TITLE OF THE INVENTION

A CONDITIONAL REPLICATING CYTOMEGALOVIRUS AS A VACCINE FOR CMV

FIELD OF INVENTION

The present invention relates to methods of inducing an immune response to cytomegalovirus (CMV) using a genetically modified CMV that is conditionally replication defective. The present invention also relates to a CMV which has been recombinantly altered to allow for external control of viral replication. Compositions comprising the replication defective CMV are also encompassed by the present invention.

BACKGROUND OF THE INVENTION

Cytomegalovirus (CMV), also known as human herpesvirus 5 (HHV-5), is a herpes virus classified as being a member of the beta subfamily of herpesviridae. According to the Centers for Disease Control and Prevention, CMV infection is found fairly ubiquitously in the human population, with an estimated 40-80% of the United States adult population having been infected. The virus is spread primarily through bodily fluids and is frequently passed from pregnant mothers to the fetus or newborn. In most individuals, CMV infection is latent, although virus activation can result in high fever, chills, fatigue, headaches, nausea, and splenomegaly.

Although most human CMV infections are asymptomatic, CMV infections in immunocompromised individuals, (such as HIV-positive patients, allogeneic transplant patients and cancer patients) or persons whose immune system has yet fully developed (such as newborns) can be particularly problematic (Mocarski et al., Cytomegalovirus, in Field Virology, 2701-2772, Editor: Knipes and Howley, 2007). CMV infection in such individuals can cause severe morbidity, including pneumonia, hepatitis, encephalitis, colitis, uveitis, retinitis, blindness, and neuropathy, among other deleterious conditions. In addition, CMV infection during pregnancy is a leading cause of birth defects (Adler, 2008 J. Clin Virol, 41:231; Arvin et al, 2004 Clin Infect Dis, 39:233; Revello et al, 2008 J Med Virol, 80:1415). CMV infects various cells *in vivo*, including monocytes, macrophages, dendritic cells, neutrophils, endothelial cells, epithelial cells, fibroblasts, neurons, smooth muscle cells, hepatocytes, and stromal cells (Plachter et al. 1996, Adv. Virus Res. 46:195). Although clinical CMV isolates replicate in a

variety of cell types, laboratory strains AD169 (Elek & Stern, 1974, Lancet 1:1) and Towne (Plotkin et al., 1975, Infect. Immun. 12:521) replicate almost exclusively in fibroblasts (Hahn et al., 2004, J. Virol. 78:10023). The restriction in tropism, which results from serial passages and eventual adaptation of the virus in fibroblasts, is stipulated a marker of attenuation (Gerna et al., 2005, J. Gen. Virol. 86:275; Gerna et al, 2002, J. Gen Virol. 83:1993; Gerna et al, 2003, J. Gen Virol. 84:1431; Dargan et al, 2010, J. Gen Virol. 91:1535). Mutations causing the loss of epithelial cell, endothelial cell, leukocyte, and dendritic cell tropism in human CMV laboratory strains have been mapped to three open reading frames (ORFs): UL128, UL130, and UL131 (Hahn et al., 2004, J. Virol. 78:10023; Wang and Shenk, 2005 J. Virol. 79:10330; Wang and Shenk, 2005 Proc Natl Acad Sci USA. 102:18153). Biochemical and reconstitution studies show that UL128, UL130 and UL131 assemble onto a gH/gL scaffold to form a pentameric gH complex (Wang and Shenk, 2005 Proc Natl Acad Sci USA. 102:1815; Ryckman et al, 2008 J. Virol. 82:60). Restoration of this complex in virions restores the viral epithelial tropism in the laboratory strains (Wang and Shenk, 2005 J. Virol. 79:10330).

Loss of endothelial and epithelial tropism has been suspected as a deficiency in the previously evaluated as vaccines such as Towne (Gerna et al, 2002, J. Gen Virol. 83:1993; Gerna et al, 2003, J. Gen Virol. 84:1431). Neutralizing antibodies in sera from human subjects of natural CMV infection have more than 15-fold higher activity against viral epithelial entry than against fibroblast entry (Cui et al, 2008 Vaccine 26:5760). Humans with primary infection rapidly develop neutralizing antibodies to viral endothelial and epithelial entry but only slowly develop neutralizing antibodies to viral fibroblast entry (Gerna et al, 2008 J. Gen. Virol. 89:853). Furthermore, neutralizing activity against viral epithelial and endothelial entry is absent in the immune sera from human subjects who received Towne vaccine (Cui et al, 2008 Vaccine 26:5760). More recently, a panel of human monoclonal antibodies from four donors with HCMV infection was described, and the more potent neutralizing clones from the panel recognized the antigens of the pentameric gH complex (Macagno et al, 2010 J. Virol. 84:1005).

SUMMARY OF THE INVENTION

The present disclosure is directed to conditional replication defective CMV (rdCMV) and the use of rdCMV in compositions and methods of treating and/or decreasing the likelihood of an infection by CMV or pathology associated with such an infection in a patient.

The rdCMV described herein comprises a nucleic acid encoding one or more fusion proteins that comprise an essential protein fused to a destabilizing protein. In the absence of a stabilizing agent, the fusion protein is degraded. Thus, the rdCMV can be grown in tissue culture under conditions that allow for replication (i.e., in the presence of the stabilizing agent) but replication is reduced, and preferably prevented, when administered to a patient (in the absence of the stabilizing agent).

In a first aspect, there is provided a conditional replication defective cytomegalovirus (CMV) comprising: (a) a pentameric gH complex comprising of UL128, UL130, UL131, gH and gL; and (b) a nucleic acid encoding a first fusion protein between an essential protein IE1/2 and a destabilizing protein and a second fusion protein between UL51 and the destabilizing protein, wherein the destabilizing protein is either FK506-binding protein (FKBP) or a FKBP derivative comprising amino acid substitutions F36V and L106P, wherein the wild type IE1/2 and UL51 are no longer present and wherein the CMV is an attenuated strain that has restored gH complex expression due to a repair of a mutation in the UL131 gene.

One embodiment of the present disclosure is a conditional replication defective CMV. The rdCMV comprises a nucleic acid encoding one or more fusion proteins that comprise an essential protein fused to a destabilizing protein. The nucleic acids encoding the wild type essential protein are no longer present in the rdCMV and thus the fusion protein is required for viral replication. In preferred embodiments, the essential proteins are selected from the group consisting of IE1/2, UL51, UL52, UL79 and UL84 and the destabilizing protein is FKBP or a derivative thereof.

In a second aspect, there is provided a composition comprising the conditional replication defective CMV as defined above and a pharmaceutically acceptable carrier.

Another embodiment of the present disclosure is a composition comprising an isolated rdCMV and a pharmaceutically acceptable carrier. The composition can further comprise an adjuvant including, but no limited to ISCOMATRIX® adjuvant and aluminium phosphate adjuvant.

In a third aspect, there is provided a composition as defined above in an immunological effective amount for use in inducing an immune response against CMV in a patient.

In a fourth aspect, there is provided use of a conditional replication defective CMV as defined above in the manufacture of a medicament for inducing a protective immune response in a patient against CMV infection.

Another embodiment of the present disclosure is use of the rdCMV composition to induce an immune response against CMV in a patient. Patients can be treated prophylactically or therapeutically by administration of the rdCMV of the present disclosure. Prophylactic treatment provides sufficient protective immunity to reduce the likelihood or severity of a CMV infection, including primary infections, recurrent infections (i.e., those resulting from reactivation of latent CMV) and super-infections (i.e., those resulting from an infection with a different stain of CMV than previously experienced by the patient). In specific embodiments, females of childbearing age, especially early adolescent females, are vaccinated to decrease the likelihood of CMV infection (either primary, recurrent or super) during pregnancy and thus decrease the likelihood of transmission of CMV to the fetus. Therapeutic treatment can be performed to reduce the length/severity of a current CMV infection.

In a fifth aspect, there is provided a method of making the conditional replication defective CMV as defined above comprising propagating the recombinant CMV in epithelial cells in the presence of Shield-1.

Another embodiment of the present disclosure is methods of making the rdCMV of the disclosure comprising propagating the rdCMV on epithelial cells, such as ARPE-19 cells (ATCC Accession No. CRL-2302), in the presence of Shield-1. In some embodiments, the

rdCMV is propagated on epithelial cells on microcarriers or other high density cell culture systems.

In a sixth aspect, there is provided a composition comprising the conditional replication defective CMV as defined above in a buffer at a pH between 5-7 comprising:

(a) between 15-35 mM Histidine; and

(b) between 100-200 mM NaCl.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. 1A-1B shows a schematic diagram of the construction of a strain of CMV with restored expression of the pentameric gH complex. **(A)** Strategy for generation of self-excisable Bacterial Artificial Chromosome (BAC) to manipulate AD169 viral genome. **(B)** Repair of the frame shift mutation in UL131 to restore its expression. **(C)** Replacement of GFP with a cre recombinase gene to create a self excisable CMV BAC.

FIGS. 2A-2D show the effect of conventional inactivation methods on gH complex immunogenicity. γ-irradiation **(A, B)** and ß-propiolactonE (BPL) **(C, D)** were used to inactivate gH complex expressing CMV. Inactivation kinetics were determined by plaque assay **(A, C)** while immunogenicity was determined by evaluating sera from mice administered the CMV for neutralizing activity against viral epithelial cell entry **(B, D)**.

FIG. 3 shows the Shield 1 concentration dependent progeny virus production of gH complex expressing CMV with various essential proteins fused to a FKBP derivative. ARPE-19 cells were infected with the rdCMV viruses at a multiplicity of 0.01 PFU/cell for 1 h, washed twice with fresh medium, and incubated in the growth medium containing 0, 0.05, 0.1 0.5 or 2 μM of Shield-1. Seven days post infection, the cell free virus was collected, and virus titers were determined by TCID50 assay on ARPE-19 cells in the presence of 2 μM of Shield 1.

FIGS. 4A-4D show growth kinetics of rdCMV in ARPE-19 cells. Cells were infected with viruses containing **(A)** IE1/2, **(B)** UL51, **(C)** IE1/2-UL51 fusion proteins or the **(D)** parental

beMAD virus at multiplicity of 0.01 PFU/cell. After one hour, the cells were washed twice with fresh medium, and incubated in the absence (open circle) or presence (closed circle) of 2 μM of Shield-1. Cell-free virus was collected at the indicated time points after infection, and infectious virus was quantified by TCID50 assay on ARPE-19 cells in the medium containing 2 μM of Shield-1.

FIGS. 5A-5E Growth kinetics of the IE1/2-UL51 rdCMV in different cell types. **(A)** MRC-5 **(B)** HUVEC **(C)** AoSMC **(D)** SKMC **(E)** CCF-STTG1 cells were infected with the rdCMV virus and incubated for one hour. The cells were washed twice with fresh medium, and then incubated in the absence (open circle) or presence (closed circle) of 2 μM of Shield-1. Cell-free virus was collected at the indicated time points after infection, and infectious virus was quantified by TCID50 assay on ARPE-19 cells in the medium containing 2 μM of Shield-1.

