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Recombinant HVT vectors expressing multiple antigens of avian pathogens and uses thereof

Abstract

The present invention provides recombinant herpesvirus of turkeys (HVT) vectors that contain and express antigens of avian pathogens, compositions comprising the recombinant HVT vectors and polyvalent vaccines comprising the recombinant HVT vectors. The present invention further provides methods of vaccination against a variety of avian pathogens and method of producing the recombinant HVT vectors.

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Field of Classification Search

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATIONS (1) This application is a continuation of U.S. patent application Ser. No. 16/393,743, filed Apr. 24, 2019, now U.S. Pat. No. 10,822,620, which is a continuation of U.S. patent application Ser. No. 15/840,764, filed Dec. 13, 2017, now U.S. Pat. No. 10,323,257, which claims the benefit of U.S. Application No. 62/433,842, filed Dec. 14, 2016, the entire contents of which are hereby incorporated by reference herein.

SEQUENCE LISTING
(1) This application contains a sequence listing which has been submitted electronically in XML

format. The sequence listing accompanying this application is hereby incorporated by reference in its entirety. Said XML copy, created on Feb. 8, 2023, is named MER16-307-US-5_SL.xml and is 94,243 bytes in size.

FIELD OF THE INVENTION

(2) The invention relates to recombinant viral vectors for the insertion and expression of foreign genes for use as safe immunization vehicles to protect against a variety of pathogens. It also relates to multivalent composition or vaccine comprising one or more recombinant viral vectors for protection against a variety of pathogens. The present invention relates to methods of making and using the recombinant viral vectors.

BACKGROUND OF THE INVENTION

(3) Poultry vaccination is widely used to protect poultry flocks against devastating diseases including Newcastle disease (ND), infectious bursal disease (IBD), Marek's disease (MD), infectious bronchitis (IB), infectious laryngotracheitis (ILT) and avian influenza (AI). ND is caused by the avian paramyxovirus 1 (APMV-1) also designated ND virus (NDV) belonging to the Paramyxoviridae family. MD is caused by Gallid herpesvirus 2 (Herpesviridae family) also designated as MD virus serotype 1 (MDV1). IB is caused by IB virus (IBV) belonging to the Coronaviridae family, ILT is caused by Gallid herpesvirus 1 (Herpesviridae family) also designated ILT virus (ILTV) and AI is caused by AI virus (AIV) belonging to the Orthomyxoviridae family.

(4) A number of recombinant avian viral vectors have been proposed with a view to vaccinating birds against these avian pathogens. The viral vectors used comprise avipox viruses, especially fowlpox (EP-A-0,517,292), Marek's virus, such as serotypes 1, 2 and 3 (HVT) (WO87/04463; WO2013/082317), or alternatively the ITLV, NDV and avian adenovirus. When some of these recombinant avian viral vectors were used for vaccination, they display variable levels of protection.

(5) Several recombinant herpesvirus of turkeys (HVT, also designated Meleagrid herpesvirus 1 or MDV serotype 3) vectors expressing antigens from various pathogens (U.S. Pat. Nos. 5,980,906, 5,853,733, 6,183,753, 5,187,087) including IBDV, NDV, ILTV and AIV have been developed and licensed. Of particular interest is a HVT vector-expressing IBDV VP2 protective gene that has shown clear advantages over classical IBD vaccines (Bublot et al J. Comp. Path. 2007, Vol. 137, S81-S84; U.S. Pat. No. 5,980,906). Other HVT vectors of interest are those expressing either NDV (Morgan et al 1992, Avian dis. 36, 858-70; U.S. Pat. Nos. 6,866,852; 5,650,153), ILTV (Johnson et al, 2010 Avian Dis 54, 1251-1259; U.S. Pat. Nos. 6,299,882; 5,853,733, EP 1801204), or NDV and IBDV (U.S. Pat. No. 9,114,108; WO2016102647, WO2013/057235, WO2015032910, WO2013144355) protective gene(s). US2016/0158347 reported the use of the oligodeoxynucleotide TLR21 agonist to increase the immune response against the antigen that expressed by HVT vector.

