (25 – 100 µL of culture supernatant), rinsed in TBS and blocked in fresh milk block (5% w/v skim milk and 1% w/v BSA in TBS containing 0.1% v/v Tween 20) for 1 hour at room temperature, rinsed in TBS and incubated in primary antibody (anti-HSVgD mAb at 1 µg/mL block, anti-ALV Gag Ab at 1:1000 dilution in block) overnight at 4°C. Plates were washed (3 x TBS+0.1%Tween 20 plus 3x TBS), incubated in appropriate secondary antibodies (HRP-conjugated anti-mouse or anti-goat antibodies diluted 1:2000 in block) for 1 hour at room temperature, washed and o-phenylenediamine substrate in citrate buffer was added. Color development was stopped with 10% sulfuric acid and plates read at 490nm.

Immunoblot Assay

[0280] Western blot assay steps were as follows: polyvinylidene fluoride (PVDF) blots were blocked 1 hour at room temperature in fresh milk block (same as above) and incubated in primary antibodies (anti-HSVgD mAb at 1 µg/mL and 1:2000 dilution of anti-ALV Gag pAb) overnight at 4 °C. Blots were washed 3 x 15 min in fresh block and incubated in AP-conjugated anti-mouse or anti-goat antibodies diluted 1:2000 in block for 1 hour at room temperature. Blots were washed 3 x 15 min in Tris-NaCl-$MgCl_2$ pH 9.5 buffer and immersed in NBT-BCIP substrate for color development. The reaction was stopped in 2 mM Na_2EDTA pH 8.0 buffer and blots dried between fresh 3MM filter paper sheets.

Electron Microscopy

[0281] UC pelleted material from the HSVgD plus alvGag-dPR transfections of HEK 293F cells were applied to nitrocellulose-coated, 300 mesh copper grids and negatively stained with 2% w/v uranyl acetate for analysis by electron microscopy. Particle images were captured as 8-bit data files with embedded scale bars, using the SIS Soft-Imaging Systems software interface.

Results

[0282] ELISA data for screening of HSVgD and alvGag-dPR transfection supernatant fluids is shown in Figure 27. HSVgD protein was detected in supernatant samples from cells transfected with the p3.1-HSVgD construct in a dose-dependent fashion. All transfectants receiving the p3.1-alvGAG-dPR construct showed substantial levels of the ALV Gag protein in supernatant fluids. Despite coating microtiter wells directly with only 25 µL of a T75 transfectant supernatant volume, even the lowest alvGAG-dPR DNA level (1.5 µg/flask) in the 5.6:1 gD:GAG ratio transfection produced strong signals with the polyclonal detection reagent. Because the HSVgD detection antibody is a monoclonal and the ALV Gag is a polyclonal antibody, direct comparison of expression levels was not performed.

[0283] Figure 28 shows the Western blot results of two HEK 293F transfection studies at the T75-flask size. Table 1 below lists the flask labels A – G, the micrograms of DNA added per T75 flask, and the resulting ratio of HSVgD and alvGAG-dPR constructs. UC pellet samples representing approximately 10% of the T75 harvest were loaded in duplicate gels, blotted, and probed with the anti-HSVgD and anti-p27 alvGAG antibody reagents. The data demonstrate DNA dose-dependent expression of the both the HSVgD and ALV Gag proteins in the mammalian host cells. As noted in the ELISA results above, expression of the ALV Gag protein was strong even at low DNA levels (Sample E with 1.5 µg input). The mass of expressed HSVgD is in the expected range, as discussed above. The ALV Gag (-dPR) would be expected to electrophorese at approximately 60 kDa, which was one of heavier signal bands in the blot profile in Figure 28 (panel (B)). The smaller bands are likely degradation products, and the larger bands may be multimers or complexes with other proteins not fully denatured or reduced in the NuPAGE gel system; similar Gag banding patterns have been presented for other Gag cores (*e.g.*, Figure 8 blot of HIV-Gag). The ELISA and Western blot data demonstrate that HSVgD and ALV Gag are co-expressed in the HEK 293F transfection system.

Table 1

HEK293F Transfection #314-85 = samples A, B, and C
Transfection #314-91 = samples D, E, F, and G

Constructs	Micrograms DNA of HSVgD to alvGAG-pPR in transfections							
	A	B	C		D	E	F	G
HSVgD	10	5	0		10	8.5	7	5
alvGAG-dPR	0	5	10		0	1.5	3	5
Ratio gD:GAG		1:1				5.6:1	2.3:1	1:1

[0284] Unlike the results observed above with co-expression of ALV-Gag and RSV F, co-expression of ALV-Gag with gD did not result in an increase in the release of high molecular weight gD in cell supernatants as would be expected if the ALV Gag was forming virus-like- particle pseudotypes with gD. Data from the ELISA and Western blot indicate that the gD protein was able to exit from cells in a manner independent of ALV Gag particle budding.

[0285] To determine whether VLPs could be visualized in these samples, aliquots were subjected to electron microscopy: p3.1-alvGAG-dPR alone (Sample C), p3.1-HSVgD alone (Sample D), and the 2.3:1 ratio gD:alvGAG-dPR transfection (Sample F). Results are shown in Figures 29, 30 and 31, containing two or more photomicrographs captured from each aliquot.

[0286] Figure 29 shows typical retroviral particles formed by ALV Gag (-dPR) transfectants in Sample C. Measurements (n = 3, separate fields of view) taken with the imaging software indicated an average VLP size of 71.7 ± 2.6 nm.

[0287] Figure 30 reveals polymorphic, heterogeneously-sized particles formed by HSVgD transfectants in Sample D. Particle sizes for some of the shapes were as follows: large triangular or folded particles were 150 – 200 nm (black line arrows); smaller oval to round particles were 90 – 120 nm (black dotted line arrows). The finding of self-budded HSVgD glycoprotein particles shows behavior similar to results obtained with RSV F alone expression yielding polymorphic self-budded VLPs.

[0288] Figure 31 shows multiple photomicrographs from the Sample F transfection with HSVgD in combination with ALV Gag-dPR. Observation of particles showing a more-organized, rounded structure of even 30-50 nm (black arrows in top two micrographs containing the 1000 nm scale bar) was rare in Sample F. Most of the protein

structures appeared disorganized and heterogeneous in sizes smaller than 30 nm. None of the material in Sample F was similar to VLPs observed in the ALV Gag alone or the HSVgD alone samples, despite viewing over 20 EM fields of view during sample screening.

[0289] The lack of VLP production in Sample F was not expected from at least two perspectives. First, the fact that neither HSVgD nor ALV Gag continued to make their independent VLP structures when the proteins were expressed together in the same host cell is counter-intuitive, especially when ELISA and Western blot data indicate substantial expression of each protein in sedimented material. Second, one might anticipate that the self-budding behavior of HSVgD alone would categorize it with RSV F, and that pseudotyping HSVgD onto ALV GAG-dPR VLPs would be as successful as with RSV F in mammalian host cells as presented in the above examples. These data illustrate the complexities and unexpected incompatibilities in pseudotyping viral glycoproteins onto retroviral Gag cores.

Example 12 - Pseudotyped SIV Gag + RSV F VLPs

[0290] This example demonstrates that a vector encoding the Gag gene product of simian immunodeficiency virus (African green monkey) (SIVagm) substituted for HIV Gag for the formation of chimeric VLPs containing RSV F. SIVagm is also a member of the lentivirus family.

Materials and Methods

[0291] Figure 32 shows a map of the plasmid p3.1-SIVagmGag. The synthetic coding sequence for SIVagm Gag is as follows:

```
atgggtgctgctacctccgctctgaaccgtcgtcagctggaccagttcgagaag
atccgtctgcgtcccaacggcaagaagaagtaccagatcaagcacctgatctgg
gctggcaaggaaatggaacgtttcggtctgcacgagcgtctgctggaaaccgag
gaaggttgcaagcgtatcatcgaggtgctgtacccccctggaacccaccggttcc
gagggcctgaagtccctgttcaacctcgtgtgcgtgctgtactgcctgcacaag
gaacagaaggtcaaggacaccgaggaagctgtggctaccgtccgtcagcactgc
```

cacctggtggagaaggaaaagtccgctaccgagacttcctccggccagaagaag
aacgacaagggtatcgctgctccccctggtggttcccagaacttccccgcccag
cagcagggaaacgcttgggtgcacgtgcctctgtccccccgtactctgaacgcc
tgggtcaaggctgtggaggaaaagaagttcggcgctgagatcgtgcccatgttc
caggctctgtccgagggttgcactccctacgacatcaaccagatgctgaacgtg
ctgggtgaccaccagggtgctctgcagatcgtgaaggaaatcatcaacgaagag
gctgctcagtgggacgtgacccaccctctgcctgctggtcctctgccagccggc
cagctgcgtgaccctcgtggttccgacatcgctggcaccacctcttccgtgcaa
gagcagctggaatggatctacaccgctaacccccgtgtggacgtgggcgctatc
taccgtcgttggatcatcctgggtctgcaaaagtgcgtgaagatgtacaaccct
gtgtccgtgctggacatccgtcagggtcccaaggaacccttcaaggactacgtg
gaccgcttctacaaggctatccgtgccgagcaggcttccggcgaggtcaagcag
tggatgaccgagtccctgctgatccagaacgctaaccccgactgcaaggtcatc
ctgaagggcctgggcatgcaccccaccctggaagagatgctgaccgcttgccag
ggtgtcggtggtccctcctacaaggccaaggtcatggctgagatgatgcagacc
atgcagaaccagaacatggtgcagcagggtggtcccaagcgtcagcgtccccct
ctgcgttgctacaactgcggcaagttcggtcacatgcagcgccagtgccctgag
cctcgcaagaccaagtgcctgaagtgcggaaagctgggtcacctggctaaggac
tgccgtggtcaagtgaacttcctgggttacggtcgttggatgggtgccaagccc
cgtaacttccctgctgctaccctgggtgccgagccttctgctccccctccccc
tccggtactacccctacgaccccgctaagaagctgctccagcagtacgctgag
aagggcaagcagctgcgcgagcagaagcgtaacccccctgctatgaaccctgac
tggaccgagggttacagcctgaactctctgttcggcgaggaccagtaa (SEQ ID NO:26)

[0292] The amino acid sequence of SIVagmGag encoded by p3.1-SIVagmGag is as follows:

mgaatsalnrrqldqfekirlrpngkkkyqikhliwagkemerfglherllete
egckriievlypleptgseglkslfnlvcvlyclhkeqkvkdteeavatvrqhc
hlvekeksatetssgqkkndkgiaappggsqnfpaqqqgnawvhvplsprtlna
wvkaveekkfgaeivpmfqalsegctpydinqmlnvlgdhqgalqivkeiinee

aaqwdvthplpagplpagqlrdprgsdiagttssvqeqlewiytanprvdvgai
yrrwiilglqkcvkmynpvsvldirqgpkepfkdyvdrfykairaeqasgevkq
wmteslliqnanpdckvilkglgmhptleemltacqgvggpsykakvmaemmqt
mqnqnmvqqggpkrqrpplrcyncgkfghmqrqcpeprktkclkcgklghlakd
crgqvnflgygrwmgakprnfpaatlgaepsappppsgttpydpakkllqqyae
kgkqlreqkrnppamnpdwtegyslnslfgedq* (SEQ ID NO:27)

[0293] Eight T175 flasks of 293F cells were transfected with p3.1-SIVagmGag and p3.1-RSVFT at a ratio of 3:1 (Gag-to-F) using LIPOFECTAMINE (TM) 2000. Approximately 8 hours post-transfection the transfection medium (DMEM + 10% FBS) was replaced with CD293 medium. Seventy-two hours post-transfection the growth medium was collected, clarified of debris and centrifuged at 100,000 x g for 1 hour at 10°C through a 20% sucrose cushion to pellet VLPs. The VLP pellet was resuspended in TBS then layered onto a 20-60% sucrose step gradient and centrifuged at 100,000 x g for 1 hour at 10°C. Gradient fractions were analyzed by SDS-PAGE to identify Gag-containing fractions. Peak Gag-containing fractions were pooled, sucrose was diluted two-fold with TBS, and VLPs were concentrated by centrifugation once again at 100,000 x g for 1 hour at 10°C then resuspended in TBS for analysis by ELISA using the Synagis monoclonal antibody (Palivizumab).

Results

[0294] ELISA data are shown in Figure 33 in which the sucrose-banded VLPs elicited a signal similar to that of live RSV virus in their reactivity to the Synagis antibody. These data are similar to the example above employing the p3.1-HIVGag expression vector demonstrating the SIVagm Gag can substitute for HIV Gag for the generation of F-containing chimeric VLPs.

Example 13 - Pseudotyped RSV F + ALV Gag VLP production via adenovirus vector transduction.

[0295] The preparation of RSV F-pseudotyped VLPs via plasmid transfection of HEK293 cells does not result in large yields of VLPs which is likely due to the inability

to achieve the delivery of a sufficient number of plasmid DNA copies into a sufficient number of cells to induce robust Gag and F expression and subsequent VLP formation. To correct this deficiency, in this example, the ALV Gag and RSV F genes were inserted into a replication-defective, recombinant adenovirus vector in order to achieve the high efficiency transduction of Gag and F coding sequences into an appropriate VLP production cell line such as Vero cells. The derivation of the recombinant adenovirus vector is summarized below.

[0296] Because expression of the RSV F gene product in tissue culture cells is toxic, the inventors reasoned that the propagation of an RSV F-expressing recombinant adenovirus vector in an HEK293 helper cell line would be problematic in that F-induced toxicity would interfere with adenovirus vector propagation resulting in low virus yields. Similarly, the inventors also reasoned that if F gene expression was inhibited in the cell line used to propagate the adenovirus vector, then sufficient quantities of the viral vector could be produced to allow for subsequent transduction of a suitable cell line for VLP production.

Materials and Methods

[0297] To achieve the inhibition of RSV F expression in an adenovirus vector during vector propagation, the adenovirus shuttle vector pShuttle-CMV, which is used to derive replication-defective adenovirus vectors, was modified by insertion of two copies of the tetracycline operator sequence into its CMV promoter. This strategy was designed to cause the inhibition of F expression when an F-containing adenovirus vector is propagated on an HEK293-based helper cell line expressing the tetracycline repressor. The modified shuttle vector was named pShuttle-CMV-TO and the functional map of this vector is shown in Figure 34 and the sequence of this vector is as follows:

catcatcaatatataccttattttggattgaagccaatatgataatgaggggg
tggagtttgtgacgtggcgcggggcgtgggaacggggcgggtgacgtagtagtg
tggcggaagtgtgatgttgcaagtgtggcggaacacatgtaagcgacggatgtg
gcaaaagtgacgttttggtgtgcgccggtgtacacaggaagtgacaattttcg
cgcggttttaggcggatgttgtagtaaatttgggcgtaaccgagtaagatttgg

ccattttcgcgggaaaactgaataagaggaagtgaaatctgaataattttgtgt
tactcatagcgcgtaatactgtaatagtaatcaattacggggtcattagttcat
agcccatatatggagttccgcgttacataacttacggtaaatggcccgcctggc
tgaccgcccaacgacccccgcccattgacgtcaataatgacgtatgttcccata
gtaacgccaatagggactttccattgacgtcaatgggtggagtatttacggtaa
actgcccacttggcagtacatcaagtgtatcatatgccaagtacgcccccctatt
gacgtcaatgacggtaaatggcccgcctggcattatgcccagtacatgaccttа
tgggactttcctacttggcagtacatctagtattagtcatcgctattaccatgg
tgatgcggttttggcagtacatcaatgggcgtggatagcggtttgactcacggg
gatttccaagtctccaccccattgacgtcaatgggagtttgttttggcaccaaa
atcaacgggactttccaaaatgtcgtaacaactccgccccattgacgcaaatgg
gcggtaggcgtgtacggtgggaggtctatataagcagagctctccctatcagtg
atagagatctccctatcagtgatagagatcgtcgacgagctcgtttagtgaacc
gtcagatcgcctggagacgccatccacgctgttttgacctccatagaagacacc
gggaccgatccagcctccggactctagcgtttcgtcgacgcggccgctcgagcc
taagcttctagataagatatccgatccaccggatctagataactgatcataatc
agccataccacatttgtagaggttttacttgctttaaaaaacctcccacacctc
cccctgaacctgaaacataaaatgaatgcaattgttgttgttaacttgtttatt
gcagcttataatggttacaaataaagcaatagcatcacaaatttcacaaataaa
gcatttttttcactgcattctagttgtggtttgtccaaactcatcaatgtatct
taacgcggatctgggcgtggttaagggtgggaaagaatatataaggtgggggtc
ttatgtagttttgtatctgttttgcagcagccgccgccgccatgagcaccaact
cgtttgatggaagcattgtgagctcatatttgacaacgcgcatgcccccatggg
ccggggtgcgtcagaatgtgatgggctccagcattgatggtcgccccgtcctgc
ccgcaaactctactaccttgacctacgagaccgtgtctggaacgccgttggaga
ctgcagcctccgccgccgcttcagccgctgcagccaccgcccgcgggattgtga
ctgactttgctttcctgagcccgcttgcaagcagtgcagcttcccgttcatccg
cccgcgatgacaagttgacggctcttttggcacaattggattctttgacccggg
aacttaatgtcgtttctcagcagctgttggatctgcgccagcaggtttctgccc
tgaaggcttcctcccctcccaatgcggtttaaaacataaataaaaaaccagact
ctgtttggatttggatcaagcaagtgtcttgctgtctttatttaggggttttgc
gcgcgcggtaggcccgggaccagcggtctcggtcgttgagggtcctgtgtattt

tttccaggacgtggtaaaggtgactctggatgttcagatacatgggcataagcc
cgtctctggggtggaggtagcaccactgcagagcttcatgctgcggggtggtgt
tgtagatgatccagtcgtagcaggagcgctgggcgtggtgcctaaaaatgtctt
tcagtagcaagctgattgccaggggcaggcccttggtgtaagtgtttacaaagc
ggttaagctgggatgggtgcatacgtggggatatgagatgcatcttggactgta
tttttaggttggctatgttcccagccatatccctccggggattcatgttgtgca
gaaccaccagcacagtgtatccggtgcacttgggaaatttgtcatgtagcttag
aaggaaatgcgtggaagaacttggagacgcccttgtgacctccaagattttcca
tgcattcgtccataatgatggcaatgggcccacgggcggcggcctgggcgaaga
tatttctgggatcactaacgtcatagttgtgttccaggatgagatcgtcatagg
ccatttttacaaagcgcgggcggagggtgccagactgcggtataatggttccat
ccggcccaggggcgtagttaccctcacagatttgcatttcccacgctttgagtt
cagatgggggatcatgtctacctgcggggcgatgaagaaaacggtttccgggg
taggggagatcagctgggaagaaagcaggttcctgagcagctgcgacttaccgc
agccggtgggcccgtaaatcacacctattaccggctgcaactggtagttaagag
agctgcagctgccgtcatccctgagcagggggccacttcgttaagcatgtccc
tgactcgcatgttttccctgaccaaatccgccagaaggcgctcgccgcccagcg
atagcagttcttgcaaggaagcaaagtttttcaacggtttgagaccgtccgccg
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gtggtcgaggtgccgtaaagcactaaatcggaaccctaaagggagcccccgatt
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gaaaggagcgggcgctagggcgctggcaagtgtagcggtcacgctgcgcgtaac
caccacacccgcgcgcttaatgcgccgctacagggcgcgtccattcgccattca
ggatcgaattaattcttaattaa (SEQ ID NO:28)

[0298] To develop a replication-defective, recombinant adenovirus vector containing both Gag and F, the protease-deleted version of the ALV Gag gene was first inserted into pShuttle-CMV and the RSV F gene was inserted into pShuttle-CMV-TO resulting in the new plasmids pShuttle-ALV Gag-dPR and pShuttle-TO-FL, respectively. The plasmid map of pShuttle-ALV-Gag-dPR is shown in Figure 35 and its sequence is as follows:

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gagcgggcgctagggcgctggcaagtgtagcggtcacgctgcgcgtaaccacca
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gaattaattcttaattaa (SEQ ID NO:29)

[0299] The plasmid map of pShuttle-TO-FL is shown in Figure 36 and its sequence is as follows:

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cgcggttttaggcggatgttgtagtaaatttgggcgtaaccgagtaagatttgg
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tgggactttcctacttggcagtacatctagtattagtcatcgctattaccatgg
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cgggcgctagggcgctggcaagtgtagcggtcacgctgcgcgtaaccaccacac
ccgcgcgcttaatgcgccgctacagggcgcgtccattcgccattcaggatcgaa
ttaattcttaattaa (SEQ ID NO:30)

[0300] After completion of the individual Gag and F shuttle vectors a combined Gag plus F shuttle vector was derived from them. Using PCR techniques DNA fragments containing the modified promoter and F coding sequences from pShuttle-TO-FL, as well as SV40 polyadenylation sequences, were generated and inserted into the HpaI site of pShuttle-ALV-Gag-dPR. This resulted in construction of a double shuttle vector in which the two genes (Gag + F) were transcriptionally opposed sharing a single SV40 polyadenylation region fragment between them. The plasmid map for the new double shuttle vector, pShuttle-dPR-TO-FL-rev, is shown in Figure 37 and its nucleotide sequence is as follows:

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attcgccattcaggatcgaattaattcttaattaa (SEQ ID NO:31)

[0301] To produce the replication-defective adenovirus vector encoding both Gag and F, the plasmid pShuttle-dPR-TO-FL-rev was linearized with PmeI then electroporated into the bacterial strain BJ5183-AD-1 in order for it to be recombined into the E1-deleted adenovirus type 5 genome. These methods of adenovirus vector generation are common to those skilled in the art. Small colonies (indicative of plasmid recombination into the adenovirus genome) were selected for expansion and isolation of the recombinant adenovirus DNA containing the inserted pShuttle-dPR-TO-FL-rev sequences. A recombinant adenovirus DNA clone containing the inserted Gag and F genes was then digested with PacI to separate the adenovirus DNA from bacterial plasmid sequences and this DNA was transfected into T-Rex 293 cells in order to generate a replication-defective adenovirus strain. T-Rex 293 cells are HEK293 cells containing the Tet repressor gene. The E1 gene contained within all 293 cell lines allows

for the replication of replication-defective adenovirus vectors and the Tet repressor in the T-Rex 293 line prevents F gene expression during virus propagation.

[0302] After successful isolation and expansion of the adenovirus vector encoding Gag and F on T-Rex 293 cells, this vector was used to transduce Vero cells for VLP production. Vero cells growing in T175 culture flasks in DMEM medium containing 10% fetal bovine serum were washed with serum-free VP-SFM medium then established in VP-SFM medium and then transduced with the Gag + F double adenovirus vector at a multiplicity of infection of 70:1. Within 24 hours the transduced Vero cells began to show cytopathic effects (CPE) consisting mainly of massive syncytia formation. By 72 hours extensive CPE were present with many large, floating syncytia observed. Medium was harvested at this time and clarified of cellular debris by centrifugation at 2000 rpm for 10 min. VLPs present in the medium were purified by centrifugation over a 2-step sucrose step gradient (30% and 60% sucrose in tris-buffered saline, pH 7.4) for 2 hours at 100,000 x g at 10 °C. A visible band at the junction of the 30% and 60% sucrose layers was observed and collected (Figure 38(a)).

