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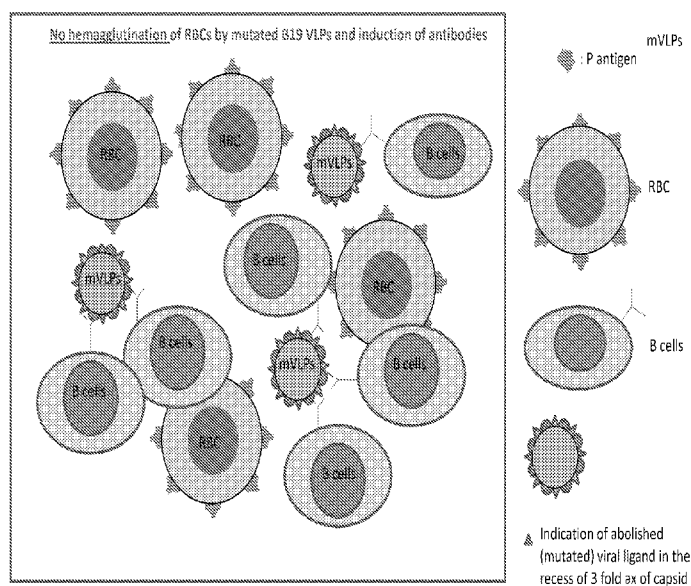
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[Continued on next page]

(54) Title: COMPOSITIONS AND METHODS FOR TREATING, INCLUDING PREVENTING, PARVOVIRUS INFECTIONS
AND RELATED DISEASES

FIG. 6C

Cartoon representation of hamagglutination of red blood cells by B19 mVLPs.



(c) Abundant free mutated B19 VLPs in vivo resulting exposure of neutralizing epitopes on
mutated VLPs and induction of high titer neutralizing antibodies as a consequence

(57) Abstract: Some embodiments of the invention include inventive polypeptides (e.g., mutant VP2 proteins) and virus-like particles made from the inventive polypeptides. Other embodiments of the invention include compositions for treating (e.g., preventing) parvovirus (e.g., erythrovirus or parvovirus B19) infection and other diseases. Further embodiments include methods for administering compositions to an animal. Other embodiments include treating (e.g., preventing) parvovirus (e.g., erythrovirus or parvovirus B19) infection and other diseases. Still other embodiments include nucleic acid sequences that encode the inventive polypeptides. Additional embodiments of the invention are also discussed.



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COMPOSITIONS AND METHODS FOR TREATING, INCLUDING PREVENTING, PARVOVIRUS INFECTIONS AND RELATED DISEASES

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Application
5 No. 61/950,623, filed March 10, 2014 which is herein incorporated by reference in its
entirety.

BACKGROUND

[0002] Parvovirus is the common name used to refer to all of the viruses in the
Parvoviridae family. Erythrovirus is a genus of the Parvoviridae family containing
10 viruses that infect erythrocyte progenitor cells. Erythroviruses and parvoviruses can
infect many animals (e.g., mammals, porcine, canine, feline, primates, monkeys, and
humans). Human erythroviruses contains three genotypes (Servant-Delmas et al., J
Virol. (October 2010) Vol. 84, No. 19, pp. 9658-9665). Genotype 1 includes
parvovirus B19 (also referred to as erythrovirus B19) and two new genotypes with a
15 genetic diversity markedly distinct (>9% nucleotide divergence on the whole genome)
from that of provirus B19. Genotype 2 includes the Lali strain and the A6 strain,
genotype 3a the V9 strain, and genotype 3b the D91.1 strain. In certain instances, the
clinical spectrum associated with genotype 2 or 3 virus infection can be similar to that
observed with parvovirus B19, a genotype 1, infection.

20 [0003] Parvovirus B19 (a species of the erythrovirus genus) can cause severe
and sometimes fatal diseases in fetuses and newborns, such as hydrops fetalis,
intrauterine fetal death and erythema infectiosum (fifth disease) in children. Older
human children and adults with either hereditary diseases (e.g., sickle cell anemia or
Thalassemia) or acquired diseases (e.g., malaria or anemia) are at risk for developing
25 parvovirus B19-induced red cell aplasia or death. Chronic anemia in

immunodeficient, organ transplant, or HIV patients has contributed to parvovirus B19 infection. A cellular receptor for parvovirus B19 is the blood group P antigen, a globoside, that is expressed in erythroid precursors and maintained on mature red blood cells (RBCs). To date, no vaccine is available to prevent human erythrovirus, including parvovirus B19 infection. Accordingly, some embodiments of the present invention include treating (e.g., preventing or vaccinating against) erythrovirus infection (e.g., parvovirus B19 infection and other erythroviruses).

[0004] Some embodiments of the invention include inventive polypeptides (e.g., mutant VP2 proteins) and virus-like particles made from the inventive polypeptides. Other embodiments of the invention include compositions for treating (e.g., preventing) erythrovirus infections, including parvovirus B19 infection and other diseases. Further embodiments include methods for treating active erythrovirus infections, including active parvovirus B19 infection and other diseases. Still other embodiments include nucleic acids that encode the inventive polypeptides.

Additional embodiments of the invention are also discussed herein.

SUMMARY

Some embodiments of the present invention include a polypeptide comprising a VP2 polypeptide with at least one amino acid modification relative to wild type VP2. In some instances, at least one amino acid modification is an insertion, a deletion, or a substitution. In other instances, the wild type VP2 has the amino acid sequence of SEQ ID NO: 1. In certain embodiments, the polypeptide forms an mVLP, which can, in some examples, have a reduced binding capacity to P antigen relative to wtVLP. In other embodiments, an amino acid modification is in or near the recess of the three-fold axis. In yet other embodiments, an amino acid modification is selected from a substitution in loop 3, a substitution in loop 4, a substitution upstream of loop 3, a

substitution upstream of loop 4, or combinations thereof. In still other embodiments, the amino acid modification is a substitution at Y401, a substitution at Q399, a substitution at Q400, a substitution at Q404, a substitution at Q368, a substitution at Q369, a substitution at Y392, or combinations thereof. The amino acid modification can also, in some instances, be Y401F, Y401W, Y401A, Q368A, Q369A, Q368N, Q369N, Q399N, Q400N, Q404T, Y392A, Y392F, Q404N, Y401P, T402A, D403A, Q404A, or combinations thereof. In some embodiments, the wild type VP2 is a wild type VP2 from parvovirus B19. In some aspects, the polypeptide is selected from construct A, construct B, construct C, construct D, construct E, construct F, construct G, construct H, construct I, construct J, construct K, construct L, construct M, construct N, construct O, construct P, construct Q, construct R, construct S, construct T, construct U, construct V, construct W, and construct X. In other embodiments, the polypeptide sequence has at least 90% identity to SEQ ID NO: 1.

[0005] In some embodiments of the invention, mVLP comprises any mutant VP2 as described herein. In other embodiments, the mVLP has reduced binding to P antigen compared to wtVLP, the mVLP has no detectable binding to P antigen, the mVLP has reduced hemagglutination of red blood cells compared to wtVLP, or the mVLP has no detectable hemagglutination. In still other embodiments, the mVLP has one or more neutralizing epitopes. In yet further embodiments, the mVLP induces the production of antibodies (e.g., a high titer of antibodies) in an animal, where the antibodies produced are capable of reducing or inhibiting hemagglutination by wtVLP.

[0006] Some embodiments of the invention include a composition comprising any mVLP as described herein. The composition, in some instances, includes an amount of mVLP from about 0.0001% (by weight total composition) to about 99%.

The composition can further comprise an adjuvant or a carrier, in some embodiments.

Aspects of the invention also include pharmaceutical compositions comprising any mVLP as described herein. In some embodiments, pharmaceutical compositions can include an amount of mVLP from about 0.0001% (by weight total composition) to

5 about 50%. In certain instances, the pharmaceutical compositions can further comprising an adjuvant or a carrier. In certain embodiments, the vaccine comprises any mVLP as described herein. In some embodiments, the vaccine can include an amount of mVLP from about 0.0001% (by weight total composition) to about 50%.

In other instances, the vaccine further comprises an adjuvant or a carrier. In certain
10 embodiments, the vaccine further comprises squalene, IL-2, RIBI adjuvant system, QS21, GM-CSF, alum hydro gel, monophosphoryl lipid A, trehalose dimycolate, Toll-like receptor ligands, Toll-like receptor agonists, CpG oligodeoxynucleotides, cell wall skeleton, adjuplex vaccine adjuvant, MF59, titermax, or combinations thereof. In still other embodiments, the vaccine does not comprise an adjuvant.

15 [0007] Some embodiments of the invention include methods for providing an animal with an mVLP comprising one or more administrations of one or more compositions comprising any mVLP described herein, where the compositions may be the same or different if there is more than one administration. In certain aspects, the one or more compositions do not comprise an adjuvant. In other aspects, the one
20 or more compositions further comprise a carrier, an adjuvant, squalene, IL-2, RIBI adjuvant system, QS21, GM-CSF, alum hydro gel, monophosphoryl lipid A, trehalose dimycolate, Toll-like receptor ligands, Toll-like receptor agonists, CpG oligodeoxynucleotides, cell wall skeleton, adjuplex vaccine adjuvant, MF59, titermax, or combinations thereof. In other embodiments, the one or more compositions
25 comprise (a) any composition described herein, (b) any pharmaceutical composition

described herein, or (c) any vaccine described herein. In still other embodiments, one or more administration can comprise parenteral administration, a mucosal administration, intravenous administration, subcutaneous administration, topical administration, intradermal administration, oral administration, sublingual administration, intranasal administration, or intramuscular administration. In some instances, if there is more than one administration at least one composition used for at least one administration is different from the composition of at least one other administration. In yet other embodiments, the mVLP of at least one of the one or more compositions is administered to the animal in an amount of from about 0.01 mg of mVLP/kg animal body weight to about 15 mg of mVLP/kg animal body weight. The animal is a human or a primate, in certain instances.

[0008] Some embodiments of the invention include methods for treating an animal for a parvovirus infection, a disease related to a parvovirus infection, an erythrovirus infection, a disease related to an erythrovirus infection, a parvovirus B19 infection, or a disease related to a parvovirus B19 infection, comprising one or more administrations of one or more compositions comprising any mVLP as described herein, wherein the compositions may be the same or different if there is more than one administration. In certain aspects, the one or more compositions do not comprise an adjuvant. In other aspects, the one or more compositions further comprise a carrier, an adjuvant, squalene, IL-2, RIBI adjuvant system, QS21, GM-CSF, alum hydro gel, monophosphoryl lipid A, trehalose dimycolate, Toll-like receptor ligands, Toll-like receptor agonists, CpG oligodeoxynucleotides, cell wall skeleton, adjuplex vaccine adjuvant, MF59, titermax, or combinations thereof. In other embodiments, the one or more compositions comprise (a) any composition described herein, (b) any pharmaceutical composition described herein, or (c) any vaccine described herein. In

still other embodiments, one or more administration can comprise parenteral administration, a mucosal administration, intravenous administration, subcutaneous administration, topical administration, intradermal administration, oral administration, sublingual administration, intranasal administration, or intramuscular administration.

5 In some instances, if there is more than one administration at least one composition used for at least one administration is different from the composition of at least one other administration. In yet other embodiments, the mVLP of at least one of the one or more compositions is administered to the animal in an amount of from about 0.01 mg of mVLP/kg animal body weight to about 15 mg of mVLP/kg animal body
10 weight. The animal is a human or a primate, in certain instances. In other embodiments, the animal is in need of the treatment. Some embodiments include methods for treating an animal for an erythrovirus infection, a disease related to an erythrovirus infection, a parvovirus B19 infection, or a disease related to a parvovirus B19 infection. While still other embodiments the method is for treating an erythrovirus
15 infection, a parvovirus B19 infection, a disease related to an erythrovirus infection, a disease related to parvovirus B19 infection, hydrops fetalis intrauterine fetal death, erythema infectiosum (i.e., fifth disease), sickle cell anemia, Thalassemia, anemia, anemia induced by malaria, parvovirus B19-induced red cell aplasia (TRCA), chronic anemia, acute arthropathy, persistent arthropathy, aplastic crisis, arthritis, hepatitis,
20 myocarditis, hepatosplenomegaly, systemic lupus erythematosus, meningencephalitis, or fibromyalgia. In some embodiments, the method induces an immune response, is a vaccination, is a prophylactic treatment, is a therapeutic treatment, or is a combination thereof.

[0009] Some aspects of the present invention include methods for inducing an
25 immune response in an animal comprising one or more administrations of one or

more compositions comprising any mVLP disclosed herein, wherein the compositions may be the same or different if there is more than one administration. In certain aspects, the one or more compositions do not comprise an adjuvant. In other aspects, the one or more compositions further comprise a carrier, an adjuvant, squalene, IL-2, 5 RIBI adjuvant system, QS21, GM-CSF, alum hydro gel, monophosphoryl lipid A, trehalose dimycolate, Toll-like receptor ligands, Toll-like receptor agonists, CpG oligodeoxynucleotides, cell wall skeleton, adjuplex vaccine adjuvant, MF59, titermax, or combinations thereof. In other embodiments, the one or more compositions comprise (a) any composition described herein, (b) any pharmaceutical composition 10 described herein, or (c) any vaccine described herein. In still other embodiments, one or more administration can comprise parenteral administration, a mucosal administration, intravenous administration, subcutaneous administration, topical administration, intradermal administration, oral administration, sublingual administration, intranasal administration, or intramuscular administration. In some 15 instances, if there is more than one administration at least one composition used for at least one administration is different from the composition of at least one other administration. In yet other embodiments, the mVLP of at least one of the one or more compositions is administered to the animal in an amount of from about 0.01 mg of mVLP/kg animal body weight to about 15 mg of mVLP/kg animal body weight. 20 The animal is a human or a primate, in certain instances. In other embodiments, the animal is in need of the treatment. In still other embodiments, the method prevents or ameliorates future infections.

[0010] Some embodiments of the present invention include methods for vaccinating an animal against a parvovirus infection, an erythrovirus infection, or a 25 parvovirus B19 infection, comprising one or more administrations of one or more

compositions comprising any mVLP disclosed herein, wherein the compositions may be the same or different if there is more than one administration. In certain aspects, the one or more compositions do not comprise an adjuvant. In other aspects, the one or more compositions further comprise a carrier, an adjuvant, squalene, IL-2, RIBI adjuvant system, QS21, GM-CSF, alum hydro gel, monophosphoryl lipid A, trehalose dimycolate, Toll-like receptor ligands, Toll-like receptor agonists, CpG oligodeoxynucleotides, cell wall skeleton, adjuplex vaccine adjuvant, MF59, titermax, or combinations thereof. In other embodiments, the one or more compositions comprise (a) any composition described herein, (b) any pharmaceutical composition described herein, or (c) any vaccine described herein. In still other embodiments, one or more administration can comprise parenteral administration, a mucosal administration, intravenous administration, subcutaneous administration, topical administration, intradermal administration, oral administration, sublingual administration, intranasal administration, or intramuscular administration. In some instances, if there is more than one administration at least one composition used for at least one administration is different from the composition of at least one other administration. In yet other embodiments, the mVLP of at least one of the one or more compositions is administered to the animal in an amount of from about 0.01 mg of mVLP/kg animal body weight to about 15 mg of mVLP/kg animal body weight.

The animal is a human or a primate, in certain instances. In other embodiments, the animal is susceptible to a parvovirus infection, an erythrovirus infection, or a parvovirus B19 infection. In still other embodiments, the method is for vaccinating against an erythrovirus infection or a parvovirus B19 infection. In yet other embodiments, the method prevents or ameliorates future infections or future diseases.

[0011] Some embodiments of the present invention include methods for producing any polypeptide as described herein comprising, culturing the host cell transfected with a vector comprising a nucleic acid sequence encoding the polypeptide, to provide expression; and then recovering the polypeptide. In certain
5 embodiments, preparing the vector comprises reverse transcription using RNA or de novo synthesis. In other aspects, the host cell is an insect cell (e.g., an Sf9 cell) or a mammalian cell. Other embodiments include the nucleic acid sequence encoding the polypeptide being selected from the group consisting of SEQ ID NO: 3; SEQ ID NO: 4; SEQ ID NO: 5; SEQ ID NO: 6; SEQ ID NO: 7; SEQ ID NO: 8; SEQ ID NO: 9;
10 SEQ ID NO: 10; SEQ ID NO: 11; SEQ ID NO: 12; SEQ ID NO: 13; SEQ ID NO: 14; SEQ ID NO: 15; SEQ ID NO: 16; SEQ ID NO: 17; SEQ ID NO: 18; SEQ ID NO: 19; SEQ ID NO: 20; SEQ ID NO: 21; SEQ ID NO: 22; SEQ ID NO: 23; SEQ ID NO: 24; SEQ ID NO: 25; and SEQ ID NO: 26.

[0012] Some embodiments of the present invention include methods for
15 producing any mVLP as described herein comprising, culturing a host cell transfected with a vector comprising a nucleic acid sequence encoding an inventive polypeptide, to provide expression of the inventive polypeptide; and then recovering the mVLP. In certain embodiments, preparing the vector comprises reverse transcription using RNA or de novo synthesis. In other aspects, the host cell is an insect cell (e.g., an Sf9 cell)
20 or a mammalian cell. Other embodiments include the nucleic acid sequence encoding the polypeptide being selected from the group consisting of SEQ ID NO: 3; SEQ ID NO: 4; SEQ ID NO: 5; SEQ ID NO: 6; SEQ ID NO: 7; SEQ ID NO: 8; SEQ ID NO: 9; SEQ ID NO: 10; SEQ ID NO: 11; SEQ ID NO: 12; SEQ ID NO: 13; SEQ ID NO: 14; SEQ ID NO: 15; SEQ ID NO: 16; SEQ ID NO: 17; SEQ ID NO: 18; SEQ ID NO:

19; SEQ ID NO: 20; SEQ ID NO: 21; SEQ ID NO: 22; SEQ ID NO: 23; SEQ ID NO: 24; SEQ ID NO: 25; and SEQ ID NO: 26.

[0013] Some embodiments of the present invention include nucleic acid molecules encoding any polypeptide described herein. In other embodiments, the nucleic acid sequence encoding the polypeptide is selected from the group consisting of SEQ ID NO: 3; SEQ ID NO: 4; SEQ ID NO: 5; SEQ ID NO: 6; SEQ ID NO: 7; SEQ ID NO: 8; SEQ ID NO: 9; SEQ ID NO: 10; SEQ ID NO: 11; SEQ ID NO: 12; SEQ ID NO: 13; SEQ ID NO: 14; SEQ ID NO: 15; SEQ ID NO: 16; SEQ ID NO: 17; SEQ ID NO: 18; SEQ ID NO: 19; SEQ ID NO: 20; SEQ ID NO: 21; SEQ ID NO: 22; SEQ ID NO: 23; SEQ ID NO: 24; SEQ ID NO: 25; and SEQ ID NO: 26. While in other embodiments, the nucleic acid sequence has at least 90% identity to SEQ ID NO: 2. In still other embodiments, the nucleic acid molecule is in a cell, an insect cell, a mammalian cell, a human cell, or an Sf9 insect cell. In still other embodiments, the nucleic acid molecule is included in a vector or plasmid. Some embodiments of the present invention include a vector comprising a nucleic acid molecule encoding any polypeptide described herein.

[0014] Other embodiments of the invention are also discussed herein.

BRIEF DESCRIPTION OF THE DRAWINGS

[0015] The following drawings form part of the present specification and are included to further demonstrate certain aspects of the present invention. The invention may be better understood by reference to one or more of these drawings in combination with the description of specific embodiments presented herein.

[0016] **FIG. 1: An example of the predicted effect of mutations on the P antigen binding pocket located at the recess of the three-fold axis. (A)** Using the

X-ray crystal structure of Kaufmann et al. 2004 (PNAS, August 4, 2004, Vol. 101, No. 32, pp. 11628-11633), the whole B19 capsid is displayed with three tyrosines shown with space filling. **(B)** The P-antigen binding site from FIG. 1A is expanded with some tyrosines shown with space filling (KEYQQ is shown in red, TYFPN is shown in yellow, and QQYTDQ is shown in green). **(C)** The predicted P-antigen binding pocket of B19 wild type VLPs (QQY₄₀₁TDQ) is shown. **(D)** The predicted modified structure of P-antigen binding pocket of B19 mVLP with mutation Y₄₀₁ to F₄₀₁ (Construct A) is shown; one of three mutated residues from the three-fold axis is circled.