(6) One of the practical problems of using several HVT-based recombinant vaccines together is their interference. Lower protection is induced at least against one of the disease when two HVT recombinants expressing different antigens are mixed (Rudolf Heine 2011; Issues of the Poultry Recombinant Viral Vector Vaccines which May Cause an Effect on the Economic Benefits of those Vaccines; paper presented at the XVII World Veterinary Poultry Association (WVPA) Congress in Cancun, Mexico, Aug. 14-18, 2011; Slacum G, Hein R. and Lynch P., 2009, The compatibility of HVT recombinants with other Marek's disease vaccines, 58.sup.th Western Poultry Disease Conference, Sacramento, CA, USA, March 23.sup.rd-25.sup.th, p 84).

(7) Considering the potential effect of animal pathogens, such as NDV and IBDV on veterinary public health and the economy, efficient methods of preventing infection and protecting animals are needed. There is a need for a solution of combined effective vector vaccines and a suitable method for making the vaccine that could alleviate the problem of interference observed between two HVT-based vector vaccines.

SUMMARY OF THE INVENTION

(8) The present invention showed surprising result when polyvalent compositions or vaccines comprising recombinant HVT vector were effective to protect animals against a variety of avian pathogens without interference. Surprising results were also observed when various combinations of promoters/linkers, codon-optimized gene, polyA tails and insertion sites conferred different levels of efficacy and stability to the expression of one or more heterologous genes in vivo and in vitro. The present invention provides stable HVT vectors which are able to efficiently express multiple genes and overcomes the well-known problem that HVT vectors with multiple inserts are less stable.
(9) The present invention relates to a recombinant HVT vector comprising one, two or more heterologous polynucleotides coding for and expressing at least one antigen of an avian pathogen.
(10) The present invention provides a composition or vaccine comprising one or more recombinant HVT vectors comprising one, two or more heterologous polynucleotides coding for and expressing at least one antigen of an avian pathogen.
(11) The present invention relates to a method of vaccinating an animal, or inducing an immunogenic or protective response in an animal, comprising at least one administration of the composition or vector of the present invention.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
(1) The following detailed description, given by way of example, and which is not intended to limit the invention to specific embodiments described, may be understood in conjunction with the accompanying figures, incorporated herein by reference, in which:
(2) FIG. **1** is a table showing the SEQ ID NO assigned to each DNA and protein sequence.
(3) FIG. **2** depicts the genome structure of HVT and its insertion sites.
(4) FIG. **3** depicts pFSV40VP2 plasmid map.
(5) FIG. **4** depicts schematic representation of primer binding sites for vHVT309.
(6) FIG. **5** depicts PCR identity result of vHVT309.
(7) FIG. **6** depicts pFIRESVP2 plasmid map.
(8) FIG. **7** depicts schematic representation of primer binding sites for vHVT310.
(9) FIG. **8** depicts PCR identity result of vHVT310.
(10) FIG. **9** depicts pFP2AVP2 plasmid map.
(11) FIG. **10** depicts schematic representation of primer binding sites for vHVT311.
(12) FIG. **11** depicts PCR identity result of vHVT311.
(13) FIG. **12** depicts pVP2IRESgD plasmid map.
(14) FIG. **13** depicts schematic representation of primer binding sites for vHVT317.
(15) FIG. **14** depicts PCR identity result of vHVT317.
(16) FIG. **15** depicts pFwtSV40VP2 plasmid map.
(17) FIG. **16** depicts schematic representation of primer binding sites for vHVT313.
(18) FIG. **17** depicts PCR identity result of vHVT313.
(19) FIG. **18** depicts pVP2IRESFwt plasmid map.
(20) FIG. **19** depicts schematic representation of primer binding sites for vHVT316.
(21) FIG. **20** depicts PCR identity result of vHVT316.
(22) FIG. **21**A-**21**D depict DNA and protein sequence alignments.
(23) FIG. **22** depicts HVT US2SVgDwtsyn plasmid map.
(24) FIG. **23** depicts pHVTIG1gDCaFopt plasmid map.
(25) FIG. **24** depicts schematic representation of primer binding sites for vHVT308.
(26) FIG. **25** depicts PCR identity result of vHVT308.
(27) FIG. **26** depicts pFwtIRESgD plasmid map.

(28) FIG. **27** depicts schematic representation of primer binding sites for vHVT322.
(29) FIG. **28** depicts PCR identity result of vHVT322.
(30) FIG. **29** depicts pHVTUS2SVgDwtsyn plasmid map.
(31) FIG. **30** depicts schematic representation of primer binding sites for vHVT406.
(32) FIG. **31** depicts PCR identity result of vHVT406.