[0303] VLPs purified in this manner from several T175 flasks were diluted 2-fold in tris-buffered saline then subjected to 3 Joules of long wave UV radiation in the presence of 50 mcg/ml aminomethyl-trimethyl psoralen in order to inactivate any residual adenovirus vector not taken up into the Vero cells. Following residual vector inactivation, VLPs were rebanded on 30-60% sucrose step gradients as a final purification step.

Results

[0304] Figure 38(b) shows a silver-stained SDS-PAGE analysis of the final purified VLP preparation and Figure 39 shows an RSV-specific Western blot demonstrating the presence of the F1 fragment (reducing conditions). Finally, an electron micrograph (Figure 40) shows the presence of enveloped VLPs in the final preparation. The adenoviral expression produced at least a ten-fold higher yield than the previous examples, showing that the viral expression is superior.

Example 14 – Immunogenicity of Pseudotyped ALV Gag + RSV F VLPs

[0305] This example further demonstrates the immunogenic and protective properties of RSV F-pseudotyped ALV Gag VLPs.

Materials and Methods

[0306] To further demonstrate that RSV F-pseudotyped VLPs are both immunogenic and protective, VLPs were prepared as described in the previous example using the adenovirus expression system and were employed in a cotton rat vaccination and challenge model. In addition to the RSV F-pseudotyped Gag VLPs produced as described above, a sample of Gag-only VLPs was also produced using an adenovirus vector containing only the ALV Gag gene. This latter batch of "naked" VLPs lacking the RSV F antigen was produced and purified in a manner similar to that for the F-pseudotyped Gag VLPs and they served as a negative control vaccine.

[0307] An immunization trial employing five immunization groups consisting of twelve animals each was designed using specific pathogen-free female cotton rats. The five immunization groups were assigned the following vaccines, respectively:

1. VLP (3 μg F antigen, 30 μg total VLP protein per dose)
2. VLP + MPL adjuvant (3 μg F antigen, 30 μg total VLP protein, 50 μg monophosphoryl lipid A adjuvant per dose)
3. Gag-only VLP (60 μg total VLP protein per dose)
4. Live RSV (positive control – $1x10^5$ pfu live RSV A per dose)
5. Navie (negative control group – no vaccination)

[0308] Vaccination groups 1-3 received primary and booster vaccination on days 0 and 21 as described above. Group 4 animals only received a single live RSV vaccination of day 0 and were not boosted on day 21. Naïve animals in group 5 received no vaccine administrations.

[0309] Serum samples were collected 2 weeks following the booster immunization (day 35) to analyze RSV-specific neutralizing antibody responses in a standard virus microneutralization assay.

[0310] All animals were challenged with $1x10^5$ pfu of live RSV A on day 49. On day 54 (5 days following challenge), six animals from each group were sacrificed for determination of RSV virus titers in lung homogenates. Virus in lung homogenates was quantified by titration of virus infectivity in cell culture using standard techniques known to those skilled in the art.

[0311] Six animals were also sacrificed for lung histopathology measurements. Lung samples were formalin fixed, paraffin-embedded and H&E stained using methods known to those skilled in the art and slides were examined for alveolitis and interstitial pneumonia by a trained pathologist.

Results

Serum antibody response

[0312] Results demonstrating the serum antibody response are shown in Figure 41. Strong neutralizing antibody titers were observed in the RSV F-pseudotyped VLP immunization groups with and without MPL adjuvant. No neutralizing responses were detected in the Gag-only VLP immunization group demonstrating the importance of the RSV F antigen for induction of specific immune responses. Finally, the live RSV positive control vaccination group exhibited modest virus neutralizing titers.

Virus titer in lung tissue

[0313] Results demonstrating the virus titer in lung homogenates are shown in Figure 42 in which naïve, non-vaccinated animals exhibited high levels of virus replication while VLP and live RSV-vaccinated animals showed significant protection from challenge. No virus was detected at all in the group immunized with VLP+MPL. A modest amount of protection was observed in the Gag-only-immunized animals and this may have been the result of innate immune activation via Gag-only VLP immunization

since there were no RSV-specific neutralizing immune responses in this group (Figure 41). The combined virus challenge and virus neutralization data demonstrate the ability of RSV F-pseudotyped VLPs to induce strong neutralizing immune responses that are protective against virus challenge.

Lung histopathology measurements

[0314] Scores of the lung histopathology measurements are shown in Figure 43 and demonstrate low pathology scores for the VLP+MPL and live RSV vaccination groups. Moderate pathology was observed in the VLP immunization group in the absence of the MPL adjuvant. The VLP+MPL vaccine formulation is therefore able to elicit strong neutralizing antibody titers resulting in complete vaccine protection against challenge in the absence of significant pathological reactions.

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What we claim is:

1. A chimeric virus-like particle comprising a lentivirus or an alpha-retrovirus Gag polypeptide and a respiratory syncytial virus F polypeptide.

2. The virus-like particle of claim 1, wherein the Gag polypeptide is from a simian immunodeficiency virus or a human immunodeficiency virus.

3. The virus-like particle of claim 1, wherein the Gag polypeptide is from an avian leukosis virus or rous sarcoma virus.

4. The virus-like particle of any one of claims 1-3, further comprising mammalian glycosylation.

5. The virus-like particle of any one of claims 1-4, further comprising an adjuvant in admixture with the virus-like particle.

6. The virus-like particle of claim 5, wherein the adjuvant is located outside the virus-like particle.

7. The virus-like particle of claim 5, wherein the adjuvant is located inside the virus-like particle.

8. The virus-like particle of any one of claims 5-7, wherein the adjuvant is covalently linked to the respiratory syncytial virus F polypeptide to form a covalent linkage.

9. The virus-like particle of any one of claims 1-8, wherein a neutralizing anti-RSV-F antibody binds to the respiratory syncytial virus F polypeptide.

10. The virus-like particle of claim 9, wherein the neutralizing anti-RSV-F antibody is Palivizumab.

11. The virus-like particle of any one of claims 1-10, further comprising an additional VLP-associating antigen.

12. The virus-like particle of any one of claims 1-10, further comprising an additional VLP-associating polypeptide linked to a second antigen.

13. A method for producing a chimeric virus-like particle, comprising:

(a) providing one or more expression vectors together which express a lentivirus or an alpha-retrovirus Gag polypeptide and a respiratory syncytial virus F polypeptide;

(b) introducing the one or more expression vectors into a eukaryotic cell in a media; and

(c) expressing the Gag polypeptide and the respiratory syncytial virus F polypeptide to produce the chimeric virus-like particle.

14. The method of claim 13, wherein the eukaryotic cell is a yeast cell, a mammalian cell, or an insect cell.

15. The method of claim 13, wherein the eukaryotic cell is a mammalian cell.

16. The method of any one of claims 13-15, wherein the Gag polypeptide is from a simian immunodeficiency virus or a human immunodeficiency virus.

17. The method of any one of claims 13-15, wherein the Gag polypeptide is from an avian leukosis virus or rous sarcoma virus.

18. The method of any one of claims 13-17, further comprising the step of recovering the virus-like particle from the media in which the eukaryotic cell is cultured.

19. The method of any one of claims 13-18, wherein the expression vector is a viral vector.

20. The method of claim 19, wherein the viral vector is selected from the group consisting of: an adenovirus, a herpesvirus, a poxvirus and a retrovirus.

21. The method of claims 19 or 20, wherein the viral vector further includes a transcriptional regulator that down-regulates expression of the respiratory syncytial virus F polypeptide when the viral vector is propagated in a helper cell or up-regulates expression of the respiratory syncytial virus F polypeptide in the eukaryotic cell.

22. The method of claim 21, wherein the transcriptional regulator is a tet repressor or a metallothionine inducible enhancer.

23. The method of any one of claims 13-22, wherein the eukaryotic cell is selected from the group consisting of a BHK cell, a VERO cell, an HT1080 cell, an MRC-5 cell, a WI 38 cell, an MDCK cell, an MDBK cell, an HEK293 cell, a 293T cell, an RD cell, a COS-7 cell, a CHO cell, a PER.C6 (TM) cell, a Jurkat cell, a HUT cell, a SUPT cell, a C8166 cell, a MOLT4/clone8 cell, an MT-2 cell, an MT-4 cell, an H9 cell, a PM1 cell, a CEM cell, a myeloma cell, SB20 cell, a LtK cell, a HeLa cell, a WI-38 cell, an L2 cell, a CMT-93, and a CEMX174 cell.

24. The method of any one of claims 13-23, further comprising an additional VLP-associating antigen.

25. The method of any one of claims 13-23, further comprising an additional VLP-associating polypeptide linked to a second antigen.

26. The method of any one of claims 13-25, wherein a neutralizing anti-RSV-F antibody binds to the expressed respiratory syncytial virus F polypeptide.

27. The method of claim 26, wherein the neutralizing anti-RSV-F antibody is Palivizumab.

28. A method for treating or preventing respiratory syncytial virus infection comprising administering to a subject an immunogenic amount of the virus-like particle of any or claims 1-10 or the virus-like particle produced by the method of any one of claims 13-27.

29. The method of claim 28, wherein the administering induces a protective immunization response in the subject.

30. The method of any one of claims 28-29, wherein the administering is selected from the group consisting of subcutaneous delivery, transcutaneous delivery, intradermal delivery, subdermal delivery, intramuscular delivery, peroral delivery, oral delivery, intranasal delivery, buccal delivery, sublingual delivery, intraperitoneal delivery, intravaginal delivery, anal delivery and intracranial delivery.

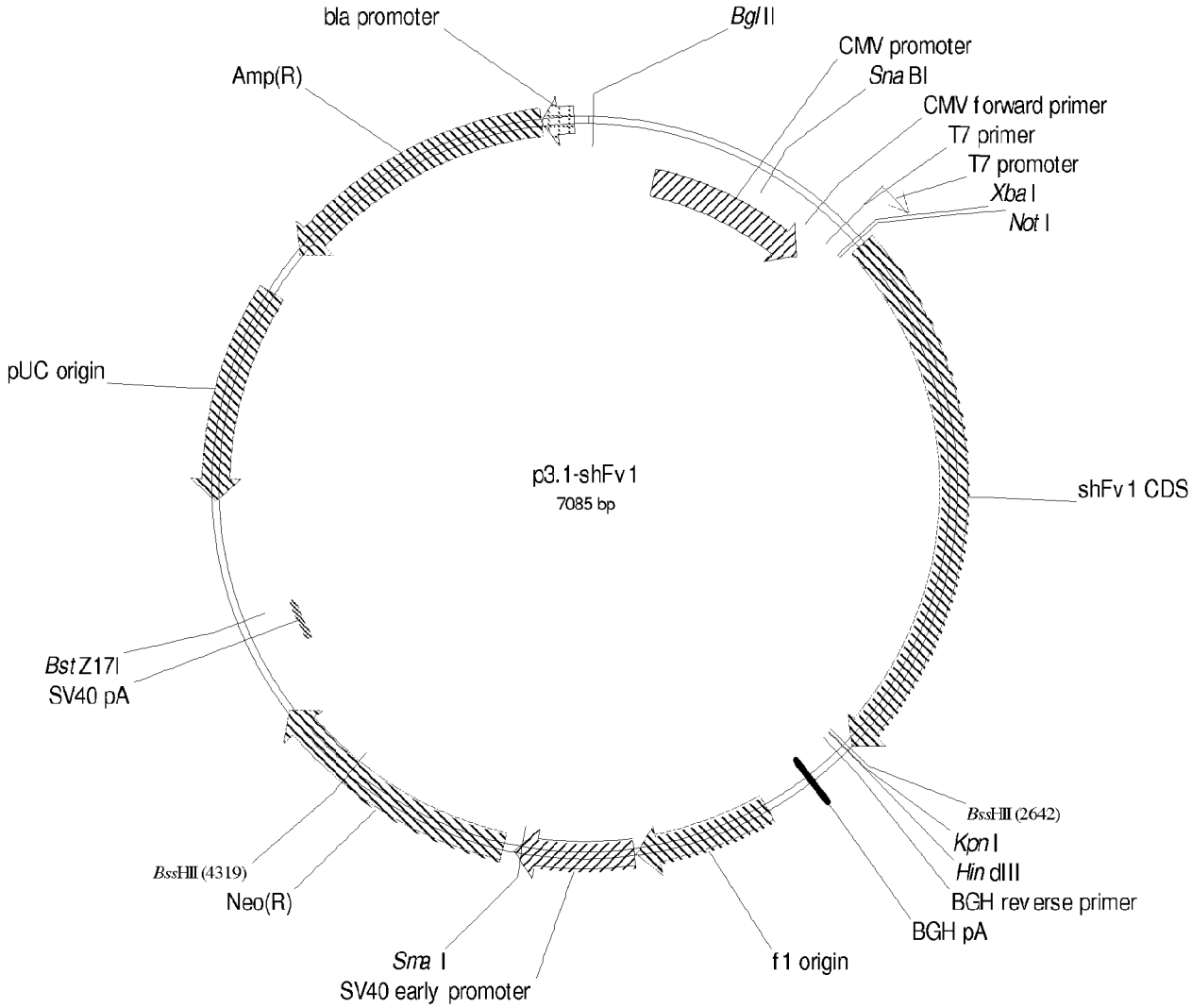
31. A pharmaceutical composition comprising an immunogenic amount of the virus-like particle of any one of claims 1-11 or the virus-like particle produced by the method of any one of claims 13-27.

32. The pharmaceutical composition of claim 31 further comprising a pharmaceutically acceptable carrier.

33. A method for providing protection against respiratory syncytial virus infection comprising administering to a subject an immunogenic amount of the virus-like particle of any one of claims 1-11 or the virus-like particle produced by the method of any one of claims 13-27.

34. The method of claim 33, wherein the administering is selected from the group consisting of subcutaneous delivery, transcutaneous delivery, intradermal delivery, subdermal delivery, intramuscular delivery, peroral delivery, oral delivery, intranasal delivery, buccal delivery, sublingual delivery, intraperitoneal delivery, intravaginal delivery, anal delivery and intracranial delivery.

Figure 1.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CMV forward primer
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T7 promoter
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7085 bp
shFv1 CDS
Bst Z17I
SV40 pA
BssHII (2642)
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Figure 2.

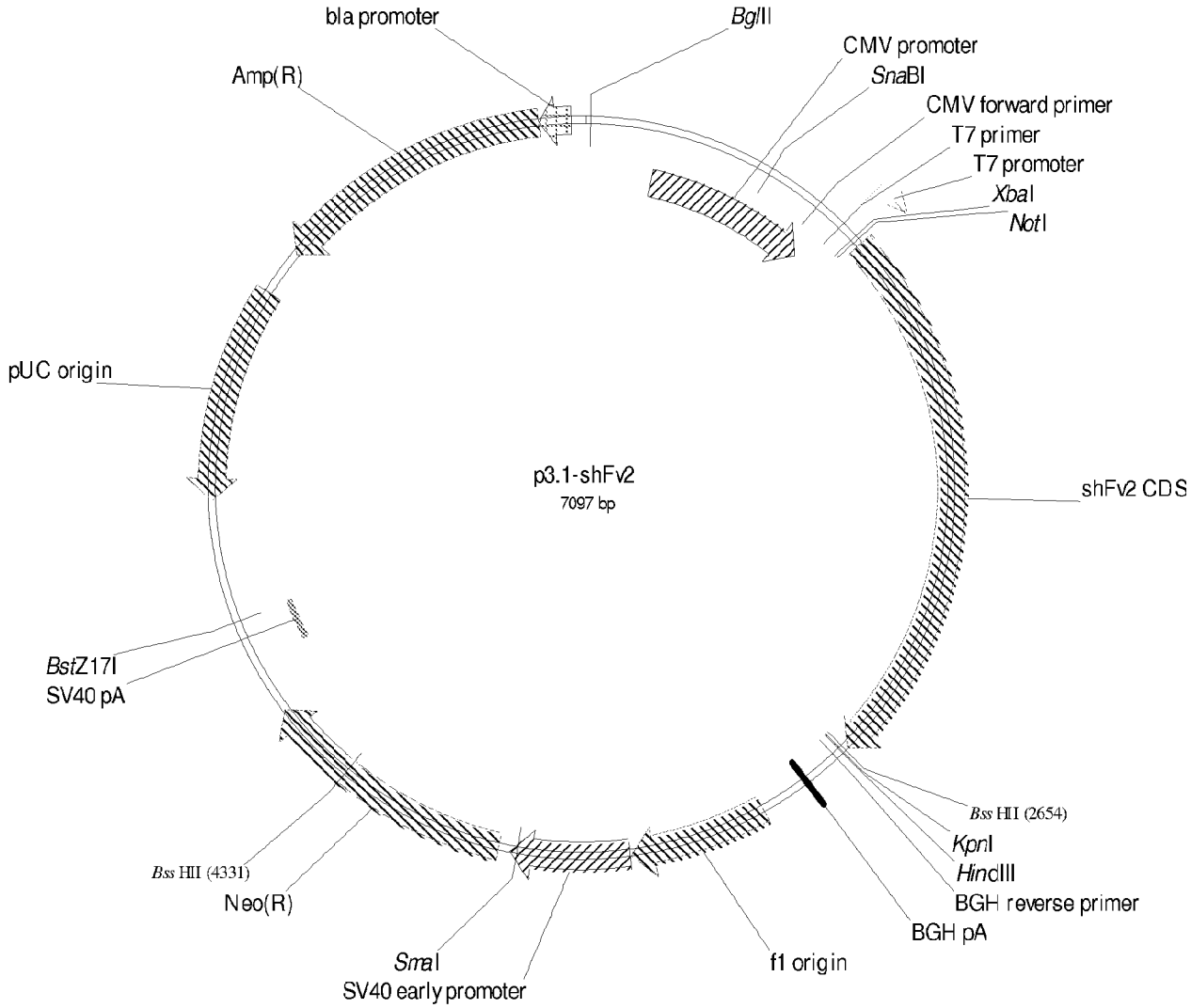
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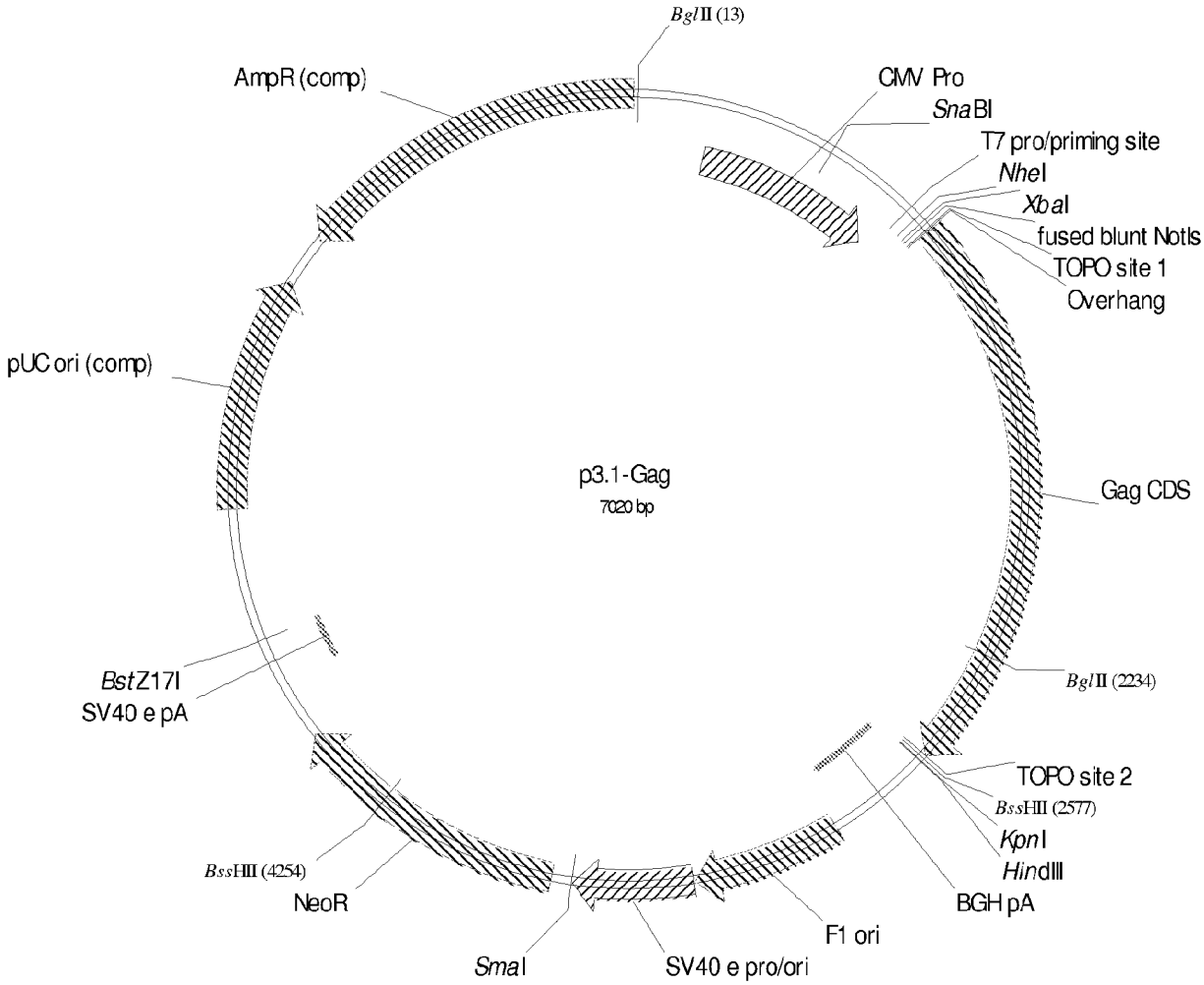
Figure 3.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fused blunt NotIs
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p3.1-Gag
7020 bp
Gag CDS
BglII (2234)
BstZ17I
SV40 e pA
TOPO site 2
BssHII (2577)
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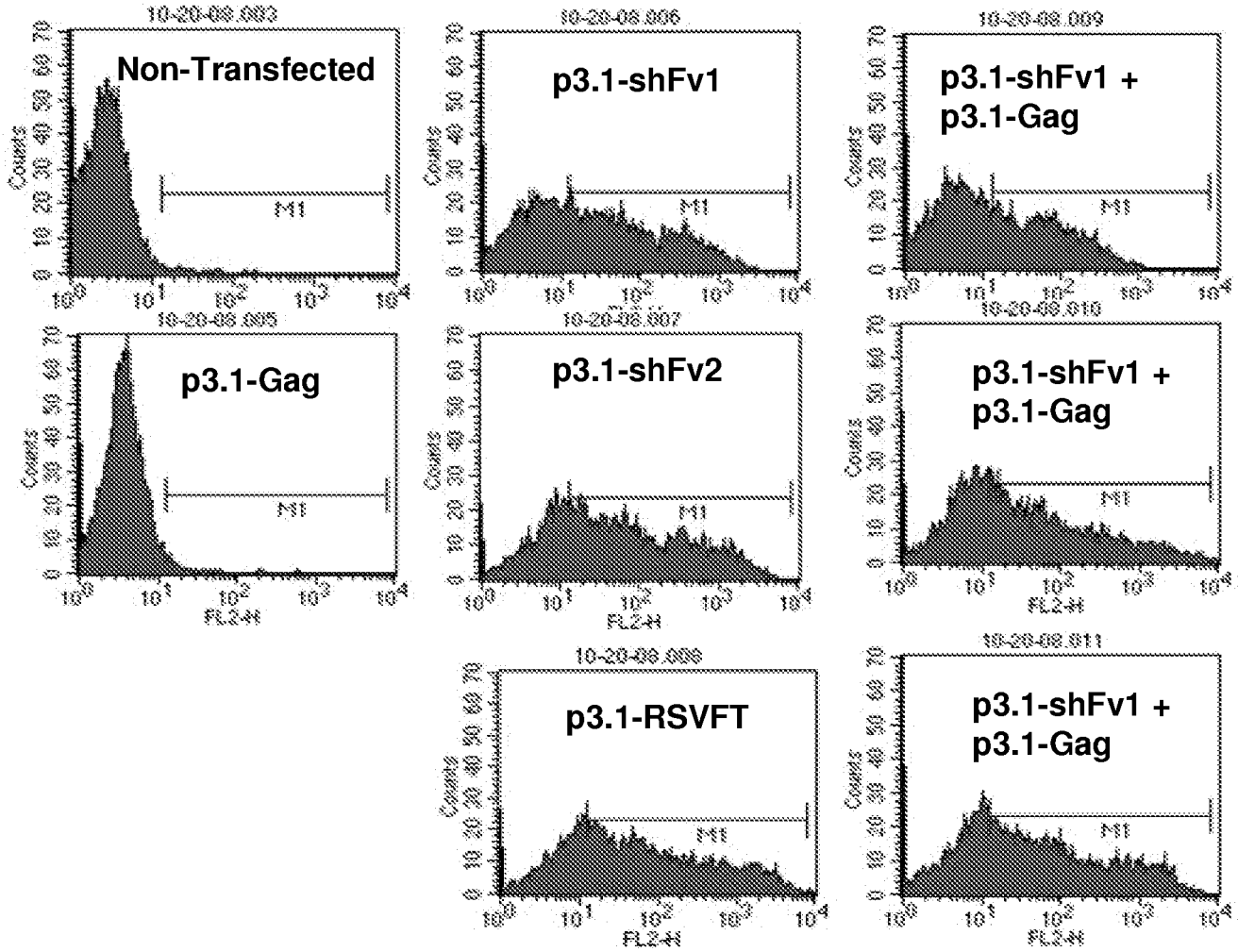
Figure 4.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p3.1-Gag
p3.1-shFv2
p3.1-shFv1 + p3.1-Gag
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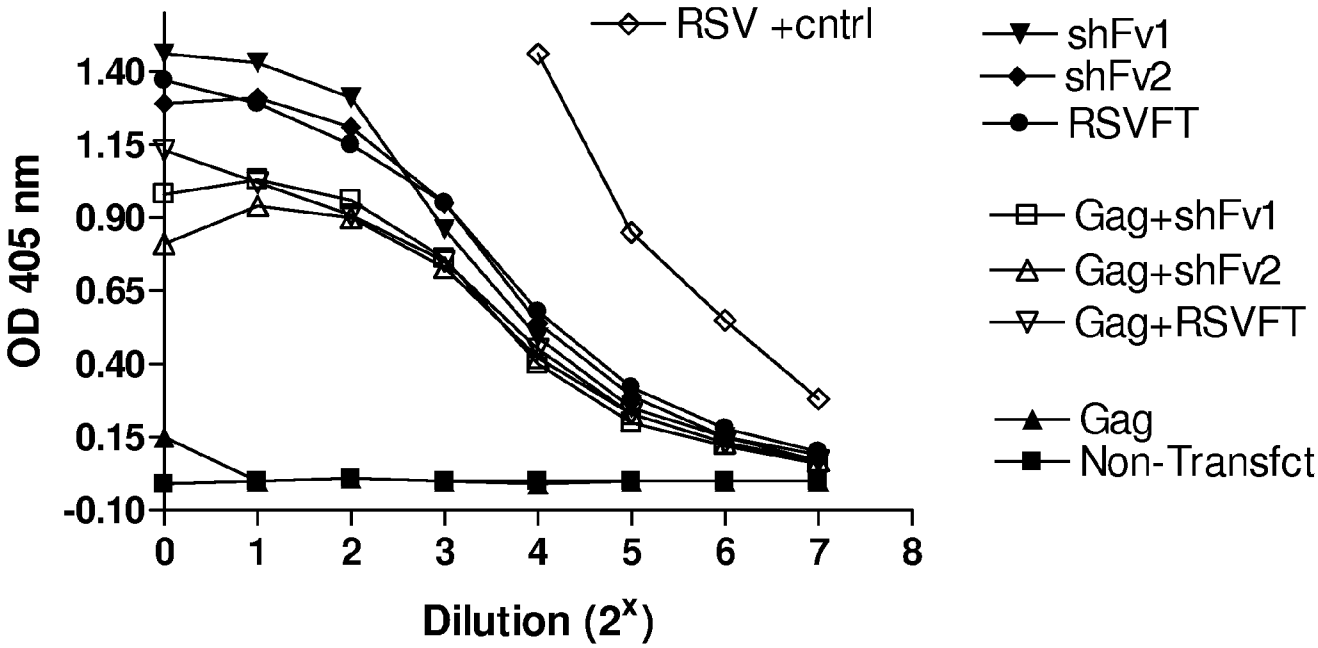
Counts
FL2-H
M1