FIGS. 6A-6C Immunogenicity analysis of the IE1/2-UL51 rdCMV in mice, rabbits and rhesus macaques. **(A)** Mice were immunized at weeks 0 and 4 with beMAD (open circle) or the IE1/2-UL51 rdCMV(closed circle). **(B)** Rabbits were immunized at weeks 0, 3 and 8 with 10 μg beMAD or the indicated rdCMV. **(C)** Rhesus macaques were immunized at weeks 0 and 8 with 100 μg beMAD or the IE1/2-UL51rdCMV. In each case, serum samples were collected and analyzed by CMV micro-neutralization assay on ARPE-19 cells. Lines indicate the geometric mean titers of the neutralization (NT50) in each group.

FIG. 7 shows longitudinal neutralizing titers in rhesus macaques vaccinated with the double fusion virus IE1/2-UL51. Groups of rhesus monkeys (n=5) were vaccinated with the indicated vaccine dose or formulations at week 0, 8, and 24 (shown as red triangles), while one group received gb/mf59 (30 mg/dose) at week 0, 4 and 24. The immune sera were collected at indicated time points and evaluated in a viral neutralization assay. The GMT of NT50 titers is plotted longitudinally with the standard error for the group. AAHS: amorphous aluminum hydroxylphosphate sulfate; IMX: ISCOMATRIX; HNS: base buffer.

FIGS. 8A-8D show IFN-γ ELISPOT in rhesus macaques with the double fusion virus IE1/2-UL51 vaccination with either a 100μg **(A)** or 10 μg **(B-D)** per dose. Either no adjuvant (A-B), AAHS **(C)** or ISCOMATRIX **(D)** were used. PBMC were stimulated with peptide pools representing HCMV antigens. Gray bars representing GMT for each antigen of the group (n=5). Responder rate for each antigen is shown at the top of each antigen within the panels.

FIGS. 9A-9B show vaccination of the double fusion virus IE1/2-UL51 is able to induce T-cell responses of both CD8+ **(A)** and CD4+ **(B)** phenotypes in rhesus macaques. PBMC were collected from monkeys given either a 100 μg or 10 μg dose of vaccine with ISCOMATRIX® as adjuvant. PBMCs were stimulated with peptide pools representing HCMV antigens, followed by staining for IFN-γ and CD4+/CD8+ surface T-cell markers. The data are presented as number of CD4+/CD8+ positive, IFN-γ positive cells per million PBMC. The lines represent the geometric means (GMT) of the group receiving the same vaccine (n=5). The numbers at the bottom of the graphs represent the GMT of both vaccinated groups (n=10). CMV: purified virus; SEB: mitogen used as positive control agent; IMX: ISCOMATRIX.

FIG. 10 shows Merck aluminum phosphate adjuvant (MAPA) can enhance neutralizing antibody titers in monkeys. Rhesus monkeys were immunized with a 30 μg dose of the double fusion virus vaccine formulated in HNS (base buffer), AAHS or MAPA at week 0 and 8. The serum samples were collected at week 12 and evaluated for neutralizing titers. The lines represent geometric means for the group.

FIGS. 11A-11B show gH expressing CMV stability in Hank's balanced salt solution (HBSS) at different temperatures. **(A)** CMV samples in HBSS were stored at the indicated temperatures for 4 days before CMV virus stability was measured using a viral entry assay. **(B)** EC50 values were calculated for the samples using the viral entry assay results. * indicates that the EC50 could not be calculated due to complete loss of infectivity.

FIGS. 12A-12B show the effect of pH on the stability of gH expressing CMV at room temperature. **(A)** CMV samples in buffers with different pH were stored at room temperature for 4 days before CMV virus stability was measured using a viral entry assay. **(B)** EC50 values were calculated for the samples using the viral entry assay results.

FIGS. 13A-13B show the effect of urea alone or in combination with sodium chloride on gH expressing CMV virus stability. (A) 2% urea alone or in combination with 150mM NaCl was added to CMV in 25 mM histidine buffer, pH 6 at room temperature for 4 days before CMV

virus stability was measured using a viral entry assay. **(B)** EC50 values were calculated for the samples using the viral entry assay results.

FIGS. 14A-14B show the effect of ionic strength on gH expressing CMV virus stability. **(A)** Increasing concentrations of NaCl (0 mM, 75 mM, 150 mM and 320 mM NaCl) was added to CMV in 25 mM histidine buffer, pH 6 at room temperature for 4 days before CMV virus stability was measured using a viral entry assay. **(B)** EC50 values were calculated for the samples using the viral entry assay results.

FIG. 15 shows the effect of cryoprotectants on gH expressing CMV stability against freezing-thawing cycles. The indicated cryoprotectants were added to CMV in 25 mM histidine buffer, pH 6 and subjected to three freeze-thaw cycles before CMV virus stability was measured using a viral entry assay. EC50 values were calculated for the samples using the viral entry assay results.

FIGS. 16A-16B show the effect of storage temperature on inducing CMV neutralizing antibodies in a mouse immunogenicity study. Mice were immunized on day 0 and boosted on day 21 followed by bleeding on day 28. The mouse serum was tested for neutralizing antibodies against a gH expressing CMV using ARPE-19 cells. NT50 titers were obtained by non-linear curve fitting. **(A)** The CMV samples were stored at different temperatures for 3 months prior to the immunogenicity study. **(B)** The CMV samples were stored at different temperatures for 8 hours following thawing and prior to the immunogenicity study.

DETAILED DESCRIPTION OF THE INVENTION

The present invention is directed to conditional replication defective CMV (rdCMV) and the use of rdCMV in compositions and methods of treating and/or decreasing the likelihood of an infection by CMV or a pathology associated with such an infection in a patient. The rdCMV described herein encodes one or more fusion proteins that comprise an essential protein fused to a destabilizing protein instead of the wild type essential protein. In the absence

of a stabilizing agent, the fusion protein is degraded by host cell machinery. In the presence of a stabilizing agent, the fusion protein is stabilized and not degraded.

Suitable fusion proteins for use in the present invention retain sufficient essential protein activity to facilitate viral replication in a host cell in the presence of a stabilizing agent and cause a decrease (preferably greater than 50%, 75%, 90%. 95%, or 99% reduction) in CMV replication in the absence of a stabilizing agent. Preferably, the essential protein for use in the fusion protein encodes non-structural proteins and are thus not packaged into the rdCMV virions. Suitable essential proteins identified herein include the CMV proteins encoded by the essential genes IE1/2, UL51, UL52, UL79 and UL84.

An example of a destabilizing protein and stabilizing agent is described in US Patent Publication 2009/0215169 which discloses compositions, systems and methods for modulating the stability of proteins using a small-molecule. Briefly, a protein is fused to a stability-affecting protein, FKBP or a derivative thereof. An exogenously added, cell permeable small-molecule, Shield-1 (Shld-1), interacts with the FKBP or derivative thereof and stabilizes the fusion protein. In the absence of Shield-1, the FKBP or derivative thereof directs the fusion protein to be degraded by host cell machinery.

In an embodiment of the present invention, an essential CMV protein is fused to a FKBP or derivative thereof. In the presence of Shield-1, the fusion protein is stabilized. However, in the absence of Shield-1, the FKBP or derivative thereof directs the fusion protein to be degraded by host cell machinery.

In the absence of fusion protein, replication of rdCMV is reduced (preferably by greater than 50%, 75%, 90%. 95%, or 99% as compared to CMV not containing a destabilized essential protein) or prevented.

The recombinant virus to be used in the method of the invention also displays an immunogenic pentameric gH complex on its virion.

Embodiments also include the recombinant CMV or compositions thereof, described herein, or a vaccine comprising or consisting of said CMV or compositions (i) for use in, (ii) for use as a medicament for, or (iii) for use in the preparation of a medicament for: (a) therapy (e.g., of the human body); (b) medicine; (c) inhibition of CMV replication; (d) treatment or prophylaxis of infection by CMV or, (e) treatment, prophylaxis of, or delay in the onset or progression of CMV-associated disease(s). In these uses, the recombinant CMV, compositions thereof, and/or vaccines comprising or consisting of said CMV or compositions can optionally be

employed in combination with one or more anti-viral agents (e.g., anti-viral compounds or anti-viral immunoglobulins; combination vaccines, described *infra*).

As used herein, the term "induce an immune response" refers to the ability of a conditional replication defective CMV to produce an immune response in a patient, preferably a mammal, more preferably a human, to which it is administered, wherein the response includes, but is not limited to, the production of elements (such as antibodies) which specifically bind, and preferably neutralize, CMV and/or cause T cell activation. A "protective immune response" is an immune response that reduces the likelihood that a patient will contract a CMV infection (including primary, recurrent and/or super-infection) and/or ameliorates at least one pathology associated with CMV infection and/or reduces the severity/length of CMV infection.

As used herein, the term "an immunologically effective amount" refers to the amount of an immunogen that can induce an immune response against CMV when administered to a patient that can protect the patient from a CMV infection (including primary, recurrent and/or super-infections) and/or ameliorate at least one pathology associated with CMV infection and/or reduce the severity/length of CMV infection in the patient. The amount should be sufficient to significantly reduce the likelihood or severity of a CMV infection. Animal models known in the art can be used to assess the protective effect of administration of immunogen. For example, immune sera or immune T cells from individuals administered the immunogen can be assayed for neutralizing capacity by antibodies or cytotoxic T cells or cytokine producing capacity by immune T cells. The assays commonly used for such evaluations include but not limited to viral neutralization assay, anti-viral antigen ELISA, interferon-gamma cytokine ELISA, interferon-gamma ELISPOT, intracellular multi-cytokine staining (ICS), and ^{51}Chromimium release cytotoxicity assay. Animal challenge models can also be used to determine an immunologically effective amount of immunogen.

As used herein, the term "conditional replication defective virus" refers to virus particles that can replicate in a certain environments but not others. In preferred embodiments, a virus is made a conditional replication defective virus by destabilization of one or more proteins essential for viral replication. The nucleic acids encoding the wild type, non-destabilized essential proteins are no longer present in the conditional replication defective virus. Under conditions where the one or more essential proteins are destabilized, viral replication is decreased by preferably greater than 50%, 75%, 90%. 95%, 99%, or 100% as compared to a virus with no

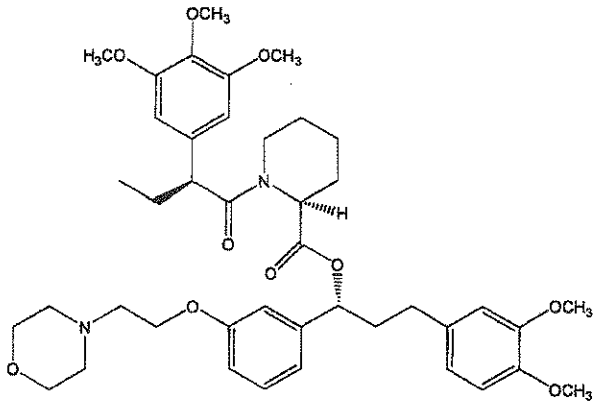
destabilized essential proteins. However, under conditions that stabilize the destabilized essential proteins, viral replication can occur at preferably at least 75%, 80%, 90%, 95%, 99% or 100% of the amount of replication of a CMV that does not contain a destabilized essential protein. In more preferred embodiments, one or more essential proteins are destabilized by fusion with a destabilizing protein such as FKBP or a derivative thereof. Such fusion proteins can be stabilized by the presence of a stabilizing agent such as Shield-1. As used herein, the term "rdCMV" refers to a conditional replication defective cytomegalovirus.