10 [0017] **FIG. 2: Electron micrographs of B19 wtVLPs and mVLPs.** All electron micrographs have a magnification of approximately 72,000X to 75,000X. **(A)** A micrograph of wild type VLPs. In the example section, wild type VLP is made only with wild type B19 VP2 proteins; no other proteins are included. In the example section, wild type B19 VLP is designated wtVLP and is also referred to as wild type B19 VLP. **(B)** A micrograph of mVLPs made with Construct A. In the example section, mutated VLP is designated mVLP and is also referred to as mutant VLP and mutated B19 VLP. **(C)** A micrograph of mVLPs made with Construct B. **(D)** A micrograph of mVLPs made with Construct D. **(E)** A micrograph of mVLPs made with Construct E. **(F)** A micrograph of mVLPs made with Construct F. **(G)** A micrograph of mVLPs made with Construct F. **(H)** A micrograph of mVLPs made with Construct G. **(I)** A micrograph of mVLPs made with Construct H. mVLPs made with constructs A, B, F, or G were morphologically identical to wtVLPs.

20 [0018] **FIG. 3: Hemagglutination assays using Type O human red blood cells.** Hemagglutination assays (HA) were performed to determine binding capacity

to P antigen. C-: Control negative for HA, ADPBS [albumin-dextrose PBS] was added instead of wtVP2 or mVLP. C+: Control positive for HA, wtVLP was added.

[0019] **FIG. 4: Hemagglutination inhibition assays (HIA) of rabbit and mouse polyclonal antibodies against VLPs.** Hemagglutination inhibition assays

5 (HIA) were used to determine the inhibition of hemagglutination by polyclonal antibodies raised against wtVLPs or mVLPs in mice and rabbits.

[0020] **FIG. 5: A cartoon representation of P antigen binding.** Without wishing to be bound by any theory or mechanism implied by the cartoon, this cartoon shows an embodiment of binding (or absence thereof) to the P antigen on the red
10 blood cell surface by the B19 virion, a B19 wtVLP, and a representative embodiment of a B19 mVLP.

[0021] **FIG. 6: Cartoon representations of hemagglutination.**

(A) Without wishing to be bound by any theory or mechanism implied by the cartoon, this cartoon shows an embodiment of the reaction that could occur between B19
15 infectious virus and red blood cells (RBCs) to form hemagglutination which may occur in vivo. (B) Without wishing to be bound by any theory or mechanism implied by the cartoon, this cartoon shows an embodiment of the reaction that could occur between wild type B19 VLPs maintaining ligand capable of binding to P antigen on RBCs so that RBCs aggregate and preclude presentation of B19 VLPs to B cells. (C)
20 Without wishing to be bound by any theory or mechanism implied by the cartoon, this cartoon shows an embodiment of the reaction that could occur between B19 mVLPs due to an absence of binding to P antigen on RBCs; this could result in abundance of free B19 mVLPs that can be presented to B cells.

DETAILED DESCRIPTION

[0022] Parvovirus is the common name used to refer to all of the viruses in the Parvoviridae family. Erythrovirus is a genus of the Parvoviridae family containing viruses that infect erythrocyte progenitor cells. Erythroviruses and parvoviruses can infect many animals (e.g., mammals, porcine, canine, feline, primates, monkeys, and humans). Human erythroviruses contains three genotypes (Servant-Delmas et al., J Virol. (October 2010) Vol. 84, No. 19, pp. 9658-9665). Genotype 1 includes parvovirus B19 (also referred to as erythrovirus B19) and two new genotypes with a genetic diversity markedly distinct (>9% nucleotide divergence on the whole genome) from that of provirus B19. Genotype 2 includes the Lali strain and the A6 strain, genotype 3a the V9 strain, and genotype 3b the D91.1 strain. In certain instances, the clinical spectrum associated with genotype 2 or 3 virus infection can be similar to that observed with parvovirus B19, a genotype 1, infection. Parvoviruses appear to have between 2-4 polypeptides including VP1 and VP2 capsid polypeptides; erythroviruses also appear to have a VP2 capsid polypeptide. Parvovirus B19 includes in its capsid a VP2 polypeptide.

[0023] Parvovirus B19 consists of approximately 5.6 kb single-stranded genomic DNA (NCBI reference sequence NC_000883.2) that encodes one nonstructural protein (NS1), two structural proteins (VP1 and VP2), and 7.5 and 11 KD proteins. Genes spanning from nt 2624 to nt 4969 encode VP1 (minor) and VP2 (major) capsid proteins. VP2 protein (58KD) overlaps C-terminus of VP1, and is composed of at least 95% of capsid. VP1 protein (81KD) is 227 amino acids longer than VP2 and consists of only 5% of capsid proteins. P antigen is a cellular receptor of Parvovirus B19; Ku80 autoantigen and $\alpha 5\beta 1$ integrin are co-receptors for the entry of Parvovirus B19 into cells. In some instances (e.g., see FIG. 5 and FIG. 6), P

antigen binding by parvovirus B19 can result in hemagglutination and thus can block access of B cells to parvovirus B19; this lack of access can, in some instances, prevent an immune response.

[0024] Inventive Polypeptides, Nucleic Acid Molecules, and Compositions

5 [0025] Some embodiments of the invention include inventive polypeptides comprising a VP2 polypeptide, where the VP2 polypeptide has at least one amino acid modification relative to wild type VP2 (“wtVP2”). The term “VP2 polypeptide” encompasses mutant VP2 polypeptides (e.g., with one or more modifications made to a wtVP2 polypeptide) and wtVP2 polypeptides. A wtVP2 polypeptide can, in some
10 embodiments, be a wild type VP2 polypeptide from a parvovirus, a wild type VP2 polypeptide from an erythrovirus, or a wild type VP2 polypeptide from a parvovirus B19. One or more modifications, in some instances, can include an insertion, a deletion, a substitution, or combinations thereof. In some embodiments, one or more modifications to wtVP2 can be in or near (e.g., near can be a distance of about 5Å,
15 about 10Å, about 15Å, about 20Å, about 25Å, about 30Å, about 35Å, about 40Å, about 45Å, about 50Å, less than about 50Å or less than about 30Å) the recess of the three-fold axis in a VLP formed by the inventive polypeptide. One or more modifications to wtVP2, in some aspects, can include a substitution in loop 3, a deletion in loop 3, a substitution in loop 4, a deletion in loop 4, a substitution
20 upstream of loop 3, a deletion upstream of loop 3, a substitution upstream of loop 4, a deletion upstream of loop 4, or combinations thereof. In some embodiments, the inventive polypeptide does not encompass a naturally occurring polypeptide.

[0026] The term “upstream” as used herein, unless otherwise indicated, refers to an amino acid position relative to the referenced amino acid or secondary structure
25 in wtVP2 (e.g., upstream of amino acid 398 or upstream of loop 3); the relative

position can be 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, or 35 amino acids away from the referenced amino acid or secondary structure. The relative position can be from about 1 to about 35, from about 5 to about 30, from about 10 to about 25, from about 12 to about 20, or from about 14 to about 18 amino acids away from the referenced amino acid or secondary structure. The relative position can be at least about 1, at least about 5, at least about 10, at least about 20, no more than about 20, no more than about 25, no more than about 30, or no more than about 35 amino acids away from the referenced amino acid or secondary structure.

10 [0027] In some embodiments, one or more modifications to wtVP2 can include a substitution or deletion to one or more amino acids exposed (e.g., accessible to interact with other molecules) or partially exposed on the outer surface of the capsid of a wtVLP or a virion such as B19 virion (e.g., at a P antigen binding site). In some embodiments, one or more modifications to wtVP2 can include a substitution or deletion to GLN43, LEU45, ILE46, PRO47, TYR48, ASP49, PRO50, GLU51, 15 HIS52, HIS53, TYR54, LYS55, VAL56, PHE57, PRO59, ALA60, ALA61, SER62, SER63, CYS64, HIS65, ASN66, ALA67, SER68, GLY69, LYS70, GLU71, ALA72, LYS73, VAL74, CYS75, THR76, ILE77, THR78, ILE80, SER84, THR85, PRO86, ASP130, VAL131, THR132, ASP133, LYS134, THR135, GLY136, GLY137, 20 GLY138, VAL139, GLN140, VAL141, THR142, ASP143, ASP168, THR169, LEU170, ALA171, PRO172, GLU173, LEU174, PRO175, ILE176, TRP177, VAL178, TYR179, PHE180, PRO182, GLN183, LEU187, VAL189, GLY190, ASP191, VAL192, ASN193, THR194, GLN195, GLY196, ILE197, SER198, GLY199, ASP200, SER201, LYS202, LYS203, LEU204, SER206, GLU207, 25 GLU208, PHE211, ASN241, GLU243, CYS245, HIS248, TYR250, GLU251,

TYR253, PRO255, LEU256, TYR257, GLY258, ARG260, GLY262, VAL263,
 PRO264, ASP265, THR266, LEU267, GLY268, GLY269, PRO271, PHE273,
 ARG274, SER275, LEU276, THR277, HIS278, GLU279, ASP280, HIS281,
 ALA282, ILE283, GLN284, SER298, THR299, LYS300, GLU301, GLY302,
 5 ASP303, SER304, SER305, ASN306, THR307, GLY308, ALA309, GLY310,
 LYS311, ALA312, LEU313, THR314, LEU316, SER321, GLN322, ASN323,
 THR324, ARG325, ILE326, SER327, HIS338, HIS339, TRP340, ASP341, THR342,
 ASP343, LYS344, TYR345, VAL346, THR347, ILE349, HIS354, GLY355,
 GLN356, THR357, THR358, TYR359, GLY360, ASN361, ALA362, GLU363,
 10 ASP364, LYS365, GLU366, TYR367, GLN368, GLN369, GLY370, VAL371,
 PHE374, PRO375, ASN376, GLU377, LYS378, GLU379, LEU381, GLN383,
 LEU384, GLN385, GLY386, ASN388, MET389, HIS390, TYR392, PHE393,
 PRO394, ASN395, LYS396, GLY397, THR398, GLN399, GLN400, TYR401,
 THR402, ASP403, GLN404, ILE405, GLU406, ASN416, ARG417, ALA419,
 15 GLU423, LYS459, ILE460, PRO462, SER464, PRO466, ILE467, GLY468,
 GLY469, ILE470, LYS471, SER472, MET473, GLY474, ILE475, THR476,
 THR477, LEU478, VAL479, TYR481, ARG502, TRP503, GLN506, PRO507,
 GLY508, VAL509, TYR510, PRO512, HIS513, ALA514, ALA515, GLY516,
 HIS517, LEU518, LEU522, TYR523, ASP524, PRO525, THR526, ALA527,
 20 THR528, ASP529, ALA530, LYS531, GLN532, HIS533, HIS534, ARG535,
 GLY537, TYR538, GLU539, LYS540, PRO541, GLU542, GLU543, LEU544,
 TRP545, THR546, LYS548, SER549, ARG550, VAL551, HIS552, PRO553,
 LEU554, or combination thereof.

[0028] In some embodiments, one or more modifications can occur at a
 25 wtVP2 (e.g., a B19 wtVP2) binding site or a virion (e.g., B19 virion) binding site,

such as a P antigen binding site. In some instances, one or more modifications to wtVP2 can include a substitution at Y401, a deletion at Y401, a substitution at Q399, a deletion at Q399, a substitution at Q400, a deletion at Q400, a substitution at Q404, a deletion at Q404, a substitution at Q368, a deletion at Q368, a substitution at Q369, a deletion at Q369, a substitution at Y392, a deletion at Y392, or combinations thereof. In yet other embodiments, one or more modifications to wtVP2 can include Y401F, Y401W, Y401A, Q368A, Q369A, Q368N, Q369N, Q399N, Q400N, Q404T, Y392A, Y392F, Q404N, Y401P, T402A, D403A, Q404A, or combinations thereof. In still other embodiments, the inventive polypeptide is construct A, construct B, construct C, construct D, construct E, construct F, construct G, construct H, construct I, construct J, construct K, construct L, construct M, construct N, construct O, construct P, construct Q, construct R, construct S, construct T, construct U, construct V, construct W, or construct X (see Table 1).

[0029] In some embodiments, the inventive polypeptide can have a polypeptide sequence with an amino acid sequence identity to wtVP2 of about 90%, about 91%, about 92%, about 93%, about 94%, about 95%, about 96%, about 97%, about 98%, about 99%, about 99.1%, about 99.2%, about 99.3%, about 99.4%, about 99.5%, about 99.6%, about 99.7%, about 99.8%, about 99.9%, about 99.95%, about 99.99%, less than about 100%, at least about 90%, at least about 95%, at least about 99%, or at least about 99.5%. In some embodiments, the inventive polypeptide sequence has an amino acid sequence identity to SEQ ID NO: 1 of about 90%, about 91%, about 92%, about 93%, about 94%, about 95%, about 96%, about 97%, about 98%, about 99%, about 99.1%, about 99.2%, about 99.3%, about 99.4%, about 99.5%, about 99.6%, about 99.7%, about 99.8%, about 99.9%, about 99.95%, about 99.99%, less than about 100%, at least about 90%, at least about 95%, at least about

99%, or at least about 99.5%. The amino acid sequence identity (e.g., percent identity) can be determined by any suitable method, such as using BLAST, BLAST-2, ALIGN, ALIGN-2, or Megalign software. Unless otherwise indicated, the amino acid sequence identity (e.g., percent identity) is determined using BLAST-2.

5 [0030] In some embodiments, mVLP made from the inventive polypeptide has a reduced binding capacity to P antigen relative to wtVLP. In other embodiments, the mVLP made from the inventive polypeptide has no measurable binding to P antigen.

[0031] Some embodiments of the invention include nucleic acid molecules that can encode for the inventive polypeptide. In certain embodiments, the nucleic acid molecule is included in a vector or a plasmid. In certain embodiments, the nucleic acid molecule is in a cell, such as an insect (e.g., Sf9) or mammalian cell (e.g., CHO or HEK).

[0032] In some embodiments, the nucleic acid molecule sequence has a sequence identity to wtVP2 of about 90%, about 91%, about 92%, about 93%, about 94%, about 95%, about 96%, about 97%, about 98%, about 99%, about 99.1%, about 99.2%, about 99.3%, about 99.4%, about 99.5%, about 99.6%, about 99.7%, about 99.8%, about 99.9%, about 99.95%, about 99.99%, less than about 100%, at least about 90%, at least about 95%, at least about 99%, or at least about 99.5%. In some embodiments, the nucleic acid molecule sequence has a sequence identity to SEQ ID NO: 2 of about 90%, about 91%, about 92%, about 93%, about 94%, about 95%, about 96%, about 97%, about 98%, about 99%, about 99.1%, about 99.2%, about 99.3%, about 99.4%, about 99.5%, about 99.6%, about 99.7%, about 99.8%, about 99.9%, about 99.95%, about 99.99%, less than about 100%, at least about 90%, at least about 95%, at least about 99%, or at least about 99.5%. The nucleic acid sequence identity (e.g., percent identity) can be determined by any suitable method,

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such as using BLAST, BLAST-2, ALIGN, ALIGN-2, or Megalign software. Unless otherwise indicated, the nucleic acid sequence identity (e.g., percent identity) is determined using BLAST-2.

[0033] In some embodiments, the nucleic acid molecule encodes for an inventive polypeptide that has one or more modifications to wtVP2 which can be in or near (e.g., near can be a distance of about 5Å, about 10Å, about 15Å, about 20Å, about 25Å, about 30Å, about 35Å, about 40Å, about 45Å, about 50Å, less than about 50Å or less than about 30Å) the recess of the three-fold axis in a VLP formed by the inventive polypeptide. The nucleic acid molecule encodes for an inventive polypeptide that has one or more modifications to wtVP2, in some aspects, which can include a substitution in loop 3, a deletion in loop 3, a substitution in loop 4, a deletion in loop 4, a substitution upstream of loop 3, a deletion upstream of loop 3, a substitution upstream of loop 4, a deletion upstream of loop 4, or combinations thereof. In some instances, the nucleic acid molecule encodes for an inventive polypeptide that has one or more modifications to wtVP2 that can include a substitution at Y401, a deletion at Y401, a substitution at Q399, a deletion at Q399, a substitution at Q400, a deletion at Q400, a substitution at Q404, a deletion at Q404, a substitution at Q368, a deletion at Q368, a substitution at Q369, a deletion at Q369, a substitution at Y392, a deletion at Y392, or combinations thereof. In yet other embodiments, the nucleic acid molecule encodes for an inventive polypeptide that has one or more modifications to wtVP2 which can include Y401F, Y401W, Y401A, Q368A, Q369A, Q368N, Q369N, Q399N, Q400N, Q404T, Y392A, Y392F, Q404N, Y401P, T402A, D403A, Q404A, or combinations thereof. In still other embodiments, the nucleic acid molecule encodes for an inventive polypeptide that is construct A, construct B, construct C, construct D, construct E, construct F, construct G, construct

H, construct I, construct J, construct K, construct L, construct M, construct N, construct O, construct P, construct Q, construct R, construct S, construct T, construct U, construct V, construct W, or construct X (see Table 1).

[0034] As modifications or changes may be made in the structure of the nucleic acid molecules and/or polypeptides of the present invention, while obtaining molecules having similar or improved characteristics, such biologically functional equivalents are also encompassed within some embodiments of the present invention. In certain instances, the biological functional equivalent may comprise a nucleic acid that has been engineered to contain distinct sequences while at the same time retaining the capacity to encode the desired inventive polypeptide. This can be accomplished owing to the degeneracy of the genetic code (i.e., the presence of multiple codons) which encode for the same amino acids. In one example, one of ordinary skill in the art may wish to introduce a restriction enzyme recognition sequence into a nucleic acid sequence while not disturbing the ability of that polynucleotide to encode a protein.

[0035] In another example, a nucleic acid molecule can be engineered to contain certain sequences that result in (and encode) a biological functional equivalent with more significant changes. In some embodiments, certain amino acids may be substituted for other amino acids in a protein structure without appreciable loss of desired function such as, for example, inter-molecular interaction among mutated VP2 proteins, mVLP formation, reduction in P-antigen binding by the mVLP, reduction of hemagglutination by the mVLP, neutralizing epitopes in the mVLP, or induction of antibodies by neutralizing epitopes in the mVLP. So-called “conservative” changes do not disrupt the desired biological activity of the protein, as the structural change is not one that impinges on the protein's ability to carry out its desired functions. Some

embodiments of the present invention encompass various changes that may be made in the sequence of nucleic acid molecules and in the sequence of polypeptides disclosed herein.

[0036] In terms of functional equivalents, it is well understood by the skilled artisan that, inherent in the definition of a "biologically functional equivalent" polypeptide or polynucleotide, is the concept that there is a limit to the number of changes that may be made within a defined portion of the molecule while retaining a molecule with an acceptable level of desired biological activity, such as, for example, inter-molecular interaction among mutated VP2 proteins, mVLP formation, reduction in P-antigen binding by the mVLP, reduction of hemagglutination by the mVLP, neutralizing epitopes in the mVLP, or induction of antibodies by neutralizing epitopes in the mVLP. Biologically functional equivalents are thus defined herein as those polypeptides (and nucleic acid molecules) in which selected amino acids (or codons) may be substituted.

[0037] In general, the shorter the length of the molecule, the fewer the changes that can be made within the molecule while retaining function. Longer domains may have an intermediate number of changes. The full-length protein will have the most tolerance for a larger number of changes. However, it must be appreciated that certain molecules or domains that are highly dependent upon their structure may tolerate little or no modification.

[0038] Amino acid substitutions are generally based on the relative similarity of the amino acid side-chain substituents, for example, their hydrophobicity, hydrophilicity, charge, size, or the like. An analysis of the size, shape or type of the amino acid side-chain substituents reveals that arginine, lysine or histidine are all positively charged residues; that alanine, glycine or serine are all of similar size; or

that phenylalanine, tryptophan or tyrosine all have a generally similar shape.

Therefore, based upon these considerations, arginine, lysine or histidine; alanine, glycine or serine; or phenylalanine, tryptophan or tyrosine; are defined herein as biologically functional equivalents. Although not grouped here, other amino acids
5 may provide functionally equivalent polypeptides.

[0039] The hydrophathic index of amino acids may also be considered. Each amino acid has been assigned a hydrophathic index on the basis of their hydrophobicity or charge characteristics, these are: isoleucine (+4.5); valine (+4.2); Leucine (+3.8); phenylalanine (+2.8); cysteine/cystine (+2.5); methionine (+1.9); alanine (+1.8);
10 glycine (-0.4); threonine (-0.7); serine (-0.8); tryptophan (-0.9); tyrosine (-1.3); proline (-1.6); histidine (-3.2); glutamate (-3.5); glutamine (-3.5); aspartate (-3.5); asparagine (-3.5); lysine (-3.9); or arginine (-4.5). Hydrophathic amino acid index can be used to confer interactive biological function on a protein. In some instances, certain amino acids may be substituted for other amino acids having a similar
15 hydrophathic index or score or still retain a similar biological activity. In making changes based upon the hydrophathic index, the substitution of amino acids with hydrophathic indices can be within ± 2 or within ± 1 , or within ± 0.5 .