Figure 5.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OD 405 nm
1.40
1.15
0.90
0.65
0.40
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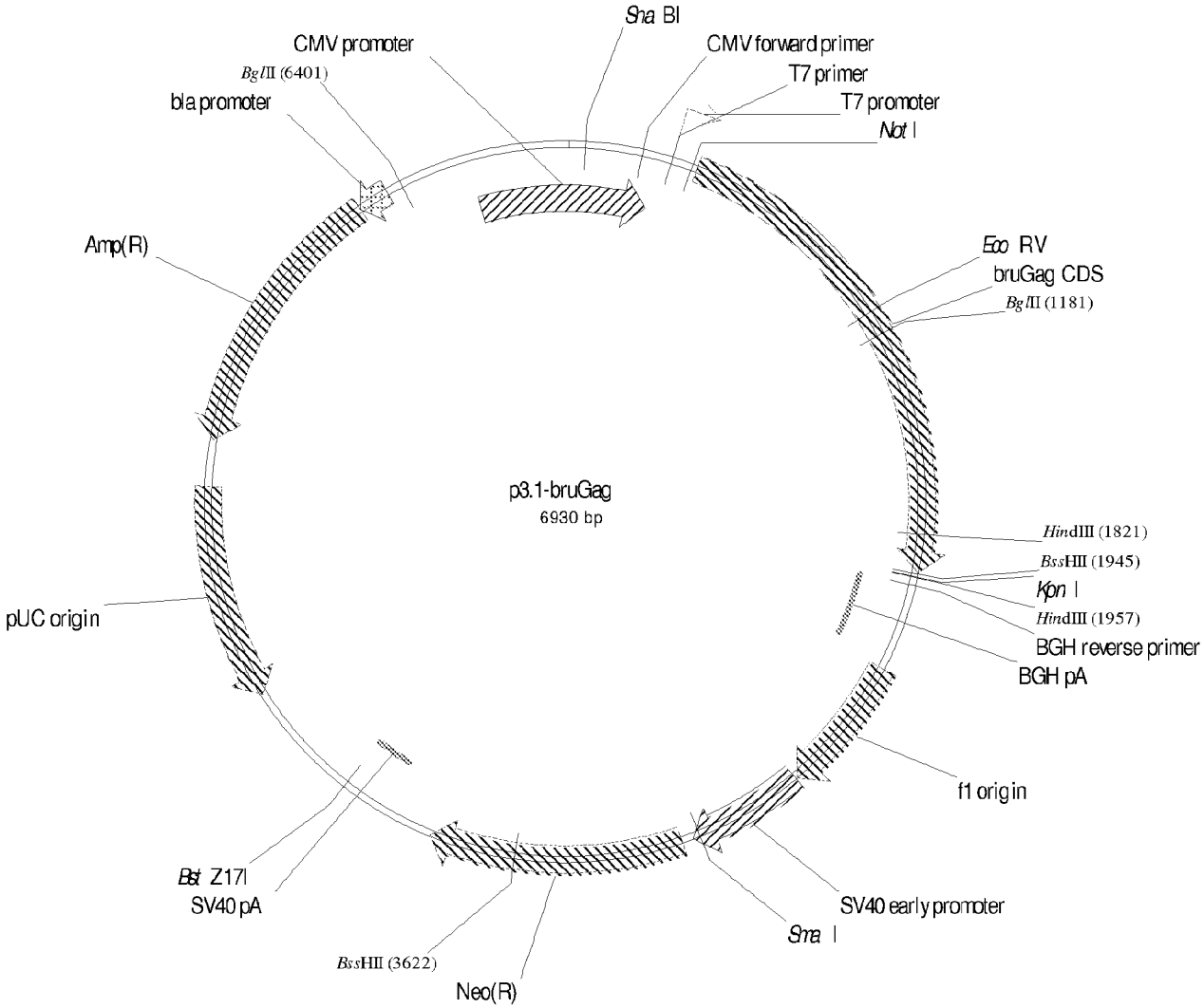
-0.10
0
1
2
3
4
5
6
7
8
Dilution (2x)

Figure 6.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CMV forward primer
BglII (6401)
T7 primer
bla promoter
T7 promoter
Not I
Amp(R)
Eco RV
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BssHII (1945)
Kpn I
HindIII (1957)
pUC origin
BGH reverse primer
BGH pA
f1 origin
Bst Z17I
SV40 pA
SV40 early promoter
Sma I
BssHII (3622)
Neo(R)

Figure 7.

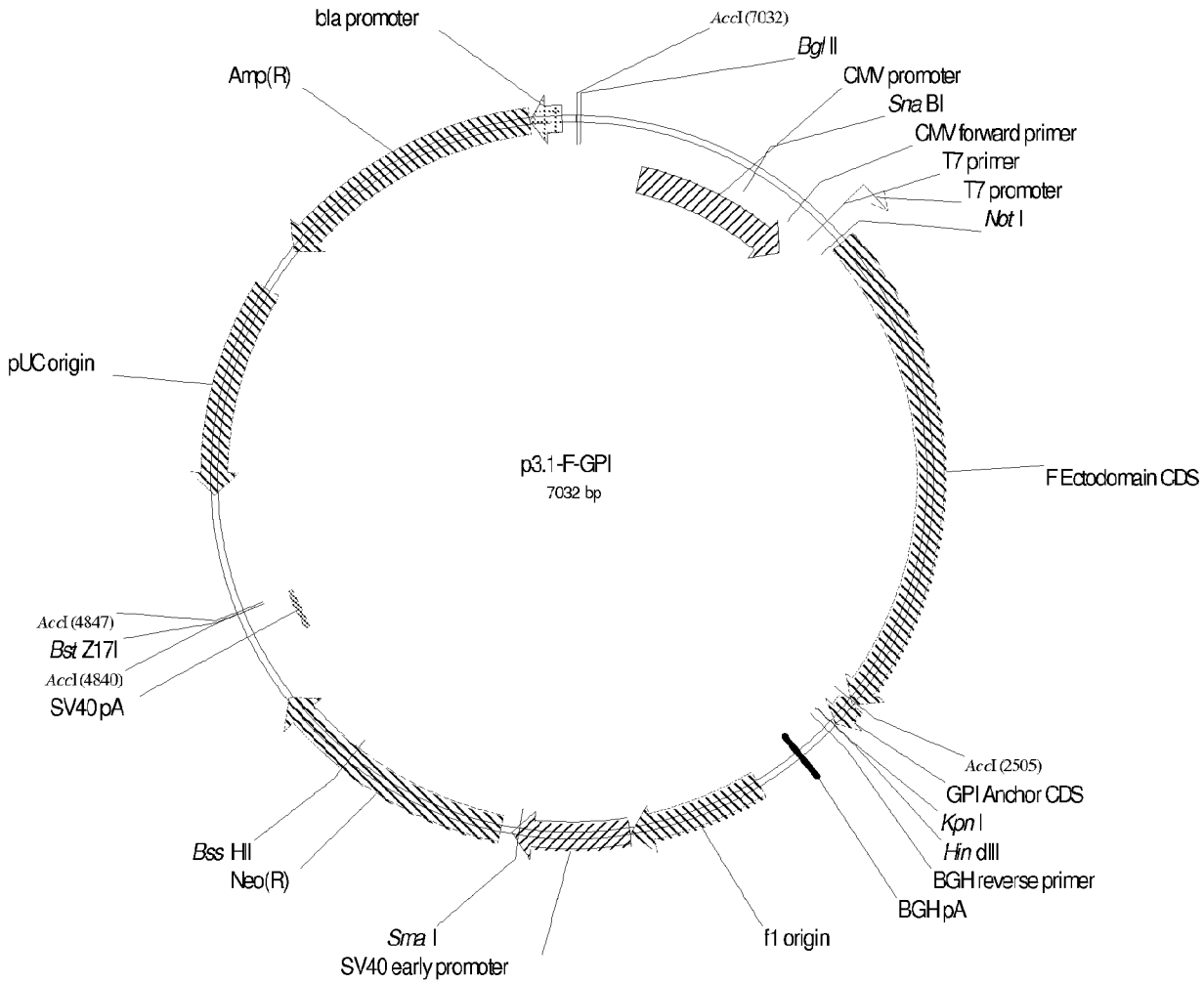

bla promoter
AccI (7032)
BglII
Amp(R)
CMV promoter
SnaBI
CMV forward primer
T7 primer
T7 promoter
NotI
pUC origin
p3.1-F-GPI
7032 bp
F Ectodomain CDS
AccI (4847)
BstZ17I
AccI (4840)
SV40 pA
AccI (2505)
GPI Anchor CDS
KpnI
HindIII
BGH reverse primer
BGH pA
BssHII
Neo(R)
SmaI
SV40 early promoter
f1 origin

Figure 8.

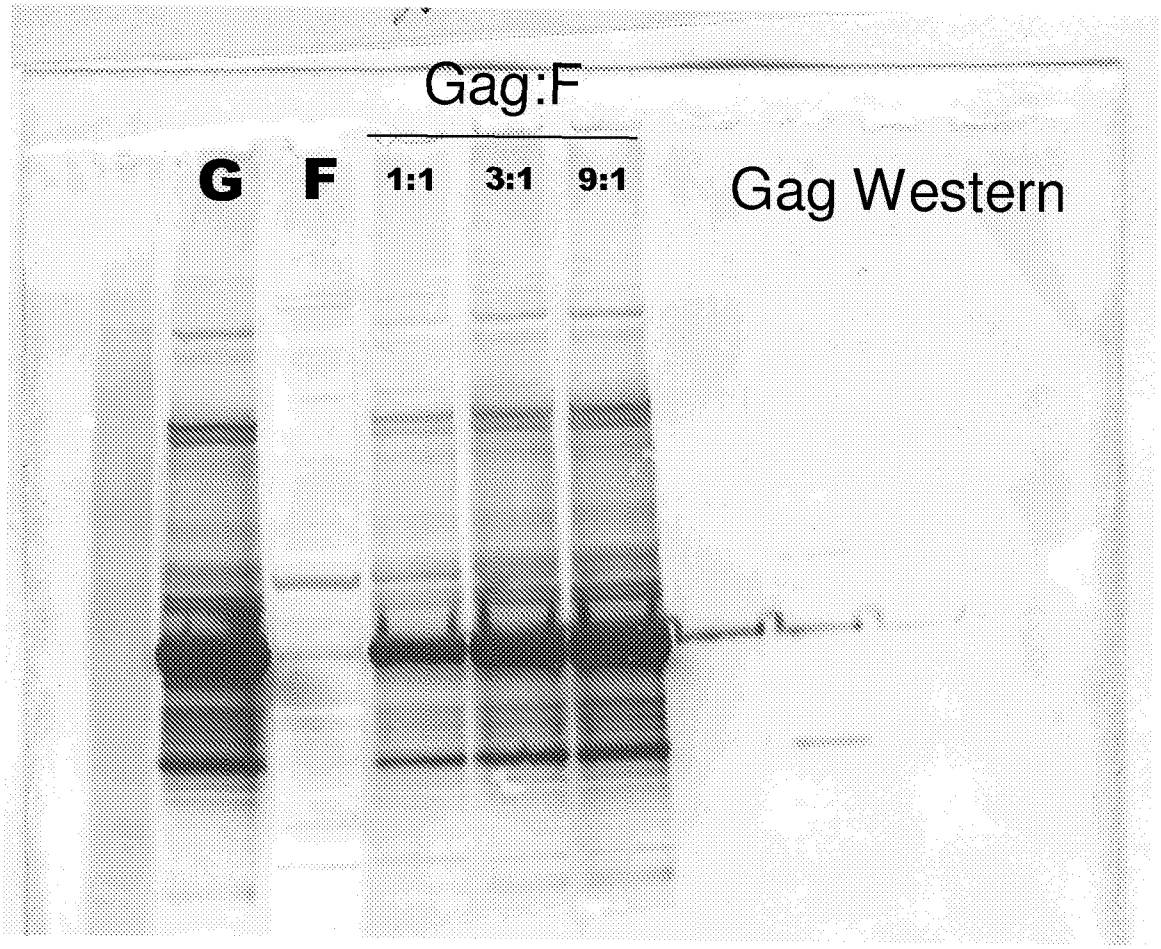


Figure 9.

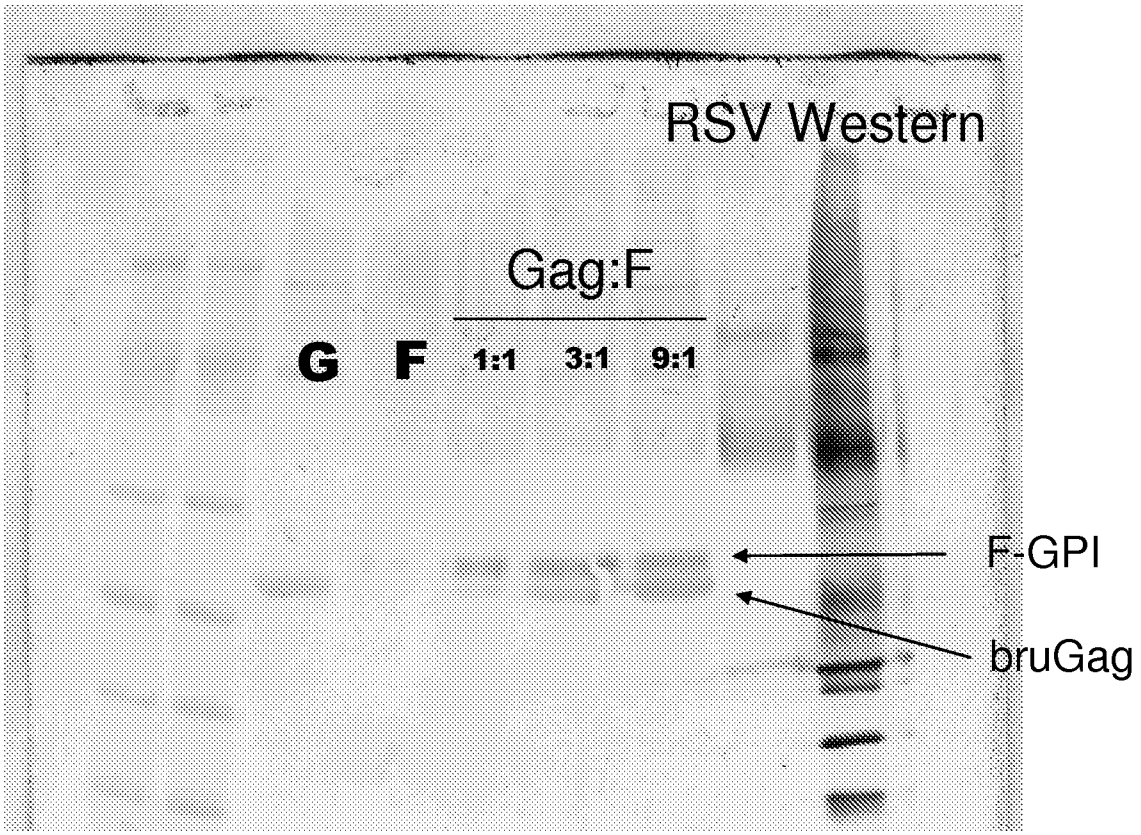


Figure 10.

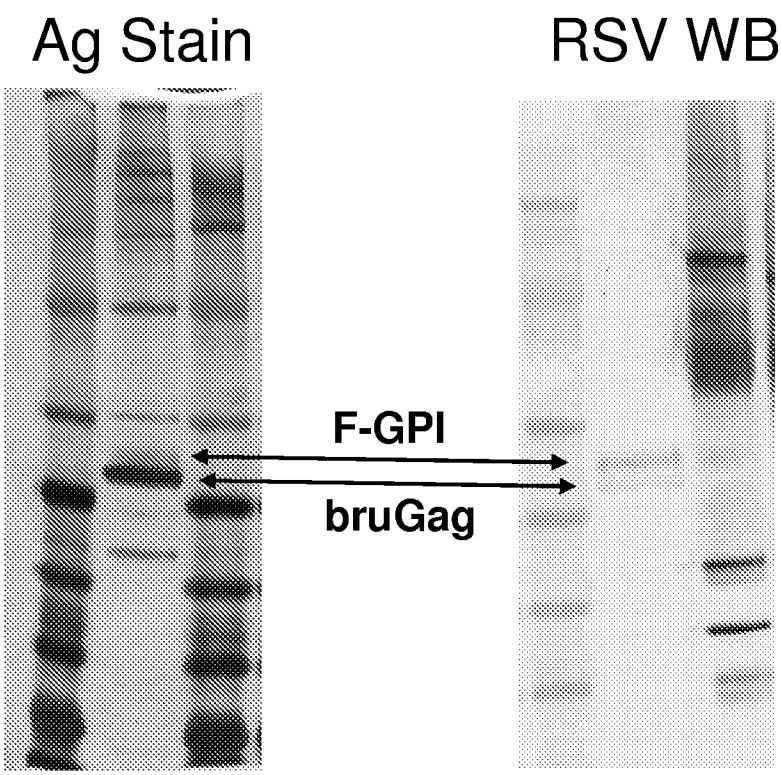


Figure 11.