DETAILED DESCRIPTION OF THE INVENTION

(33) While the invention has been described in connection with specific embodiments thereof, it will be understood that it is capable of further modifications and this application is intended to cover any variations, uses, or adaptations of the invention following, in general, the principles of the invention and including such departures from the present disclosure as come within known or customary practice within the art to which the invention pertains and as may be applied to the essential features hereinbefore set forth and as follows in the scope of the appended claims. This invention includes all modifications and equivalents of the subject matter recited in the aspects or claims presented herein to the maximum extent permitted by applicable law.

(34) It is noted that in this disclosure and particularly in the claims, terms such as “comprises”, “comprised”, “comprising” and the like can have the meaning attributed to it in U.S. Patent law; e.g., they can mean “includes”, “included”, “including”, and the like; and that terms such as “consisting essentially of” and “consists essentially of” have the meaning ascribed to them in U.S. Patent law, e.g., they allow for elements not explicitly recited, but exclude elements that are found in the prior art or that affect a basic or novel characteristic of the invention.

(35) The singular terms “a,” “an,” and “the” include plural referents unless context clearly indicates otherwise. Similarly, the word “or” is intended to include “and” unless the context clearly indicate otherwise. The word “or” means any one member of a particular list and also includes any combination of members of that list.

(36) It will also be understood that, although the terms first, second, etc. may be used herein to describe various elements, these elements should not be limited by these terms. These terms are only used to distinguish one element from another. For example, a first gesture could be termed a second gesture, and, similarly, a second gesture could be termed a first gesture, without departing from the scope of the present invention. All methods or processes described herein can be performed in any suitable order unless otherwise indicated herein or otherwise clearly contradicted by context.

(37) The term “animal” is used herein to include all mammals, birds and fish. The animal as used herein may be selected from the group consisting of equine (e.g., horse), canine (e.g., dogs, wolves, foxes, coyotes, jackals), feline (e.g., lions, tigers, domestic cats, wild cats, other big cats, and other felines including cheetahs and lynx), bovine (e.g., cattle), swine (e.g., pig), ovine (e.g., sheep, goats, lamas, bisons), avian (e.g., chicken, duck, goose, turkey, quail, pheasant, parrot, finches, hawk, crow, ostrich, emu and cassowary), primate (e.g., prosimian, tarsier, monkey, gibbon, ape), humans, and fish. The term “animal” also includes an individual animal in all stages of development, including embryonic and fetal stages.

(38) The term “about” as used herein, means approximately, in the region of, roughly, or around. When the term “about” is used in conjunction with a numerical range, it modifies that range by extending the boundaries above and below the numerical values set forth. In general, the term “about” is used herein to modify a numerical value above and below the stated value by a variance of 10%. In one aspect, the term “about” means plus or minus 20% of the numerical value of the number with which it is being used. Therefore, about 50% means in the range of 45%-55%. Numerical ranges recited herein by endpoints include all numbers and fractions subsumed within that range (e.g. 1 to 5 includes 1, 1.5, 2, 2.75, 3, 3.90, 4, and 5). It is also to be understood that all numbers and fractions thereof are presumed to be modified by the term “about.”

(39) The terms “polypeptide” and “protein” are used interchangeably herein to refer to a polymer of consecutive amino acid residues.