[0040] The substitution of like amino acids can also be made on the basis of hydrophilicity, particularly where the biological functional equivalent polypeptide or
20 peptide thereby created is intended for use in immunological embodiments, as in certain embodiments of the present invention. U.S. Patent 4,554,101 states that the greatest local average hydrophilicity of a polypeptide, as governed by the hydrophilicity of its adjacent amino acids, can correlate with its immunogenicity or antigenicity (i.e., with a biological property of the polypeptide).

[0041] As detailed in U.S. Patent 4,554,101, the following hydrophilicity values have been assigned to amino acid residues: arginine (+3.0); lysine (+3.0); aspartate (+3.0 $\pm$ 1); glutamate (+3.0 $\pm$ 1); serine (+0.3); asparagine (+0.2); glutamine (+0.2); glycine (0); threonine (-0.4); proline (-0.5 $\pm$ 1); alanine (-0.5); histidine (-0.5);
 5 cysteine (-1.0); methionine (-1.3); valine (-1.5); leucine (-1.8); isoleucine (-1.8); tyrosine (-2.3); phenylalanine (-2.5); tryptophan (-3.4). In making changes based upon similar hydrophilicity values, the substitution of amino acids with hydrophilicity values can be within ± 2 , or within ± 1 , or within ± 0.5 .

[0042] Conservatively substituted sequence indicates that a given amino acid
 10 residue is replaced by a residue having similar physiochemical characteristics. Examples of conservative substitutions include substitution of one aliphatic residue for another, such as Ile, Val, Leu, or Ala for one another, or substitutions of one polar residue for another, such as between Lys and Arg; Glu and Asp; or Gln and Asn. Other such conservative substitutions include, for example, substitutions of entire
 15 regions having similar hydrophobicity characteristics.

[0043] While discussion has focused on functionally equivalent polypeptides arising from amino acid changes, it will be appreciated that these changes may be effected by alteration of the encoding DNA; taking into consideration also that the genetic code is degenerate and that two or more codons may code for the same amino
 20 acid. A table of amino acids and their codons is presented below for use in such embodiments, as well as for other uses, such as in the design of probes and primers and the like.

Tables A and B. Amino acid designations and codon table

Table A - Amino Acid Designations			Table B - Codons for Amino Acids			
Alanine	Ala	A	GCA	GCC	GCG	GCU

Cysteine	Cys	C	UGC UGU
Aspartic acid	Asp	D	GAC GAU
Glutamic acid	Glu	E	GAA GAG
Phenylalanine	Phe	F	UUC UUU
Glycine	Gly	G	GGA GGC GGG GGU
Histidine	His	H	CAC CAU
Isoleucine	Ile	I	AUA AUC AUU
Lysine	Lys	K	AAA AAG
Leucine	Leu	L	UUA UUG CUA CUC CUG CUU
Methionine	Met	M	AUG
Asparagine	Asn	N	AAC AAU
Proline	Pro	P	CCA CCC CCG CCU
Glutamine	Gln	Q	CAA CAG
Arginine	Arg	R	AGA AGG CGA CGC CGG CGU
Serine	Ser	S	AGC AGU UCA UCC UCG UCU
Threonine	Thr	T	ACA ACC ACG ACU
Valine	Val	V	GUA GUC GUG GUU
Tryptophan	Trp	W	UGG
Tyrosine	Tyr	Y	UAC UAU

[0044] The term "functionally equivalent codon" is used herein to refer to codons that encode the same amino acid, such as the six codons for arginine or serine, and also refers to codons that encode biologically equivalent amino acids (see Codon Table, above).

5 [0045] It will also be understood that amino acid and nucleic acid sequences may include additional residues, such as additional N- or C-terminal amino acids or 5' or 3' sequences, and yet still be essentially as set forth in one of the sequences disclosed herein, so long as the sequence meets the criteria set forth above, including the maintenance of biological activity where polypeptide expression is concerned.

10 The addition of terminal sequences particularly applies to nucleic acid sequences that

may, for example, include various non-coding sequences flanking either of the 5' or 3' portions of the coding region or may include various internal sequences, (i.e., introns) which are known to occur within genes.

[0046] The present invention, in some aspects, relies on the synthesis of peptides and polypeptides *in cyto*, via transcription and translation of appropriate polynucleotides. These peptides and polypeptides will include the twenty “natural” amino acids, and post-translational modifications thereof. However, *in vitro* peptide synthesis permits the use of modified or unusual amino acids. A table of exemplary, but not limiting, modified or unusual amino acids is provided in Table C.

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<u>Table C - Modified or Unusual Amino Acids</u>			
<u>Abbr.</u>	<u>Amino Acid</u>	<u>Abbr.</u>	<u>Amino Acid</u>
Aad	2-Aminoadipic acid	EtAsn	N-Ethylasparagine
BAad	3- Aminoadipic acid	Hyl	Hydroxylysine
BAla	beta-alanine, beta-Amino-propionic acid	AHyl	allo-Hydroxylysine
Abu	2-Aminobutyric acid	3Hyp	3-Hydroxyproline
4Abu	4- Aminobutyric acid, piperidinic acid	4Hyp	4-Hydroxyproline
Acp	6-Aminocaproic acid	Ide	Isodesmosine
Ahe	2-Aminoheptanoic acid	Aile	allo-Isoleucine
Aib	2-Aminoisobutyric acid	MeGly	N-Methylglycine, sarcosine
BAib	3-Aminoisobutyric acid	MeIle	N-Methylisoleucine
Apm	2-Aminopimelic acid	MeLys	6-N-Methyllysine
Dbu	2,4-Diaminobutyric acid	MeVal	N-Methylvaline
Des	Desmosine	Nva	Norvaline
Dpm	2,2'-Diaminopimelic acid	Nle	Norleucine
Dpr	2,3-Diaminopropionic acid	Orn	Ornithine
EtGly	N-Ethylglycine		

[0047] The presently-disclosed subject matter further includes a method of producing a polypeptide (or VLP, including a polypeptide that self-assembles into a VLP) comprising a VP2 polypeptide mutant. Eukaryotic expression systems include plant-based systems; insect cell systems via recombinant baculoviruses; whole insect systems via recombinant baculoviruses; genetically engineered yeast systems, including but not limited to *Saccharomyces sp.* and *Picchia spp.*; and mammalian cell systems, including but not limited to Chinese hamster ovary cells or other cell lines commonly used for industrial scale expression of recombinant proteins. In some embodiments, useful plant-based expression systems can include transgenic plant systems. In some embodiments, useful plant-based expression systems can include transplastomic plant systems.

[0048] In some embodiments, a method of producing the inventive polypeptide (which can self-assemble into a VLP) includes providing a host cell comprising a polynucleotide, as disclosed herein, operatively linked to a promoter operable under conditions whereby the encoded polypeptide is expressed; and recovering the polypeptide from the host cell.

[0049] One or more VP2 polypeptide mutants can be part of a composition and can be in an amount (by weight of the total composition) of at least about 0.0001%, at least about 0.001%, at least about 0.10%, at least about 0.15%, at least about 0.20%, at least about 0.25%, at least about 0.50%, at least about 0.75%, at least about 1%, at least about 10%, at least about 25%, at least about 50%, at least about 75%, at least about 90%, at least about 95%, at least about 99%, at least about 99.99%, no more than about 75%, no more than about 90%, no more than about 95%, no more than about 99%, or no more than about 99.99%, from about 0.0001% to

about 99%, from about 0.0001% to about 50%, from about 0.01% to about 95%, from about 1% to about 95%, from about 10% to about 90%, or from about 25% to about 75%.

[0050] One or more VP2 polypeptide mutants can be purified or isolated in an amount (by weight of the total composition) of at least about 0.0001%, at least about 0.001%, at least about 0.10%, at least about 0.15%, at least about 0.20%, at least about 0.25%, at least about 0.50%, at least about 0.75%, at least about 1%, at least about 10%, at least about 25%, at least about 50%, at least about 75%, at least about 90%, at least about 95%, at least about 99%, at least about 99.99%, no more than about 75%, no more than about 90%, no more than about 95%, no more than about 99%, no more than about 99.99%, from about 0.0001% to about 99%, from about 0.0001% to about 50%, from about 0.01% to about 95%, from about 1% to about 95%, from about 10% to about 90%, or from about 25% to about 75%. Some embodiments of the present invention include compositions comprising one or more VP2 polypeptide mutants. In certain embodiments, the composition is a pharmaceutical composition (e.g., a vaccine), such as compositions that are suitable for administration to animals (e.g., mammals, primates, monkeys, humans, canine, porcine, mice, rabbits, or rats).

[0051] Virus Like Particles and Compositions including Pharmaceutical Compositions

[0052] In some embodiments of the invention, the inventive polypeptide can form a virus-like particle. As defined herein, unless otherwise indicated, "VLP" is a virus-like particle. A VLP is a small particle that comprises one or more polypeptides from the outer coat (e.g., capsid) of a virus. VLPs do not contain any genetic material

from the virus and thus cannot cause an infection. In some instances, VLPs can be used to make vaccines. The expression of some viral structural proteins (e.g., envelope or capsid proteins) can result in the self-assembly of VLPs. As defined herein, unless otherwise indicated, “wtVLP” (also referred to as “wild type VLP”) is a VLP made only from VP2 proteins (i.e., with no modifications to the VP2 amino acid sequence); wtVLPs do not include any other proteins other than VP2 (i.e., VP1 is not included). As defined herein, unless otherwise indicated, “mVLP” (also referred to as “mutant VLP”) is a virus-like particle formed from inventive polypeptides, where the inventive polypeptide has at least one amino acid modification relative to wild type VP2. In certain embodiments, the mVLP can be morphologically similar to wtVLP (e.g., as determined using electron microscopy). In some embodiments, the mVLP can have reduced binding to P antigen compared to wtVLP (e.g., as measured using a hemagglutination assay). In some embodiments, the mVLP can have no detectable binding to P antigen (e.g., as measured using a hemagglutination assay). In other embodiments, the mVLP has reduced hemagglutination of red blood cells compared to wtVLP (e.g., as measured using a hemagglutination assay). In still other embodiments, the mVLP has no detectable hemagglutination (e.g., as measured using a hemagglutination assay). In certain embodiments, the mVLP can have one or more neutralizing epitopes (e.g., conformational epitopes) which can be determined by any suitable method (e.g., by using a hemagglutination inhibition assay). In some embodiments, an epitope is a region on the surface of the mVLP (e.g., a conformational change in an mVLP can create or induce the appearance of an epitope) capable of eliciting an immune response; in certain embodiments, a neutralizing epitope is an epitope (e.g., a conformation epitope) that can induce an immune response to an mVLP, a wtVLP, a parvovirus, an erythrovirus, a B19

parvovirus, or combinations thereof. In some embodiments, the epitope is created by a conformational change in one or more mVP2s of the mVLP (e.g., one or more VP2 on the surface of the mVLP) capable of eliciting an immune response; in certain embodiments, a neutralizing epitope is an epitope created by a conformation epitope that can induce an immune response to an mVLP, a wtVLP, a parvovirus, an erythrovirus, a B19 parvovirus, or combinations thereof. In other embodiments, the mVLP can induce the production of antibodies (e.g., a high titer of antibodies) in an animal (e.g., mammals, humans, rats, mice, feline, canine, porcine, monkeys, or primates) where the antibodies are capable of inhibiting hemagglutination by wtVLP (e.g., as determined using a hemagglutination inhibition assay).

[0053] In some embodiments, the mVLP can be made from an inventive polypeptide that has one or more modifications to wtVP2 which can be in or near (e.g., near can be a distance of about 5Å, about 10Å, about 15Å, about 20Å, about 25Å, about 30Å, about 35Å, about 40Å, about 45Å, about 50Å, less than about 50Å or less than about 30Å) the recess of the three-fold axis in a VLP formed by the inventive polypeptide. The mVLP can be made from an inventive polypeptide that has one or more modifications to wtVP2, in some aspects, which can include a substitution in loop 3, a deletion in loop 3, a substitution in loop 4, a deletion in loop 4, a substitution upstream of loop 3, a deletion upstream of loop 3, a substitution upstream of loop 4, a deletion upstream of loop 4, or combinations thereof. In some instances, the mVLP can be made from an inventive polypeptide that has one or more modifications to wtVP2 that can include a substitution at Y401, a deletion at Y401, a substitution at Q399, a deletion at Q399, a substitution at Q400, a deletion at Q400, a substitution at Q404, a deletion at Q404, a substitution at Q368, a deletion at Q368, a substitution at Q369, a deletion at Q369, a substitution at Y392, a deletion at Y392, or

combinations thereof. In yet other embodiments, the mVLP can be made from an inventive polypeptide that has one or more modifications to wtVP2 which can include Y401F, Y401W, Y401A, Q368A, Q369A, Q368N, Q369N, Q399N, Q400N, Q404T, Y392A, Y392F, Q404N, Y401P, T402A, D403A, Q404A, or combinations thereof.

5 In still other embodiments, the mVLP can be made from an inventive polypeptide that is construct A, construct B, construct C, construct D, construct E, construct F, construct G, construct H, construct I, construct J, construct K, construct L, construct M, construct N, construct O, construct P, construct Q, construct R, construct S, construct T, construct U, construct V, construct W, or construct X (see Table 1).

10 [0054] One or more mVLPs can be part of a composition and can be in an amount (by weight of the total composition) of at least about 0.0001%, at least about 0.001%, at least about 0.10%, at least about 0.15%, at least about 0.20%, at least about 0.25%, at least about 0.50%, at least about 0.75%, at least about 1%, at least about 10%, at least about 25%, at least about 50%, at least about 75%, at least about
15 90%, at least about 95%, at least about 99%, at least about 99.99%, no more than about 75%, no more than about 90%, no more than about 95%, no more than about 99%, or no more than about 99.99%, from about 0.0001% to about 99%, from about 0.0001% to about 50%, from about 0.01% to about 95%, from about 1% to about 95%, from about 10% to about 90%, or from about 25% to about 75%.

20 [0055] One or more mVLPs can be purified or isolated in an amount (by weight of the total composition) of at least about 0.0001%, at least about 0.001%, at least about 0.10%, at least about 0.15%, at least about 0.20%, at least about 0.25%, at least about 0.50%, at least about 0.75%, at least about 1%, at least about 10%, at least about 25%, at least about 50%, at least about 75%, at least about 90%, at least about
25 95%, at least about 99%, at least about 99.99%, no more than about 75%, no more

than about 90%, no more than about 95%, no more than about 99%, no more than about 99.99%, from about 0.0001% to about 99%, from about 0.0001% to about 50%, from about 0.01% to about 95%, from about 1% to about 95%, from about 10% to about 90%, or from about 25% to about 75%.

5 [0056] Some embodiments of the present invention include compositions comprising one or more mVLPs. In certain embodiments, the composition is a pharmaceutical composition (e.g., a vaccine), such as compositions that are suitable for administration to animals (e.g., mammals, primates, monkeys, humans, canine, feline, porcine, mice, rabbits, or rats). In some instances, the pharmaceutical
10 composition is non-toxic, does not cause side effects, or both. In some embodiments, there may be inherent side effects (e.g., it may harm the patient or may be toxic or harmful to some degree in some patients).

[0057] "Therapeutically effective amount" means an amount effective to achieve a desired and/or beneficial effect. An effective amount can be administered
15 in one or more administrations. For some purposes of this invention, a therapeutically effective amount is an amount appropriate to treat an indication. By treating an indication is meant achieving any desirable effect, such as one or more of palliate, ameliorate, stabilize, reverse, slow, or delay disease progression, increase the quality of life, or to prolong life. Such achievement can be measured by any method known
20 in the art, such as measurement of antibody titers.

[0058] In some embodiments, one or more mVLPs can be part of a pharmaceutical composition (e.g., a vaccine) and can be in an amount of at least about 0.0001%, at least about 0.001%, at least about 0.10%, at least about 0.15%, at least about 0.20%, at least about 0.25%, at least about 0.50%, at least about 0.75%, at least
25 about 1%, at least about 10%, at least about 25%, at least about 50%, at least about

75%, at least about 90%, at least about 95%, at least about 99%, at least about 99.99%, no more than about 75%, no more than about 90%, no more than about 95%, no more than about 99%, no more than about 99.99%, from about 0.001% to about 99%, from about 0.001% to about 50%, from about 0.1% to about 99%, from about 1% to about 95%, from about 10% to about 90%, or from about 25% to about 75%. In some embodiments, the pharmaceutical composition can be presented in a dosage form which is suitable for the topical, subcutaneous, intrathecal, intraperitoneal, oral, parenteral, rectal, cutaneous, nasal, vaginal, or ocular administration route. In other embodiments, the pharmaceutical composition can be presented in a dosage form which is suitable for parenteral administration, a mucosal administration, intravenous administration, subcutaneous administration, topical administration, intradermal administration, oral administration, sublingual administration, intranasal administration, or intramuscular administration. The pharmaceutical composition can be in the form of, for example, tablets, capsules, pills, powders granulates, suspensions, emulsions, solutions, gels (including hydrogels), pastes, ointments, creams, plasters, drenches, delivery devices, suppositories, enemas, injectables, implants, sprays, aerosols or other suitable forms.

[0059] In some embodiments, the pharmaceutical composition can include one or more formulary ingredients. A “formulary ingredient” can be any suitable ingredient (e.g., suitable for the drug(s), for the dosage of the drug(s), for the timing of release of the drugs(s), for the disease, for the disease state, or for the delivery route) including, but not limited to, water (e.g., boiled water, distilled water, filtered water, pyrogen-free water, or water with chloroform), sugar (e.g., sucrose, glucose, mannitol, sorbitol, xylitol, or syrups made therefrom), ethanol, glycerol, glycols (e.g., propylene glycol), acetone, ethers, DMSO, surfactants (e.g., anionic surfactants,

cationic surfactants, zwitterionic surfactants, or nonionic surfactants (e.g., polysorbates)), oils (e.g., animal oils, plant oils (e.g., coconut oil or arachis oil), or mineral oils), oil derivatives (e.g., ethyl oleate, glyceryl monostearate, or hydrogenated glycerides), excipients, preservatives (e.g., cysteine, methionine, antioxidants (e.g., vitamins (e.g., A, E, or C), selenium, retinyl palmitate, sodium citrate, citric acid, chloroform, or parabens, (e.g., methyl paraben or propyl paraben)), or combinations thereof.

[0060] In certain embodiments, pharmaceutical compositions can be formulated to release the active ingredient (e.g., one or more mVLPs) substantially immediately upon the administration or any substantially predetermined time or time after administration. Such formulations can include, for example, controlled release formulations such as various controlled release compositions and coatings.

[0061] Other formulations (e.g., formulations of a pharmaceutical composition) can, in certain embodiments, include those incorporating the drug (or control release formulation) into food, food stuffs, feed, or drink.

[0062] Other embodiments of the invention can include methods of administering or treating an organism, which can involve treatment with an amount of at least one mVLP that is effective to treat the disease, condition, or disorder that the organism has, or is suspected of having, or is susceptible to, or to bring about a desired physiological effect. In some embodiments, the composition or pharmaceutical composition (e.g., a vaccine) comprises at least one mVLP which can be administered to an animal (e.g., mammals, primates, monkeys, or humans) in an amount of about 0.01 to about 15 mg/kg body weight, about 0.1 to about 10 mg/kg body weight, about 0.5 to about 7 mg/kg body weight, about 0.01 mg/kg, about 0.05 mg/kg, about 0.1 mg/kg, about 0.5 mg/kg, about 1 mg/kg, about 3 mg/kg, about 5

mg/kg, about 5.5 mg/kg, about 6 mg/kg, about 6.5 mg/kg, about 7 mg/kg, about 7.5 mg/kg, about 8 mg/kg, about 10 mg/kg, about 12 mg/kg, or about 15 mg/kg. In regard to some conditions, the dosage can be about 0.5 mg/kg human body weight or about 6.5 mg/kg human body weight. In some instances, some animals (e.g.,

5 mammals, mice, rabbits, feline, porcine, or canine) can be administered a dosage of about 0.01 to about 15 mg/kg body weight, about 0.1 to about 10 mg/kg body weight, about 0.5 to about 7 mg/kg body weight, about 0.01 mg/kg, about 0.05 mg/kg, about 0.1 mg/kg, about 1 mg/kg, about 5 mg/kg, about 10 mg/kg, about 20 mg/kg, about 30 mg/kg, about 40 mg/kg, about 50 mg/kg, about 80 mg/kg, about 100 mg/kg, or about

10 150 mg/kg. Of course, those skilled in the art will appreciate that it is possible to employ many concentrations in the methods of the present invention, and using, in part, the guidance provided herein, will be able to adjust and test any number of concentrations in order to find one that achieves the desired result in a given circumstance. In other embodiments, the compounds of the invention can be

15 administered in combination with one or more other therapeutic agents for a given disease, condition, or disorder.