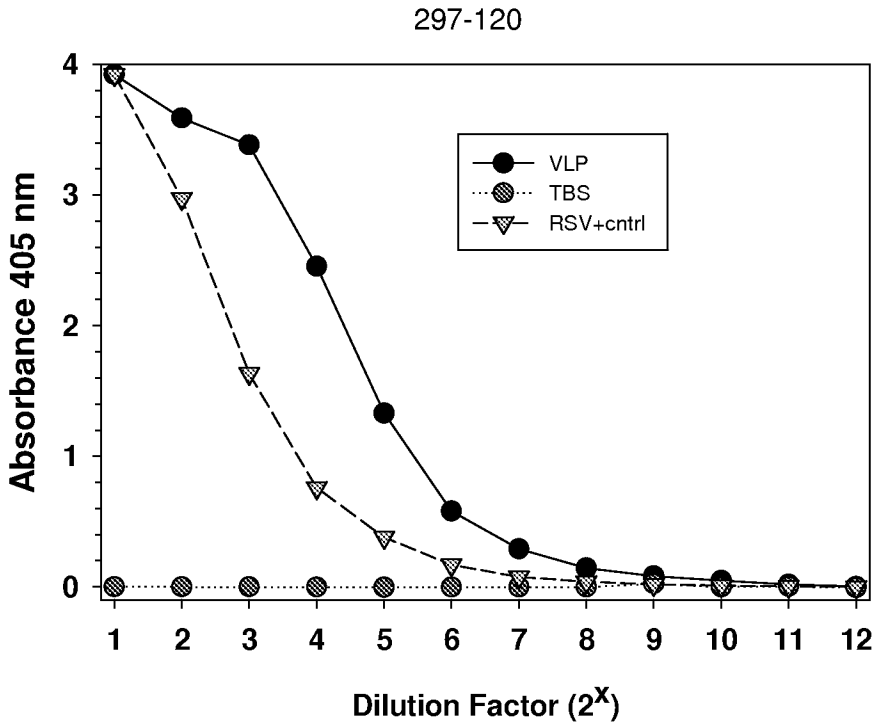

297-120
Absorbance 405 nm
Dilution Factor (2^X)
VLP
TBS
RSV+cntrl
0
1
2
3
4
1
2
3
4
5
6
7
8
9
10
11
12

Figure 12.

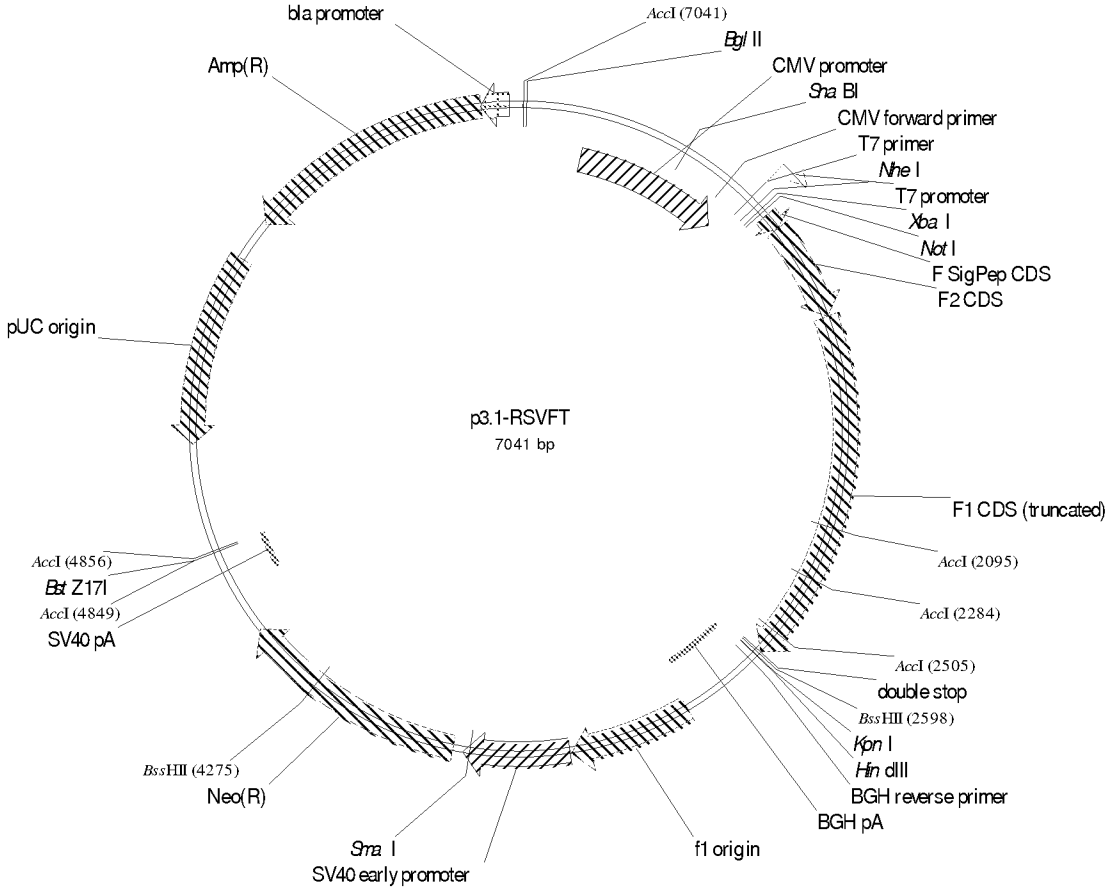

bla promoter
AccI (7041)
Bgl II
Amp(R)
CMV promoter
Sna BI
CMV forward primer
T7 primer
Nhe I
T7 promoter
Xba I
Not I
F SigPep CDS
F2 CDS
pUC origin
p3.1-RSVFT
7041 bp
F1 CDS (truncated)
AccI (2095)
AccI (2284)
AccI (2505)
double stop
BssHII (2598)
Kpn I
Hin dIII
BGH reverse primer
BGH pA
f1 origin
Sma I
SV40 early promoter
BssHII (4275)
Neo(R)
AccI (4856)
Bst Z17I
AccI (4849)
SV40 pA

Figure 13.

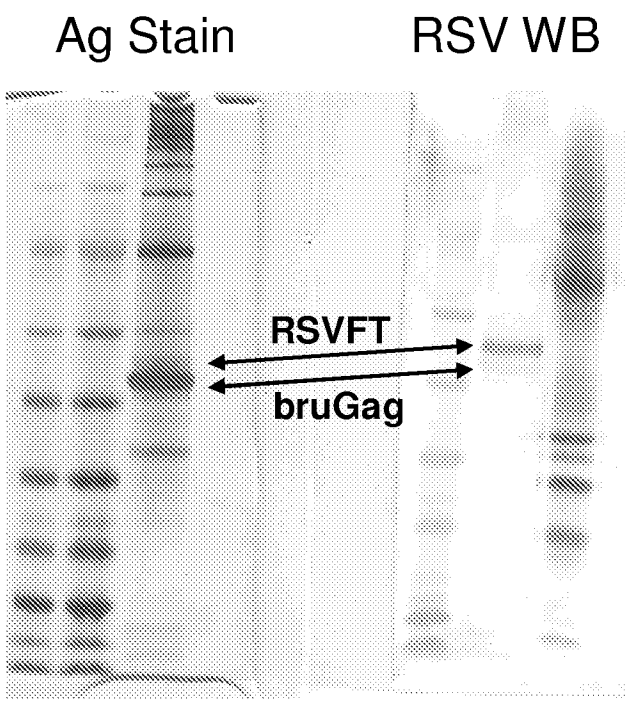


Figure 14.

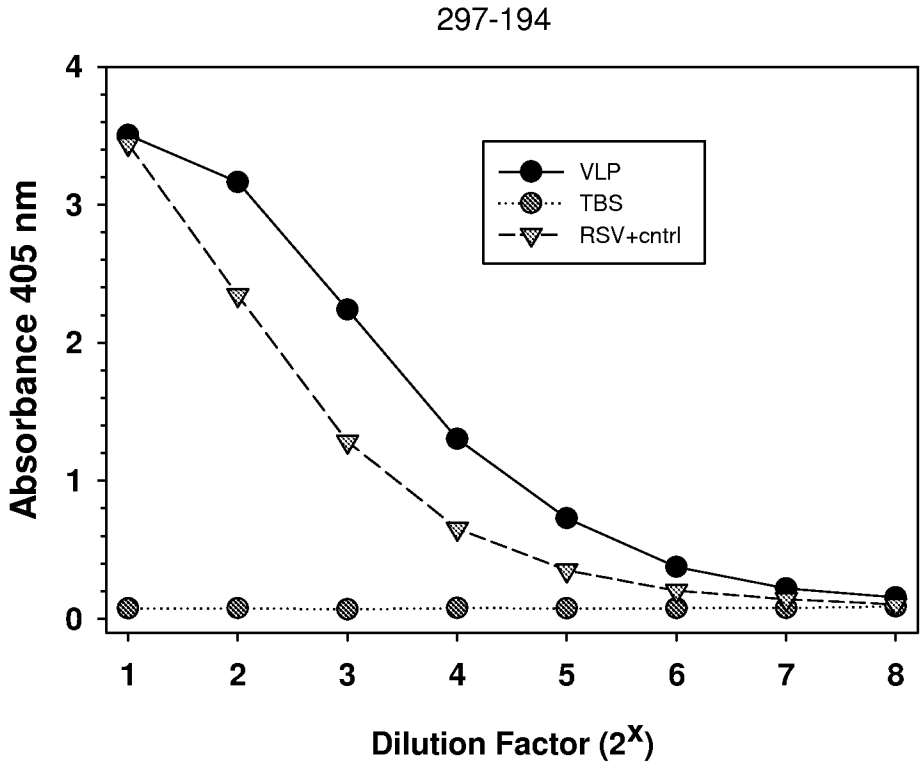

297-194
Absorbance 405 nm
Dilution Factor (2^X)
VLP
TBS
RSV+cntrl
0
1
2
3
4
1
2
3
4
5
6
7
8

Figure 15.

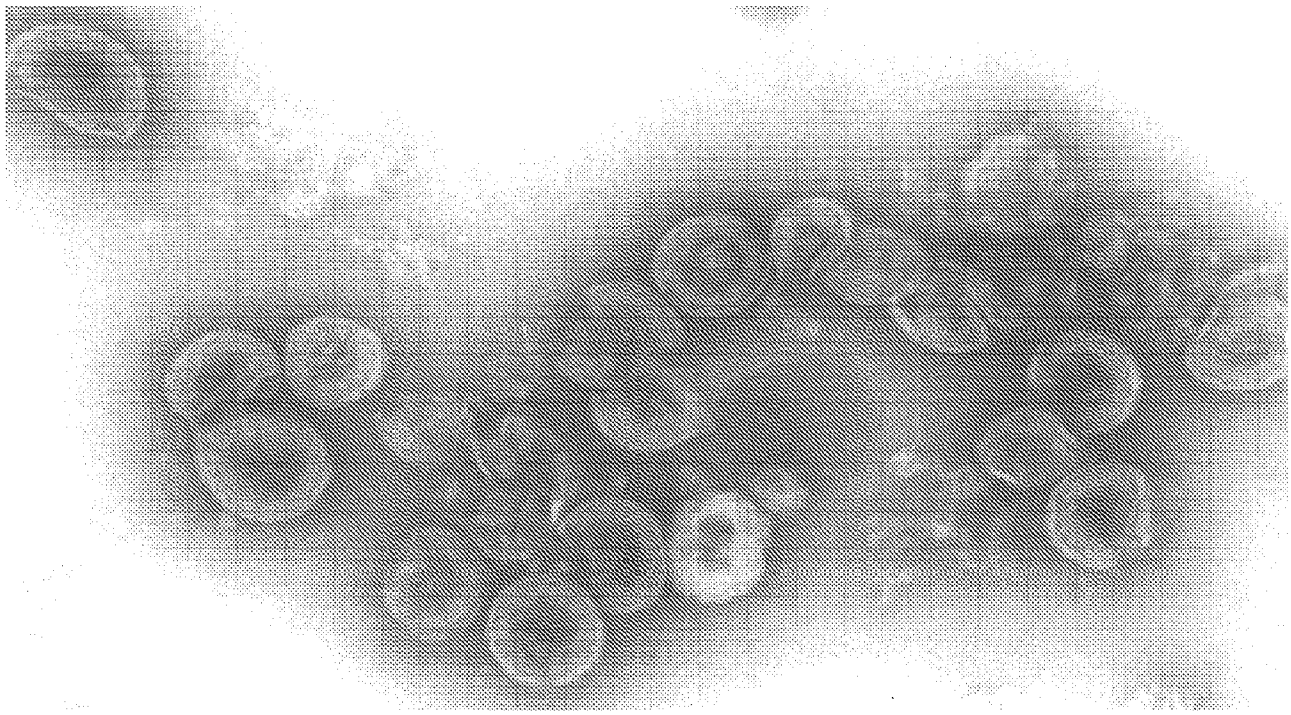


Figure 16

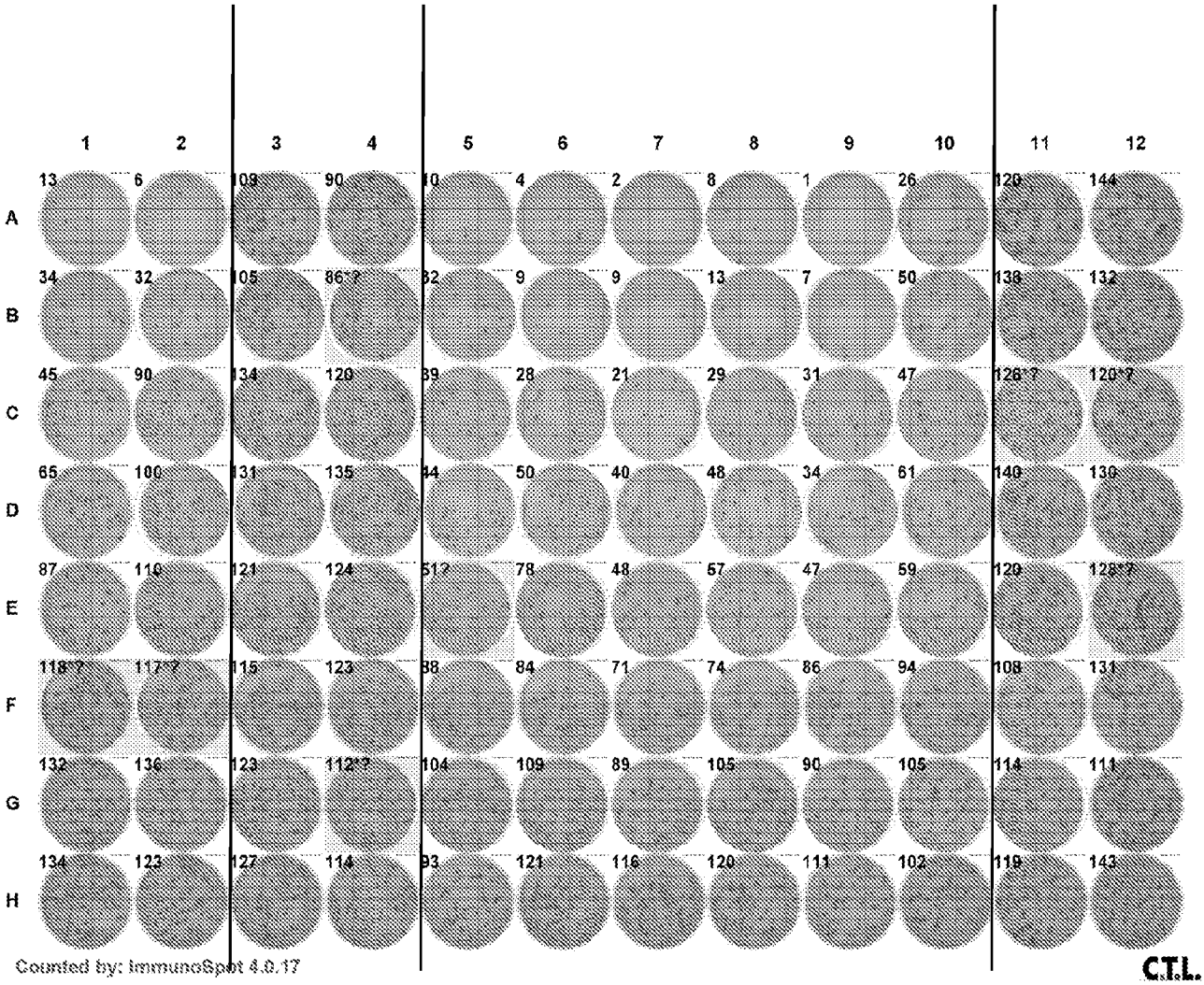

1 2 3 4 5 6 7 8 9 10 11 12
A 13 6 109 90 10 4 2 8 1 26 120 144
B 34 32 105 86* 32 9 9 13 7 50 138 132
C 45 90 134 120 39 28 21 29 31 47 126* 120*
D 65 100 131 135 44 50 40 48 34 61 140 130
E 87 110 121 124 51? 78 48 57 47 59 129 128*
F 118* 117* 115 123 88 84 71 74 86 94 108 131
G 132 136 123 112* 104 109 89 105 90 105 114 111
H 134 123 127 114 93 121 116 120 111 102 119 143
Counted by: ImmunoSpot 4.0.17
C.T.L.

Figure 17.

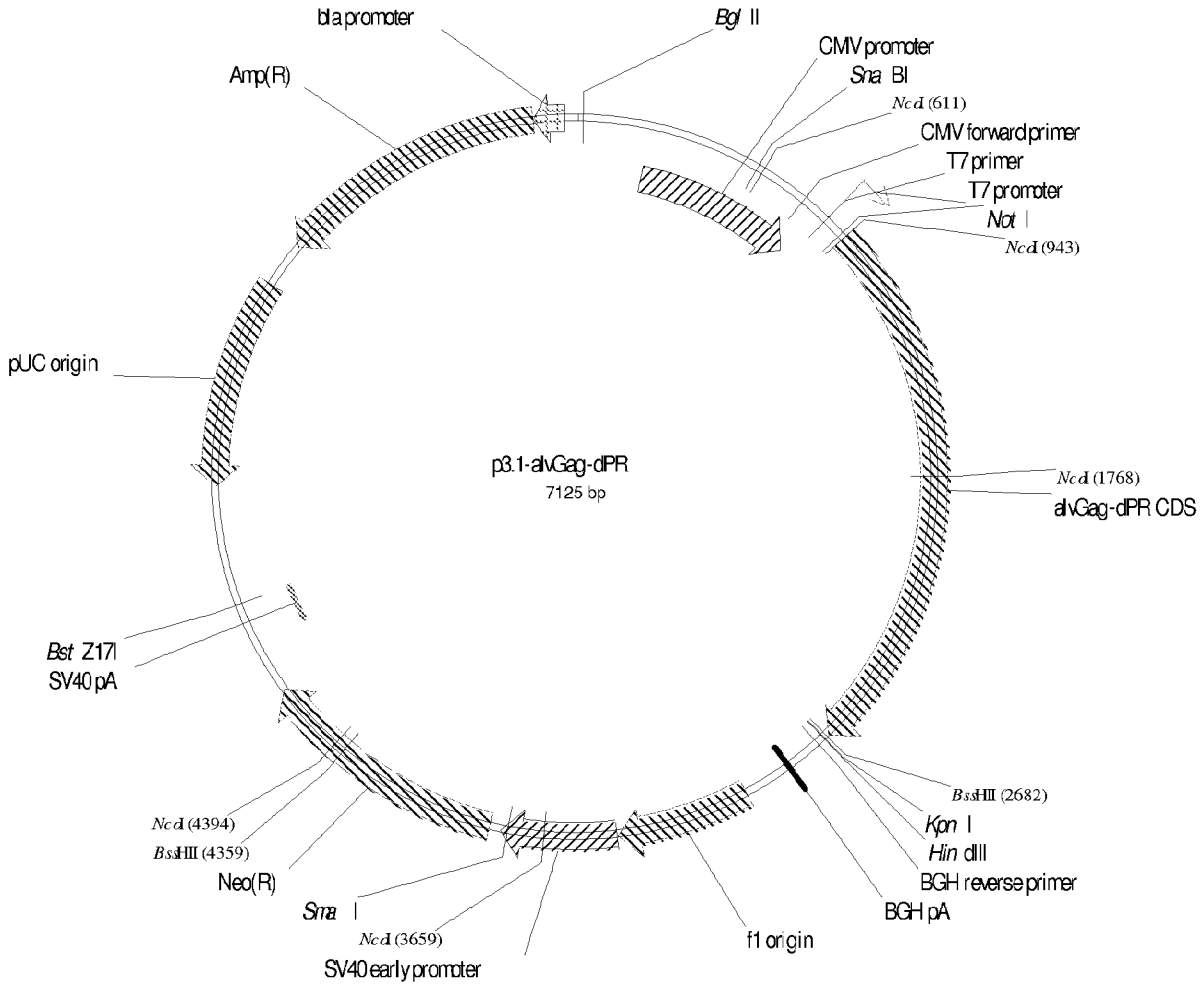

bla promoter
Bgl II
CMV promoter
Sna BI
Amp(R)
NcoI (611)
CMV forward primer
T7 primer
T7 promoter
Not I
NcoI (943)
pUC origin
p3.1-alvGag-dPR
7125 bp
NcoI (1768)
alvGag-dPR CDS
Bst Z17I
SV40 pA
BssHII (2682)
KpnI
HindIII
BGH reverse primer
BGH pA
NcoI (4394)
BssHII (4359)
Neo(R)
SmaI
NcoI (3659)
SV40 early promoter
f1 origin

Figure 18.

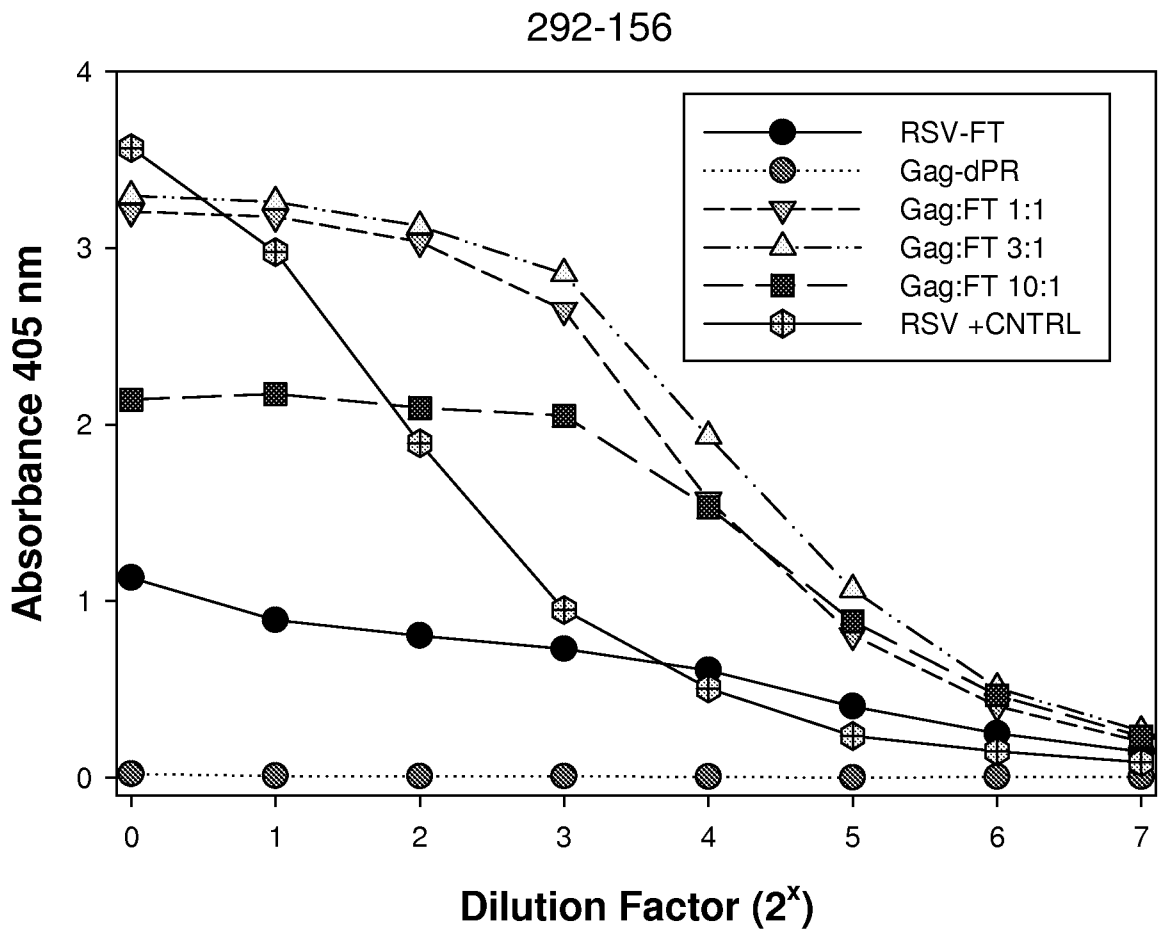

292-156
Absorbance 405 nm
Dilution Factor (2x)
RSV-FT
Gag-dPR
Gag:FT 1:1
Gag:FT 3:1
Gag:FT 10:1
RSV +CNTRL
0
1
2
3
4
5
6
7

Figure 19.