In preferred embodiments, the immune response induced by a replication defective virus as compared to its live virus counterpart is the same or substantially similar in degree and/or breadth. In other preferred embodiments, the morphology of a replication defective virus by electron microscopy analysis is indistinguishable or substantially similar to its live virus counterpart.

As used herein, the term "FKBP" refers to a destabilizing protein of SEQ ID NO:11. Fusion proteins containing FKBP are degraded by host cell machinery. As used herein, the term "FKBP derivative" refers to a FKBP protein or portion thereof that has been altered by one or more amino acid substitutions, deletions and/or additions. The FKBP derivatives retain substantially all of the destabilizing properties of FKBP when fused to a protein and also retain substantially all of the ability of FKBP to be stabilized by Shield-1. Preferred FKBP derivatives have one or more of the following substitutions at the denoted amino acid positions F15S, V24A, H25R, F36V, E60G, M66T, R71G, D100G, D100N, E102G, K105I and L106P. The FKBP derivative having the F36V and L106P substitutions (SEQ ID NO:12) is particularly preferred. In preferred embodiments, the nucleic acid that encodes the FKBP or FKBP derivative contains at least some codons that are not commonly used in humans for endogenous FKBP. This decreases the likelihood that the FKBP or FKBP derivative of the fusion protein will rearrange or recombine with its counterpart in human genome. The nucleic acid sequence of SEQ ID NO:13 encodes SEID NO:12 using such codons.

As used herein, the terms "Shield-1" or "Shld1" refer to a synthetic small molecule that binds to wild-type FKBP and derivatives thereof and acts as a stabilizing agent. Binding is about 1,000-fold tighter to the F36V derivative compared to wild-type FKBP (Clackson et al., 1998, PNAS 95:10437-42). Shield-1 can be synthesized (essentially as described in Holt et al., 1993, J. Am. Chem. Soc. 115:9925-38 and Yang et al., 2000, J. Med. Chem. 43:1135-42 and Grimley et al., 2008, Bioorganic & Medicinal Chemistry Letters 18:759)

or is commercially available from Cheminpharma LLC (Farmington, CT) or Clontech Laboratories, INC. (Mountain View, CA). Salts of Shield-1 can also be used in the methods of the invention. Shield-1 has the following structure:



As used herein, the terms "fused" or "fusion protein" refer to two polypeptides arranged in-frame as part of the same contiguous sequence of amino acids. Fusion can be direct such there are no additional amino acid residues between the polypeptides or indirect such that there is a small amino acid linker to improve performance or add functionality. In preferred embodiments, the fusion is direct.

As used herein, the terms "pentameric gH complex" or "gH complex" refer to a complex of five viral proteins on the surface of the CMV virion. The complex is made up of proteins encoded by UL128, UL130, and UL131 assembled onto a gH/gL scaffold (Wang and Shenk, 2005 Proc Natl Acad Sci USA. 102:1815; Ryckman et al, 2008 J. Virol. 82:60). The sequences of the complex proteins from CMV strain AD169 are shown at GenBank Accession Nos. NP_783797.1 (UL128), NP_040067 (UL130), CAA35294.1 (UL131), NP_040009 (gH, also known as UL75) and NP_783793 (gL, also known as UL115). Some attenuated CMV strains have one or more mutations in UL131 such that the protein is not expressed and therefore the gH complex is not formed. In such cases, UL131 should be repaired (using methods such as those in Wang and Shenk, 2005 J. Virol. 79:10330) such that the gH complex is expressed in the rdCMV of the invention. The viruses of the present invention express the five viral proteins that make up the pentameric gH complex and assemble the pentameric gH complex on the viral envelope.

As used herein, the term "essential protein" refers to a viral protein that is needed for viral replication *in vivo* and in tissue culture. Examples of essential proteins in CMV include,

but are not limited to, IE1/2, UL37x1, UL44, UL51, UL52, UL53, UL56, UL77, UL79, UL84, UL87 and UL105.

As used herein, the term "destabilized essential protein" refers to an essential protein that is expressed and performs its function in viral replication and is degraded in the absence of a stabilizing agent. In preferred embodiments, the essential protein is fused to a destabilizing protein such as FKBP or a derivative thereof. Under normal growth conditions (i.e., without a stabilizing agent present) the fusion protein is expressed but degraded by host cell machinery. The degradation does not allow the essential protein to function in viral replication thus the essential protein is functionally knocked out. Under conditions where a stabilizing agent such as Shield-1, is present the fusion protein is stabilized and can perform its function at a level that can sustain viral replication that is preferably at least 75%, 80%, 90%, 95%, 99% or 100% of the amount of replication of a CMV that does not contain a destabilized essential protein.

Replication Defective CMV

The methods of the present invention use a replication defective CMV (rdCMV) that expresses the pentameric gH complex. Any attenuated CMV virus that expresses the pentameric gH complex can be made replication defective according to the methods of the invention. In one embodiment, the attenuated CMV is AD169 that has restored gH complex expression due to a repair of a mutation in the UL131 gene (see Example 1).

Conditionally replication defective viruses are mutants in which one or more essential viral proteins have been replaced by a destabilized counterpart of the essential proteins. The destabilized counterpart is encoded by a nucleic acid that encodes a fusion protein between the essential protein and a destabilizing protein. The destabilized essential protein can only function to support viral replication when a stabilizing agent is present. In preferred embodiments, methods described in US Patent Publication 2009/0215169 are used to confer a conditionally replication defective phenotype to a pentameric gH complex expressing CMV. Briefly, one or more proteins essential for CMV replication are fused to a destabilizing protein, a FKBP or FKBP derivative. The nucleic acids encoding the wild type essential protein are no longer present in the rdCMV. In the presence of an exogenously added, cell permeable small-molecule stabilizing agent, Shield-1 (Shld-1), the fusion protein is stabilized and the essential protein can function to support viral replication. Replication of the rdCMV in the presence of the stabilizing agent is preferably at least 75%, 80%, 90%, 95%, 99% or 100% of the amount of

replication of a CMV that does not contain a destabilizing fusion protein (e.g, the parental attenuated CMV used to construct the rdCMV). In the absence of Shield-1, the destabilizing protein of the fusion protein directs the fusion protein to be substantially degraded by host cell machinery. With no or minimal amounts of essential protein present, the CMV cannot replicate at an amount to produce or maintain a CMV infection in a patient. Replication of the rdCMV in the absence of the stabilizing agent does not take place or is reduced by preferably greater than 50%, 75%, 90%. 95%, or 99% as compared to a CMV that does not contain a destabilizing fusion protein (e.g, the parental attenuated CMV used to construct the rdCMV).

Using recombinant DNA methods well known in the art, the nucleic acid encoding an essential protein for CMV replication and/or establishment/maintenance of CMV infection is attached to a nucleic acid that encodes FKBP or a derivative thereof. The encoded fusion protein comprises the FKBP or FKBP derivative fused in-frame to the essential protein. The encoded fusion protein is stable in the presence of Shield-1. However, the encoded fusion protein is destabilized in the absence of Shield-1 and is targeted for destruction. In preferred embodiments, the FKBP is SEQ ID NO:11. In other preferred embodiments, the FKBP derivative is FKBP comprising one or more amino acid substitutions selected from the group consisting of: F15S, V24A, H25R, F36V, E60G, M66T, R71G, D100G, D100N, E102G, K105I and L106P. In a more preferred embodiment, the FKBP derivative comprises the F36V and/or the L106P substitutions (SEQ ID NO:12). In a more preferred embodiment, the FKBP derivative is encoded by SEQ ID NO:13.

The essential proteins targeted for destabilization by fusion with FKBP or a derivative thereof 1) are essential for viral replication; 2) can accommodate the fusion of the destabilizing protein without substantially disrupting function of the essential protein; and 3) can accommodate the insertion of a nucleic acid encoding the FKBP or derivative thereof at the 5' or 3' end of the viral ORF encoding the essential protein without substantially disrupting the ORFs of other surrounding viral genes. In preferred embodiments, the essential proteins targeted for destabilization by fusion with FBBP or derivative thereof encode non-structural proteins and, as such, have a decreased likelihood of being packaged into recombinant CMV virions. Table 1 shows CMV genes that meet the aforementioned criteria.

Table 1: Viral genes selected for construction of FKBP fusion

Viral Gene	Function*	Kinetic phase	Fusion of FKBP	Sequence of Fusion Protein
IE1/2 (UL123/122)	viral transcriptional modulators	Immediate early	N-term	SEQ ID NOS:1-2
UL37x1	Viral gene regulations	Immediate early	N-term	-
UL51	DNA packaging	Late	N-term	SEQ ID NOS:3-4
UL52	DNA packaging and cleavage	Late	N-term	SEQ ID NOS:5-6
UL53	Capsid egress; nuclear egress	Early	C-term	-
UL77	DNA packaging	Early	C-term	-
UL79	Unknown	Late	N-term	SEQ ID NOS:7-8
UL84	DNA replication	Early-Late	C-term	SEQ ID NOS:9-10
UL87	Unknown	?	N-term	-

* according to Mocarski, Shenk and Pass, Cytomegalovirus, in Field Virology, 2701-2772, Editor: Knipes and Howley, 2007

The present invention encompasses rdCMV that comprise fusion proteins with an essential protein or derivative thereof fused to the destabilizing protein. Essential protein derivatives contain one or more amino acid substitutions, additions and/or deletions relative to the wild type essential protein yet can still provide the activity of the essential protein at least well enough to support viral replication in the presence of Shield-1. Examples of measuring virus activity are provided in the Examples infra. Methods known in the art can be used to determine the degree of difference between the CMV essential protein of interest and a derivative. In one embodiment, sequence identity is used to determine relatedness. Derivatives of the invention will be preferably at least 85% identical, at least 90% identical, at least 95% identical, at least 97% identical, at least 99% identical to the base sequence. The percent identity is defined as the number of identical residues divided by the total number of residues and multiplied by 100. If sequences in the alignment are of different lengths (due to gaps or extensions), the length of the longest sequence will be used in the calculation, representing the value for total length.