[0063] In some embodiments, the compositions can include a unit dose of one or more mVLPs in combination with a pharmaceutically acceptable carrier and, in addition, can include other medicinal agents, pharmaceutical agents, carriers,

20 adjuvants, diluents, and excipients. In certain embodiments, the carrier, vehicle or excipient can facilitate administration, delivery and/or improve preservation of the composition. In other embodiments, the one or more carriers, include but are not limited to, saline solutions such as normal saline, Ringer's solution, PBS (phosphate-buffered saline), and generally mixtures of various salts including potassium and

25 phosphate salts with or without sugar additives such as glucose. Carriers can include

aqueous and non-aqueous sterile injection solutions that can contain antioxidants, buffers, bacteriostats, bactericidal antibiotics, and solutes that render the formulation isotonic with the bodily fluids of the intended recipient; and aqueous and non-aqueous sterile suspensions, which can include suspending agents and thickening agents. In

5 other embodiments, the one or more excipients can include, but are not limited to water, saline, dextrose, glycerol, ethanol, or the like, and combinations thereof. Nontoxic auxiliary substances, such as wetting agents, buffers, or emulsifiers may also be added to the composition. Oral formulations can include such normally employed excipients as, for example, pharmaceutical grades of mannitol, lactose, starch, magnesium stearate, sodium saccharine, cellulose, and magnesium carbonate.

[0064] In certain embodiments, compositions (e.g., pharmaceutical compositions or vaccines) can include one or more adjuvants. In some embodiments, adjuvants are not included in the composition. In still other embodiments, the composition comprises one or more adjuvants, such as, but not limited to polymers of

15 acrylic or methacrylic acid, maleic anhydride and alkenyl derivative polymers; immunostimulating sequences (ISS), an oil in water emulsion (e.g., the SPT emulsion described on p 147 of “Vaccine Design, The Subunit and Adjuvant Approach” published by M. Powell, M. Newman, Plenum Press 1995, and the emulsion MF59 described on p 183 of the same reference), cation lipids containing a quaternary

20 ammonium salt, $AlK(SO_4)_2$, $AlNa(SO_4)_2$, $AlNH(SO_4)_4$, silica, alum, $Al(OH)_3$, $Ca_3(PO_4)_2$, kaolin, carbon, aluminum hydroxide, muramyl dipeptides, N-acetyl-muramyl-L-threonyl-D-isoglutamine (thr-DMP), N-acetyl-nornuramyl-L-alanyl-D-isoglutamine (CGP 11687, also referred to as nor-MDP), N-acetylmuramyl-L-alanyl-D-isoglutaminyl-L-alanine-2-(1`2`-dipalmitoyl-s- n-glycero-3-

25 hydroxphosphoryloxy)-ethylamine (CGP 19835A, also referred to as MTP-PE), RIBI

(MPL+TDM+CWS) in a 2% squalene/Tween-80.RTM. emulsion, lipopolysaccharides and its various derivatives, including lipid A, Freund's Complete Adjuvant (FCA), Freund's Incomplete Adjuvants, Merck Adjuvant 65, polynucleotides (for example, poly IC and poly AU acids), wax D from

5 Mycobacterium, tuberculosis, substances found in Corynebacterium parvum, Bordetella pertussis, and members of the genus Brucella, liposomes or other lipid emulsions, ISCOMS, Quil A, ALUN, Lipid A derivatives, cholera toxin derivatives, HSP derivatives, LPS derivatives, synthetic peptide matrixes or GMDP, cytokines, Interleukin 1, Interleukin 2, Montanide ISA-51, QS-21, Titermax, or Adjuvax

10 Vaccine Adjuvant.

[0065] In some embodiments, additional adjuvants or compounds that can be used (e.g., to modify or stimulate the immune response) include ligands for Toll-like receptors (TLRs). In mammals, TLRs are a family of receptors expressed on DCs that recognize and respond to molecular patterns associated with microbial pathogens.

15 Several TLR ligands have been intensively investigated as vaccine adjuvants.

Bacterial lipopolysaccharide (LPS) is the TLR4 ligand and its detoxified variant mono-phosphoryl lipid A (MPL) is an approved adjuvant for use in humans. TLR5 is expressed on monocytes and DCs and responds to flagellin whereas TLR9 recognizes bacterial DNA containing CpG motifs. Oligonucleotides (OLGs) containing CpG

20 motifs are potent ligands for, and agonists of, TLR9 and have been intensively investigated for their adjuvant properties. In some embodiments, the adjuvant is alum. In some embodiments the adjuvant is not M59 adjuvant.

[0066] In certain embodiments, administration of the compositions (e.g., pharmaceutical compositions or vaccines) induces an immune response to prevent or

25 ameliorate the effects of future infection. Depending on the intended mode of

administration, the compositions of the present invention can be in various forms of pharmaceutical compositions. Any method of preparation of vaccines and immunizing agents can be used, as exemplified by U.S. Pat. Nos. 4,608,251; 4,601,903; 4,599,231; 4,599,230; 4,596,792; and 4,578,770. Typically, such vaccines are prepared as injectables either as liquid solutions or suspensions; solid forms suitable for solution in, or suspension in, liquid prior to injection may also be prepared. The preparation may also be emulsified. In addition, if desired, the vaccine may contain minor amounts of auxiliary substances such as wetting or emulsifying agents, pH buffering agents, or adjuvants that enhance the effectiveness of the vaccines.

[0067] Parenteral administration, if used, is generally characterized by injection. Sterile injectables can be prepared in conventional forms, either as liquid solutions or suspensions, solid forms suitable for solution or suspension in liquid prior to injection, or as emulsions.

[0068] Administration Routes and Treatments of Disease

[0069] The mVLPs of the invention can be administered to animals by any number of suitable administration routes or formulations. The mVLPs of the invention can also be used to treat animals for a variety of diseases. Animals include but are not limited to mammals, primates, monkeys (e.g., macaque, rhesus macaque, or pig tail macaque), humans, canine, feline, bovine, porcine, avian (e.g., chicken), mice, rabbits, and rats. As used herein, the term "subject" refers to both human and animal subjects. A subject susceptible to a parvovirus infection, an erthrovirus infection, or a B19 parvovirus (e.g., human) infection can be a human or an animal subject.

[0070] The route of administration of the mVLPs of the invention can be of any suitable route. Administration routes can be, but are not limited to the oral route, the parenteral route, the cutaneous route, the nasal route, the rectal route, the vaginal route, and the ocular route. In other embodiments, administration routes can be parenteral administration, a mucosal administration, intravenous administration, subcutaneous administration, topical administration, intradermal administration, oral administration, sublingual administration, intranasal administration, or intramuscular administration. The choice of administration route can depend on the mVLP identity (e.g., the physical and chemical properties of the mVLP) as well as the age and weight of the animal, the particular disease, and the severity of the disease. Of course, combinations of administration routes can be administered, as desired.

[0071] Some embodiments of the invention include a method for providing a subject with a composition comprising an mVLP described herein (e.g., a pharmaceutical composition) which comprises one or more administrations of one or more such compositions; the compositions may be the same or different if there is more than one administration.

[0072] Diseases that can be treated in an animal (e.g., mammals, porcine, canine, avian (e.g., chicken), bovine, feline, primates, monkeys, rabbits, and humans) using the mVLPs include, but are not limited to parvovirus infections, diseases related to parvovirus infections, erythrovirus infections, diseases related to erythrovirus infections, parvovirus B19 infections, and diseases related to parvovirus B19 infection. Some diseases related to parvovirus infections (e.g., erythrovirus infections or parvovirus B19 infections) include, but are not limited to, hydrops fetalis intrauterine fetal death, erythema infectiosum (i.e., fifth disease), hereditary diseases (e.g., sickle cell anemia or Thalassemia), acquired diseases (e.g., anemia or anemia

induced by malaria), parvovirus B19-induced red cell aplasia (TRCA), chronic anemia, diseases related to immunodeficient individuals (e.g., recipients of organ transplants, animals undergoing chemotherapy, animals undergoing bone marrow transplant, or HIV-positive animals), acute arthropathy, persistent arthropathy, 5 aplastic crisis, arthritis, hepatitis, myocarditis, hepatosplenomegaly, acute thyroiditis, subacute thyroiditis, Graves' disease, Hashimoto's thyroiditis, and autoimmune diseases (e.g., autoimmune thyroid diseases, systemic lupus erythematosus (SLE), meningi-encephalitis, or fibromyalgia). Other diseases related to parvovirus infections (e.g., erythrovirus infections or parvovirus B19 infections) include, but are not limited to, 10 gastrointestinal tract damage, dehydration, cardiac syndrome, lethargy, diarrhea (e.g., severe diarrhea), fever, vomiting, loss of appetite, stillbirth, mummification, embryonic death, infertility, low white blood cell count, cerebellar hypoplasia, lymphadenopathy, splenomegaly, glomerulonephritis, and anemia. Animals that can be treated include but are not limited to mammals, primates, monkeys (e.g., macaque, 15 rhesus macaque, pig tail macaque), humans, canine, feline, porcine, avian (e.g., chicken), bovine, mice, rabbits, and rats. As used herein, the term "subject" refers to both human and animal subjects. A subject susceptible to a parvovirus infection, an erthrovirus infection, or a B19 parvovirus (e.g., human) infection can be a human or animal subject. In some instances, the animal is in need of the treatment (e.g., a 20 prophylactic treatment).

[0073] As used herein, the term "treating" (and its variations, such as "treatment") is to be considered in its broadest context. In particular, the term "treating" does not necessarily imply that an animal is treated until total recovery. Accordingly, "treating" includes amelioration of the symptoms, relief from the 25 symptoms or effects associated with a condition, decrease in severity of a condition,

or preventing, preventively ameliorating symptoms, or otherwise reducing the risk of developing a particular condition. As used herein, reference to "treating" an animal includes but is not limited to prophylactic treatment (e.g., vaccination) and therapeutic treatment. Any of the compositions (e.g., pharmaceutical compositions or vaccines) described herein can be used to treat an animal.

[0074] As related to treating a parvovirus infection (e.g., an erythrovirus infection or a parvovirus B19 infection), treating can include but is not limited to prophylactic treatment and therapeutic treatment. As such, treatment can include, but is not limited to: conferring protection against a parvovirus infection (e.g., an erythrovirus infection or a parvovirus B19 infection); preventing a parvovirus infection (e.g., an erythrovirus infection or a parvovirus B19 infection); reducing the risk of parvovirus infection (e.g., an erythrovirus infection or a parvovirus B19 infection); ameliorating or relieving symptoms of a parvovirus infection (e.g., an erythrovirus infection or a parvovirus B19 infection); eliciting an immune response against a parvovirus (e.g., an erythrovirus or a parvovirus B19) or an antigenic component thereof; inhibiting the development or progression of a parvovirus infection (an erythrovirus infection or a parvovirus B19 infection); inhibiting or preventing the onset of symptoms associated with a parvovirus infection (e.g., an erythrovirus infection or a parvovirus B19 infection); reducing the severity of a parvovirus infection (e.g., an erythrovirus infection or a parvovirus B19 infection); and causing a regression of a parvovirus infection (e.g., an erythrovirus infection or a parvovirus B19 infection) or one or more of the symptoms associated with a parvovirus infection (e.g., an erythrovirus infection or a parvovirus B19 infection). In some embodiments, treating does not include prophylactic treatment (e.g., vaccination or otherwise preventing or ameliorating future disease).

[0075] Symptoms associated with parvovirus infection (e.g., an erythrovirus infection or a parvovirus B19 infection) are known to those of ordinary skill in the art and can include those described herein and well-known to those of ordinary skill in the art. The presence of an infection can be assessed using methods known to those
5 or ordinary skill in the art. In some cases, the presence of a parvovirus infection (e.g., an erythrovirus infection or a parvovirus B19 infection) can be determined using methods known to those of ordinary skill in the art.

[0076] Treatment of an animal can occur using any suitable administration method (such as those disclosed herein) and using any suitable amount of mVLPs
10 (such as those disclosed herein). In some embodiments, methods of treatment comprise treating an animal for a parvovirus infection (e.g., in a human or primate), a disease related to a parvovirus infection (e.g., in a human or primate), an erythrovirus infection (e.g., in a human or primate), a disease related to an erythrovirus infection (e.g., in a human or primate), a disease related to a parvovirus B19 infection (e.g., in a
15 human or primate), a parvovirus B19 infection (e.g., in a human or primate), or combinations thereof. Some embodiments of the invention include a method for treating a subject (e.g., an animal such as a human or primate) with a composition comprising an mVLP described herein (e.g., a pharmaceutical composition) which comprises one or more administrations of one or more such compositions; the
20 compositions may be the same or different if there is more than one administration.

[0077] In some embodiments, the method of treatment includes administering an effective amount of a composition comprising an mVLP. As used herein, the term “effective amount” refers to a dosage or a series of dosages sufficient to affect
treatment (e.g., to treat a parvovirus infection such as an erythrovirus infection or a
25 parvovirus B19 infection or to treat diseases related to a parvovirus infection such as

diseases related to an erythrovirus infection or diseases related to a parvovirus B19 infection) in an animal. In some embodiments, an effective amount can encompass a therapeutically effective amount, as disclosed herein. In certain embodiments, an effective amount can vary depending on the subject and the particular treatment being

5 affected. The exact amount that is required can, for example, vary from subject to subject, depending on the age and general condition of the subject, the particular adjuvant being used (if applicable), administration protocol, and the like. As such, the effective amount can, for example, vary based on the particular circumstances, and an appropriate effective amount can be determined in a particular case. An effective

10 amount can, for example, include any dosage or composition amount disclosed herein. In some embodiments, an effective amount of at least one mVLP (which can be administered to an animal such as mammals, primates, monkeys or humans) can be an amount of about 0.01 to about 15 mg/kg body weight, about 0.1 to about 10 mg/kg body weight, about 0.5 to about 7 mg/kg body weight, about 0.01 mg/kg, about 0.05

15 mg/kg, about 0.1 mg/kg, about 0.5 mg/kg, about 1 mg/kg, about 3 mg/kg, about 5 mg/kg, about 5.5 mg/kg, about 6 mg/kg, about 6.5 mg/kg, about 7 mg/kg, about 7.5 mg/kg, about 8 mg/kg, about 10 mg/kg, about 12 mg/kg, or about 15 mg/kg. In regard to some conditions, the dosage can be about 0.5 mg/kg human body weight or about 6.5 mg/kg human body weight. In some instances, some animals (e.g.,

20 mammals, mice, rabbits, feline, porcine, or canine) can be administered a dosage of about 0.01 to about 15 mg/kg body weight, about 0.1 to about 10 mg/kg body weight, about 0.5 to about 7 mg/kg body weight, about 0.01 mg/kg, about 0.05 mg/kg, about 0.1 mg/kg, about 1 mg/kg, about 5 mg/kg, about 10 mg/kg, about 20 mg/kg, about 30 mg/kg, about 40 mg/kg, about 50 mg/kg, about 80 mg/kg, about 100 mg/kg, or about

25 150 mg/kg.

[0078] As used herein, “immunizing” and “immune response” refers to a response by the immune system of a subject. For example, immune responses include, but are not limited to, a detectable alteration (e.g., increase) in Toll receptor activation, lymphokine (e.g., cytokine (e.g., Th1 or Th2 type cytokines) or chemokine) expression and/or secretion, macrophage activation, dendritic cell activation, T cell activation (e.g., CD4+ or CD8+ T cells), NK cell activation, and/or B cell activation (e.g., antibody generation and/or secretion). Additional examples of immune responses include binding of an immunogen to an MHC molecule and inducing a cytotoxic T lymphocyte (“CTL”) response, inducing a B cell response (e.g., antibody production), and/or T-helper lymphocyte response, and/or a delayed type hypersensitivity (DTH) response against the antigen from which the immunogenic polypeptide is derived, expansion (e.g., growth of a population of cells) of cells of the immune system (e.g., T cells, B cells (e.g., of any stage of development (e.g., plasma cells))), and increased processing and presentation of antigen by antigen presenting cells. An immune response can be to immunogens that the subject’s immune system recognizes as foreign (e.g., non-self antigens from microorganisms (e.g., pathogens), or self-antigens recognized as foreign). Thus, it is to be understood that, as used herein, “immune response” refers to any type of immune response, including, but not limited to, innate immune responses (e.g., activation of Toll receptor signaling cascade and/or activation of complement), cell-mediated immune responses (e.g., responses mediated by T cells (e.g., antigen-specific T cells) and non-specific cells of the immune system), and humoral immune responses (e.g., responses mediated by B cells (e.g., via generation and secretion of antibodies into the plasma, lymph, and/or tissue fluids)). The term “immune response” is meant to encompass all aspects of the capability of a subject’s immune system to respond to antigens and/or

immunogens (e.g., both the initial response to an immunogen (e.g., a pathogen) as well as acquired (e.g., memory) responses that are a result of an adaptive immune response).

[0079] In some embodiments, the treatment comprises vaccination. In some aspects, vaccination comprises vaccinating an animal (e.g., mammals, primates, monkeys (e.g., macaque, rhesus macaque, pig tail macaque), humans, canine, feline, bovine, porcine, avian (e.g., chicken), mice, rabbits, and rats) against a parvovirus, an erthyrovirus, parvovirus B19, or combinations thereof. Any suitable administration methods or protocols can be used for vaccinating an animal. Some embodiments for vaccination include a method for providing a subject with a composition comprising an mVLP described herein (e.g., a pharmaceutical composition) which comprises one or more administrations of one or more such compositions; the compositions may be the same or different if there is more than one administration. For example, a single dose can be administered to a subject, or alternatively, two or more inoculations can take place with intervals of several weeks to several months. The extent and nature of the immune responses induced in the subject can be assessed using a variety of techniques generally known in the art. For example, sera can be collected from the subject and tested, for example, for parvovirus DNA or RNA in a sera sample, detecting the presence of antibodies to parvovirus or antigenic fragments thereof using, for example, parvovirus VLPs, or monitoring a symptom associated with parvovirus infection. Relevant techniques are well described in the art, e.g., Coligan et al. Current Protocols in Immunology, John Wiley & Sons Inc. (1994), which is incorporated herein by this reference.

[0080] The timing of administration of the vaccine and the number of doses required for immunization can be determined from standard vaccine administration

protocols. In some instances, a vaccine composition will be administered in two doses. The first dose will be administered at the elected date and a second dose will follow at one month from the first dose. A third dose can be administered if necessary, and desired time intervals for delivery of multiple doses of a particular mVLP can be determined. In other embodiments, the mVLP may be given as a single dose.

[0081] In some instances, for each recipient, the total vaccine amount necessary can be deduced from protocols for immunization with other vaccines. In some embodiments, the exact amount of mVLP required can vary from subject to subject, depending on the species, age, weight and general condition of the subject, the particular fusion protein used, its mode of administration, and the like. In other embodiments, dosage will approximate that which is typical for the administration of other vaccines, and may be in the range of from about 1 ng/kg to about 1 mg/kg body weight, from about 10 ng/kg to about 15 mg/kg, or from about 10 ng/kg to about 100 mg/kg.

[0082] Up to 85% of the adult population is sero-positive for Parvovirus B19 infection. Parvovirus B19 infection can cause hydrops fetalis and intrauterine fetal death, although it is most widely known to be related to erythema infectiosum (fifth disease) and can be asymptomatic in healthy individuals. Older children and adults with either hereditary (sickle cell anemia) or acquired (anemia induced by malaria) anemia are at risk for developing parvovirus B19 -induced red cell aplasia (TRCA) or death. The cause of the chronic anemia in immunodeficient individuals, such as recipients of organ transplants or HIV-positive patients, was contributed to parvovirus B19 infection. In some instances, the pathological manifestations of parvovirus B19 infection can be affected by the patient's immunologic and hematologic status, and

can induce more severe disease, such as acute or persistent arthropathy, aplastic crisis, and also been implicated in arthritis, hepatitis, myocarditis, hepatosplenomegaly, a spectrum of autoimmune diseases such as systemic lupus erythematosus (SLE), meningiensephalitis, or fibromyalgia.

5 [0083] In some embodiments, children (i.e., ages from about 0 to about 18) can be vaccinated before they enter elementary school (i.e., ages from about 0 to about 13). In other embodiments, immunization can be administered to animals at risk. Animal at risk include but are not limited to animals that have had a transfusion, an organ transplant, animals with infectious disease (e.g., HIV or malaria), pregnant
10 animals (e.g., human women) with children (e.g., under the age of 18), animals infected by parvovirus B19 infection, animals (e.g., children) living in an area where malaria is prevalent, immunodeficient animals (e.g., recipients of organ transplants, animals undergoing chemotherapy, animals undergoing bone marrow transplant, or HIV-positive animals), or animals with an autoimmune disease (e.g., systemic lupus
15 erythematosus; SLE, meningiensephalitis and fibromyalgia).