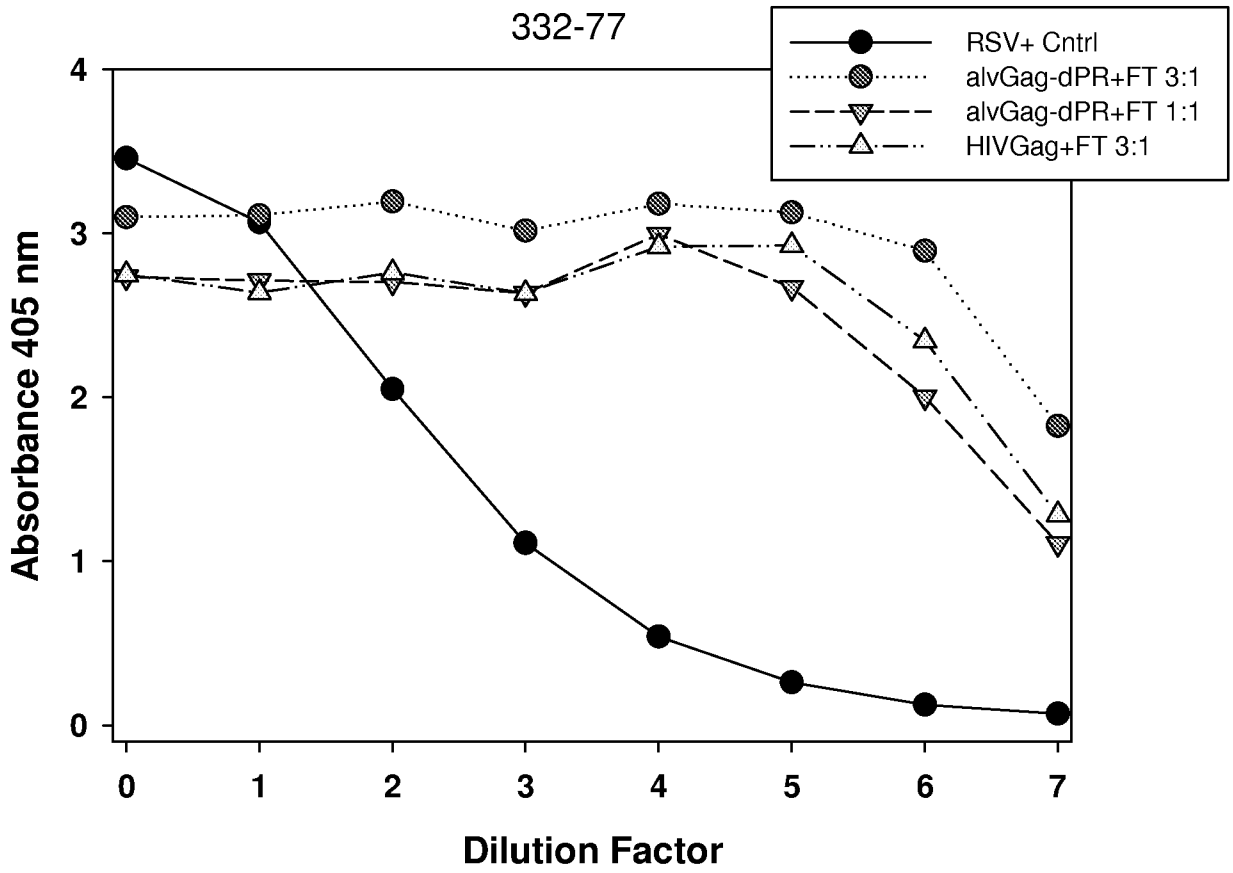

332-77
RSV+ Cntrl
alvGag-dPR+FT 3:1
alvGag-dPR+FT 1:1
HIVGag+FT 3:1
Absorbance 405 nm
Dilution Factor
0
1
2
3
4
5
6
7

Figure 20.

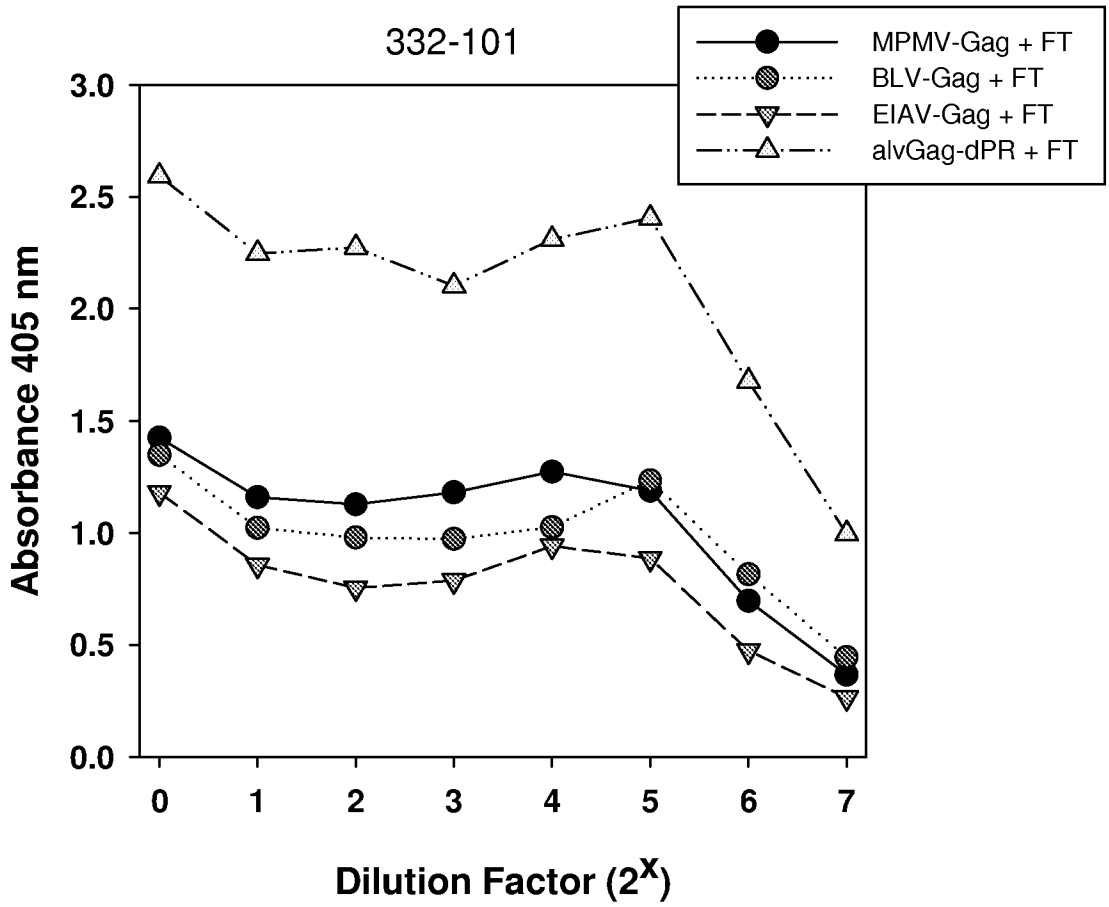

332-101
MPMV-Gag + FT
BLV-Gag + FT
EIAV-Gag + FT
alvGag-dPR + FT
Absorbance 405 nm
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
1
2
3
4
5
6
7
Dilution Factor (2X)

Figure 21.

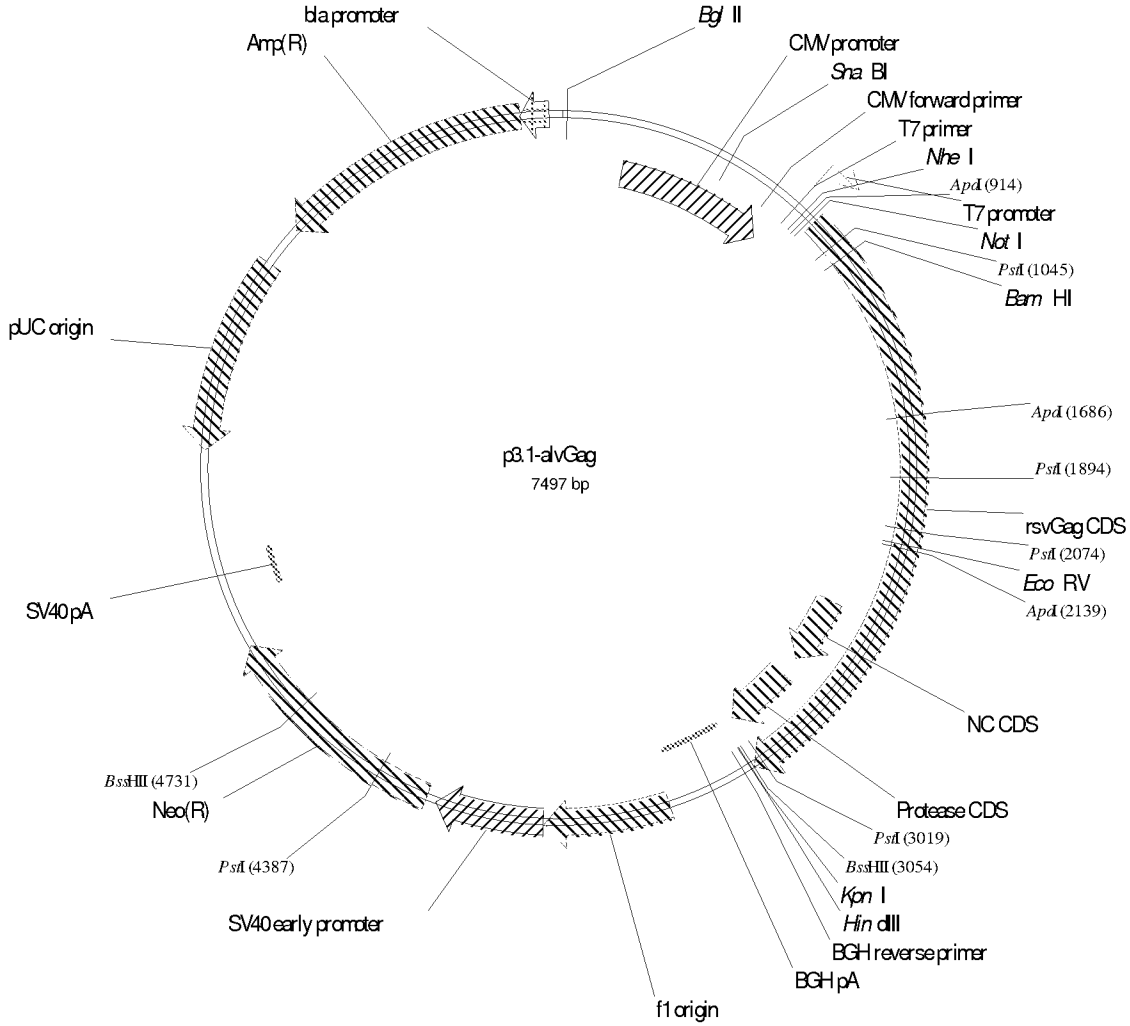

bla promoter
Amp(R)
Bgl II
CMV promoter
Sna BI
CMV forward primer
T7 primer
Nhe I
ApaI (914)
T7 promoter
Not I
PstI (1045)
Bam HI
pUC origin
ApaI (1686)
p3.1-alvGag
7497 bp
PstI (1894)
rsvGag CDS
PstI (2074)
Eco RV
ApaI (2139)
SV40 pA
NC CDS
BssHII (4731)
Neo(R)
Protease CDS
PstI (3019)
PstI (4387)
BssHII (3054)
Kpn I
Hin dIII
SV40 early promoter
BGH reverse primer
BGH pA
f1 origin

Figure 22.

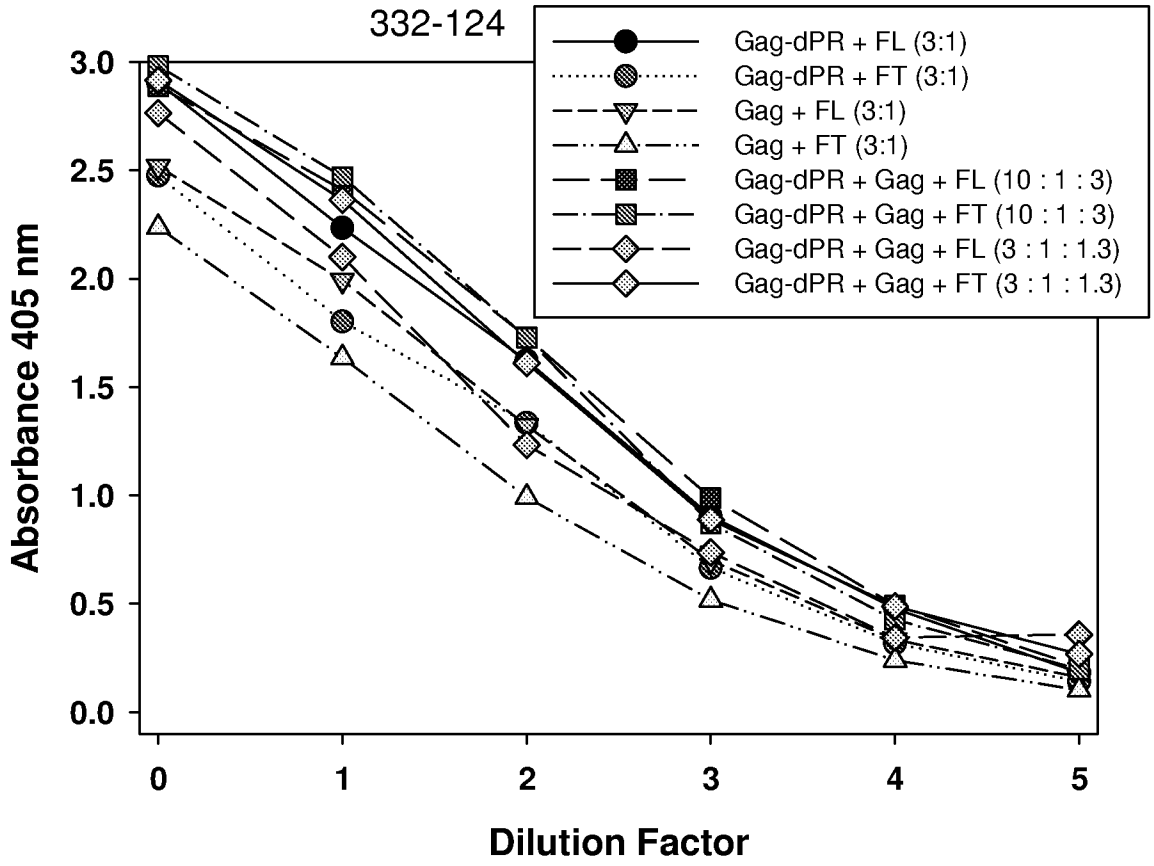

332-124
Gag-dPR + FL (3:1)
Gag-dPR + FT (3:1)
Gag + FL (3:1)
Gag + FT (3:1)
Gag-dPR + Gag + FL (10 : 1 : 3)
Gag-dPR + Gag + FT (10 : 1 : 3)
Gag-dPR + Gag + FL (3 : 1 : 1.3)
Gag-dPR + Gag + FT (3 : 1 : 1.3)
Absorbance 405 nm
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
1
2
3
4
5
Dilution Factor

Figure 23.

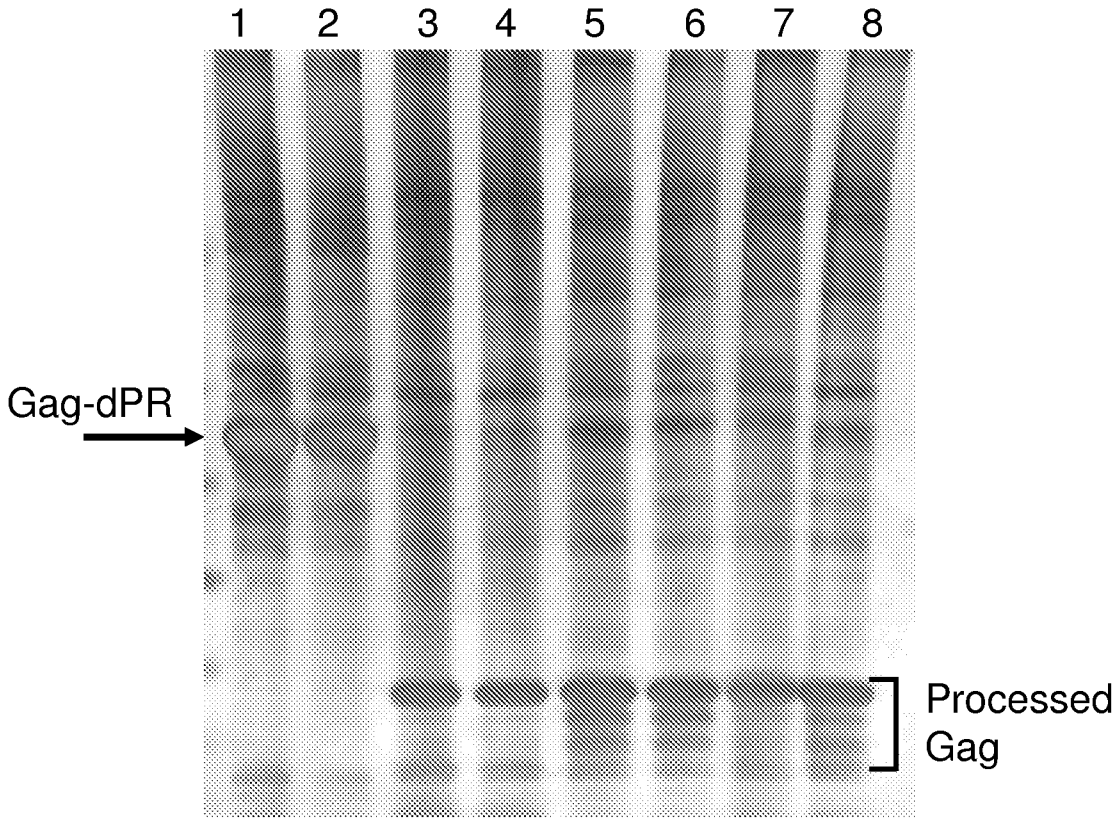


Figure 24.

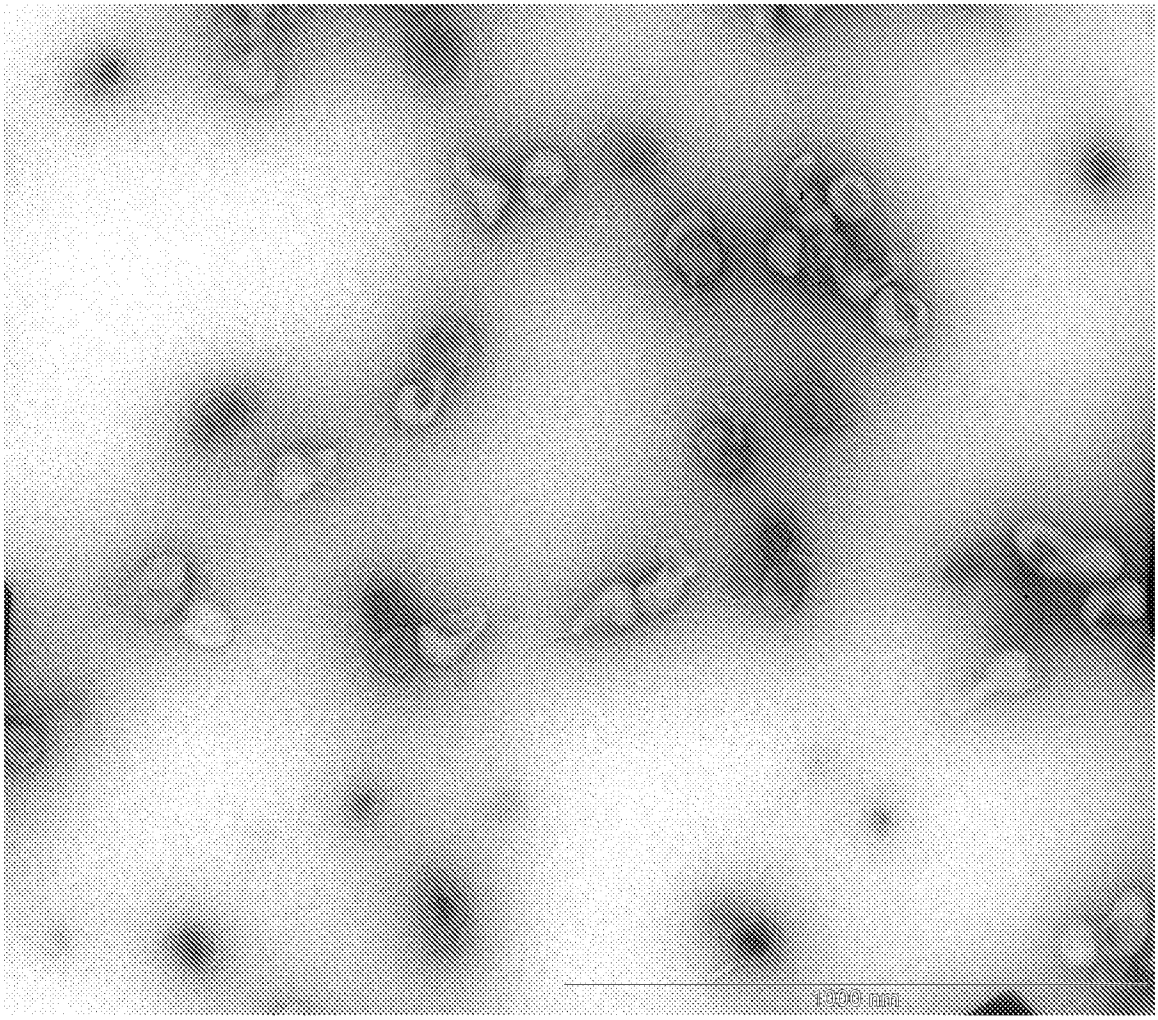


Figure 25.