In some embodiments, the one or more viral proteins essential for viral replication targeted for destabilization are selected from the group consisting of IE1/2, UL51, UL52, UL84, UL79, UL87, UL37x 1, UL77 and UL53 or derivatives thereof. In a specific embodiment, the one or more viral proteins essential for viral replication targeted for destabilization are selected

from the group consisting of IE1/2, UL51, UL52, UL84, UL79, UL87. In a more specific embodiment, the one or more viral proteins essential for viral replication targeted for destabilization are selected from the group consisting of IE1/2, UL51, UL52, UL79 and UL84.

More than one essential protein can be destabilized by fusion to FKBP or derivative thereof. In some embodiments, the essential proteins function at different stages of CMV replication and/or infection (including but not limited to, immediate early, early or late stages). In preferred embodiments, the combination of viral proteins essential for viral replication targeted for destabilization are selected from the group consisting of IE1/2 and UL51, IE1/2 and UL52, IE1/2 and UL79, IE1/2 and UL84, UL84 and UL51 and UL84 and UL52. In a more preferred embodiment, IE1/2 and UL51 are targeted for destabilization in the same recombinant CMV. In a most preferred embodiment, the fusion protein comprising IE1/2 is SEQ ID NO:1 and the fusion protein comprising UL51 is SEQ ID NO:3. SEQ ID NOS:1 and 3 can be encoded by SEQ ID Nos:2 and 4, respectively. The genome of the rdCMV with the destabilized IE1/2 and UL51 is shown in SEQ ID NO:14.

The FKBP or derivative thereof can be fused to the essential protein either directly or indirectly. In preferred embodiments, the FKBP or derivative thereof is fused to the essential protein directly.

The FKBP or derivative thereof can be fused to the essential protein either at either the N- or C-terminus of the essential protein. In preferred embodiments, the FKBP is fused to the N-terminus of the essential protein.

More than one FKBP or derivative thereof can be fused to the essential protein. In embodiments where there is more than one FKBP or derivative there of fused to the essential protein, each of the individual FKBP or derivatives there of can be the same or different. In preferred embodiments, there is one FKBP or derivative thereof fused to the essential protein.

Additional Inactivation Methods

In some embodiments, the rdCMV described *supra* is inactivated further using a chemical or physical inactivation. Examples of such include heat treatment, incubation with formaldehyde, ß-Propiolactone (BPL), or binary ethyleneimine (BEI), or gamma irradiation. Preferred methods do not disrupt or substantially disrupt the immunogenicity, including, but not limited to, the immunogenicity induced by the pentameric gH complex. As such, the immune response elicited by the CMV that has been further inactivated is preserved or substantially

preserved as compared to rdCMV with no additional inactivation treatment. In preferred embodiments, the ability of the further inactivated CMV to induce neutralizing antibodies is comparable to those induced by rdCMV with no additional inactivation treatment. Inactivation regimen by any one or combination of the chemical or physical methods is determined empirically to ensure immunogenicity of CMV, including the pentameric gH complex.

Evaluation of Viral Replication

One skilled in the art can use viral replication assays to determine the utility of a particular essential protein fused to FKBP or derivative thereof. Because gene expression/encoded product function should not be substantially affected by the attachment of the FKBP or derivative thereof to the essential protein in the presence of Shield-1, the rdCMV should replicate at a rate that is comparable to the parental CMV in the presence of Shield-1 (preferably at least 75%, 80%, 90%, 95%, 99% or 100% of the parental virus levels). Replication of the rdCMV is substantially altered from the parental CMV in the absence of Shield-1 (reduced by preferably greater than 50%, 75%, 90%. 95%, 99% or 100% as compared to a CMV that does not contain a destabilizing fusion protein).

In preferred embodiments, the rdCMV in the presence of at least 2 μM Shield-1 replicates preferably at least 90%, more preferably at least 95%, most preferably at least 99%, of the amount that a non-rdCMV replicates.

In one embodiment, a composition comprising the rdCMV of the invention has a viral titer of at least 10^5 pfu/ml, more preferably at least 10^7 pfu/ml, in the presence of at least 2 μM Shield-1.

Conversely, rdCMV should not replicate substantially in the absence of Shield-1. The quality of a replication defective mechanism is judged by how stringent the control is under the conditions not permissive for viral replication, i.e., the infectious titers of progeny virions under these conditions. The rdCMV of the present invention cannot replicate substantially (either in cell culture or within a patient) without Shield-1 present. Its replication in ARPE-19 cells and other types of human primary cells is conditional, and a molar concentration of Shield-1 greater than 0.1 μM, preferable at least 2 μM, in the culture medium is required to sustain viral replication.

In one embodiment, a composition comprising the rdCMV of the invention has a viral titer of less than 2 pfu/ml, more preferably less than 1 pfu/ml, in the absence of Shield-1.

Methods to assess CMV replication can be used to assess rdCMV replication either in the absence or presence of Shield-1. However, in preferred embodiments, the TCID50 is used.

In another embodiment, rdCMV titers are determined by a 50% Tissue Culture Infective Dose (TCID50) assay. Briefly, this dilution assay quantifies the amount of virus required to kill 50% of infected hosts. Host cells (e.g., ARPE-19 cells) are plated and serial dilutions of the virus are added. After incubation, the percentage of cell death (i.e. infected cells) is observed and recorded for each virus dilution. Results are used to mathematically calculate the TCID50.

In another embodiment, the rdCMV titers are determined using a plaque assay. Viral plaque assays determine the number of plaque forming units (pfu) in a virus sample. Briefly, a confluent monolayer of host cells (e.g., ARPE-19 cells) is infected with the rdCMV at varying dilutions and covered with a semi-solid medium, such as agar or carboxymethyl cellulose, to prevent the virus infection from spreading indiscriminately. A viral plaque is formed when a virus infects a cell within the fixed cell monolayer. The virus infected cell will lyse and spread the infection to adjacent cells where the infection-to-lysis cycle is repeated. The infected cell area will create a plaque (an area of infection surrounded by uninfected cells) which can be seen visually or with an optical microscope. Plaques are counted and the results, in combination with the dilution factor used to prepare the plate, are used to calculate the number of plaque forming units per sample unit volume (pfu/mL). The pfu/mL result represents the number of infective particles within the sample and is based on the assumption that each plaque formed is representative of one infective virus particle.

In another embodiment, a hu-SCID mouse model is used to evaluate the ability of an rdCMV to replicate *in vivo*. Briefly, pieces of human fetal tissues (such as thymus and liver) are surgically implanted in kidney capsules of SCID mice. The rdCMV is inoculated 2-3 months later when the human tissues are vascularized. Viral titers are assessed 3-4 weeks after inoculation in plaque assays. The animal experiments can be performed in the absence or presence of Shield-1.

Evaluation of Immune Response

Administration of rdCMV of the invention to a patient elicits an immune response to CMV, preferably a protective immune response, that can treat and/or decrease the likelihood

of an infection by CMV or pathology associated with such an infection in a patient. The immune response is, at least in part, to the pentameric gH complex.

The immune response elicited by the rdCMV can be assessed using methods known in the art.

Animal models known in the art can be used to assess the protective effect of administration of the rdCMV. In one embodiment, immune sera from individuals administered the rdCMV can be assayed for neutralizing capacity, including but not limited to, blockage of viral attachment or entry to a host cell. In other embodiments, T cells from individuals administered the rdCMV can be assayed for cytokine producing capacity including, but not limited to, interferon gamma, in the presence of an antigen of interest. Animal challenge models can also be used to determine an immunologically effective amount of immunogen.

Viral neutralization refers to viral specific antibodies capable of interrupting viral entry and/or replication in cultures. The common assay for measuring neutralizing activities is viral plaque reduction assay. The neutralization assays in this invention refer to serum titrations that can block virus entering cells. NT50 titers are defined as reciprocal serum dilutions to block 50% of input virus in viral neutralization assays. NT50 titers are obtained from nonlinear logistic four-parameter curve fitting.

Manufacture of Replication Defective CMV

The present invention encompasses methods of making the rdCMV. The rdCMV of the invention are propagated in the presence of a stabilizing agent such as Shield-1 on epithelial cells, preferably human epithelial cells, and more preferably human retinal pigmented epithelial cells. In additional embodiments, the human retinal pigmented epithelial cells are ARPE-19 cells deposited with the American Type Culture Collection (ATCC) as Accession No. CRL-2302. In some embodiments, Shield-1 is present at a concentration of at least 0.5 μM in the tissue culture media. In preferred embodiments, Shield-1 is present at a concentration of at least 2.0 μM in the tissue culture media.

In some embodiments, the cells used to propagate the rdCMV are grown on microcarriers. A microcarrier is a support matrix allowing for the growth of adherent cells in spinner flasks or bioreactors (such as rotating wall microgravity bioreactors and fluidized bed bioreactors). Microcarriers are typically 125 - 250 μM spheres with a density that allows them to be maintained in suspension with gentle stirring. Microcarriers can be made from a number of

different materials including, but not limited to, DEAE-dextran, glass, polystyrene plastic, acrylamide, and collagen. The microcarriers can have different surface chemistries including, but not limited to, extracellular matrix proteins, recombinant proteins, peptides and charged molecules. Other high density cell culture systems, such as Corning HyperFlask® and HyperStack® systems can also be used.

The cell-free tissue culture media can be collected and rdCMV can be purified from it. CMV viral particles are about 200 nm in diameter and can be separated from other proteins present in the harvested media using techniques known in the art including, but not limited to ultracentrifugation through a density gradient or a 20% Sorbitol cushion. The protein mass of the vaccines can be determined by Bradford assay.

Shield-1 can be used to control replication of the rdCMV in conjunction with FKBP. After the desired amount of viral propagation in tissue culture cells is completed, the ability to replicate is no longer desirable. Shield-1 is withdrawn from the rdCMV to make the virus replication deficient (e.g., in order to be administered to a patient). In one embodiment, the rdCMV is purified from Shield-1 by washing one or more times. In another embodiment, the rdCMV is purified from Shield-1 through ultracentrifugation. In another embodiment, the rdCMV is purified from Shield-1 through diafiltrations. Diafiltrations is commonly used to purify viral particles. In one embodiment, filters are used with pore size of approximately 750 kilodalton which would only allow Shield-1 to pass through the pores.

After purification of rdCMV from Shield-1, there may a small amount be of residual Shield-1 remaining in the rdCMV composition. In one embodiment, the level of Shld-1 in the CMV composition after purification is at least 100-fold below the level needed to sustain replication in tissue culture. In another embodiment, the level of Shield-1 in the rdCMV composition after purification is 0.1 μM or less. In another embodiment, the level of Shield-1 in the rdCMV composition after purification is undetectable.

Determination of Shield-1 levels in a composition can be detected using a LC/MS (liquid chromatography-mass spectroscopy) or HPLC/MS (high performance liquid chromatography-mass spectroscopy) assays. These techniques combine the physical separation capabilities of LC or HPLC with the mass analysis capabilities of and can detect chemicals of interest in complex mixtures.