[0084] In some embodiments, the treatments disclosed herein can include use of other drugs (e.g., antibiotics) or therapies for treating disease. For example, antibiotics can be used to treat infections and can be combined with a mVLP to treat disease (e.g., infections). In other embodiments, intravenous immunoglobulin (IVIG)
20 therapy can be used as part of the treatment regime (i.e., in addition to administration of mVLPs) of parvovirus infection (e.g., erythrovirus infection or parvovirus B19 infection).

[0085] The presently-disclosed subject matter is further illustrated by the following specific but non-limiting examples. The following examples may include

compilations of data that are representative of data gathered at various times during the course of development and experimentation related to the present invention.

EXAMPLES

5

Introduction and design and generation of B19 VP2 mutants

[0086] We mutated the P-antigen binding site on VP2, generated mVLPs, and tested their immunities in mice (in some instances, mice are known to be no to low responder to wtVLPs) (Rosenfeld et al., "Unique region of the minor capsid protein of human parvovirus B19 is exposed on the virion surface" J Clin Invest. (1992) Vol. 89, No. 6, pp. 2023-2029; Bansal et al., "Candidate recombinant vaccine for human B19 parvovirus" J Infect Dis. (1993) Vol. 167, No. 5, pp 1034-1044). In certain mutants, amino acids (e.g., amino acids in H₃₉₀TYFPN₃₉₅, Q₃₉₉QYTDQ₄₀₄, or K₃₆₅EYQQ₃₆₉) located at or in the vicinity of loop 4 (Q₃₈₃LQGLNMHTYFPNKGTTQQYTDQ₄₀₄) were replaced with other amino acids that had the similar characteristics (e.g., size, backbone structure, hydrophobicity, and/or charge) to that of the amino acids replaced. Two mutated VP2 (N₃₉₉NFTDT₄₀₄ and N₃₉₉NYTDT₄₀₄) formed mVLPs, showed altered agglutination of human RBCs, and were immunogenic in mice.

Without being bound by theory, a single mutation can have a potentially greater impact on the P antigen binding if the mutation occurs on or near the three-fold axis, because it can theoretically, in some instances, effectively triple the change at the viral ligand (P-antigen) binding site (e.g., FIG. 1A and 1B). An example of the predicted 3-D structures of potential wild type and mutant VLPs are shown in FIG. 1C (wild type: QQT₄₀₁YDQ) and FIG. 1D (Constrict A: QQF₄₀₁TDQ).

[0087] Each mutated VP2 gene was generated by double PCR method. For this, N-terminus and C-terminus DNA fragments were generated separately using two

sets of primers, and full length VP2 gene was generated by annealing these two fragments and performing another PCR using primers annealing 5' and 3' end of VP2 ORF. Full length PCR products were cloned into pFAST Bac1 from which recombinant baculovirus (rBac) was generated. VP2 was then expressed in Sf9 insect cells using rBac.

Cloning and expression of mutated B19 VP2 genes

[0088] The targeted mutations were created by double PCRs on baculovirus codon-optimized VP1 minigene (Integrated Technologies, Iowa) of genotype 1 (NCBI reference sequence NC_000883.2) as template. Full-length VP2 gene fragments, that were amplified with Platinum Tag DNA polymerase High Fidelity (Life Technologies, CA), were gel-purified (QIAquick gel extraction kit; Qiagen, CA), cloned into pCR-XL-Topo (Life Technologies, CA) plasmid, fully sequenced, and subcloned into pFASTBac1, from which recombinant bacimids and consecutively baculoviruses were generated according to the procedure provided by the manufacturer of the kit (Bac-to-Bac Baculovirus Expression System; Life Technologies, CA). The expression of mVP2 in Sf9 insect cells was first checked by immunofluorescence (IF) and immunoblot (IB) (Ghim et al. Virology (1992) vol. 190, No. 1, pp. 548-552). Recombinant E.coli, generated for the clonings of mVP2 genes, and innocula for recombinant baculoviruses having correct VP2 proteins, were frozen for future studies.

[0089] The B19 VP2 polypeptide mutants were constructed with one or more amino acid insertion or point mutations at H₃₉₀TYFPN₃₉₅ and Q₃₉₉QYTDQ₄₀₄ in loop 4 and at K₃₆₅EYQQ₃₆₉ upstream of loop 4, as indicated in Table 1.

Table 1: B19 VP2 Polypeptide Wild Type and Mutants

Construct designation:	Mutation	Amino acids(s) mutated	Nucleic acid sequences used to construct	Primers used
B19 Wild Type	none	none	SEQ ID NO: 2	SEQ ID NO: 27 & SEQ ID NO: 28
A	QQYTDQ to QQFTDQ	Y401F	SEQ ID NO: 3	SEQ ID NO: 29 & SEQ ID NO: 30
B	QQYTDQ to QQWTDQ	Y401W	SEQ ID NO: 4	SEQ ID NO: 31 & SEQ ID NO: 32
C	QQYTDQ to QQATDQ	Y401A	SEQ ID NO: 5	SEQ ID NO: 33 & SEQ ID NO: 34
D	KEYQQ to KEYAA	Q368A and Q369A	SEQ ID NO: 6	SEQ ID NO: 35 & SEQ ID NO: 36
E	KEYQQ to KEYNN	Q368N and Q369N	SEQ ID NO: 7	SEQ ID NO: 37 & SEQ ID NO: 38
F	QQYTDQ to NNFTDT	Q399N, Q400N, Y401F, and Q404T	SEQ ID NO: 8	SEQ ID NO: 39 & SEQ ID NO: 40
G	QQYTDQ to NNYTDT	Q399N, Q400N, and Q404T	SEQ ID NO: 9	SEQ ID NO: 41 & SEQ ID NO: 42
H	HTYFPN to HTAFPN	Y392A	SEQ ID NO: 10	SEQ ID NO: 43 & SEQ ID NO: 44
I	HTYFPN to HTFFPN	Y392F	SEQ ID NO: 11	SEQ ID NO: 45 & SEQ ID NO: 46
J	QQYTDQ to NNFTDN	Q399N, Q400N, Y401F and Q404N	SEQ ID NO: 12	SEQ ID NO: 47 & SEQ ID NO: 48
K	QQYTDQ to NNYTDN	Q399N, Q400N, and Q404N	SEQ ID NO: 13	SEQ ID NO: 49 & SEQ ID NO: 50
L	Adding "DPIG" after QQYTDQ	[insertion]	SEQ ID NO: 14	SEQ ID NO: 51 & SEQ ID NO: 52
M	QQYTDQ to AAYTDQ	Q399A and Q400A	SEQ ID NO: 15	SEQ ID NO: 53 & SEQ ID NO: 54
N	QQYTDQ to QQPAAA	Y401P, T402A, D403A, and Q404A	SEQ ID NO: 16	SEQ ID NO: 55 & SEQ ID NO: 56

O	QQYTDQ to NNWTDT	Q399N, Q400N, Y401W and Q404T	SEQ ID NO: 17	SEQ ID NO: 57 & SEQ ID NO: 58
P	(QQYTDQ to NNWTDT) + (HTYFPN to HTAFPN)	See Construct O and Construct H	SEQ ID NO: 18	SEQ ID NO: 59 & SEQ ID NO: 60
Q	(QQYTDQ to QQFTDQ) + (KEYQQ to KEYAA)	See Construct A and Construct D	SEQ ID NO: 19	SEQ ID NO: 61 & SEQ ID NO: 62
R	(QQYTDQ to NNFTDT) + (KEYQQ to KEYAA)	See Construct F and Construct D	SEQ ID NO: 20	SEQ ID NO: 63 & SEQ ID NO: 64
S	(QQYTDQ to QQWTDQ) + (HTYFPN to HTAFPN)	See Construct B and Construct H	SEQ ID NO: 21	SEQ ID NO: 65 & SEQ ID NO: 66
T	(QQYTDQ to NNWTDT) + (HTYFPN to HTAFPN) + (KEYQQ to KEYAA)	See Construct O, Construct H, and Construct D	SEQ ID NO: 22	SEQ ID NO: 67 & SEQ ID NO: 68
U	(QQYTDQ to QQFTDT) + (HTYFPN to HTAFPN) + (KEYQQ to KEYAA)	Y401F and Q404T; Also see Construct H and Construct D	SEQ ID NO: 23	SEQ ID NO: 69 & SEQ ID NO: 70
V	(QQYTDQ to QQFTDT) + (HTYFPN to HTAFPN)	Y401F and Q404T; Also see Construct H	SEQ ID NO: 24	SEQ ID NO: 71 & SEQ ID NO: 72
W	(QQYTDQ to QQWTDQ) + (HTYFPN to HTAFPN) + (KEYQQ to KEYAA)	See Construct B, Construct H, and Construct D	SEQ ID NO: 25	SEQ ID NO: 73 & SEQ ID NO: 74

X	(HTYFPN to HTAFPN) + (KEYQQ to KEYAA)	See Construct H and Construct D	SEQ ID NO: 26	SEQ ID NO: 75 & SEQ ID NO: 76
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The B19 VP2 polypeptides were examined for their ability to form B19 Virus Like Particles (VLPs) by electron microscopy.

[0090] For purification of B19 wtVLPs (B19 wild type VLPs) and B19 mutant VLPs (B19 mVLPs), cells were collected (750 rpm, 10 min) at 72 hrs post-infection by rBac, suspended in Tris buffer (20mM Tris, 0.25M NaCl, pH8.5), downs homogenized, and incubated for 10 min at 45°C. The pH and density were adjusted to 7.2 and 1.30 g/ml, respectively, prior to overnight ultracentrifugation at 32,000 rpm in SW55Ti (Beckman Coulter, MO). VLP bands were collected, and dialyzed against Dulbecco's phosphate-buffered saline (DPBS). The protein concentrations of VLP stock solution were measured (Bio-Rad Protein Assay; BioRad, CA).

[0091] For electron microscopy, purified VLPs and mVLPs were loaded onto a formvar-carbon coated 300-mesh copper grid, stained with 2% phosphotungstic acid (pH 6.8), and visualized under the transmission electron microscope (EM: 100S, JEOL Ltd., Tokyo, JPN).

[0092] Constructions of mutant B19 VLPs (mVLPs) were attempted using only the mutated B19 VP2 proteins; no other proteins were included in the mVLPs. Although a few of the VP2 mutants did not form mVLPs, most formed mVLPs that were morphologically similar to wild type VLPs (e.g., see FIG. 2A-FIG. 2I), but with varying yields; the tightness of VLP-assemblage also varied.

Hemagglutination Assays (HA) and Hemagglutination Inhibition Assays (HIA)

[0093] A hemagglutination assay of purified B19 VLPs was performed with human RBCs to study binding capacity to P antigen (See FIG. 5 and FIG. 6 which represent some embodiments of hemagglutination caused by P antigen binding, and possible effects therefrom). HIA assays determine the inhibition of hemagglutination by antibodies raised against VLPs made of wild type B19 VP2 protein ("wild type VLPs" or "wtVLPs") or VLPs made of the mutated B19 VP2 polypeptide ("mutant VLPs" or "mVLPs"); HIA assays are used to establish evidence for the presence of conformational epitopes capable of inducing neutralizing antibodies.

[0094] Immunization of rabbits and mice: Rabbits were immunized subcutaneously, and Balb/c mice were immunized intraperitoneally. Rabbits and mice were injected with 100 µg per injection twice at two weeks interval with the use of Titermax or Adjuplex Vaccine Adjuvant (Sigma-Aldrich, MO) and then with a final boost one month later. If necessary, maximum bleeding was done one week to 10 days after the final boost.

[0095] ELISA Assays: To carry out ELISA assays, VLPs diluted in PBS (pH7.2) were coated on ELISA plates (Immunolon II, Dynatech) for 1hr at 37°C. After saturation of the plates with PBS containing 5% bovine serum albumin (5% PBSA) for 1 hour at 37°C, primary antibodies diluted with 1% PBSA were added for another one hour at 37°C. Alkaline phosphatase-labeled secondary antibodies and Sigma 104 substrate (Sigma-Aldrich, MO) were employed for the detection of bound primary antibodies.

[0096] Hemagglutination Assays (HA): Briefly, 100 µl of VLP solution (0.01 to 0.5 µg/ml in ADPBS [albumin-dextrose PBS; 0.05M PBS, pH 6.3, 0.2% Bovine serum albumin, 5g/L dextrose]) was placed in the wells of a round-bottom microtiter

plate, and 50µl of 2% hRBC (human red blood cells that were pretested for the presence of P antigen using wild type VLPs as antigen: O type human blood; Innovative Research, MI) in ADPBS was added for 2 hours of incubation at 4°C. The result was read.

5 [0097] Hemagglutination Inhibition Assays (HIA): Fifty µl of antibodies serially diluted in ADPBS were incubated with 50 µl of VLPs diluted in ADPBS for 30 min at RT. Fifty µl of two percent hRBCs was then added for 2 hrs incubation at 4°C prior to reading the outcome of hemagglutination.

[0098] Results of HA and HIA Assays: FIG. 3 shows results from
10 hemagglutination assay (HA) of wtVLPs or mVLPs. Type O human red blood cells were employed in this HA. FIG. 4 includes results from hemagglutination inhibition assays of rabbit or mouse polyclonal antibodies raised against B19 VLPs containing wild type VP2 or mVP2. Type O human red blood cells and wild type VLPs were used in this assay.

15 [0099] Table 2 provides an overview summary of some characteristics of the various constructs and the respective mVLPs.

Table 2. B19 VP2 mutation analysis and summary of partial characterization

Construct	Formation of VLPs	Hemagglutination (HA) by VLPs	Immunogenicity of VLPs in mice ¹	HIA ²
A	Yes	No HA	OK	Yes (1/100)
B	Yes (increased yield)	Yes	High	Yes (1/100)
C	No	NA	NA	NA
D	Yes	Partial HA	Low	Yes (1/100 dilution)

E	Yes	Partial HA	N/A	No
F	Yes	No HA	High	Yes (1/500 dilution)
G	Yes	Partial HA	High	Yes (over 1/500 dilution)
H	Yes	Partial HA	Low	Yes (weak)
I	-	No HA	N/A	N/A
O	Yes	N/A	N/A	N/A
P	VLP formation but with significant unassembled material	N/A	N/A	N/A
W	VLP formation but with significant unassembled material	N/A	N/A	N/A

Constructs J, K, M, and N did not yield purified mVLPs under these conditions.

¹Immunogenicity in mice: wtVLPs do not hemagglutinate murine red blood cells.

Still, it is not certain that there is absolutely no weak binding between them. Therefore, this result does not necessarily reflect the immunities of mVLPs in human.

- 5 ²HIA (Hemagglutination inhibition assay): Inhibition of hemagglutination of wtVLPs by antibody raised against mVLPs. This test was carried out using murine polyclonal antibodies. TiterMax adjuvant was employed for the immunization.

[00100] Table 3 shows cross-reactivities of rabbit sera raised against B19 wild
 10 type VLPs or B19 mVLPs. Antibodies were diluted to 1/4000 and their reactivities were measured by direct ELISA. Alkaline-phosphatase-tagged goat antibody anti-IgG of rabbit was used as secondary antibody, and the optical density was measured at 410nm.

Table 3 - Cross-Reactivities

Antigen\ Rabbit sera	Wild type VLPs	<VLPs made from Construct A	< VLPs made from Construct B
Wild type VLPs	0.408	0.608	0.749
VLPs made from Construct A	0.716	1.300	1.362
VLPs made from Construct B	1.006	1.985	2.018

PBA with albumin (control negative)	0.133	0.133	0.132
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< - indicates antibodies raised against this antigen

[00101] Table 4 shows the titration of mouse polyclonal antibodies raised against B19 wild type VLPs or B19 mutated VLPs. Antibody titers were measured by ELISA. Wild type VLPs are known to be non immunogenic in mice. The immunogen employed to raise each polyclonal antibodies were used as antigen for this analysis. ODs were measured at 410nm. All antibodies gave less than 0.200 OD when they were reacted with bovine albumin as control negative antigen.

Table 4. Antibodies diluted to 1/500. ODs over 1.00 indicated in bold.

Antigen\ sera	<Wild type	<Construct A	<Construct B	<Construct D	<HTYFPN	<Construct F	<Construct G
Wild type	0.211	0.278	0.333	0.754	0.324	0.949	0.707
Construct A	0.235	0.615	0.755	1.786	0.598	2.398	1.96
Construct B	0.333	0.820	1.794	2.832	0.788	3.642	3.368
Construct D	0.210	0.591	0.645	1.103	0.481	1.511	1.287
HTYFPN	0.199	0.502+	0.467	1.032	0.385	1.259	0.803

< - indicates antibodies raised against this antigen

[00102] mVLPs made from Construct F were HA-negative, immunogenic in mice (Table 2 and FIG. 3), and induced antibodies capable of inhibiting HA by wtVLPs (FIG. 4).

[00103] Of three targeted locations, the “Y” in QQY₄₀₁TDQ and HTY₃₉₂FPN, which are located in the P-antigen binding pocket, appear to be influential in forming viral ligand for P-antigen. Construct A formed mVLPs; the mVLPs were HA negative, but were moderately immunogenic in mice. Construct B mVLPs made good mVLPs with good yield; the mVLPs were immunogenic in mice, but they were HA positive. Rabbit antibodies anti-wtVLPs, anti-Construct A mVLPs, and anti-

Construct B mVLPs were generated. These rabbit sera showed the high cross-reactivities among wtVLPs, Construct A mVLPs and Construct B mVLPs (Table 3).

[00104] Construct D mVLPs induced HIA positive antibodies in mice but were HA positive (FIG. 4 and Table 4). Construct F mVLPs were HA negative, induced high titer antibody immune response in mice (Table 4), and gave good HIA titer against wtVLPs (FIG. 4). Construct G mVLPs were partially negative for HA, but induced murine antibodies with high titer for HIA. The three Qs in Q₃₉₃Q₄₀₀YTDQ₄₀₄ seem to have partial influence for HA, but may be more influential for the formation of VLPs, particularly the third Q (Q₄₀₄). The two Qs in KEYQ₃₆₈Q₃₆₉ appeared to have minor effects on HA. At this time, we have not successfully purified VLPs from the VP2 mutants of Construct J, Construct M, Construct N, or Construct C.

[00105] “QQYTDQ”, especially the residue Y, appears influential for the binding capability of Parvovirus B19 to RBCs. Any of three “Q”s in “QQYTDQ”, “QQ” in “KEYQQ” and “Y” in HTYFPN appeared to affect the affinity of mVLPs to RBCs, suggesting some contributions of these amino acids. VP2 with the mutation from Y to A in HTYFPN as well as VP2 with the mutation from QQ to AA in KEYQQ formed mVLPs with weaker affinity to RBCs than wtVLPs. Adding four amino acids “DPIG” after “QQYTDQ” appeared to abolish the capacity of VP2 protein to form VLPs.

[00106] mVLPs composed of VP2 mutated from Y to F in QQYTDQ (i.e., construct A) formed VLPs morphologically comparable to wtVLPs, appeared to abolish hemagglutination of RBCs, and induced antibodies in mice and rabbit, that recognized wtVLPs as well as other mVLPs. Also, antibodies raised against construct A mVLPs were also capable of blocking hemagglutination of wtVLPs. Y and F have

the same amino acid back bone structure except that Y has a hydroxyl group at position 4 of the benzene ring while F has none.

[00107] mVLPs made from construct B mVLPs (i.e., Y to W in QQYTDQ) formed mVLPs morphologically comparable to wtVP2. Although they
5 hemagglutinated RBCs, they induced high titer antibodies in mice and rabbit, RBCs of which are known not to bind to B19. Antibodies to construct B mVLPs recognized wtVLPs as well as other mVLPs, and also blocked hemagglutination of wtVLPs, indicating that it shared cross-reactive epitopes with wtVLPs and other mVLPs. In fact, construct B mVLPs yielded higher and formed better VLPs than wtVLPs and
10 construct A mVLPs when observed under the electron microscope, and were immunogenic in mice and rabbit.

[00108] Rabbit anti-sera that were raised against wild type VLPs, recognized construct A mVLPs and construct B mVLPs, as determined by ELISA assays, demonstrating again the presence of cross-reactive epitopes on these mVLPs.

15 [00109] Construct C mVLPs (i.e., with mutation from Y to A in QQYTDQ) did not form purifiable VLPs under the condition employed in this study.