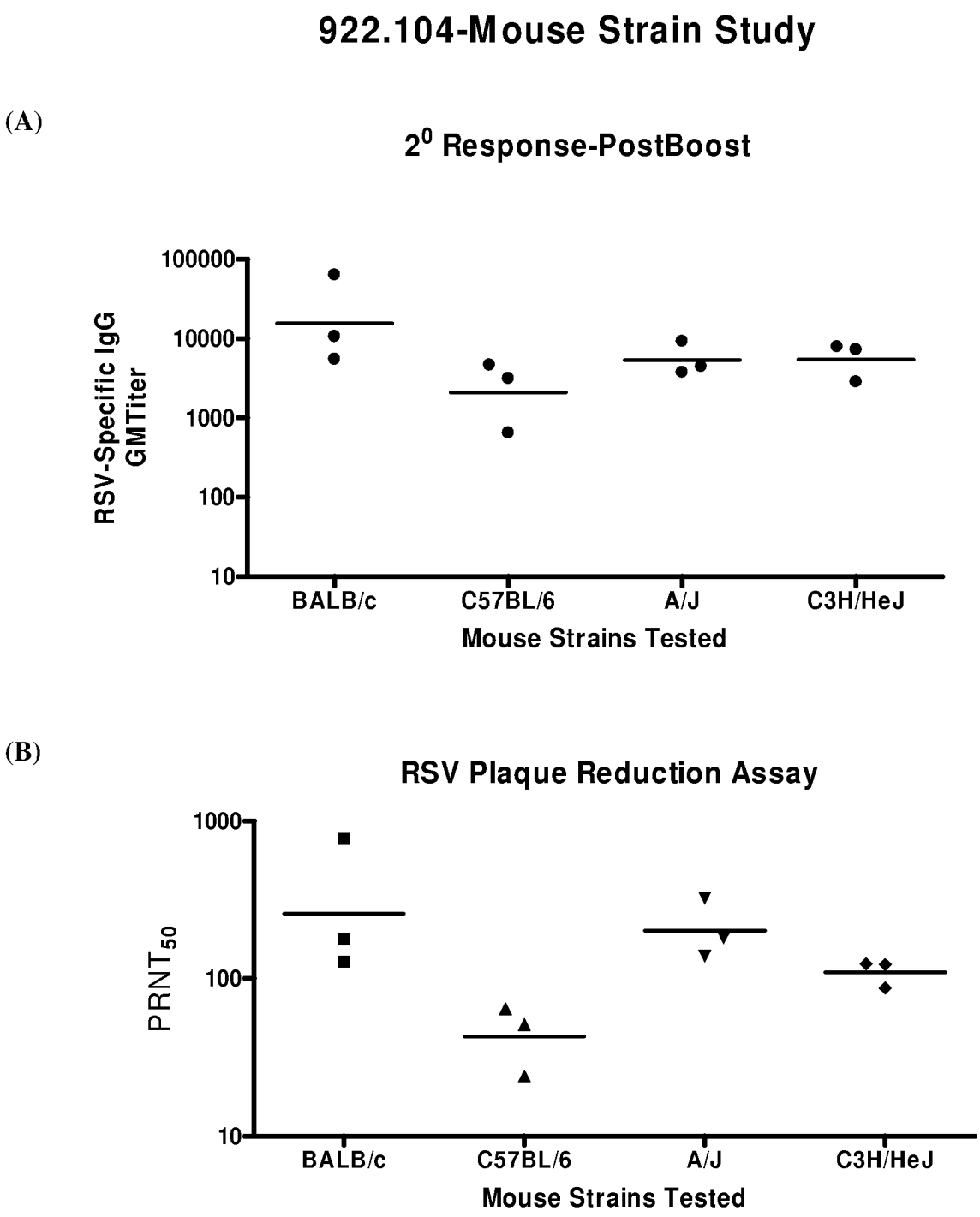

922.104-Mouse Strain Study
(A)
2^0 Response-PostBoost
RSV-Specific IgG GMTiter
100000
10000
1000
100
10
BALB/c
C57BL/6
A/J
C3H/HeJ
Mouse Strains Tested
(B)
RSV Plaque Reduction Assay
PRNT50
1000
100
10
BALB/c
C57BL/6
A/J
C3H/HeJ
Mouse Strains Tested

Figure 26.

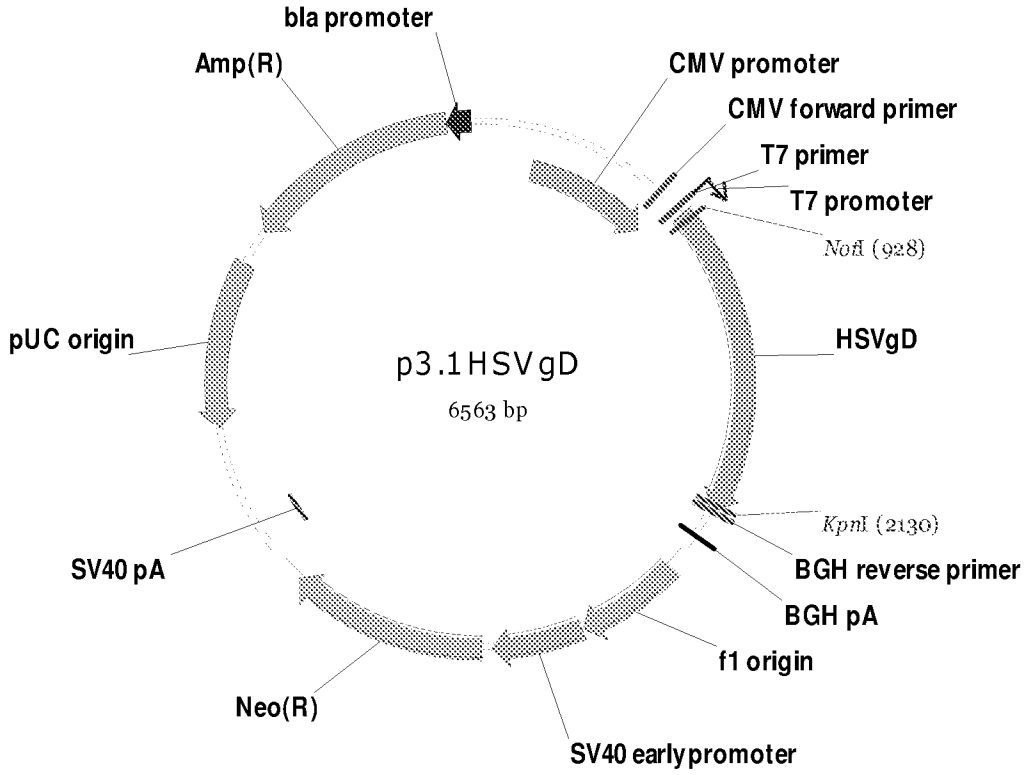

bla promoter
Amp(R)
CMV promoter
CMV forward primer
T7 primer
T7 promoter
NotI (928)
pUC origin
p3.1HSVgD
6563 bp
HSVgD
KpnI (2130)
SV40 pA
BGH reverse primer
BGH pA
f1 origin
Neo(R)
SV40 early promoter

Figure 27.

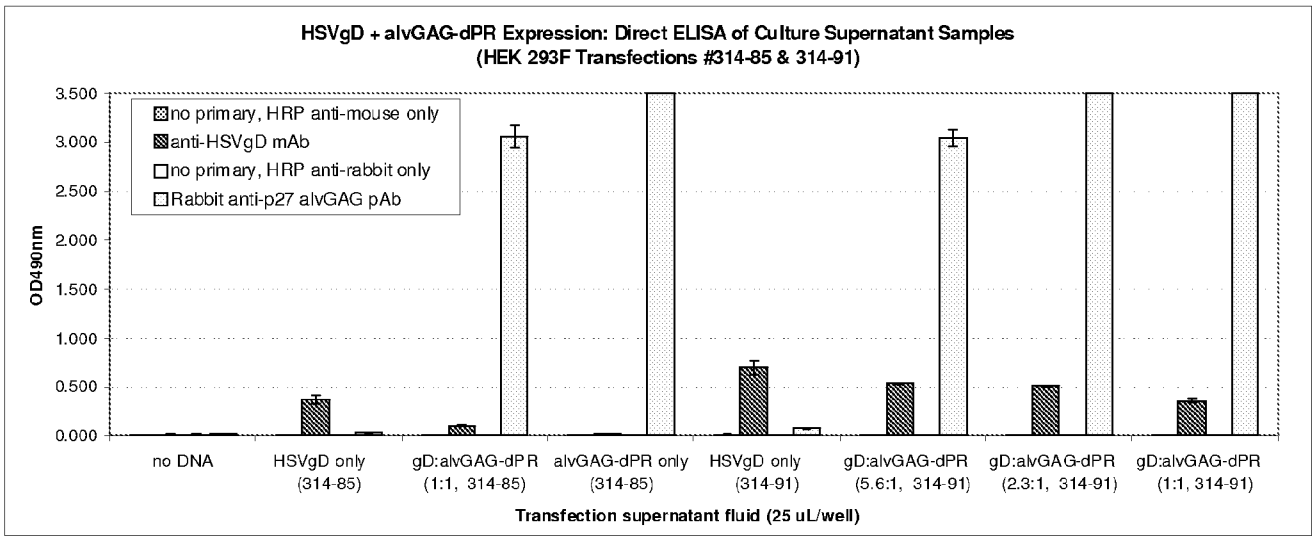
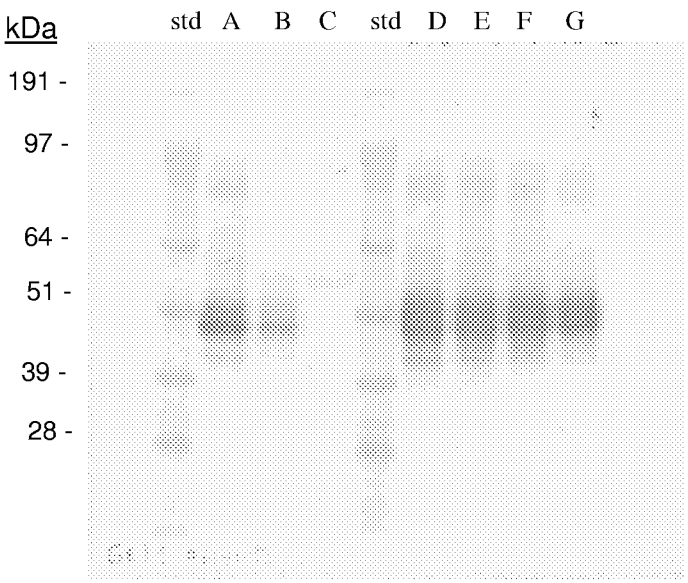

HSVgD + alvGAG-dPR Expression: Direct ELISA of Culture Supernatant Samples
(HEK 293F Transfections #314-85 & 314-91)
OD490nm
3.500
3.000
2.500
2.000
1.500
1.000
0.500
0.000
no primary, HRP anti-mouse only
anti-HSVgD mAb
no primary, HRP anti-rabbit only
Rabbit anti-p27 alvGAG pAb
no DNA
HSVgD only (314-85)
gD:alvGAG-dPR (1:1, 314-85)
alvGAG-dPR only (314-85)
HSVgD only (314-91)
gD:alvGAG-dPR (5.6:1, 314-91)
gD:alvGAG-dPR (2.3:1, 314-91)
gD:alvGAG-dPR (1:1, 314-91)
Transfection supernatant fluid (25 uL/well)

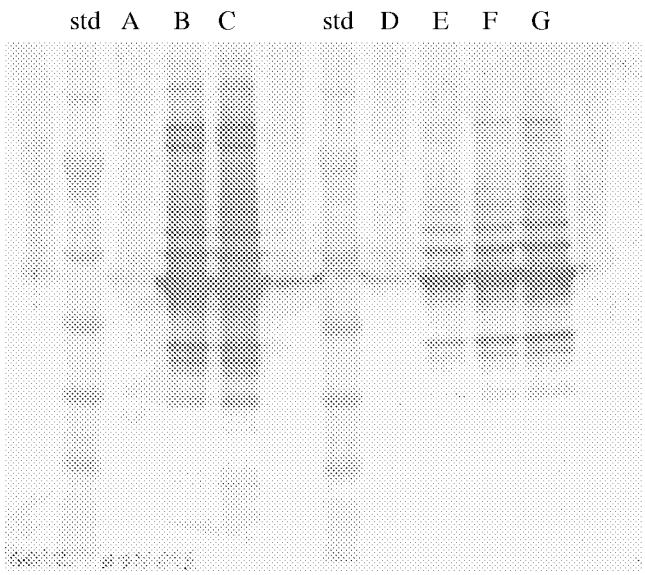
Figure 28.

(A)



1°: α-HSVgD mAb
2°: HRP Goat anti-mouse Igs

(B)



1°: Rabbit α–p27 alvGAG pAb
2°: HRP Goat anti-rabbit IgG

Figure 29.

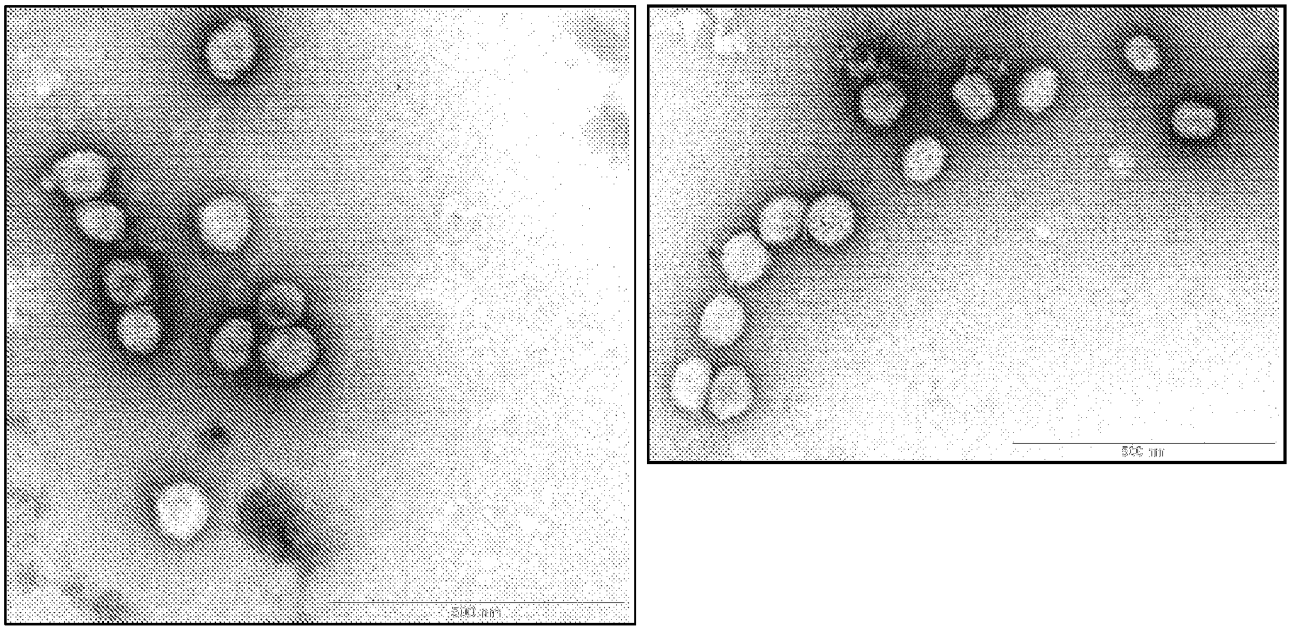
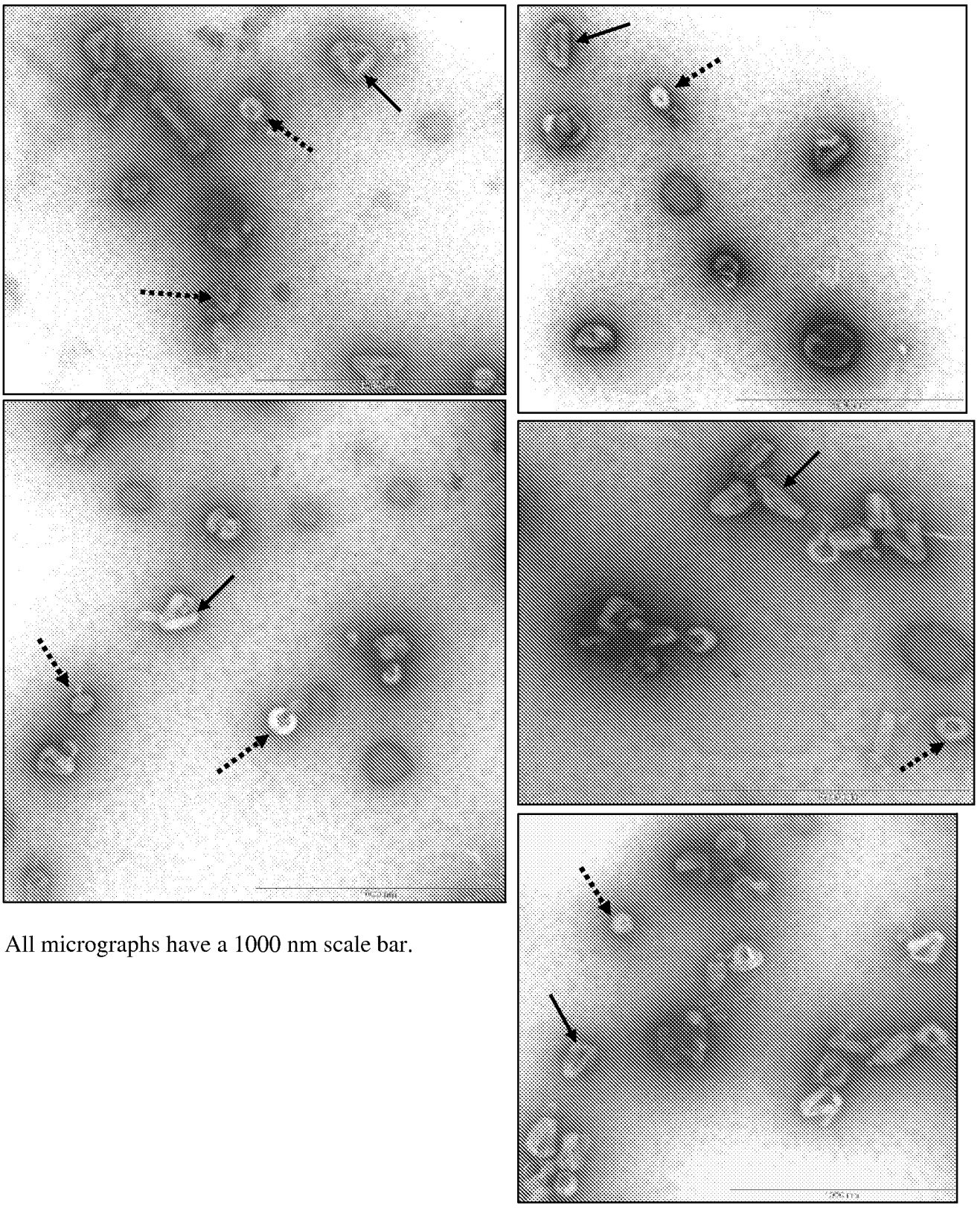


Figure 30.



All micrographs have a 1000 nm scale bar.

Figure 31.

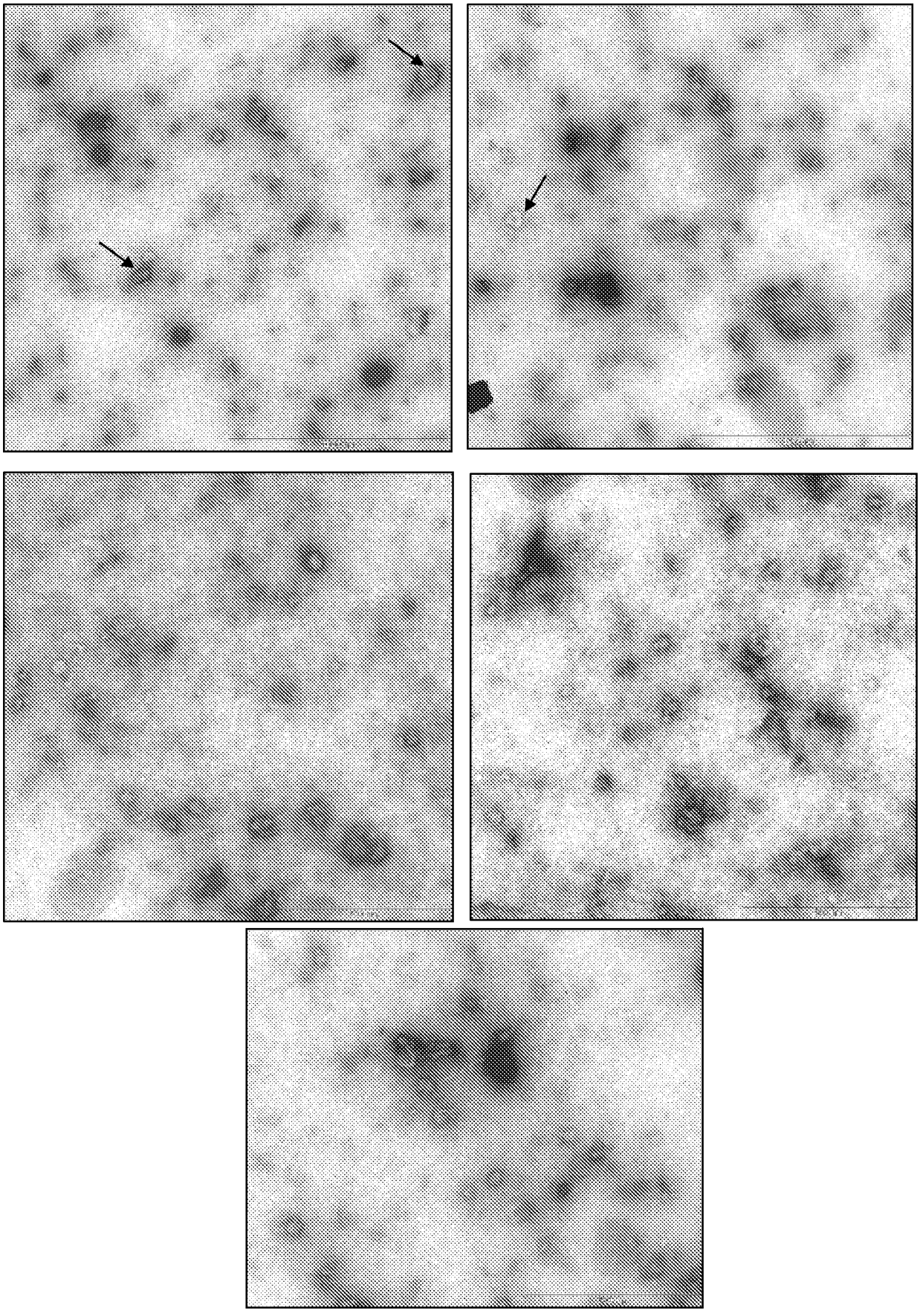


Figure 32.