Adjuvants

Adjuvants are substances that can assist an immunogen in producing an immune response. Adjuvants can function by different mechanisms such as one or more of the following: increasing the antigen biologic or immunologic half-life; improving antigen delivery to antigen-presenting cells; improving antigen processing and presentation by antigen-presenting cells; achieving dose-sparing, and, inducing production of immunomodulatory cytokines (Vogel, 2000, Clin Infect Dis 30:S266). In some embodiments, the compositions of the invention comprise a rdCMV and an adjuvant.

A variety of different types of adjuvants can be employed to assist in the production of an immune response. Examples of particular adjuvants include aluminum hydroxide; aluminum phosphate, aluminum hydroxyphosphate, amorphous aluminum hydroxyphosphate sulfate adjuvant (AAHSA) or other salts of aluminum; calcium phosphate; DNA CpG motifs; monophosphoryl lipid A; cholera toxin; *E. coli* heat-labile toxin; pertussis toxin; muramyl dipeptide; Freund's incomplete adjuvant; MF59; SAF; immunostimulatory complexes; liposomes; biodegradable microspheres; saponins; nonionic block copolymers; muramyl peptide analogues; polyphosphazene; synthetic polynucleotides; IFN-γ; IL-2; IL-12; and ISCOMS. (Vogel, 2000, Clin Infect Dis 30:S266; Klein et al., 2000, J Pharm Sci 89:311; Rimmelzwaan et al., 2001, Vaccine 19:1180; Kersten, 2003, Vaccine 21:915; O'Hagen, 2001, Curr. Drug Target Infect. Disord. 1:273.)

In some embodiments, oil-based adjuvants including, but not limited to, incomplete Freund's adjuvant and MF59, are not used in the compositions of the invention.

In other embodiments, particulate adjuvants including, but not limited to, ISCOMATRIX® adjuvant and/or aluminium phosphate adjuvant are used in the compositions of the invention.

Pharmaceutical Compositions

A further feature of the invention is the use of a recombinant CMV described herein in a composition, preferably an immunogenic composition or vaccine, for treating patients with a CMV infection and/or reducing the likelihood of a CMV infection. Suitably, the composition comprises a pharmaceutically acceptable carrier.

A "pharmaceutically-acceptable carrier" is meant to mean a liquid filler, diluent or encapsulating substance that may be safely used in systemic administration. Depending upon the particular route of administration, a variety of pharmaceutically acceptable carriers, well known in the art may be used. These carriers may be selected from a group including sugars, starches, cellulose and its derivatives, malt, gelatine, talc, calcium sulfate, vegetable oils, synthetic oils, polyols, alginic acid, phosphate buffered solutions including phosphate buffered saline, emulsifiers, isotonic saline, and pyrogen-free water. In particular, pharmaceutically acceptable carriers may contain different components such as a buffer, sterile water for injection, normal saline or phosphate-buffered saline, sucrose, histidine, salts and polysorbate. Terms such as "physiologically acceptable", "diluent" or "excipient" can be used interchangeably.

Procedures for vaccine formulations are disclosed, for example, in New Generation Vaccines (1997, Levine et al., Marcel Dekker, Inc. New York, Basel, Hong Kong), which is incorporated herein by reference.

Formulations

In some embodiments, the rdCMV of the invention is administered to a patient to elicit an immune response. It is desirable to minimize or avoid the loss of the rdCMV composition potency during storage of the immunogenic composition. The conditions to support such an aim include but not limited to (1) sustained stability in storage, (2) resistant to stressed freezing-thawing cycles, (3) stable at ambient temperatures for up to a week, (4) maintenance of immunogenicity, (5) compatible with adjuvanting strategy. Conditions that affect rdCMV stability include, but are not limited to, buffer pH, buffer ionic strength, presence/absence of particular excipients and temperature. The compositions comprise buffers to increase the stability of purified rdCMV viral particles suitable as vaccine composition.

The preservation of the integrity of viral particles can be assessed by immunogenicity assays in mice and/or viral entry assays. Viral entry events dependent on the integrity and functions of viral glycoproteins, including the pentameric gH complex. The pentameric gH complex also provides the substantial immunogenicity of rdCMV, thus the two properties are linked.

In some embodiments, the rdCMV is stored in buffer comprising 15-35 mM Histidine and100-200 mM NaCl at a pH of between 5 and 7. In a more specific embodiment, the buffer comprises 25 mM Histidine and 150 mM NaCl at pH6.

In other embodiments, sugars can be added to provide further stability, such as polyols (including, but not limited to, mannitol and sorbitol); monosaccharides (including, but not limited to, glucose, mannose, galactose and fructose); disaccharides (including, but not limited to, lactose, maltose, maltose, sucrose, lactulose and trehalose) and trisaccharides (including, but not limited to, raffinose and melezitose). In a more specific embodiment, the sugar is sucrose. In an even more specific embodiment, the sucrose is between 5-15%.

In preferred embodiments, the rdCMV is stored in buffer comprising 25 mM Histidine, 150 mM NaCl, 9% Sucrose at pH 6.

Administration

A rdCMV described herein can be formulated and administered to a patient using the guidance provided herein along with techniques well known in the art. Guidelines for pharmaceutical administration in general are provided in, for example, *Vaccines* Eds. Plotkin and Orenstein, W.B. Sanders Company, 1999; *Remington's Pharmaceutical Sciences 20th Edition*, Ed. Gennaro, Mack Publishing, 2000; and *Modern Pharmaceutics 2nd Edition*, Eds. Banker and Rhodes, Marcel Dekker, Inc., 1990.

Vaccines can be administered by different routes such as subcutaneous, intramuscular, intravenous, mucosal, parenteral, transdermal or intradermal. Subcutaneous and intramuscular administration can be performed using, for example, needles or jet-injectors. In an embodiment, the vaccine of the invention is administered intramuscularly. Transdermal or intradermal delivery can be accomplished through intradermal syringe needle injecton, or enabling devices such as micron-needles or micron array patches.

The compositions described herein may be administered in a manner compatible with the dosage formulation, and in such amount as is immunogenically-effective to treat and/or reduce the likelihood of CMV infection (including primary, recurrent and/or super). The dose administered to a patient, in the context of the present invention, should be sufficient to effect a beneficial response in a patient over time such as a reduction in the level of CMV infection, ameliorating the symptoms of disease associated with CMV infection and/or shortening the

length and/or severity of CMV infection, or to reduce the likelihood of infection by CMV (including primary, recurrent and/or super).

Suitable dosing regimens may be readily determined by those of skill in the art and are preferably determined taking into account factors well known in the art including age, weight, sex and medical condition of the patient; the route of administration; the desired effect; and the particular composition employed. In determining the effective amount of the rdCMV to be administered in the treatment or prophylaxis against CMV, the physician may evaluate circulating plasma levels of virus, progression of disease, and/or the production of anti-CMV antibodies. The dose for a vaccine composition consists of the range of 10^3 to 10^{12} plaque forming units (pfu). In different embodiments, the dosage range is from 10^4 to 10^{10} pfu, 10^5 to 10^9 pfu, 10^6 to 10^8 pfu, or any dose within these stated ranges. When more than one vaccine is to be administered (*i.e.*, in combination vaccines), the amount of each vaccine agent is within their described ranges.

The vaccine composition can be administered in a single dose or a multi-dose format. Vaccines can be prepared with adjuvant hours or days prior to administrations, subject to identification of stabilizing buffer(s) and suitable adjuvant composition. Vaccines can be administrated in volumes commonly practiced, ranging from 0.1 mL to 0.5 mL.

The timing of doses depends upon factors well known in the art. After the initial administration one or more additional doses may be administered to maintain and/or boost antibody titers and T cell immunity. Additional boosts may be required to sustain the protective levels of immune responses, reflected in antibody titers and T cell immunity such as ELISPOT. The levels of such immune responses are subject of clinical investigations.

For combination vaccinations, each of the immunogens can be administered together in one composition or separately in different compositions. A rdCMV described herein is administered concurrently with one or more desired immunogens. The term "concurrently" is not limited to the administration of the therapeutic agents at exactly the same time, but rather it is meant that the rdCMV described herein and the other desired immunogen(s) are administered to a subject in a sequence and within a time interval such that the they can act together to provide an increased benefit than if they were administered otherwise. For example, each therapeutic agent may be administered at the same time or sequentially in any order at different points in time; however, if not administered at the same time, they should be administered sufficiently close in

time so as to provide the desired therapeutic effect. Each therapeutic agent can be administered separately, in any appropriate form and by any suitable route.

Patient Population

A "patient" refers to a mammal capable of being infected with CMV. In a preferred embodiment, the patient is a human. A patient can be treated prophylactically or therapeutically. Prophylactic treatment provides sufficient protective immunity to reduce the likelihood or severity of a CMV infection, including primary infections, recurrent infections (i.e., those resulting from reactivation of latent CMV) and super-infections (i.e., those resulting from an infection with a different stain of CMV than previously experienced by the patient). Therapeutic treatment can be performed to reduce the severity of a CMV infection or decrease the likelihood/severity of a recurrent or super- infection.

Treatment can be performed using a pharmaceutical composition comprising a rdCMV as described herein. Pharmaceutical compositions can be administered to the general population, especially to those persons at an increased risk of CMV infection (either primary, recurrent or super) or for whom CMV infection would be particularly problematic (such as immunocompromised individuals, transplant patients or pregnant women). In one embodiment, females of childbearing age, especially early adolescent females, are vaccinated to decrease the likelihood of CMV infection (either primary, recurrent or super) during pregnancy.

Those in need of treatment include those already with an infection, as well as those prone to have an infection or in which a reduction in the likelihood of infection is desired. Treatment can ameliorate the symptoms of disease associated with CMV infection and/or shorten the length and/or severity of CMV infection, including infection due to reactivation of latent CMV.

Persons with an increased risk of CMV infection (either primary, recurrent or super) include patients with weakened immunity or patients facing therapy leading to a weakened immunity (e.g., undergoing chemotherapy or radiation therapy for cancer or taking immunosuppressive drugs). As used herein, "weakened immunity" refers to an immune system that is less capable of battling infections because of an immune response that is not properly functioning or is not functioning at the level of a normal healthy adult. Examples of patients with weakened immunity are patients that are infants, young children, elderly, pregnant or a

patient with a disease that affects the function of the immune system such as HIV infection or AIDS.

EXAMPLES

Examples are provided below to further illustrate different features of the present invention. The examples also illustrate useful methodology for practicing the invention. These examples do not limit the claimed invention.

Example 1: Restoration of the pentameric gH complex

An infectious CMV bacterial artificial chromosome clone was constructed so that the encoded virion that expressed the pentameric gH complex consisting of UL128, UL130 and UL131 assembled onto a gH/gL scaffold.