(40) The term "nucleic acid", "nucleotide", and "polynucleotide" are used interchangeably and refer to RNA, DNA, cDNA, or cRNA and derivatives thereof, such as those containing modified backbones. It should be appreciated that the invention provides polynucleotides comprising sequences complementary to those described herein. The "polynucleotide" contemplated in the present invention includes both the forward strand (5′ to 3′) and reverse complementary strand (3′ to 5′). Polynucleotides according to the invention can be prepared in different ways (e.g. by chemical synthesis, by gene cloning etc.) and can take various forms (e.g. linear or branched, single or double stranded, or a hybrid thereof, primers, probes etc.).
(41) The term "genomic DNA" or "genome" is used interchangeably and refers to the heritable genetic information of a host organism. The genomic DNA comprises the DNA of the nucleus (also referred to as chromosomal DNA) but also the DNA of the plastids (e.g., chloroplasts) and other cellular organelles (e.g., mitochondria). The genomic DNA or genome contemplated in the present invention also refers to the RNA of a virus. The RNA may be a positive strand or a negative strand RNA. The term "genomic DNA" contemplated in the present invention includes the genomic DNA containing sequences complementary to those described herein. The term "genomic DNA" also refers to messenger RNA (mRNA), complementary DNA (cDNA), and complementary RNA (cRNA).
(42) The term "gene" is used broadly to refer to any segment of polynucleotide associated with a biological function. Thus, genes or polynucleotides include introns and exons as in genomic sequence, or just the coding sequences as in cDNAs, such as an open reading frame (ORF), starting from the start codon (methionine codon) and ending with a termination signal (stop codon). Genes and polynucleotides can also include regions that regulate their expression, such as transcription initiation, translation and transcription termination. Thus, also included are promoters and ribosome binding regions (in general these regulatory elements lie approximately between 60 and 250 nucleotides upstream of the start codon of the coding sequence or gene; Doree S M et al.; Pandher K et al.; Chung J Y et al.), transcription terminators (in general the terminator is located within approximately 50 nucleotides downstream of the stop codon of the coding sequence or gene; Ward C K et al.). Gene or polynucleotide also refers to a nucleic acid fragment that expresses mRNA or functional RNA, or encodes a specific protein, and which includes regulatory sequences.
(43) The term "heterologous DNA" as used herein refers to the DNA derived from a different organism, such as a different cell type or a different species from the recipient. The term also refers a DNA or fragment thereof on the same genome of the host DNA wherein the heterologous DNA is inserted into a region of the genome which is different from its original location.
(44) As used herein, the term "antigen" or "immunogen" means a substance that induces a specific immune response in a host animal. The antigen may comprise a whole organism, killed, attenuated or live; a subunit or portion of an organism; a recombinant vector containing an insert with immunogenic properties; a piece or fragment of DNA capable of inducing an immune response upon presentation to a host animal; a polypeptide, an epitope, a hapten, or any combination thereof. Alternately, the immunogen or antigen may comprise a toxin or antitoxin.
(45) The term "immunogenic protein or peptide" as used herein includes polypeptides that are immunologically active in the sense that once administered to the host, it is able to evoke an immune response of the humoral and/or cellular type directed against the protein. Preferably the protein fragment is such that it has substantially the same immunological activity as the total protein. Thus, a protein fragment according to the invention comprises or consists essentially of or consists of at least one epitope or antigenic determinant. An "immunogenic" protein or polypeptide, as used herein, includes the full-length sequence of the protein, analogs thereof, or immunogenic fragments thereof. By "immunogenic fragment" is meant a fragment of a protein which includes one or more epitopes and thus elicits the immunological response described above. Such fragments can be identified using any number of epitope mapping techniques, well known in the art. For example, linear epitopes may be determined by e.g., concurrently synthesizing large numbers of

peptides on solid supports, the peptides corresponding to portions of the protein molecule, and reacting the peptides with antibodies while the peptides are still attached to the supports. Similarly, conformational epitopes are readily identified by determining spatial conformation of amino acids such as by, e.g., x-ray crystallography and 2-dimensional nuclear magnetic resonance.

(46) The term “immunogenic protein or peptide” further contemplates deletions, additions and substitutions to the sequence, so long as the polypeptide functions to produce an immunological response as defined herein. The term “conservative variation” denotes the replacement of an amino acid residue by another biologically similar residue, or the replacement of a nucleotide in a nucleic acid sequence such that the encoded amino acid residue does not change or is another biologically similar residue. In this regard, particularly preferred substitutions will generally be conservative in nature, i.e., those substitutions that take place within a family of amino acids. For example, amino acids are generally divided into four families: (1) acidic—aspartate and glutamate; (2) basic—lysine, arginine, histidine; (3) non-polar—alanine, valine, leucine, isoleucine, proline, phenylalanine, methionine, tryptophan; and (4) uncharged polar—glycine, asparagine, glutamine, cysteine, serine, threonine, tyrosine. Phenylalanine, tryptophan, and tyrosine are sometimes classified as aromatic amino acids. Examples of conservative variations include the substitution of one hydrophobic residue such as isoleucine, valine, leucine or methionine for another hydrophobic residue, or the substitution of one polar residue for another polar residue, such as the substitution of arginine for lysine, glutamic acid for aspartic acid, or glutamine for asparagine, and the like; or a similar conservative replacement of an amino acid with a structurally related amino acid that will not have a major effect on the biological activity. Proteins having substantially the same amino acid sequence as the reference molecule but possessing minor amino acid substitutions that do not substantially affect the immunogenicity of the protein are, therefore, within the definition of the reference polypeptide. All of the polypeptides produced by these modifications are included herein. The term “conservative variation” also includes the use of a substituted amino acid in place of an unsubstituted parent amino acid provided that antibodies raised to the substituted polypeptide also immunoreact with the unsubstituted polypeptide.