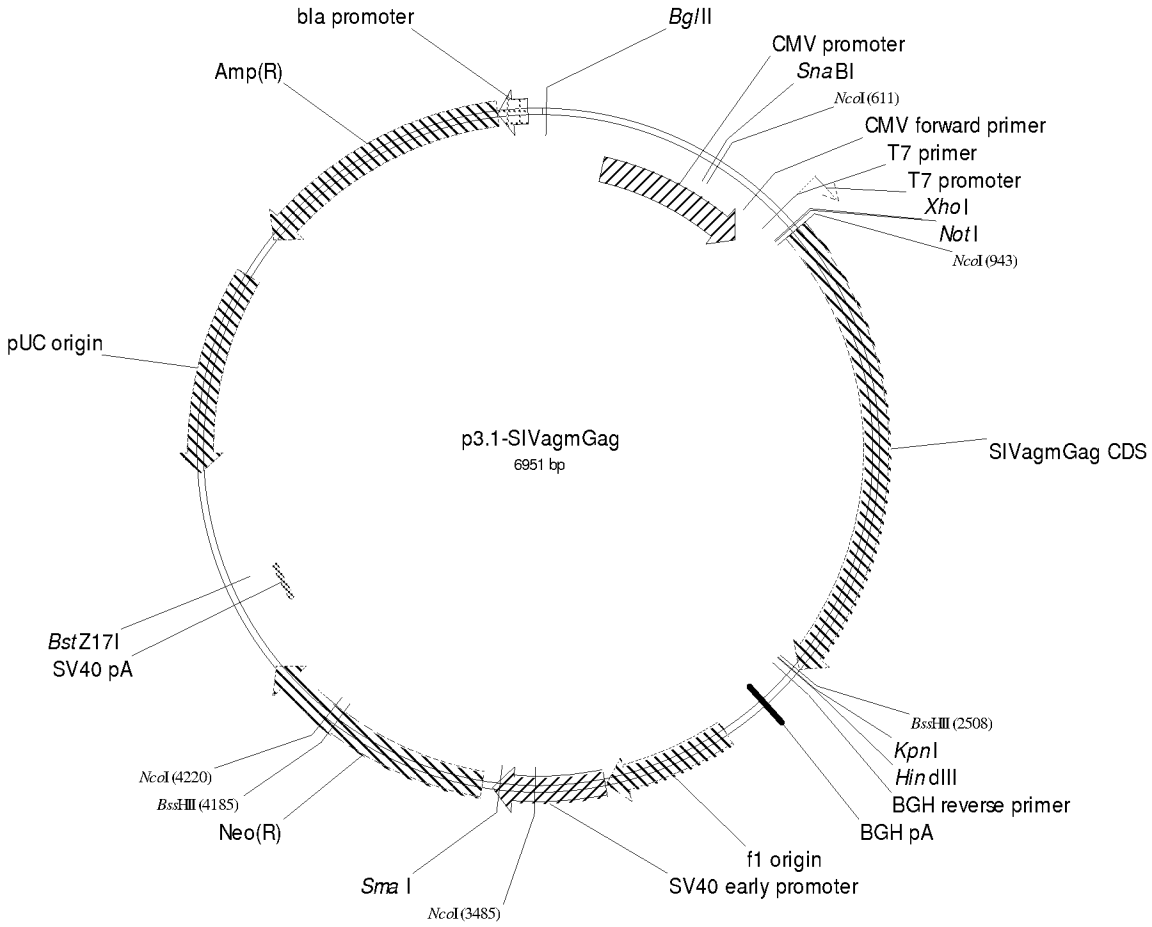

bla promoter
BglII
CMV promoter
SnaBI
NcoI (611)
CMV forward primer
T7 primer
T7 promoter
XhoI
NotI
NcoI (943)
Amp(R)
pUC origin
p3.1-SIVagmGag
6951 bp
SIVagmGag CDS
BstZ17I
SV40 pA
BssHII (2508)
KpnI
HindIII
BGH reverse primer
BGH pA
NcoI (4220)
BssHII (4185)
Neo(R)
f1 origin
SV40 early promoter
SmaI
NcoI (3485)

Figure 33.

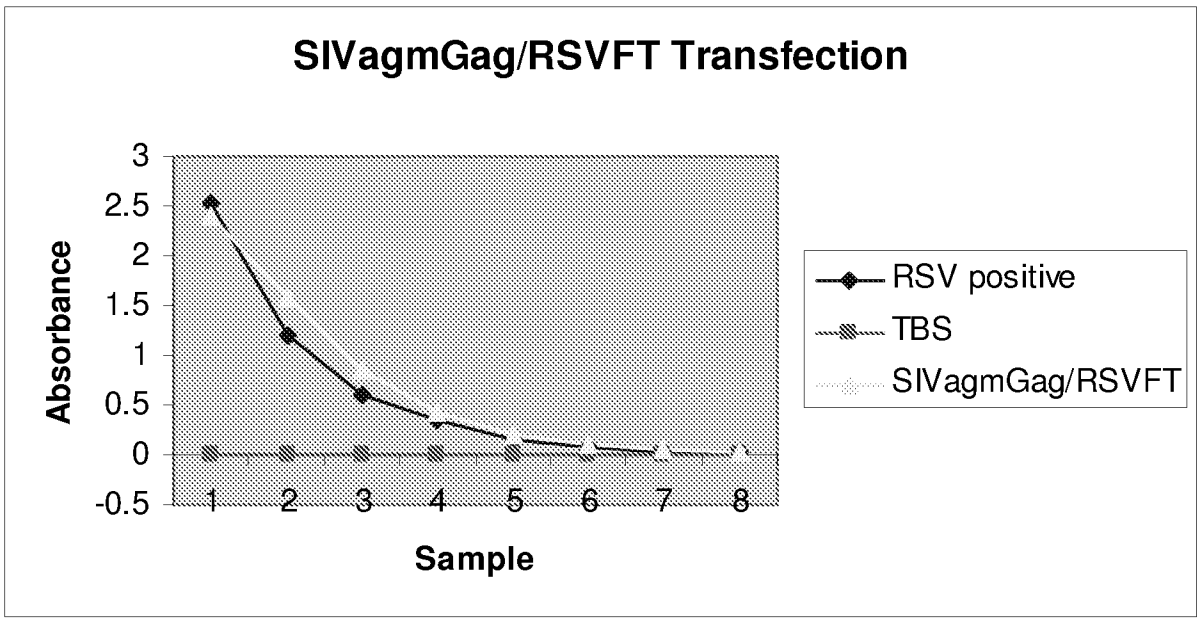

SIVagmGag/RSVFT Transfection
Absorbance
3
2.5
2
1.5
1
0.5
0
-0.5
1
2
3
4
5
6
7
8
Sample
RSV positive
TBS
SIVagmGag/RSVFT

Figure 34.

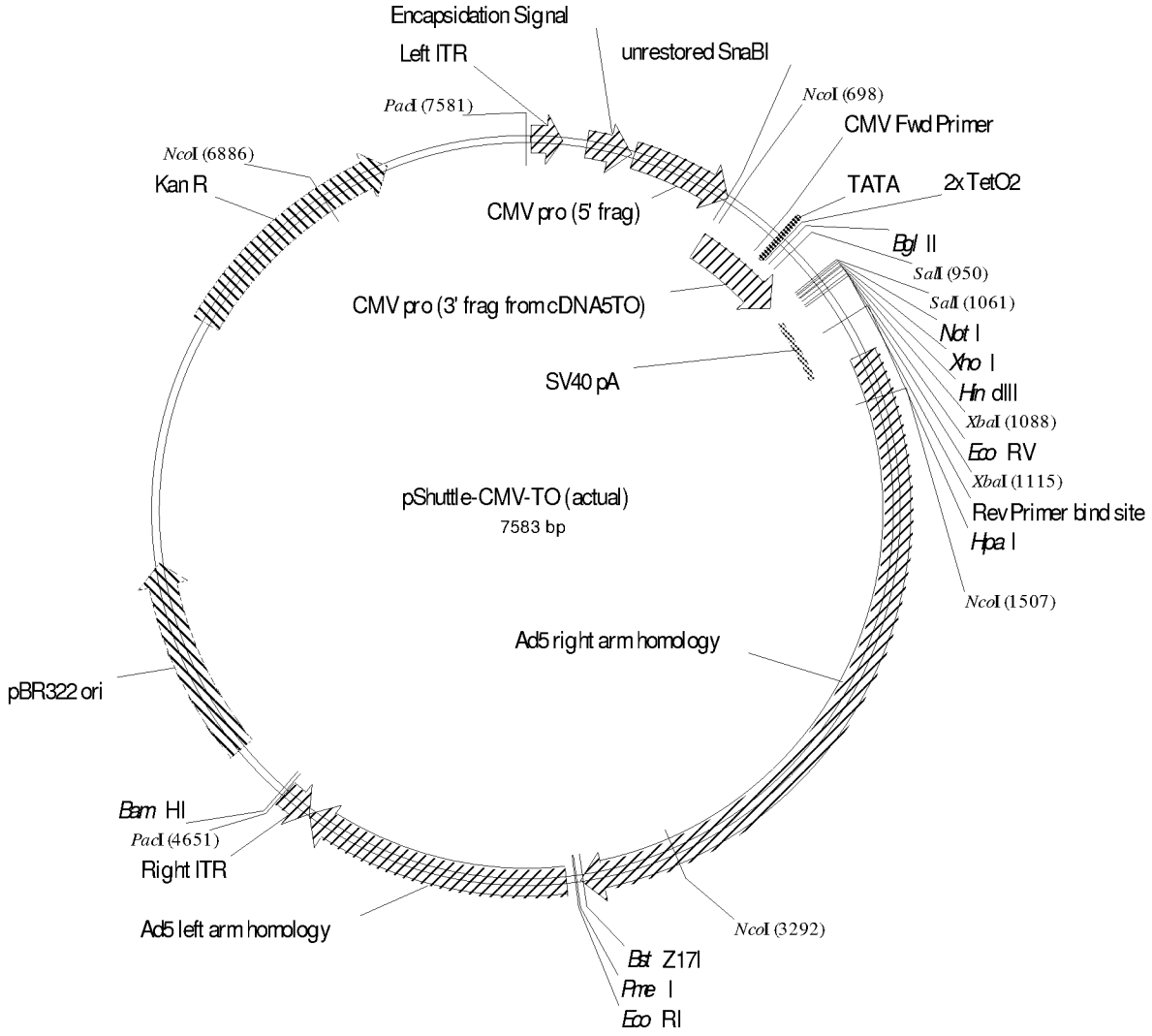

Encapsidation Signal
Left ITR
unrestored SnaBI
NcoI (698)
CMV Fwd Primer
PacI (7581)
NcoI (6886)
Kan R
TATA
2x TetO2
CMV pro (5' frag)
BglII
SalI (950)
CMV pro (3' frag from cDNA5TO)
SalI (1061)
NotI
XhoI
HindIII
XbaI (1088)
SV40 pA
EcoRV
XbaI (1115)
pShuttle-CMV-TO (actual)
7583 bp
Rev Primer bind site
HpaI
NcoI (1507)
Ad5 right arm homology
pBR322 ori
BamHI
PacI (4651)
Right ITR
Ad5 left arm homology
NcoI (3292)
BstZ17I
PmeI
EcoRI

Figure 35.

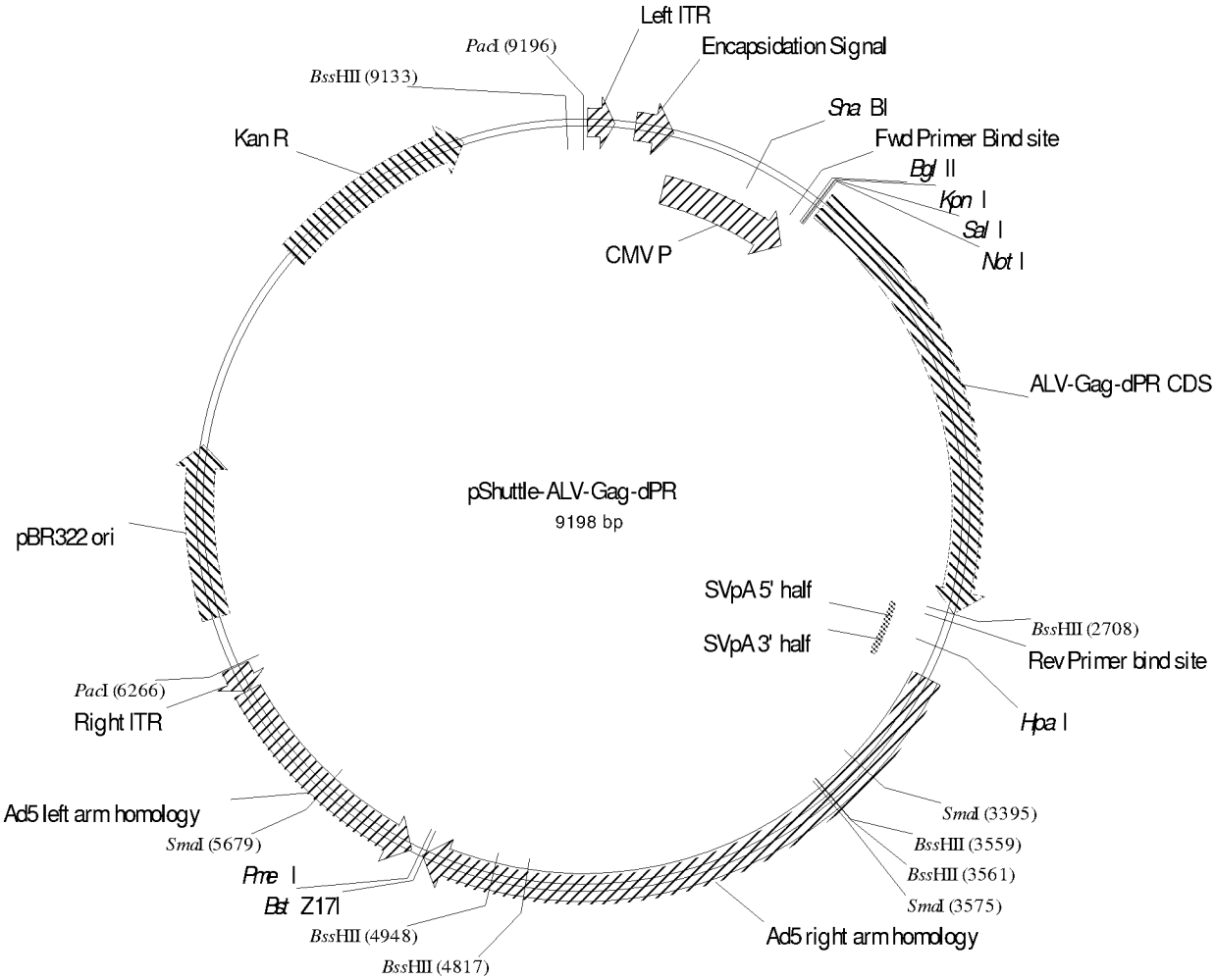

Left ITR
PacI (9196)
Encapsidation Signal
BssHII (9133)
Sna BI
Kan R
Fwd Primer Bind site
BglII
KpnI
SalI
NotI
CMV P
ALV-Gag-dPR CDS
pShuttle-ALV-Gag-dPR
9198 bp
pBR322 ori
SVpA 5' half
SVpA 3' half
BssHII (2708)
Rev Primer bind site
PacI (6266)
Right ITR
HpaI
Ad5 left arm homology
SmaI (3395)
SmaI (5679)
BssHII (3559)
PmeI
BssHII (3561)
Bst Z17I
SmaI (3575)
BssHII (4948)
Ad5 right arm homology
BssHII (4817)

Figure 36.

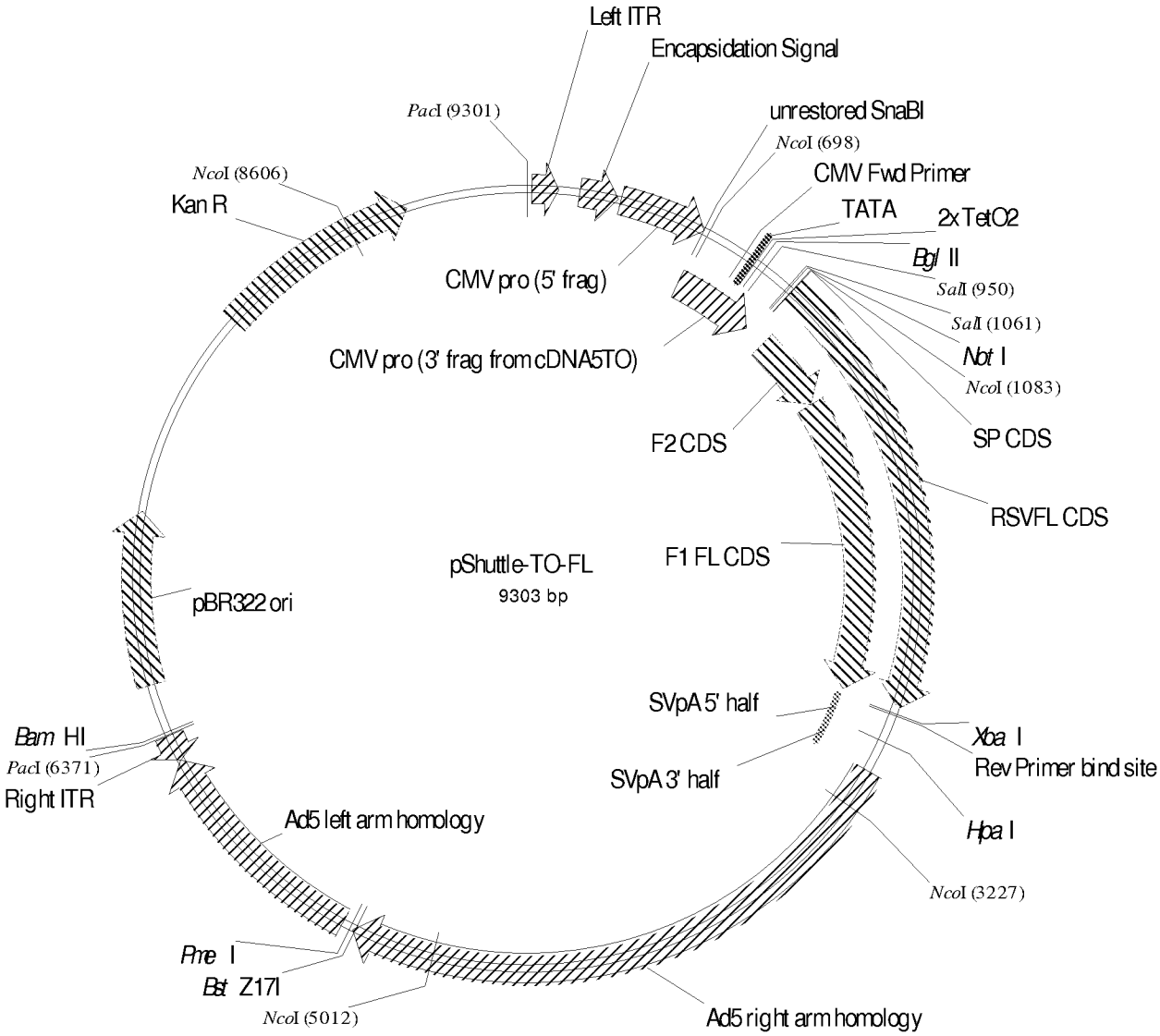

Left ITR
Encapsidation Signal
PacI (9301)
unrestored SnaBI
NcoI (698)
NcoI (8606)
CMV Fwd Primer
Kan R
TATA
2x TetO2
BglII
CMV pro (5' frag)
SalI (950)
SalI (1061)
CMV pro (3' frag from cDNA5TO)
NotI
NcoI (1083)
F2 CDS
SP CDS
RSVFL CDS
pShuttle-TO-FL
9303 bp
F1 FL CDS
pBR322 ori
SVpA 5' half
XbaI
Rev Primer bind site
SVpA 3' half
BamHI
PacI (6371)
Right ITR
Ad5 left arm homology
HpaI
NcoI (3227)
PmeI
BstZ17I
NcoI (5012)
Ad5 right arm homology

Figure 37.

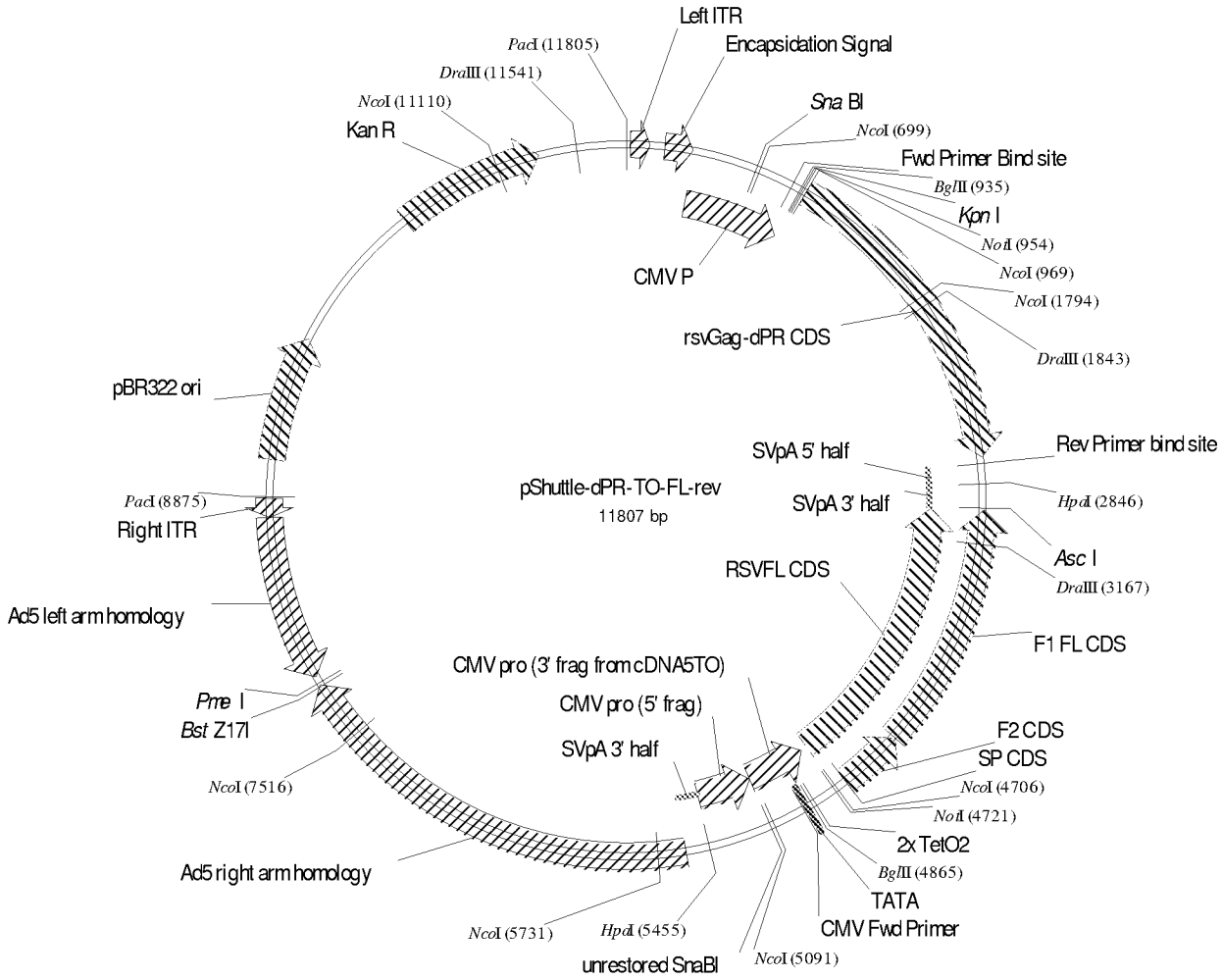

Left ITR
Encapsidation Signal
PacI (11805)
DraIII (11541)
NcoI (11110)
Kan R
Sna BI
NcoI (699)
Fwd Primer Bind site
BglII (935)
Kpn I
NotI (954)
NcoI (969)
NcoI (1794)
DraIII (1843)
CMV P
rsvGag-dPR CDS
pBR322 ori
SVpA 5' half
Rev Primer bind site
pShuttle-dPR-TO-FL-rev
11807 bp
SVpA 3' half
HpaI (2846)
PacI (8875)
Right ITR
Asc I
DraIII (3167)
RSVFL CDS
Ad5 left arm homology
F1 FL CDS
CMV pro (3' frag from cDNA5TO)
Pme I
CMV pro (5' frag)
Bst Z17I
F2 CDS
SVpA 3' half
SP CDS
NcoI (4706)
NcoI (7516)
NotI (4721)
2x TetO2
BglII (4865)
Ad5 right arm homology
TATA
NcoI (5731)
HpaI (5455)
CMV Fwd Primer
NcoI (5091)
unrestored SnaBI