[00110] Mutations of three Qs in construct F (i.e., QQYTDQ to NNFTDT) or in construct G (i.e., QQYTDQ to NNYTDT) resulted in formation of mVLPs that were not only morphologically similar to wtVLPs, but were also immunogenic.

20 Construct F mVLPs and construct G mVLPs did not hemagglutinate or partially hemagglutinated RBC, respectively. However, constructs J, K, M, and N were not able to form stable mVLPs under the condition employed in this study. This may indicate the influence of the third "Q" in this ligand site (i.e., QQYTDQ) in the formation of mVLPs and in the binding to P antigen. The choices of substituted

amino acids can, in some instances, influence not only for the formation of mVLPs but also the mVLP immunogenicity.

[00111] When the two “Q”s in “KEYQQ” were replaced by AA (i.e., construct D), the resulting mVLPs were morphologically comparable to wtVLPs and they could partially hemagglutinated RBCs, but they were not immunogenic in mice. When the two “Q”s in “KEYQQ” were replaced by NN (i.e., construct E), mVLPs were morphologically good and comparable to wtVLPs; they hemagglutinated RBCs and were immunogenic in mice.

[00112] Mutation of Y in HTYFPN to HTFFPN (Construct I) resulted in formation of good mVLPs which partially hemagglutinated RBCs but their immunogenicity in mice was low.

[00113] The headings used in the disclosure are not meant to suggest that all disclosure relating to the heading is found within the section that starts with that heading. Disclosure for any subject may be found throughout the specification.

[00114] It is noted that terms like “preferably,” “commonly,” and “typically” are not used herein to limit the scope of the claimed invention or to imply that certain features are critical, essential, or even important to the structure or function of the claimed invention. Rather, these terms are merely intended to highlight alternative or additional features that may or may not be utilized in a particular embodiment of the present invention.

[00115] As used in the disclosure, “a” or “an” means one or more than one, unless otherwise specified. As used in the claims, when used in conjunction with the word “comprising” the words “a” or “an” means one or more than one, unless otherwise specified. As used in the disclosure or claims, “another” means at least a second or more, unless otherwise specified. As used in the disclosure, the phrases

“such as”, “for example”, and “e.g.” mean “for example, but not limited to” in that the list following the term (“such as”, “for example”, or “e.g.”) provides some examples but the list is not necessarily a fully inclusive list. The word “comprising” means that the items following the word “comprising” may include additional unrecited elements or steps; that is, “comprising” does not exclude additional unrecited steps or elements.

[00116] In certain instances, sequences disclosed herein are included in publicly-available databases, such as GENBANK[®] and SWISSPROT. Unless otherwise indicated or apparent the references to such publicly-available databases are references to the most recent version of the database as of the filing date of this Application.

[00117] Unless otherwise indicated, all numbers expressing quantities of ingredients, properties such as reaction conditions, and so forth used in the specification and claims are to be understood as being modified in all instances by the term “about”. Accordingly, unless indicated to the contrary, the numerical parameters set forth in this specification and claims are approximations that can vary depending upon the desired properties sought to be obtained by the presently-disclosed subject matter.

[00118] As used herein, the term “about,” when referring to a value or to an amount of mass, weight, time, volume, concentration or percentage is meant to encompass variations of in some embodiments $\pm 20\%$, in some embodiments $\pm 10\%$, in some embodiments $\pm 5\%$, in some embodiments $\pm 1\%$, in some embodiments $\pm 0.5\%$, and in some embodiments $\pm 0.1\%$ from the specified amount, as such variations are appropriate to perform the disclosed method.

[00119] Detailed descriptions of one or more embodiments are provided herein.

It is to be understood, however, that the present invention may be embodied in various

forms. Therefore, specific details disclosed herein (even if designated as preferred or advantageous) are not to be interpreted as limiting, but rather are to be used as an illustrative basis for the claims and as a representative basis for teaching one skilled in the art to employ the present invention in any appropriate manner. Indeed, various
5 modifications of the invention in addition to those described herein will become apparent to those skilled in the art from the foregoing description and the accompanying figures. Such modifications are intended to fall within the scope of the appended claims.

[00120] What is claimed is:

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CLAIMS

1. A polypeptide comprising a VP2 polypeptide with at least one amino acid modification relative to wild type VP2.
- 5 2. The polypeptide of claim 1, wherein the at least one amino acid modification is an insertion, a deletion, or a substitution.
3. The polypeptide of claim 1 or claim 2, wherein the wild type VP2 has the amino acid sequence of SEQ ID NO: 1.
- 10 4. The polypeptide of any of claims 1-3, wherein the polypeptide forms an mVLP.
5. The polypeptide of any of claims 1-4, wherein the mVLP formed from the polypeptide has reduced binding to P antigen relative to wtVLP.
- 15 6. The polypeptide of any of claims 1-5, wherein the at least one amino acid modification is in or near the recess of the three-fold axis.
7. The polypeptide of any of claims 1-6, wherein the at least one amino acid modification is selected from a substitution in loop 3, a substitution in loop 4, a substitution upstream of loop 3, a substitution upstream of loop 4, or combinations thereof.
- 20 8. The polypeptide of any of claims 1-7, wherein the at least one amino acid modification is a substitution at Y401, a substitution at Q399, a substitution at Q400,
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a substitution at Q404, a substitution at Q368, a substitution at Q369, a substitution at Y392, Y401F, Y401W, Y401A, Q368A, Q369A, Q368N, Q369N, Q399N, Q400N, Q404T, Y392A, Y392F, Q404N, Y401P, T402A, D403A, Q404A, or combinations thereof.

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9. The polypeptide of any of claims 1-8, wherein the wild type VP2 is a wild type VP2 from parvovirus B19.

10. The polypeptide of any of claims 1-9, wherein the polypeptide is selected from the group consisting of construct A, construct B, construct C, construct D, construct E, construct F, construct G, construct H, construct I, construct J, construct K, construct L, construct M, construct N, construct O, construct P, construct Q, construct R, construct S, construct T, construct U, construct V, construct W, and construct X.

11. The polypeptide of any of claims 1-10, wherein the polypeptide sequence has at least 90% identity to SEQ ID NO: 1.

12. An mVLP comprising a polypeptide of any of claims 1-11.

13. The mVLP of claim 12, wherein the mVLP has reduced binding to P antigen compared to wtVLP, the mVLP has no detectable binding to P antigen, the mVLP has reduced hemagglutination of red blood cells compared to wtVLP, or the mVLP has no detectable hemagglutination.

14. The mVLP of claim 12 or claim 13, wherein the mVLP has one or more neutralizing epitopes.

15. The mVLP of any of claims 12-14, wherein the mVLP induces the production of antibodies in an animal, where the antibodies produced are capable of reducing or inhibiting hemagglutination by wtVLP.

16. A composition comprising an mVLP of any of claims 12-15.

17. The composition of claim 16, wherein the amount of mVLP is from about 0.0001% (by weight total composition) to about 99%.

18. The composition of claim 16 or claim 17, further comprising an adjuvant or a carrier.

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19. A pharmaceutical composition comprising an mVLP of any of claims 12-15.

20. The pharmaceutical composition of claim 19, wherein the amount of mVLP is from about 0.0001% (by weight total composition) to about 50%.

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21. The pharmaceutical composition of claim 19 or claim 20, further comprising an adjuvant or a carrier.

22. A vaccine comprising an mVLP of any of claims 12-15.

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23. The vaccine of claim 22, wherein the amount of mVLP is from about 0.0001% (by weight total composition) to about 50%.

24. The vaccine of claim 22 or claim 23, further comprising an adjuvant or a carrier.

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25. The vaccine of any of claims 22-24, further comprising squalene, IL-2, RIBI adjuvant system, QS21, GM-CSF, alum hydro gel, monophosphoryl lipid A, trehalose dimycolate, Toll-like receptor ligands, Toll-like receptor agonists, CpG oligodeoxynucleotides, cell wall skeleton, adjuplex vaccine adjuvant, MF59, titermax, or combinations thereof.

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26. The vaccine of claim 22 or claim 23, wherein the vaccine does not comprise an adjuvant.

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27. A method for providing an animal with an mVLP comprising one or more administrations of one or more compositions comprising the mVLP of any of claims 12-15, wherein the compositions may be the same or different if there is more than one administration.

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28. The method of claim 27, wherein at least one of the one or more compositions does not comprise an adjuvant.

29. The method of claim 27 or claim 28, wherein at least one of the one or more compositions further comprises a carrier or an adjuvant.

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30. The method of any of claims 27-29, wherein at least one of the one or more compositions further comprises squalene, IL-2, RIBI adjuvant system, QS21, GM-CSF, alum hydro gel, monophosphoryl lipid A, trehalose dimycolate, Toll-like receptor ligands, Toll-like receptor agonists, CpG oligodeoxynucleotides, cell wall skeleton, adjuplex vaccine adjuvant, MF59, titermax, or combinations thereof.

31. The method of any of claims 27-30, wherein at least one of the one or more compositions comprises the composition of any of claims 16-18, the pharmaceutical composition of any of claims 19-21, or the vaccine of any of claims 22-26.

32. The method of any of claims 27-30, wherein at least one of the one or more administrations comprises parenteral administration, a mucosal administration, intravenous administration, subcutaneous administration, topical administration, intradermal administration, oral administration, sublingual administration, intranasal administration, or intramuscular administration.

33. The method of any of claims 27-32, wherein if there is more than one administration at least one composition used for at least one administration is different from the composition of at least one other administration.

34. The method of any of claims 27-33, wherein the mVLP of at least one of the one or more compositions is administered to the animal in an amount of from about 0.01 mg of mVLP/kg animal body weight to about 15 mg of mVLP/kg animal body weight.

35. The method of any of claims 27-34, wherein the animal is a human or a primate.

36. A method for treating an animal for a parvovirus infection, a disease related to a parvovirus infection, an erythrovirus infection, a disease related to an erythrovirus

5 infection, a parvovirus B19 infection, or a disease related to a parvovirus B19 infection, comprising one or more administrations of one or more compositions comprising the mVLP of any of claims 12-15, wherein the compositions may be the same or different if there is more than one administration.

10 37. The method of claim 36, wherein at least one of the one or more compositions does not comprise an adjuvant.

38. The method of claim 36 or claim 37, wherein at least one of the one or more compositions further comprises a carrier or an adjuvant.

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39. The method of any of claims 36-38, wherein at least one of the one or more compositions further comprises squalene, IL-2, RIBI adjuvant system, QS21, GM-CSF, alum hydro gel, monophosphoryl lipid A, trehalose dimycolate, Toll-like receptor ligands, Toll-like receptor agonists, CpG oligodeoxynucleotides, cell wall skeleton, adjuplex vaccine adjuvant, MF59, titermax, or combinations thereof.

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40. The method of any of claims 36-39, wherein at least one of the one or more the compositions comprises the composition of any of claims 16-18, the pharmaceutical composition of any of claims 19-21, or the vaccine of any of claims 22-26.

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41. The method of any of claims 36-39, wherein at least one of the one or more administrations comprises parenteral administration, a mucosal administration, intravenous administration, subcutaneous administration, topical administration, intradermal administration, oral administration, sublingual administration, intranasal administration, or intramuscular administration.
42. The method of any of claims 36-41, wherein if there is more than one administration at least one composition used for at least one administration is different from the composition of at least one other administration.
43. The method of any of claims 36-42, wherein the mVLP of at least one of the one or more compositions is administered to the animal in an amount of from about 0.01 mg of mVLP/kg animal body weight to about 15 mg of mVLP/kg animal body weight.
44. The method of any of claims 36-43, wherein the animal is a human or a primate.
45. The method of any of claims 36-44, wherein the animal is in need of the treatment.
46. The method of any of claims 36-45, wherein the method is for treating an erythrovirus infection, a disease related to an erythrovirus infection, a parvovirus B19 infection, or a disease related to a parvovirus B19 infection,.

47. The method of any of claims 36-46, wherein the method is for treating an
erthrovirus infection, a parvovirus B19 infection, a disease related to an erythrovirus
infection, a disease related to parvovirus B19 infection, hydrops fetalis intrauterine
fetal death, erythema infectiosum (i.e., fifth disease), sickle cell anemia, Thalassemia,
5 anemia, anemia induced by malaria, parvovirus B19-induced red cell aplasia (TRCA),
chronic anemia, acute arthropathy, persistent arthropathy, aplastic crisis, arthritis,
hepatitis, myocarditis, hepatosplenomegaly, systemic lupus erythematosus,
meningencephalitis, or fibromyalgia.
- 10 48. The method of any of claims 36-47, wherein the method induces an immune
response, is a vaccination, is a prophylactic treatment, is a therapeutic treatment, or is
a combination thereof.
- 15 49. A method for inducing an immune response in an animal comprising one or more
administrations of one or more compositions comprising the mVLP of any of claims
12-15, wherein the compositions may be the same or different if there is more than
one administration.
- 20 50. The method of claim 49, wherein at least one of the one or more compositions
does not comprise an adjuvant.
51. The method of claim 49 or claim 50, wherein at least one of the one or more
compositions further comprises a carrier or an adjuvant.

52. The method of any of claims 49-51, wherein at least one of the one or more compositions further comprises squalene, IL-2, RIBI adjuvant system, QS21, GM-CSF, alum hydro gel, monophosphoryl lipid A, trehalose dimycolate, Toll-like receptor ligands, Toll-like receptor agonists, CpG oligodeoxynucleotides, cell wall skeleton, adjuplex vaccine adjuvant, MF59, titermax, or combinations thereof.

53. The method of any of claims 49-52, wherein at least one of the one or more compositions comprises the composition of any of claims 16-18, the pharmaceutical composition of any of claims 19-21, or the vaccine of any of claims 22-26.

10

54. The method of any of claims 49-53, wherein at least one of the one or more administrations comprises parenteral administration, a mucosal administration, intravenous administration, subcutaneous administration, topical administration, intradermal administration, oral administration, sublingual administration, intranasal administration, or intramuscular administration.

15

55. The method of any of claims 49-54, wherein if there is more than one administration at least one composition used for at least one administration is different from the composition of at least one other administration.

20

56. The method of any of claims 49-55, wherein the mVLP of at least one of the one or more compositions is administered to the animal in an amount of from about 0.01 mg of mVLP/kg animal body weight to about 15 mg of mVLP/kg animal body weight.

25

57. The method of any of claims 49-56, wherein the animal is a human or a primate.

58. The method of any of claims 49-57, wherein the animal is in need of the treatment.

5

59. The method of any of claims 49-58, wherein the method prevents or ameliorates future infections.

60. A method for vaccinating an animal against a parvovirus infection, an erythrovirus infection, or a parvovirus B19 infection, comprising one or more administrations of one or more compositions comprising the mVLP of any of claims 12-15, wherein the compositions may be the same or different if there is more than one administration.

61. The method of claim 60, wherein at least one of the one or more compositions does not comprise an adjuvant.

62. The method of claim 60 or claim 61, wherein at least one of the one or more compositions further comprises a carrier or an adjuvant.

20

63. The method of any of claims 60-62, wherein at least one of the one or more compositions further comprises squalene, IL-2, RIBI adjuvant system, QS21, GM-CSF, alum hydro gel, monophosphoryl lipid A, trehalose dimycolate, Toll-like receptor ligands, Toll-like receptor agonists, CpG oligodeoxynucleotides, cell wall skeleton, adjuplex vaccine adjuvant, MF59, titermax, or combinations thereof.

25

64. The method of any of claims 60-63, wherein at least one of the one or more compositions comprises the composition of any of claims 16-18, the pharmaceutical composition of any of claims 19-21, or the vaccine of any of claims 22-26.

5

65. The method of any of claims 60-64, wherein at least one of the one or more administrations comprises parenteral administration, a mucosal administration, intravenous administration, subcutaneous administration, topical administration, intradermal administration, oral administration, sublingual administration, intranasal administration, or intramuscular administration.

10

66. The method of any of claims 60-65, wherein if there is more than one administration at least one composition used for at least one administration is different from the composition of at least one other administration.

15

67. The method of any of claims 60-66, wherein the mVLP of at least one of the one or more compositions is administered to the animal in an amount of from about 0.01 mg of mVLP/kg animal body weight to about 15 mg of mVLP/kg animal body weight.

20

68. The method of any of claims 60-67, wherein the animal is a human or a primate.

69. The method of any of claims 60-68, wherein the animal is susceptible to a parvovirus infection, an erythrovirus infection, or a parvovirus B19 infection.

25

70. The method of any of claims 60-69, wherein the method is for vaccinating against an erythrovirus infection or a parvovirus B19 infection.

71. The method of any of claims 60-70, wherein the method prevents or ameliorates future infections or future diseases.

72. A method for producing a polypeptide of any of claims 1-11 comprising,
- culturing a host cell transfected with a vector comprising a nucleic acid sequence encoding the polypeptide, to provide expression of the polypeptide; and
- recovering the polypeptide.

73. The method of claim 72, wherein the preparing the vector comprises reverse transcription using RNA or de novo synthesis.

74. The method of claim 72 or claim 73, wherein the host cell is an insect cell or a mammalian cell.

75. The method of any of claims 72-74, wherein the host cell is an Sf9 cell.

76. The method of any of claims 72-75, wherein the nucleic acid sequence encoding the polypeptide is selected from the group consisting of SEQ ID NO: 3; SEQ ID NO: 4; SEQ ID NO: 5; SEQ ID NO: 6; SEQ ID NO: 7; SEQ ID NO: 8; SEQ ID NO: 9; SEQ ID NO: 10; SEQ ID NO: 11; SEQ ID NO: 12; SEQ ID NO: 13; SEQ ID NO: 14; SEQ ID NO: 15; SEQ ID NO: 16; SEQ ID NO: 17; SEQ ID NO: 18; SEQ ID NO: 19;

SEQ ID NO: 20; SEQ ID NO: 21; SEQ ID NO: 22; SEQ ID NO: 23; SEQ ID NO: 24;
SEQ ID NO: 25; and SEQ ID NO: 26.

77. A method for producing an mVLP of any of claims 12-15 comprising,

- 5 - culturing a host cell transfected with a vector comprising a nucleic acid
sequence encoding a polypeptide of any of claims 1-11, to provide expression of the
polypeptide; and
 - recovering the mVLP.

10 78. The method of claim 77, wherein the preparing the vector comprises reverse
transcription using RNA or de novo synthesis.

79. The method of claim 77 or claim 78, wherein the host cell is an insect cell or a
mammalian cell.

15

80. The method of any of claims 77-79, wherein the host cell is an Sf9 cell.

81. The method of any of claims 77-80, wherein the nucleic acid sequence encoding
the polypeptide is selected from the group consisting of SEQ ID NO: 3; SEQ ID NO:
20 4; SEQ ID NO: 5; SEQ ID NO: 6; SEQ ID NO: 7; SEQ ID NO: 8; SEQ ID NO: 9;
SEQ ID NO: 10; SEQ ID NO: 11; SEQ ID NO: 12; SEQ ID NO: 13; SEQ ID NO: 14;
SEQ ID NO: 15; SEQ ID NO: 16; SEQ ID NO: 17; SEQ ID NO: 18; SEQ ID NO: 19;
SEQ ID NO: 20; SEQ ID NO: 21; SEQ ID NO: 22; SEQ ID NO: 23; SEQ ID NO: 24;
SEQ ID NO: 25; and SEQ ID NO: 26.

25

82. A nucleic acid molecule encoding the polypeptide of any of claims 1-11.

83. The nucleic acid molecule of claim 82, wherein the nucleic acid sequence encoding the polypeptide is selected from the group consisting of SEQ ID NO: 3;

5 SEQ ID NO: 4; SEQ ID NO: 5; SEQ ID NO: 6; SEQ ID NO: 7; SEQ ID NO: 8; SEQ ID NO: 9; SEQ ID NO: 10; SEQ ID NO: 11; SEQ ID NO: 12; SEQ ID NO: 13; SEQ ID NO: 14; SEQ ID NO: 15; SEQ ID NO: 16; SEQ ID NO: 17; SEQ ID NO: 18; SEQ ID NO: 19; SEQ ID NO: 20; SEQ ID NO: 21; SEQ ID NO: 22; SEQ ID NO: 23; SEQ ID NO: 24; SEQ ID NO: 25; and SEQ ID NO: 26.

10

84. The nucleic acid molecule of claim 82 or claim 83, wherein the nucleic acid sequence has at least 90% identity to SEQ ID NO: 2.

85. The nucleic acid molecule of any of claims 82-84, wherein the nucleic acid

15 molecule is in a cell, an insect cell, a mammalian cell, a human cell, or an Sf9 insect cell.

86. The nucleic acid molecule of any of claims 82-85, wherein the nucleic acid molecule is included in a vector or plasmid.