CMV strain AD169 strain was originally isolated from the adenoids of a 7-year-old girl (Elek and Stern, 1974, Lancet, 1:1). The virus was passed 58 times in several types of human fibroblasts to attenuate the virus (Neff et al, 1979, Proc Soc Exp Biol Med, 160:32, with the last 5 passages in WI-38 human fibroblasts. This passaged variant of AD169 virus, referred in this study as Merck AD169 (MAD169), was used as the parental virus to construct the infectious BAC clone. Neither the parental virus AD169 nor the passaged variant virus MAD169 expressed UL131 or the pentameric gH complex.

The MAD169 was used as the parental virus to construct an infectious bacterial artificial chromosome (BAC) clone. A BAC vector is a molecular tool that allows the genetic manipulation of a large size DNA fragment, such as the CMV genome (~230Kb), in *E. coli*. A BAC element along with a GFP marker gene was inserted immediately after the stop codon of US28 open reading frame (between US28 and US29 ORFs in the viral genome) with a LoxP site created at the both ends of the fragment (FIG. 1A). Briefly, a DNA fragment containing a GFP expression cassette flanked by two loxP sites and CMV US28-US29 sequences were synthesized and cloned into pBeloBAC11 vector. The BAC vector was linearized with restriction enzyme Pme I, and cotransfected into MRC-5 cells with MAD169 DNA extracted from purified virions. The recombinant variants, identified by green fluorescence expression, were plaque purified. After one round of amplification, the circular form of viral genome was extracted from the infected cells, and electroporated into *E. coli* DH10 cells. The bacterial colonies were screened

by PCR for the presence of US28 and US29 regions. Candidate clones were further examined by EcoR I, EcoR V, Hind III, Spe I and Bam HI restriction analyses. After screening, one clone, bMAD-GFP, showed identical restriction pattern with the parental MAD169 virus.

The frame-shift mutation in the first exon of UL131 underlying the epithelial tropism deficiency in MAD169 was repaired genetically in *E. coli* (FIG. 1B). Specifically, one adenine nucleotide (nt) from the 7 nt A-stretch in the UL131 gene was deleted (FIG. 1B). Deletion of 1 nt was sufficient to rescue the epithelial and endothelial cell tropism due to UL131, and thus the pentameric gH complex, now being expressed. Expression was confirmed by ELISA and western blot (data not shown). This clone was further modified by removing the BAC segment by LoxP/Cre recombination. The BAC DNA was transfected in ARPE-19 cells, human retinal pigmented epithelial cells (ATCC Accession No. CRL-2302), to recover the infectious virus (FIG. 1C). The resultant infectious virus, termed BAC-derived epithelial-tropic MAD169 virus (beMAD), differs from MAD169 only in two loci, (1) UL131 ORF where a single adenine nucleotide was deleted and (2) a 34bp LoxP site inserted between US28 and US29 ORFs (see Table 2).

The genome of the BAC clone beMAD was completely sequenced. The overall genome structure of beMAD is identical to that reported in the ATCC AD169 variant (GenBank Accession No. X17403), which is comprised of two unique regions, unique long (UL) and unique short (US). Each unique regions are bracketed by two repeat sequences, terminal repeat long (TRL)-internal repeat long (IRL), terminal repeat short (TRS)-internal repeat short (IRS). The growth kinetics of the passaged variant MAD169 and the beMAD derived virus were indistinguishable in MRC-5 cells, a human fibroblast cell line (ATCC Accession No. CCL-171) (data not shown). Because the gH complex is not needed for growth on fibroblast cells, the differences in gH complex expression between the MAD169 and beMAD are not relevant.

Table 2: Molecular difference of CMV viruses

Virus ID	Genetic composition	Proteins in virions
AD169	ATCC laboratory strain containing frame-shift mutation in UL131 causing deficiency in epithelial tropism	
MAD169	Contains frame-shift mutation in UL131 identical to ATCC AD169	Identical to AD169 from ATCC
beMAD	Repaired frame-shift mutation in UL131; LoxP sequence (34 bp) between US28 and US29 ORFs	Identical to MAD169, with addition of the pentameric gH complex

Example 2: Effect of Conventional Inactivation Methods on gH Complex

The effect of two conventional methods of viral inactivation, γ-irradiation and ß-Propiolactone (BPL), were investigated on the CMV expressing gH.

The γ-irradiation was performed on lyophilized virions. Recombinant CMV vaccine at a concentration of 0.15 mg/mL in HNS (25 mM Histidine, 150 mM NaCl, 9% w/v Sucrose, pH 6.0) formulation was lyophilized using a conservative lyophilization cycle (-50 °C freezing and primary drying at -35 °C for ~30 hrs followed by secondary drying at 25 °C for 6 hrs) to obtain dry powder. The vaccine was lyophilized in a 3 mL glass vial with 0.5ml filled in each vial. At the end of lyophilization, the vials were stoppered in a nitrogen environment and the samples were removed, labelled, crimped and stored at -70°C until gamma irradiation. The vials were irradiated under a Co irradiator for the desired dosage of irradiation.

For BPL treatment, a BPL stock solution was added to the crude viral culture supernatant from growth on ARPE-19 cells to reach the final concentrations of 0.01% or 0.1% (v/v). The reaction was terminated with sodium thiosulfate at various time points. The BPL-treated gH expressing CMV were then purified by ultracentrifugation.

The inactivation kinetics for both methods were determined by plaque assay in ARPE-19 cells. Briefly, serial dilutions of viral samples in PBS were made and 0.1 mL was used to inoculate each well of a 6-well plate that had been seeded with ARPE-19 cells. The plates are incubated at 37°C for 1 hr before addition of a 6 mL per well overlay medium containing 0.5% agarose. The plates are incubated for 18 days at 37°C. To visualize the plaques, about 0.5 mL MTT solution at 5 mg/mL (Thiazolyl blue tetrazolium bromide, Sigma M5655) was added to

each well. The plates were incubated at 37°C for 2-4 hr and the plaques were counted under lightbox. (FIGS. 2A and 2C).

Immunogenicity of the inactivated gH expressing CMV was assayed by determining the neutralizing antibody titers induced in mice. Briefly, female Balb/c mice (n=10) were immunized with 2.5 μg of CMV per dose at weeks 0 and 3. The sera was collected at week 4 and evaluated for neutralizing activity against viral epithelial entry. The neutralization titer (NT50) was defined as a reciprocal dilution of serum causing a 50% reduction in viral epithelial entry as compared to the negative control. The results from mouse immunogenicity studies showed that both conventional methods for inactivation had negative effects on neutralizing antibody titers induced by the gH expressing CMV (FIGS. 2B and 2D). The reduction of NT50 titers correlated with the duration of treatment by γ-irradiation or BPL. The prolonged treatments rendered the pentameric gH complex-expressing CMV more like the parental AD169 CMV in terms of immunogenicity in mice. Similar results were observed in rabbits and rhesus monkeys when vaccines inactivated with γ -irradiation or BPL were tested (data not shown). These observations showed that the pentameric gH complex is sensitive to both inactivation methods under the selected inactivation conditions.

Example 3: Construction and screening of FKBP-essential protein fusions

A CMV was constructed using the attenuated AD169 strain backbone that regains its epithelial tropism while being conditionally replication defective. Methods described in Example 1 were used to restore epithelial tropism.

The viral proteins to be fused to the FKBP derivative were selected based on two criteria. First, the proteins of interest were not detected in CMV virions by proteomics analysis (Varnum et al., 2004, J. Virol. 78:10960), thus, decreasing the likelihood that the FKBP fusion protein will be incorporated into virus. Second, the proteins of interest are essential for viral replication in tissue culture.

Using beMAD as the parental virus, the FKBP derivative (SEQ ID NO:12) was fused to 12 essential viral proteins individually, including IE1/2 (SEQ ID NO:1), pUL37x1, pUL44, pUL51 (SEQ ID NO:3), pUL52 (SEQ ID NO:5), pUL53, pUL56, pUL77, pUL79 (SEQ ID NO:7), pUL84 (SEQ ID NO:9), pUL87 and pUL105. A virus with two different essential proteins fused to FKBP was also constructed that fused each of IE1/2 and UL51 the FKBP

derivative (the genome of the rdCMV with the destabilized IE1/2 and UL51 is shown in SEQ ID NO:14). After construction, all recombinant BAC DNAs were transfected into ARPE-19 cells, and cultured in the medium containing Shld-1.

The dependence of viral growth on Shld-1 was examined. The IE1/2, UL51, UL52, UL84, UL79 and UL87 fusion viruses were readily rescued in 2 μM Shld-1 in plaque assays (data not shown). The UL37x 1, UL77 and UL53 viruses also produced plaques, but the plaques were small, and they grew significantly slower, comparing to the parental beMAD. Increasing the Shld-1 concentration to 10 μM did not significantly expedite the viral growth (data not shown). The UL56 and UL105 fusions were not recovered, suggesting that tagging of these proteins disrupts the function of these proteins, or expression of neighboring genes.

Varying concentrations of Shld-1 were used in additional experiments to further assess viral replication in the presence or absence of Shld-1. ARPE-19 cells were infected by the gH expressing CMV that also contained a FKBP derivative fused to an essential protein at MOI of 0.01 pfu/ml. After infection for 1 hour, the cells were washed twice with fresh medium to remove the Shld-1 from the inoculums. The inoculums were then added to ARPE-19 cells cultured in medium containing 0.05, 0.1, 0.5 or 2 μM of Shield-1. Seven days post infection, the cell-free progeny virus in the supernatant was collected and titrated on ARPE-19 cells supplemented with 2 mM of Shield-1. Virus titers were determined by a 50% Tissue Culture Infective Dose (TCID50) assay. Briefly, this dilution assay quantifies the amount of virus required to kill 50% of infected hosts. ARPE-19 cells were plated and serial dilutions of the virus were added. After incubation, the percentage of cell death (i.e. infected cells) was manually observed and recorded for each virus dilution. Results were used to mathematically calculate the TCID50.

As shown in FIG. 3, efficient replication of all FKBP fusion containing CMV depended on Shield-1 concentration, albeit to varying degrees. Lower concentration of Shield-1 in general reduced the titer of progeny virus production. Among the viruses with a single fusion, only UL51 and UL52 absolutely required Shield-1 for replication. Other viruses with a single fusion, IE1/2, UL84, UL79, and UL87, could produce detectable progeny virus in the absence of Shield-1. The regulation was tightest when the FKBP derivative was fused to UL51 or UL52.

The growth kinetics of viruses with IE1/2, UL51, IE1/2-UL51 fusions were compared to the parental beMAD virus in the presence or absence of 2 μM of Shld-1. As shown in FIG. 4, in the presence of Shld-1, the single or double fusions had growth kinetics comparable

to the parental beMAD. However, in the absence of Shld-1, only the IE1/2 could replicate, albeit at a lower and slower rate than the parental beMAD.