Figure 38 (a)

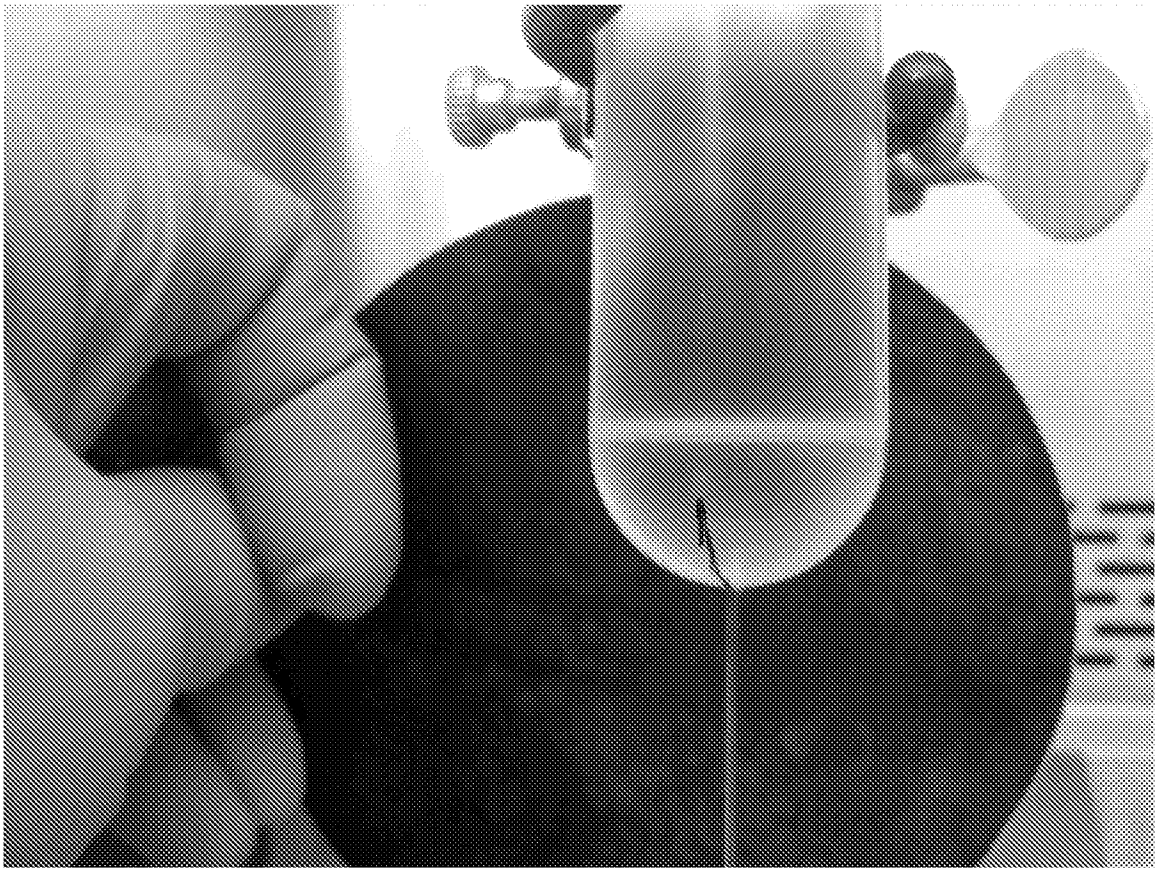


Figure 38 (b)

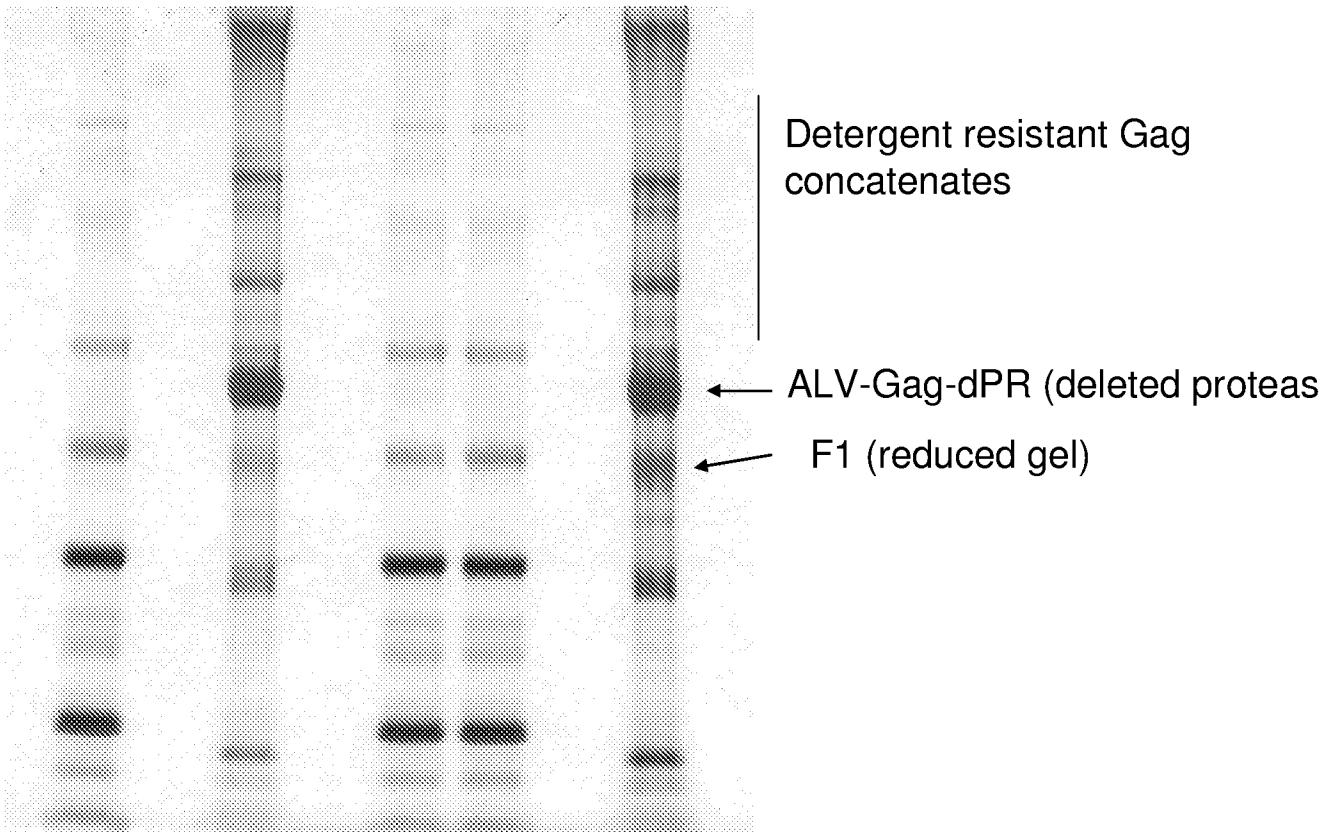

Detergent resistant Gag concatenates
ALV-Gag-dPR (deleted proteas
F1 (reduced gel)

Figure 39

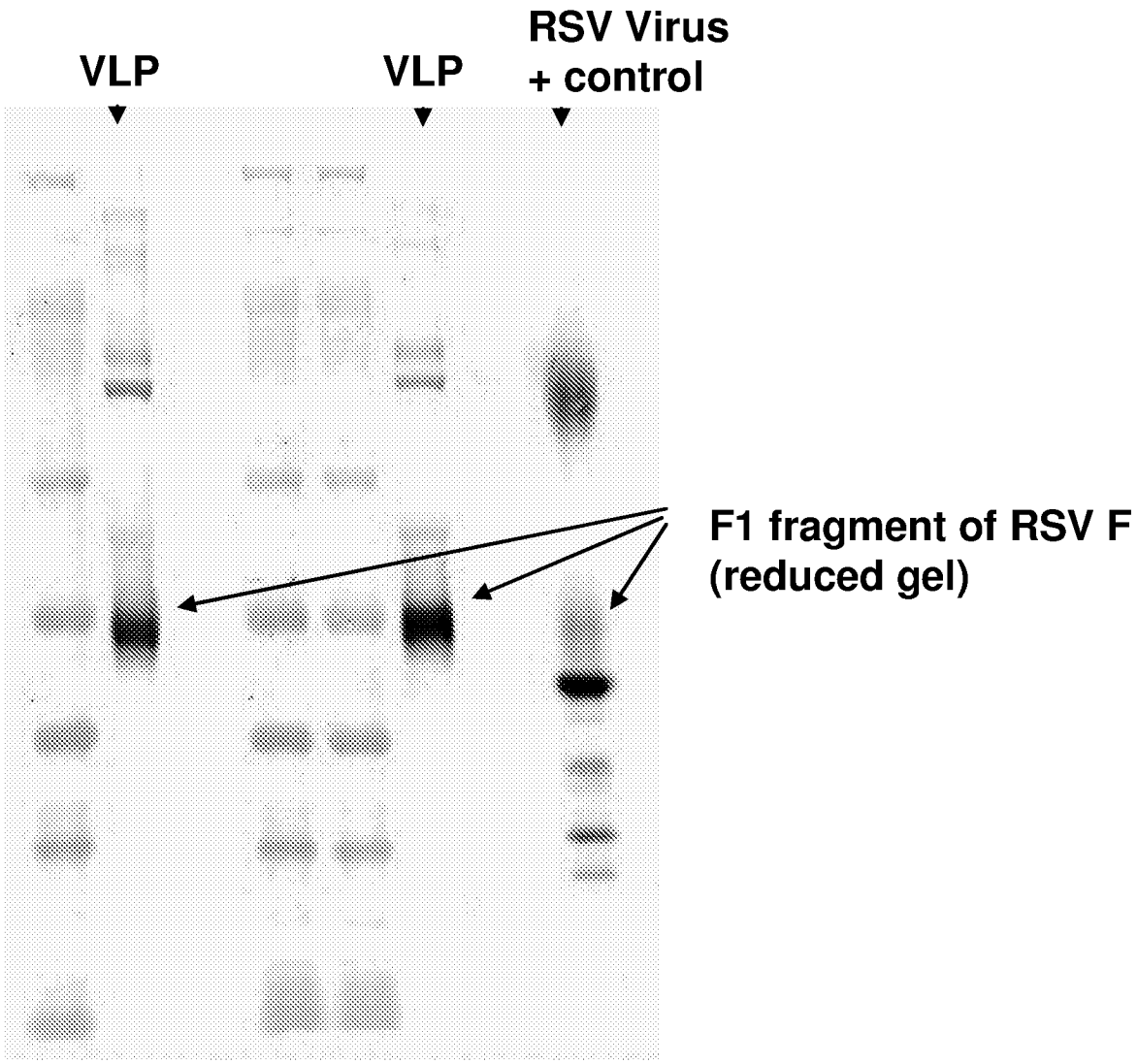


Figure 40

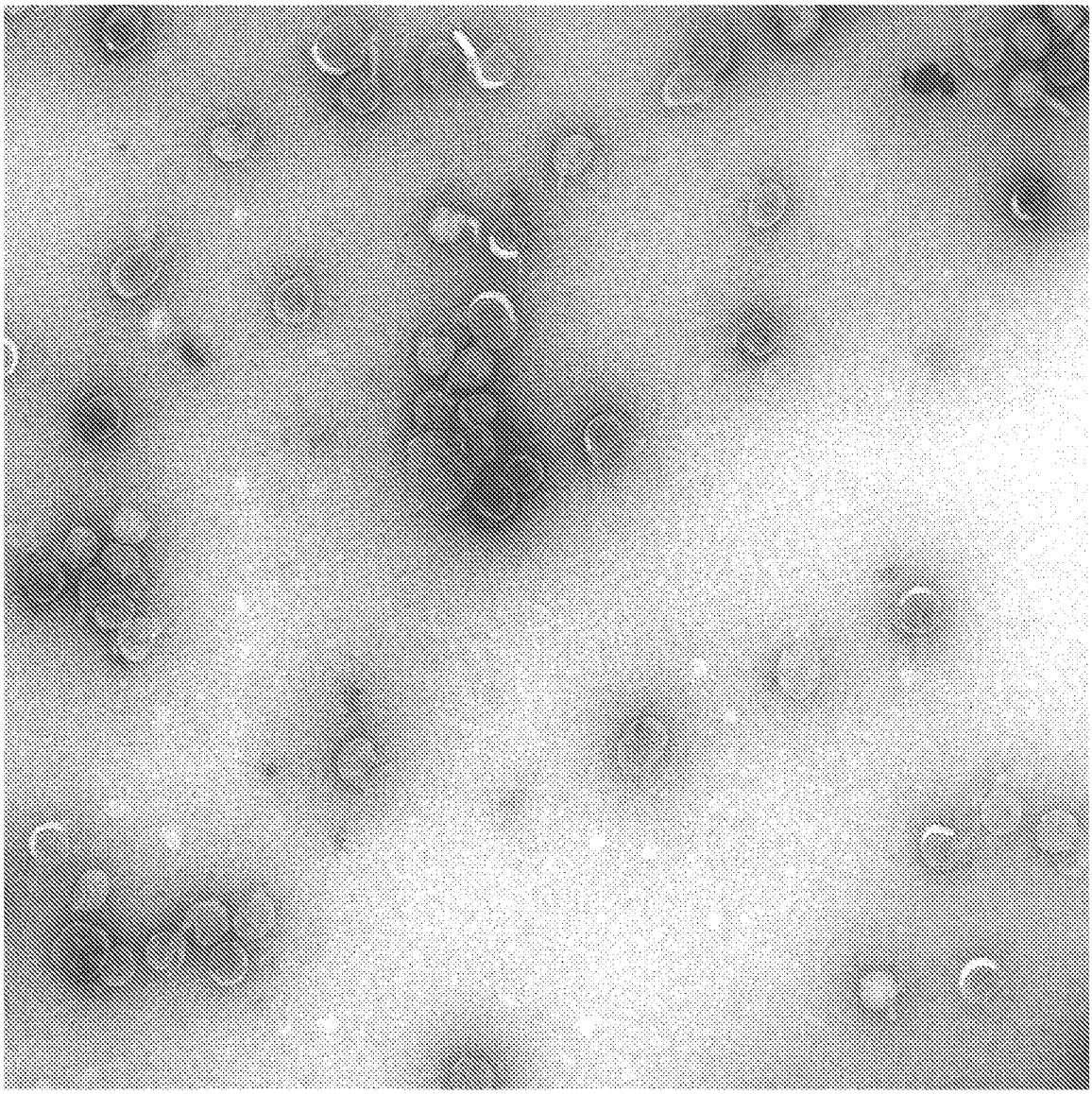


Figure 41

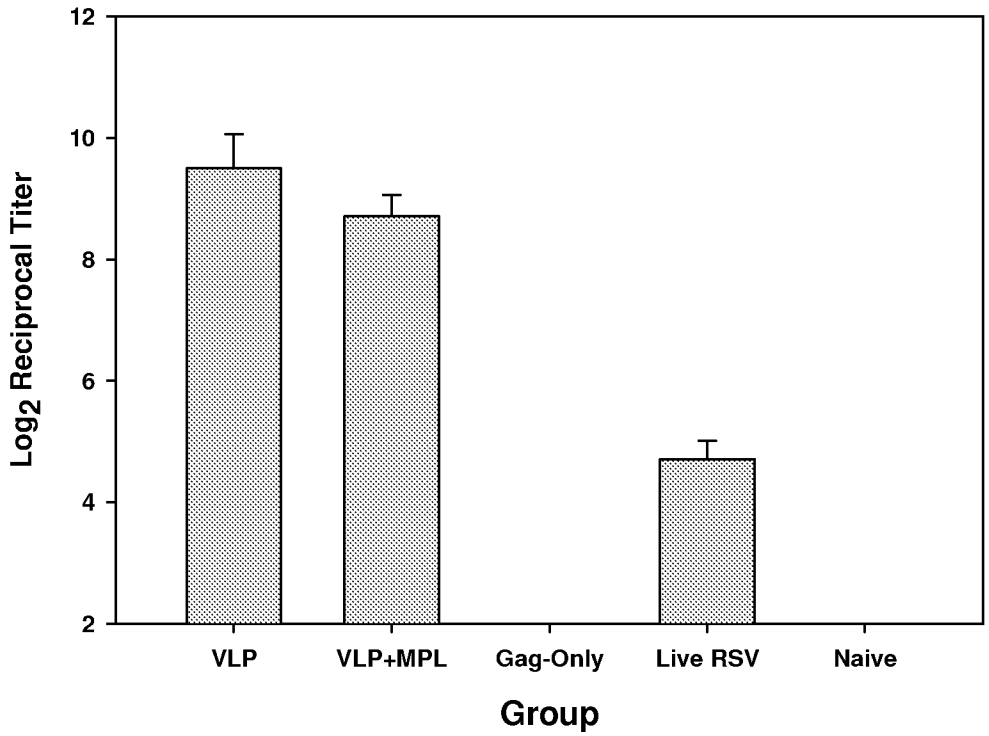

12
10
8
6
4
2
Log2 Reciprocal Titer
VLP
VLP+MPL
Gag-Only
Live RSV
Naive
Group

Figure 42

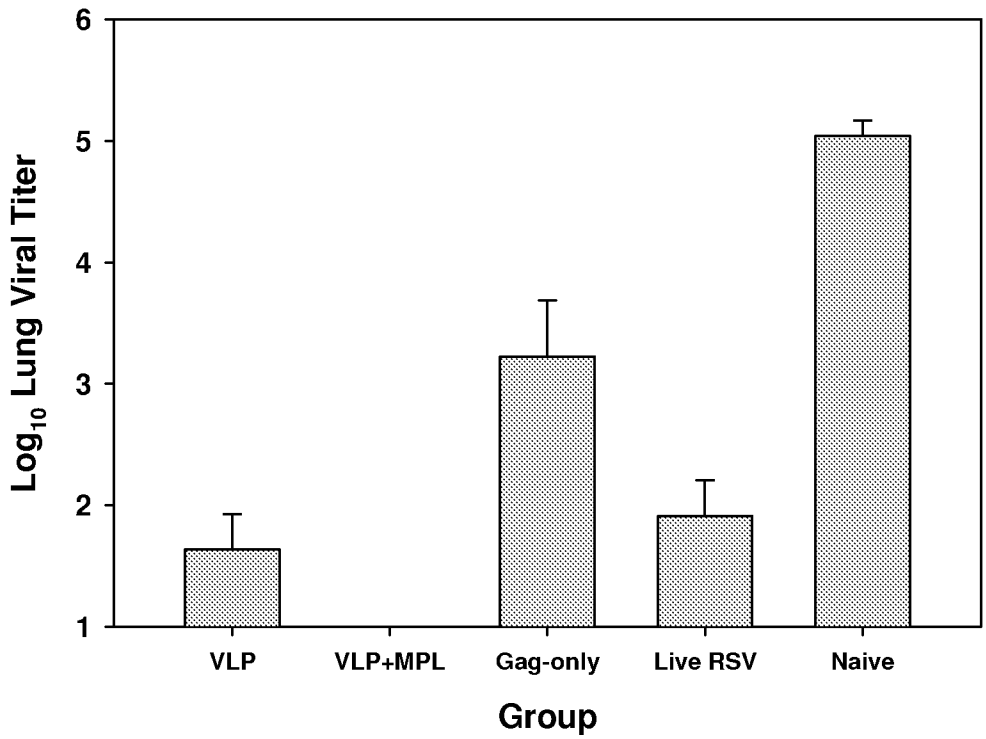
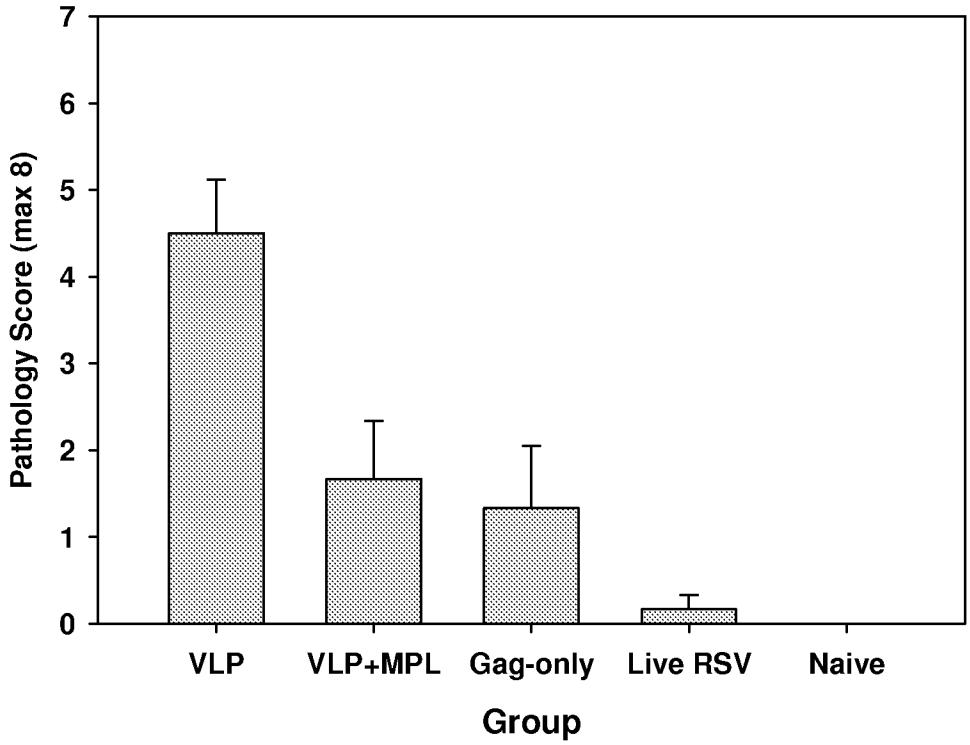

6
5
4
3
2
1
Log10 Lung Viral Titer
VLP
VLP+MPL
Gag-only
Live RSV
Naive
Group

Figure 43


Pathology Score (max 8)
0
1
2
3
4
5
6
7
VLP
VLP+MPL
Gag-only
Live RSV
Naive
Group