20

87. A vector comprising any of the nucleic acid sequences of claims 82-85.

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FIG. 1A

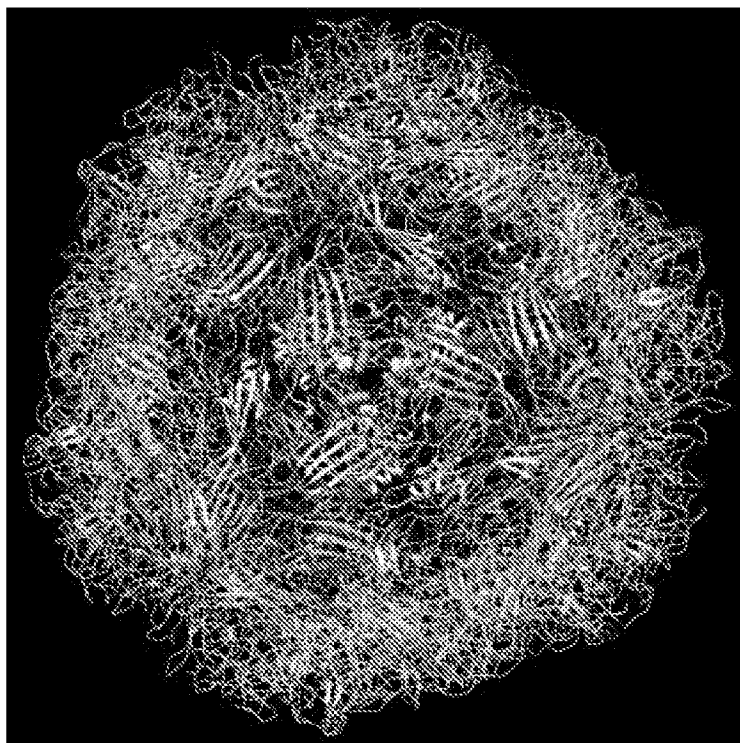
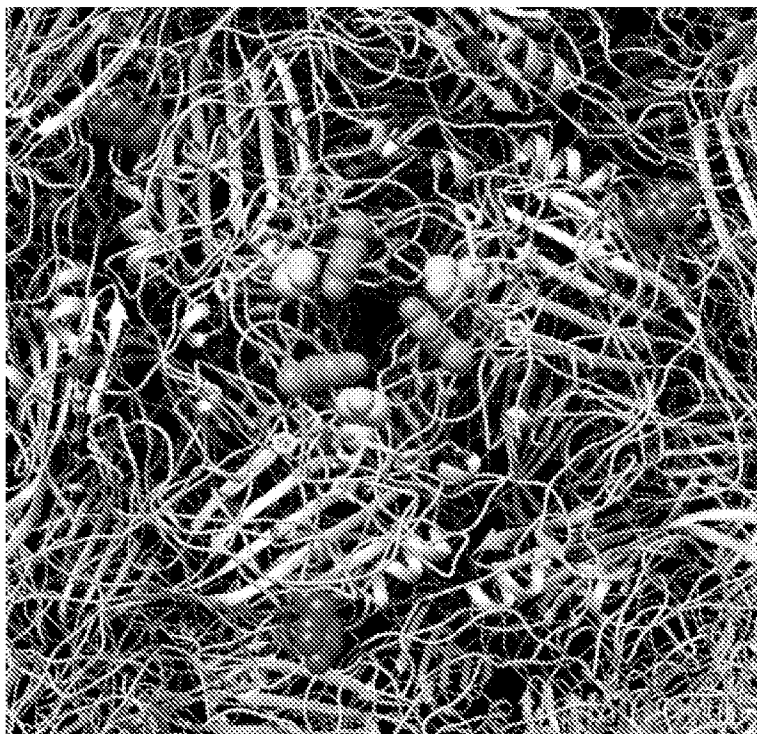


FIG. 1B



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FIG. 1C

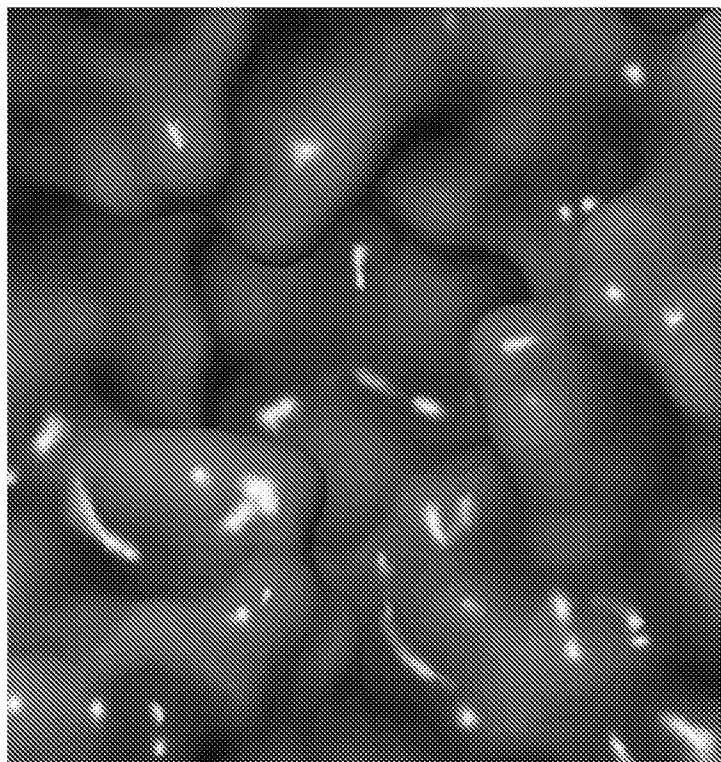
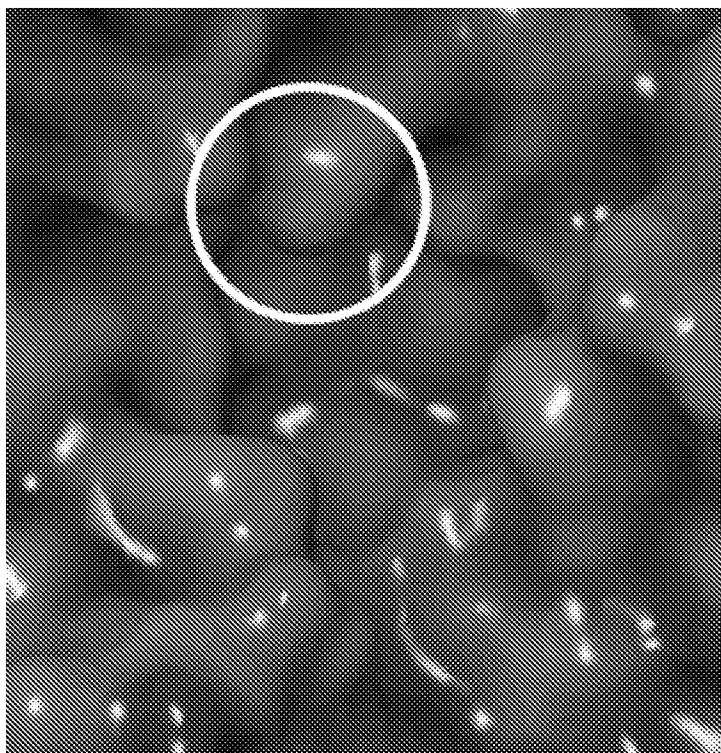


FIG. 1D



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FIG. 2A

Wild Type VLP

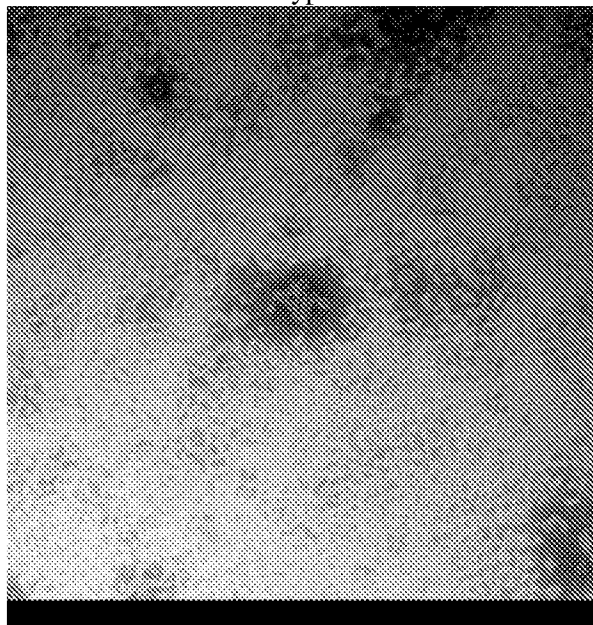
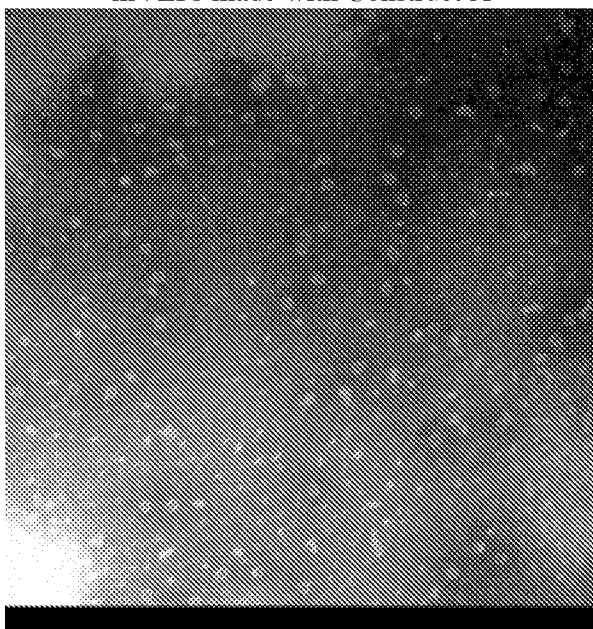


FIG. 2B

mVLPs made with Construct A



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FIG. 2C

mVLPs made with Construct B

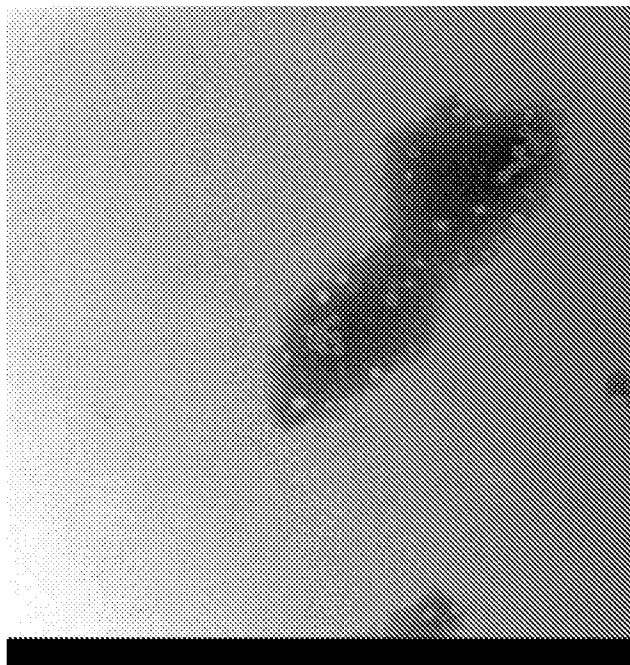
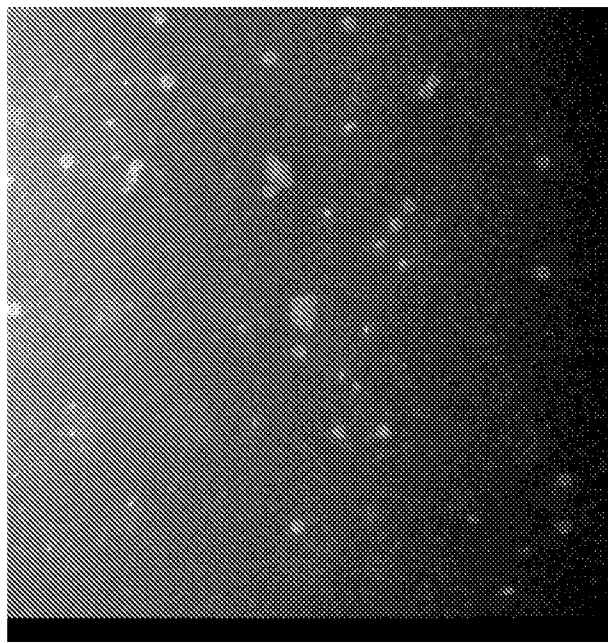


FIG. 2D

mVLPs made with Construct D



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FIG. 2E

mVLPs made with Construct E

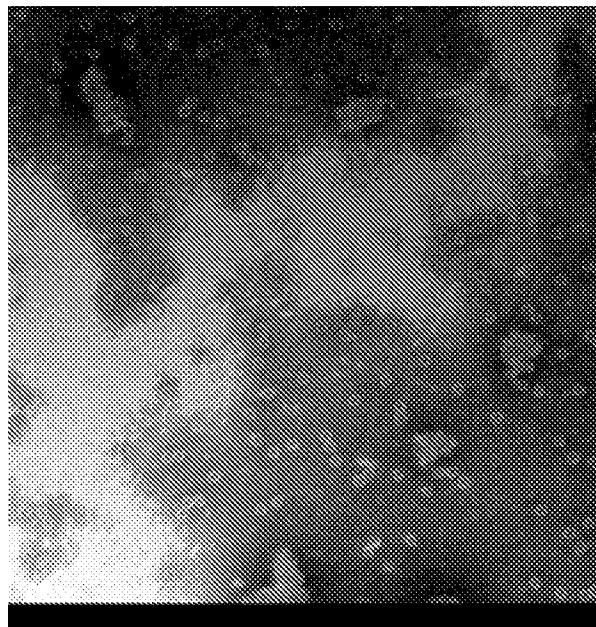
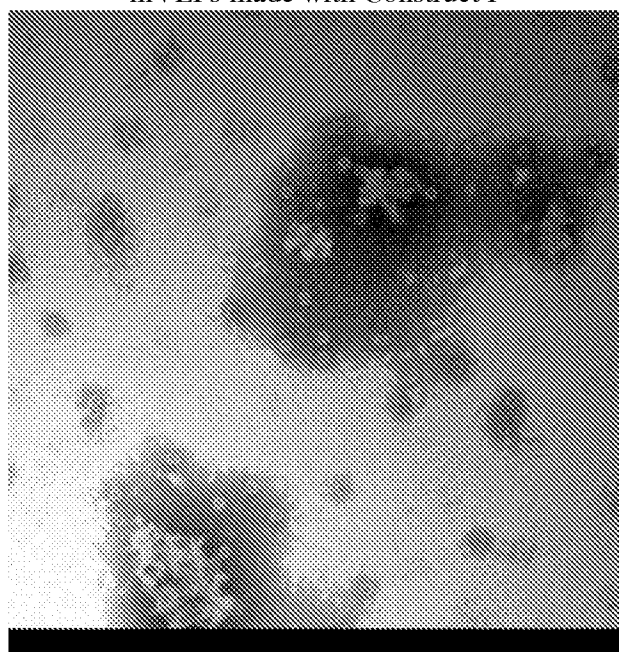