The tightness of the control of virus replication in the double fusion virus was also tested in different cell types (FIG. 5). These cells included human umbilical vein cells (HUVECs), MRC-5 fibroblasts, aortic smooth muscle cells (AoMCs), skeletal muscle cells (SKMCs) and CCF-STTG1 astrocytoma cells. The cells were infected by the IE1/2-UL51 fusion virus at MOI of 0.01 pfu/cell (except for CCF-STTG1 which was infected with a MOI of 5 pfu/cell), and then incubated in the medium in the presence or absence of Shield-1. All cell types were able to support lytic viral replication in the presence of Shield-1. No virus production was detected in the absence of Shield-1.

Example 4: Immunogenicity of the IE1/2-UL51 double fusion virus in animals

The immunogenicity of the IE1/2-UL51 double fusion virus was evaluated in mice, rabbits and rhesus monkeys. Dose dependent neutralizing response against the IE1/2-UL51 double fusion virus or the parental beMAD virus in mice was first compared (FIG. 6A). Six-week-old female BALB/c mice were immunized at weeks 0 and 4 with beMAD or the IE1/2-UL51 double fusion virus at doses ranging from 0.12 μg to 10 μg. Serum samples from week 6 were collected and analyzed by CMV micro-neutralization assay on ARPE-19 cells as described previously (Tang et al, Vaccine, "A novel throughput neutralization assay for supporting clinical evaluations of human cytomegalovirus vaccines" e-published August 30, 2011 at doi:10.1016/j.vaccine.2011.08.086). The responses were compared at doses of 0.12, 0.37, 1.1, 3.3 and 10 μg. At the low dose range (0.12 to 1.1 μg), the beMAD was slightly more immunogenic with neutralizing antibodies consistently detected when dosage levels were above 0.37 μg. At the high dose range (3.3 and 10 μg), the neutralizing antibody titers induced by the two viruses were comparable.

Next, the immunogenicity of different viruses in rabbits at dose of 10 μg was compared. Female NZW rabbits were immunized at weeks 0, 3 and 8 with 10 μg of beMAD or the indicated fusion viruses. Week 10 sera were collected and analyzed by CMV micro-neutralization assay on ARPE-19 cells (FIG. 5B). The beMAD, single fusion viruses IE1/2 or UL51 and the double fusion virus IE1/2-UL51 could induce significantly higher titers of neutralizing antibodies than MAD169, a virus similar to AD169 and lacking the pentameric gH

complex. This confirmed that expression of the gH complex by the virus significantly increased the immunogenicity of recombinant CMV.

Next, the immunogenicity of 100 μg of the double fusion IE1/2-UL51 virus or the parental beMAD virus was tested in rhesus macaques. Week 12 sera was collected and analyzed by CMV micro-neutralization assay on ARPE-19 cells. The GMT NT50 titers at week 12 (post dose 3) were 11500 or 15600, respectively. These titers were comparable to the NT50 titers seen in naturally infected individuals (FIG. 5C).

The longevity of the double fusion virus IE1/2-UL51 CMV vaccine-induced immune response was demonstrated in rhesus macaques. Animals were vaccinated with either 10 μg/dose or 100 μg/dose double fusion virus IE1/2-UL51 (based on total protein mass). Formulations of 10 μg/dose vaccine with amorphous aluminum hydroxylphosphate sulfate (AAHS) or ISCOMATRIX® adjuvant were also included. Vaccines were administered at weeks 0, 8, and 24 in rhesus macaques (n=5). For comparison, a control group received recombinant gB at 30 μg/dose formulated with MF59 adjuvant at weeks 0, 4 and 24. Geometric means for reciprocal NT50 titers (GMT) for all groups are presented longitudinally (FIG. 7). Prior to vaccination, there was no detectable neutralizing antibody titer >40 for any of the monkeys. Minimal neutralizing activity was detected after the first dose at week 4 for all groups with the neutralizing antibody titers peaking around week 12 and week 28 (four weeks after the second and the third vaccination, respectively). The peak GMT at week 28 for the 100 μg/dose group was 14,500 (about 3-fold higher than the titer of 4,660 for the 10 μg/dose group). ISCOMATRIX® adjuvant, but not AAHS, provided adjuvanting benefit when compared with the 10 μg/dose group. The GMT at week 28 for the ISCOMATRIX® group measured 15,800 whereas the AAHS group was 3,000 and the 10 μg/dose group was 4,660. Minimal neutralizing activity was detected for the control (gB/MF59) group, with the peak GMT never exceeding 200. At study week 72, close to 1 year after completion of the vaccination regimen at weeks 0, 8 and 24, the GMT for the 100 μg/dose group and the ISCOMATRIX® formulation group were maintained at 1400 and 3000, respectively. At this time, the GMT for the 10 μg/dose group and the AAHS group was around 200.

Peripheral blood mononuclear cells (PBMC) from rhesus macaques were collected at week 28 (4 weeks postdose 3) of the vaccination regimen and were evaluated in the IFN-γ ELISPOT assay. Monkeys were vaccinated with either 100 μg/dose (FIG. 8A) or 10

μg/dose (FIGS. 8B-8D) of the double fusion virus IE1/2-UL51. Additionally, the 10 μg/dose was formulated either with no adjuvant (FIG. 8B) or with AAHS (FIG. 8C) or ISCOMATRIX® (FIG. 8D) adjuvant. The antigens of pooled overlapping peptides representing five HCMV antigens were used to stimulate IFN-γ production *ex-vivo*. The HCMV antigens used were IE1 and IE2 (both viral regulatory proteins) and pp65, gB and pp150 (predominant viral structural antigens). Quality of the T-cell responses was assessed by the magnitude (geometric means) of ELISPOT responses as well as the responder rate to viral antigens. Prior to vaccination, there was no antigen-specific ELISPOT titer in any monkey (data not shown).

At week 28, the geometric means for ELISPOT responses to the five HCMV antigens (i.e., IE1, IE2, pp65, gB and pp150) were 186, 132, 253, 87, 257 spot-forming cells (SFC)/10^6 PBMC for the 100 μg/dose group versus 21, 24, 107, 111, 33 SFC/10^6 PBMC for the 10 μg/dose group, respectively (FIGS. 8A and 8B). A responder in each group (n=5) was scored based on cutoff criteria of more than 55 SFC/10^6 PBMC and more than 3-fold rise in antigen-specific response over dimethyl sulfoxide (DMSO) response. The number of responders to the five HCMV antigens (i.e., IE1, IE2, pp65, gB and pp150) were 4, 4, 5, 1, 3 for the 100 μg/dose group versus 1, 1, 5, 4, 0 for the 10 μg/dose group.

The effect of ISCOMATRIX® adjuvant on T- cell responses to a 10 μg/dose of the double fusion virus IE1/2-UL51 is shown in FIG. 8D. Geometric means of ELISPOT responses to the five HCMV antigens (i.e., IE1, IE2, pp65, gB and pp150) were 114, 53, 491, 85, 113 SFC/10^6 PBMC, respectively, and the number of responders in the group (n=5) are 3, 2, 5, 3, 3, respectively. The magnitude and breadth of the T-cells responses in the group with ISCOMATRIX® adjuvant were similar to those in the 100 μg/dose group.

The PBMC from animals vaccinated with either a 10 μg/dose or 100 μg/dose double fusion virus IE1/2-UL51 (based on total protein mass) with ISCOMATRIX® were further analyzed in intracellular cytokine staining after being stimulated with HCMV antigens (pp65, IE1, IE2 or whole HCMV virion). The negative control was one naïve monkey not vaccinated with double fusion virus IE1/2-UL51 while the positive control was staphalococcus enterotoxin B (SEB). FIG. 9 shows that the negative control showed minimal responses to all antigen stimulations but responded to the positive control agent staphalococcus enterotoxin B (SEB) as expected. All ten vaccinated monkeys from both groups responded to HCMV-specific antigens with similar magnitude and patterns. The geometric mean values to each antigen were computed

for all ten monkeys. All monkeys showed comparable CD8+ (FIG. 9A) and CD4+ (FIG. 9B) T-cell responses when their PBMCs were stimulated with CMV antigen peptide pools (i.e., pp65, IE1 and IE2) but preferentially showed CD4+ T-cell responses when stimulated with whole HCMV virions. This was not unexpected since whole virions are protein antigens and are likely processed as exogenous antigens and presented by MHC class II molecules to CD4+ T-cells. The double fusion virus IE1/2-UL51 can elicit T-cell responses of both CD4+ and CD8+ phenotypes, similar to those commonly seen in healthy subjects with HCMV infection.

Different formulations of the double fusion virus IE1/2-UL51 with aluminum salts were compared for theor ability to generate neutralizing antibodies in rhesus macaques (FIG. 10). 30 μg/dose double fusion virus IE1/2-UL51 was formulated with either HNS (base buffer), amorphous aluminum hydroxylphosphate sulfate (AAHS) or Merck Aluminum Phosphate Adjuvant (MAPA) and administered at weeks 0 and 8. Serum samples collected at week 12 showed that although MAPA enhanced the neutralizing antibody induction, the enhancement was not statistically significant (two-tailed unpaired t-test).

Example 5: <u>Identification of Buffers for Storage</u>

The CMV virus in HBSS (Hank's Balanced Salt Solution) and stored at -70 °C until used was diluted ~10x with appropriate buffer. The residual components of the HBSS buffer in each sample included potassium chloride 0.533 mM, potassium phosphate monobasic 0.044 mM, sodium phosphate dibasic 0.034 mM, sodium chloride 13.79 mM, sodium bicarbonate 0.417 mM and glucose 0.1% w/v. The samples were then stored at room temperature or between 2°C-8°C temperatures for 4 days or freeze thawed. For freezing-thawing, the sample was stored at -70 °C for at least 1 hour and thawed at RT for 30 minutes for either one or three cycles. The stability of the samples was tested on day 4 using a viral entry assay. Briefly, the assay was performed using several different sample dilutions to obtain a response curve and EC50 (μg/mL) values were obtained from the viral entry assay results by non-linear curve fitting. Lower EC50 values represent better stability. EC50 values of the stability samples were compared against -70 °C frozen control sample.

Viral entry assay measures the ability of CMV to infect ARPE-19 cells and express IE1 (immediate early protein 1). The assay is performed in transparent 96-well plates. The IE1 specific primary antibodies and biotinylated secondary antibodies are used to detect

target proteins in fixed cells and fluorescent signal from each well is quantified using an IR Dye 800CW Streptavidin together with Sapphire 700/DRAQ5 (for cell input normalization). The results were plotted as 800/700 Integrated Intensity Ratio (Integ. Ratio) vs. CMV concentration (total protein, μg/mL). EC50 values were also obtained from the infectivity assay results using non-linear curve fitting. Since viral infection of ARPE-19 cells relies on integrity of viral glycoprotein antigens, in particular the pentameric gH complex, the EC50 values reflect how well the viral particles are preserved under these conditions.

As shown in FIG. 11, the CMV loses infectivity when stored for four days in HBSS at RT. Moreover, 3 cycles of freezing-thawing in HBSS lead to complete loss of infectivity when assessed by viral entry assay. Thus, HBSS was not an optimal buffer for CMV storage.