FIG. 2F

mVLPs made with Construct F



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FIG. 2G

mVLPs made with Construct F

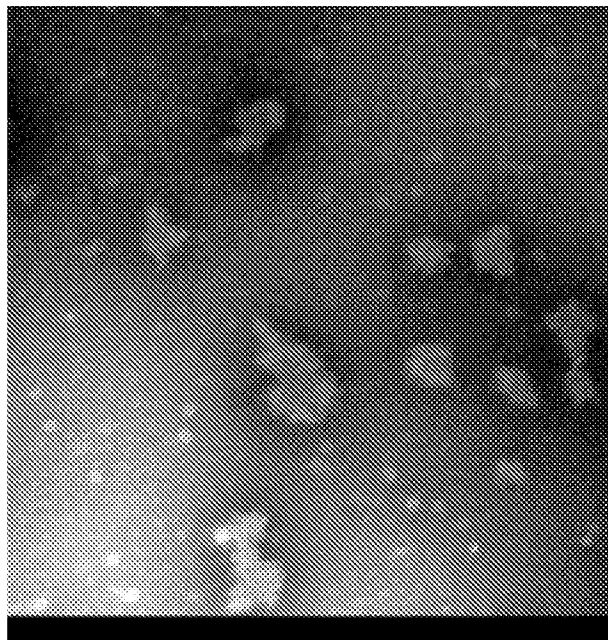


FIG. 2H

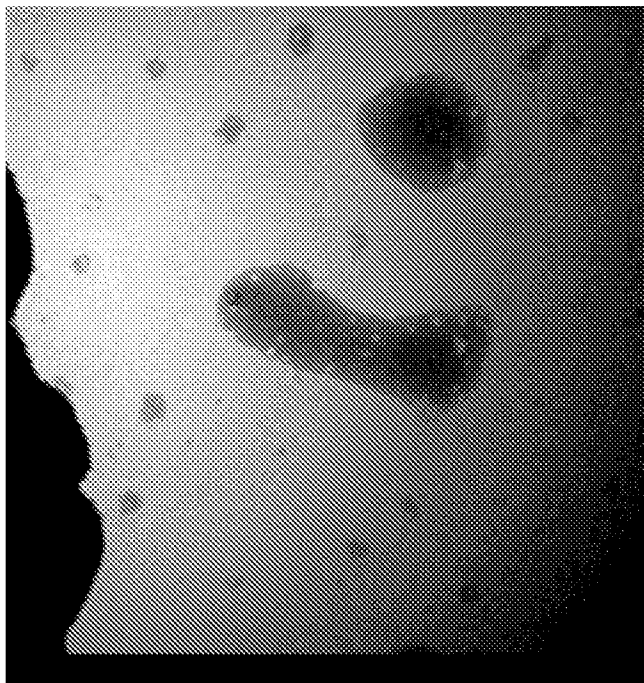
mVLPs made with Construct G



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FIG. 2I

mVLPs made with Construct H



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FIG. 3

Hemagglutination assays using Type O human red blood cells

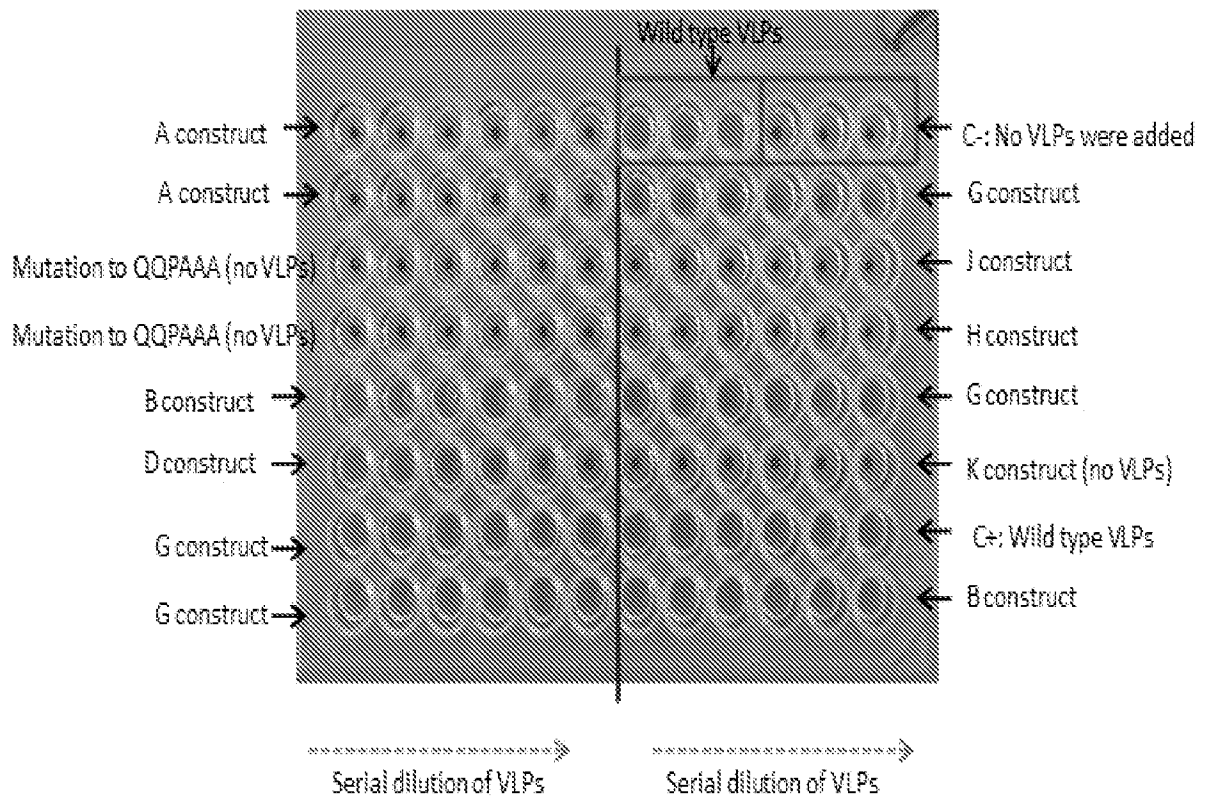
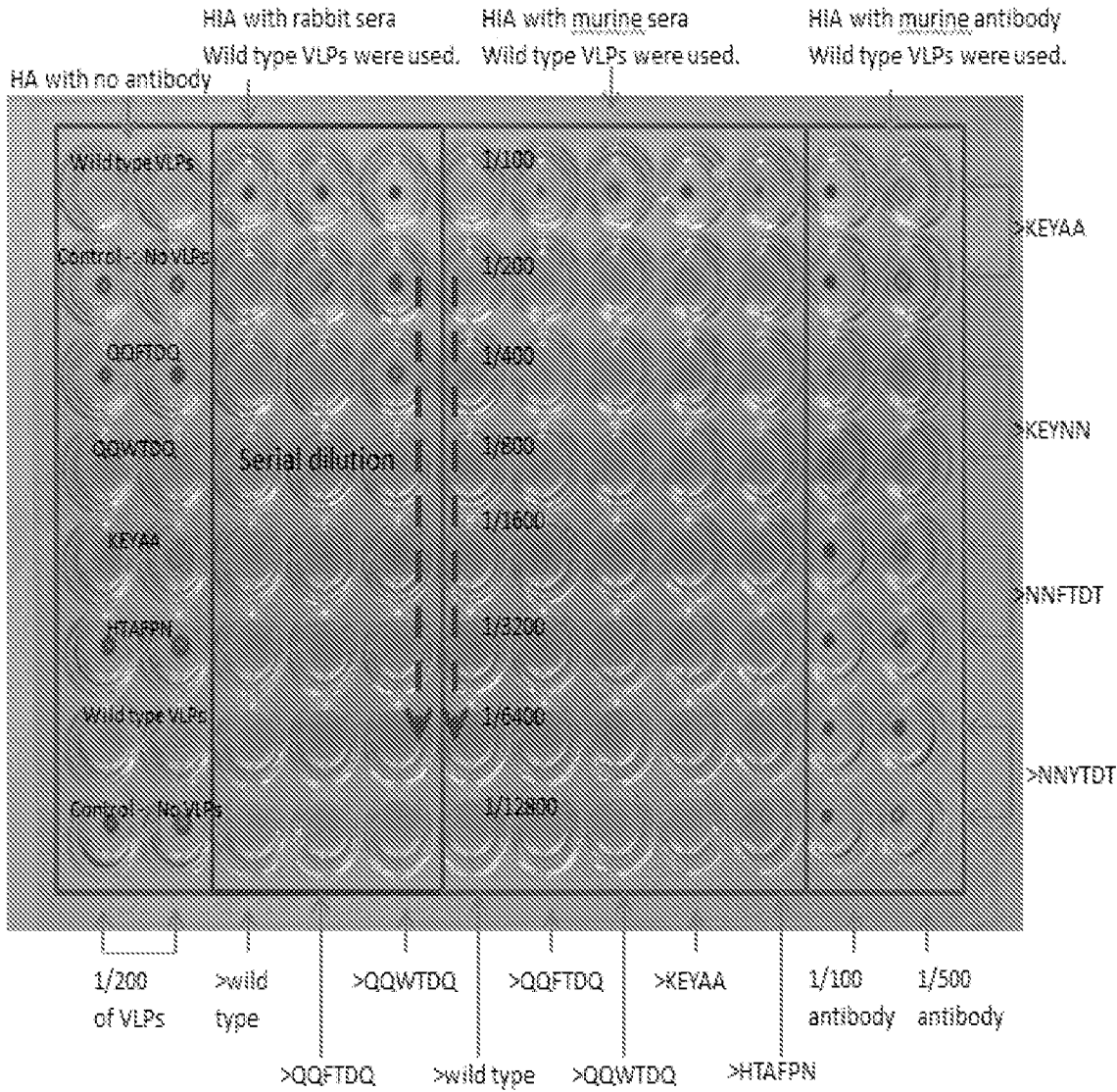


FIG. 4

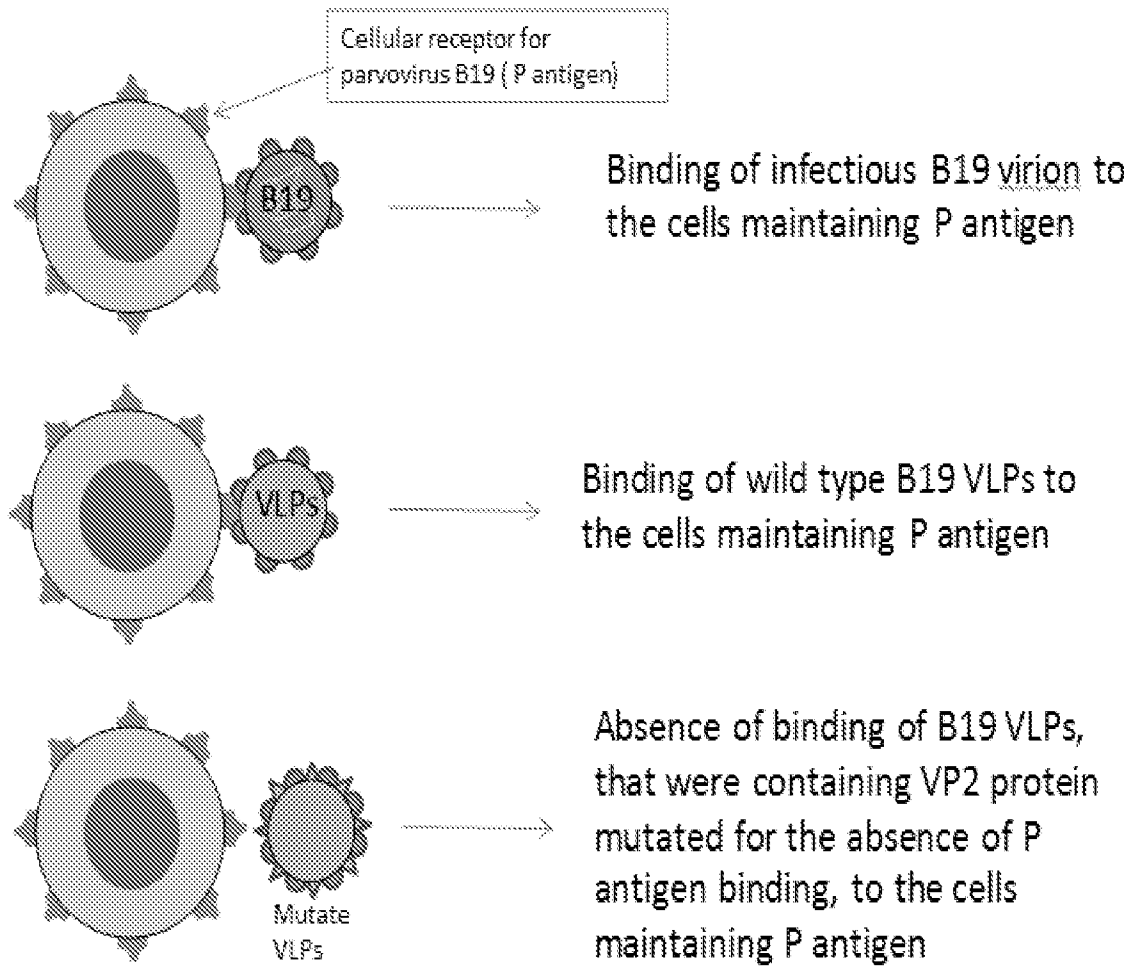
HIA Assays of rabbit and mouse raise polyclonal antibodies



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FIG. 5

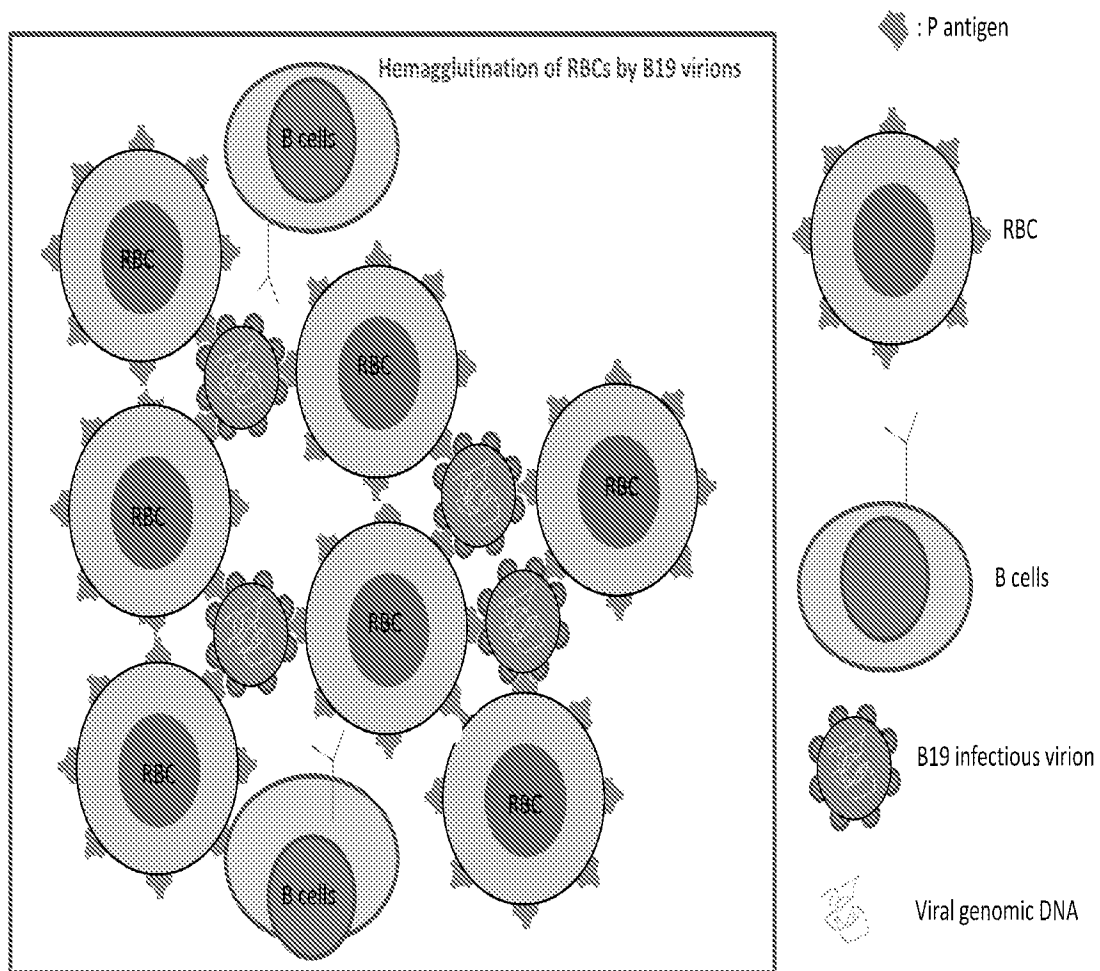
Binding to the P antigen of a red blood cell.



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FIG. 6A

Cartoon representation of hamagglutination of red blood cells by B19 virions.

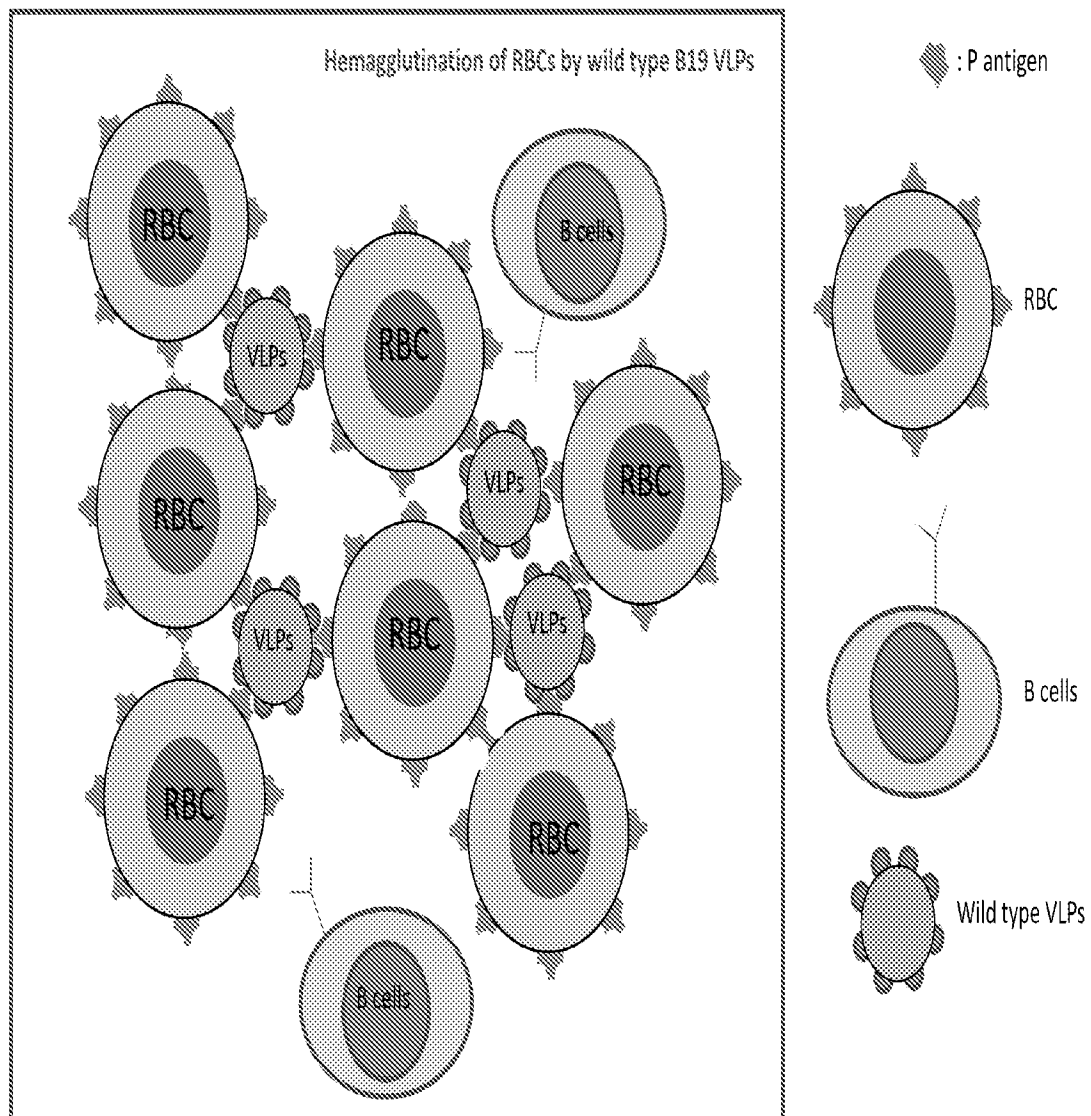


(a) Infectious B19 virion/virus may not be high immunogenic because of hamagglutination of RBC by B19 virions and theoretical inaccessibility to B19 virus by B cells

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FIG. 6B

Cartoon representation of hamagglutination of red blood cells by B19 wtVLPs.

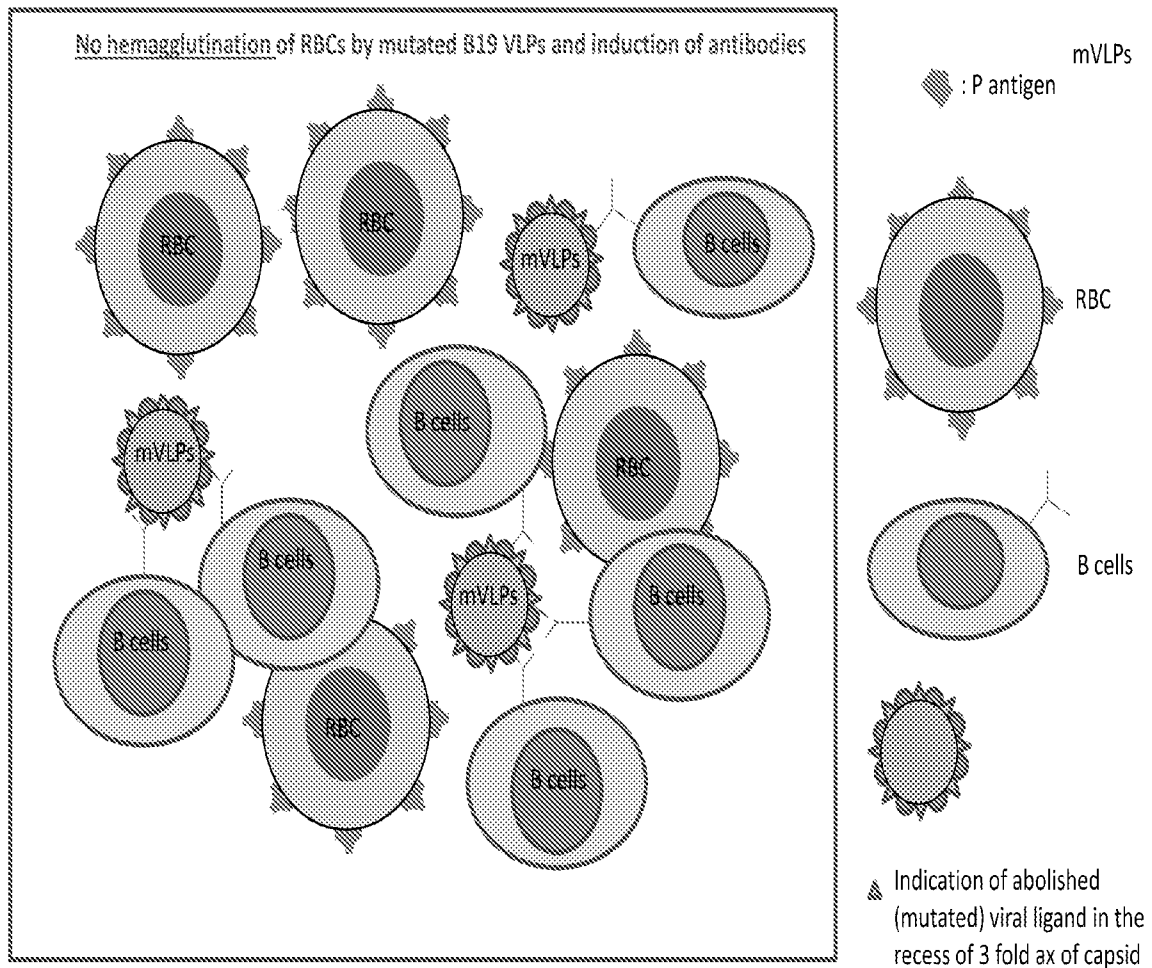


(b) Due to internalization of wild type VLPs by Hemagglutination of RBCs, wild type VLPs can be not readily accessible by B cells

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FIG. 6C

Cartoon representation of hamagglutination of red blood cells by B19 mVLPs.



(c) Abundant free mutated B19 VLPs in vivo resulting exposure of neutralizing epitopes on mutated VLPs and induction of high titer neutralizing antibodies as a consequence

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 15/19664

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - A61K 39/23; C07H 21/04; C12Q 1/70, 1/68; C12N 15/00 (2015.01)

CPC - C07K 14/005; C07K 14/015

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
CPC: C07K 14/005; C07K 14/015

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
CPC: C07K 14/005; C07K 14/015 (text search)
USPC: 424/233.1; 536/23.72; 435/5, 6.1, 320.1 (text search)

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
Electronic data bases: PatBase; Google Scholar; Google Patents; Gencore sequence search (AA, NT)
Search terms: VP2 protein, mutant or variant polypeptide, parvovirus B19, erythrovirus, nucleic acid, composition

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X --- Y	US 2003/0170612 A1(PICHUANTES et al.) 11 September 2003 (11.09.2003). Especially SEQ ID NO: 29, para [0171], [0172], [0177], [0178], sheet 21 fig 7B.	1, 2 ----- 3
Y	US 2013/0052226 A1 (ZHI et al.) 28 February 2013 (28.02.2013). Especially SEQ ID NO: 2	3

☐ Further documents are listed in the continuation of Box C. ☐

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search
27 April 2015 (27.04.2015)

Date of mailing of the international search report

10 JUN 2015

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PCT OSP: 571-272-7774

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 15/19664

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:
2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
3. ☒ Claims Nos.: 4-87
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
- ☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- ☐ No protest accompanied the payment of additional search fees.