The effect of pH on CMV stability at room temperature was examined using the pH range of 3 to 8. The following buffers were utilized: Citrate buffer (25 mM), pH 3.0; Acetate buffer (25 mM), pH 4; Acetate buffer (25 mM), pH 5; Histidine buffer (25 mM), pH 6; HEPES buffer (25 mM), pH 7; Hanks' Balanced Salt Solution (HBSS), pH 7.5 and Tris buffer (25 mM), pH 8.

The samples were prepared by dilution of the viral bulk 10 times with the appropriate buffer. The samples were stored at RT (25 °C) for 4 days. On day 4, the stability of the samples was measured by utilizing the viral entry assay. The CMV in HBSS stored frozen at -70 °C was treated as a control. The UV-Vis spectra for each of the samples were obtained at time 0 and on day 4 to examine the structural changes and aggregation that occurred during storage.

As shown in FIG. 12, 25 mM Histidine buffer at pH 6 provided better stability for CMV by retaining higher infectivity at RT compared to other pH tested. The second derivative of the UV-spectra indicated similar structural profile of the virus at all pHs (data not shown). No significant aggregation was observed at any of the pH tested as measured by optical density at 350 nm (data not shown).

The effect of urea alone or in combination with sodium chloride on CMV virus stability was tested in 25 mM Histidine buffer, pH 6. Addition of 2% urea alone did not have an effect on CMV stability. However, 2% urea in combination with 150 mM NaCl improved the stability of CMV at RT (FIG. 13).

The effect of ionic strength on CMV stability was examined at pH 6. Increasing concentrations of NaCl (0 mM, 75 mM, 150 mM and 320 mM NaCl) were added to 25 mM Histidine buffer at pH 6. The CMV stability was dependent on ionic strength where higher ionic strength led to better stability (FIG. 14). Presence of urea had no or minimal effect on CMV stability (data not shown).

Additionally, several other excipients (sucrose, sorbitol, glycerol, and proline) were screened for their effect on gH expressing CMV stability at room temperature. Exipients to be tested were added to CMV in 25 mm Histidine buffer, pH 6 at room temperature for 4 days before CMV virus stability was measured using a viral entry assay. EC_{50} values were calculated for the samples. Among all the excipients tested, 150 mM NaCl alone or in combination with 9% w/v sucrose provided better stability at pH 6 (data not shown). Therefore, the recommended buffer for CMV storage at RT is 25 mM Histidine (pH 6) with 150 mM NaCl with or without 9% w/v sucrose.

The effect of cryoprotectants on CMV stability during freezing-thawing was investigated. As indicated previously (FIG. 11), CMV in HBSS completely lost its infectivity when subjected to three freezing-thawing cycles. Several cryoprotectants (including sucrose, sorbitol, glycerol) were screened for the ability to diminish the freeze-thaw stress on CMV. For each freeze-thawing cycle, the samples were frozen at -70 °C for at least 1 hour and thawed at RT for 30 minutes. The addition of cryoprotectants led to increased stability of the virus. Moreover, 9% w/v sucrose in combination with 150 mM sodium chloride led to significantly enhanced stability of the virus when compared to other cryoprotectants tested (FIG. 15). Therefore, the recommended buffer composition for CMV storage at -70 °C or up to 3 freezing-thawing cycles is 25 mM Histidine, 150 mM NaCl and 9% sucrose (HNS buffer).

HNS buffer was compared with HBSS buffer for protection of CMV stability during three freeze-thaw cycles, refrigeration (2-8 °C) and RT (25 °C). The HNS buffer provided better stability for CMV live virus at all the storage conditions tested (data not shown).

Example 6: CMV Stability in HNS Buffer

The double fusion IE1/2-UL51 CMV virus stock was supplied in HNS buffer and stored at -70 °C until used. The stability study was performed at a concentration of 100 μg/mL (based on total protein content measured by Bradford assay). The bulk virus was diluted with HNS buffer to obtain the final virus concentration. The samples were then stored at appropriate

temperatures and tested as described for up to 3 months. For freezing-thawing, the samples were frozen at -70 °C for at least 1 hour and thawed at room temperature for 30 minutes. The samples were pulled at different time points and kept stored frozen at -70 °C until analyzed.

Total protein content of the samples was measured using a Bradford assay. The total protein content of the samples did not change over the 3 month period (data not shown).

Particle size of the CMV in the samples over time was monitored by measuring the hydrodynamic diameter of the sample using DLS method. This method monitored any aggregation or disruption of the virus particles over time and at different storage temperatures. No real trending was observed with sporadic changes in the particle size of certain samples (data not shown). The results indicated that the virus particles were intact and not aggregated at elevated temperatures.

Example 7: Effect of Storage Conditions on Viral Entry and Immunogenicity

Significant changes in viral entry titers (EC50 values) were observed by subjecting the CMV samples to different storage temperatures (data not shown). Storage at -20 °C resulted in lower viral entry titers compared to 2-8 °C and 25 °C. The titers of 2-8 °C samples were found to be lower viral entry titers compared to 25 °C storage. Based on the EC50 values the storage temperatures were ranked in the following order (from most stable to least stable): 25 °C > 2-8 °C > -20 °C up to a 1 month time point. The viral entry titers were not detectable at the 3 month time point for the samples stored at -20 °C, 2-8 °C and 25 °C.

A mouse immunogenicity study was initiated at the end of the stability study to determine the effect of storage temperature on the ability of CMV to induce CMV neutralizing antibodies. The mice were immunized with 2.5 μg per dose vaccine i.m. on day 0 and boosted on day 21 followed by bleeding on day 28. The mouse serum was tested for neutralizing antibodies against a gH expressing CMV using ARPE 19 cells and NT50 titers were obtained by non-linear curve fitting.

The effect of storage at different temperatures for 3 months on the IE1/2-UL51 double fusion CMV immunogenicity was evaluated. The NT50 titers were dependent on the storage temperature, with higher temperatures resulting in decreased titers compared to -70 °C frozen control although not significantly ($p=0.2584$, one way ANOVA) (FIG. 16A). The NT50 titer for formulations stored at -20 °C was lower by less than 2-fold, but the viral entry assay titers for these samples were significantly affected compared to -70 °C frozen control. The

trending of NT50 titers for -20 °C, 2-8 °C and 25 °C stability samples follows the CMV mass ELISA titers obtained for these samples.

The effect of storage at different temperatures for 8 hours after thawing on the IE1/2-UL51 double fusion CMV immunogenicity was evaluated. The NT50 titers of the formulations were compared to a -70 °C frozen control. The NT50 titers were not affected (p=0.5865, one way ANOVA) by storing the samples for 8 hours at any of the temperatures tested (FIG. 16B).

The effect of the double fusion IE1/2-UL51 CMV storage at 25 °C for different time points after thawing the samples was evaluated in a mouse immunogenicity study. The NT50 titers of these formulations were compared to a -70 °C frozen control. The NT50 titers were not affected (p=0.1848, unpaired two-tailed t-test) by storing the samples at 25 °C for up to a week. At 3 months, the NT 50 titers dropped by a little over 2-fold indicating possible stability issues of the formulation at 25 °C for longer time (data not shown).

The effect of 3 cycles of freeze-thaw on the double fusion IE1/2-UL51 CMV formulated in HNS buffer was evaluated by mouse immunogenicity. Three cycles of freeze-thaw (F/T) of the double fusion CMV formulation did not affect the immunogenicity (p=0.2103, unpaired two tailed t-test) compared to a -70 °C frozen control (data not shown).

Other embodiments are within the following claims. While several embodiments have been shown and described, various modifications may be made without departing from the spirit and scope of the present invention.

WHAT IS CLAIMED IS:

1. A conditional replication defective cytomegalovirus (CMV) comprising:

(a) a pentameric gH complex comprising of UL128, UL130, UL131, gH and gL; and

(b) a nucleic acid encoding a first fusion protein between an essential protein IE1/2 and a destabilizing protein and a second fusion protein between UL51 and the destabilizing protein, wherein the destabilizing protein is either FK506-binding protein (FKBP) or a FKBP derivative comprising amino acid substitutions F36V and L106P, wherein the wild type IE1/2 and UL51 are no longer present and wherein the CMV is an attenuated strain that has restored gH complex expression due to a repair of a mutation in the UL131 gene.

2. The conditional replication defective CMV of claim 1, wherein the destablisizing protein is a FKBP derivative comprising amino acid substitutions F36V and L106P.

3. The conditional replication defective CMV of claim 1 or 2, wherein

(a) the first fusion protein is SEQ ID NO:1 or an amino acid that is at least 95% identical to SEQ ID NO:1; and

(b) the second fusion protein is SEQ ID NO:3 or an amino acid that is at least 95% identical to SEQ ID NO:3.

4. The conditional replication defective CMV of claim 3, wherein

(a) the first fusion protein is encoded by SEQ ID NO:2 or a nucleic acid that is at least 95% identical to SEQ ID NO:2; and

(b) the second fusion protein is encoded by SEQ ID NO:4 or a nucleic acid that is at least 95% identical to SEQ ID NO:4.

5. The conditional replication defective CMV of any one of claims 1-4, wherein the CMV is AD169 that has restored gH complex expression due to a repair of a mutation in the UL131 gene.

6. A composition comprising the conditional replication defective CMV of any of claims 1-5 and a pharmaceutically acceptable carrier.

7. The composition of claim 6 further comprising an adjuvant.

8. The composition of claims 6 or 7 in an immunological effective amount for use in inducing an immune response against CMV in a patient.

9. The composition of claim 8, wherein the immune response is protective immune response in a patient against CMV infection.

10. The composition of claim 8 or 9, wherein the patient has weakened immunity.

11. The composition of claim 8 or 9, wherein the patient is a human female of childbearing age.

12. Use of a conditional replication defective CMV of any of claims 1-5 in the manufacture of a medicament for inducing a protective immune response in a patient against CMV infection.

13. The conditional replication defective CMV of any of claims 1-5 for use in a medicine to treat CMV infection in a patient.

14. A method of making the conditional replication defective CMV of any of claims 1-5 comprising propagating the recombinant CMV in epithelial cells in the presence of Shield-1.

15. The method of claim 14, wherein the epithelial cells are human pigmented retinal epithelial cells.

16. The method of claim 15, wherein the human retinal pigmented epithelial cells are ARPE-19 cells deposited with the American Type Culture Collection (ATCC) as Accession No. CRL-2302.

17. The method of claim 14, wherein the Shield-1 is present at a concentration of at least 0.5 μM.

18. A composition comprising the conditional replication defective CMV of any of claims 1-5 in a buffer at a pH between 5-7 comprising:

(a) between 15-35 mM Histidine; and

(b) between 100-200 mM NaCl.

19. The composition of claim 18 wherein the buffer comprises 25 mM Histidine with 150 mM NaCl at a pH of 6.

20. The composition of claim 19 further comprising 9% w/v sucrose.