(47) The term “epitope” refers to the site on an antigen or hapten to which specific B cells and/or T cells respond. The term is also used interchangeably with “antigenic determinant” or “antigenic determinant site”. Antibodies that recognize the same epitope can be identified in a simple immunoassay showing the ability of one antibody to block the binding of another antibody to a target antigen.

(48) An “immunological response” to a composition or vaccine is the development in the host of a cellular and/or antibody-mediated immune response to a composition or vaccine of interest. Usually, an “immunological response” includes but is not limited to one or more of the following effects: the production of antibodies, B cells, helper T cells, and/or cytotoxic T cells, directed specifically to an antigen or antigens included in the composition or vaccine of interest. Preferably, the host will display either a therapeutic or protective immunological response such that resistance to new infection will be enhanced and/or the clinical severity of the disease reduced. Such protection will be demonstrated by either a reduction or lack of symptoms normally displayed by an infected host, a quicker recovery time and/or a lowered viral titer in the infected host.

(49) The terms “recombinant” and “genetically modified” are used interchangeably and refer to any modification, alteration or engineering of a polynucleotide or protein in its native form or structure, or any modification, alteration or engineering of a polynucleotide or protein in its native environment or surrounding. The modification, alteration or engineering of a polynucleotide or protein may include, but is not limited to, deletion of one or more nucleotides or amino acids, deletion of an entire gene, codon-optimization of a gene, conservative substitution of amino acids, insertion of one or more heterologous polynucleotides.

(50) The terms “polyvalent vaccine or composition”, “combination or combo vaccine or composition” and “multivalent vaccine or composition” are used interchangeably to refer to a

composition or vaccine containing more than one composition or vaccines. The polyvalent vaccine or composition may contain two, three, four or more compositions or vaccines. The polyvalent vaccine or composition may comprise recombinant viral vectors, active or attenuated or killed wild-type viruses, or a mixture of recombinant viral vectors and wild-type viruses in active or attenuated or killed forms.
(51) One embodiment of the invention provides a recombinant HVT viral vector comprising one, two or more heterologous polynucleotides coding for and expressing at least one antigen or polypeptide of an avian pathogen. The HVT strains used for the recombinant viral vector may be any HVT strains, including, but not limited to, the HVT strain FC126 (Igarashi T. et al., J. Gen. Virol. 70, 1789-1804, 1989).
(52) The genes coding for antigen or polypeptide may be those coding for Newcastle Disease Virus fusion protein (NDV-F), Newcastle Disease Virus hemagglutinin neuraminidase (NDV-HN), Marek's Disease Virus glycoprotein C (gC), Marek's Disease Virus glycoprotein B (gB), Marek's Disease Virus glycoprotein E (gE), Marek's Disease Virus glycoprotein I (gI), Marek's Disease Virus glycoprotein H (gH) or Marek's Disease Virus glycoprotein L (gL), Infectious Bursal Disease Virus (IBDV) VP2, IBDV VPX, IBDV VP3, IBDV VP4, ILTV glycoprotein B, ILTV glycoprotein I, ILTV UL32, ILTV glycoprotein D, ILTV glycoprotein E, ILTV glycoprotein C, influenza hemagglutinin (HA), influenza neuraminidase (NA), protective genes derived from *Mycoplasma gallisepticum* (MG), or *Mycoplasma synoviae* (MS), or combinations thereof. The antigen or polypeptide may be any antigen from the poultry pathogen selected form the group consisting of avian encephalomyelitis virus, avian reovirus, avian paramyxovirus, avian metapneumovirus, avian influenza virus, avian adenovirus, fowl pox virus, avian coronavirus, avian rotavirus, chick anemia virus, avian astrovirus, avian parvovirus, avian retrovirus, avian picornavirus, coccidiosis (*Eimeria* sp.), *Campylobacter* sp., *Salmonella* sp., *Pasteurella* sp., *Avibacterium* sp., *Mycoplasma gallisepticum*, *Mycoplasma synoviae*, *Clostridium* sp., and *Escherichia coli*.
(53) Moreover, homologs of aforementioned antigen or polynucleotides are intended to be within the scope of the present invention. As used herein, the term “homologs” includes orthologs, analogs and paralogs. The term “analogs” refers to two polynucleotides or polypeptides that have the same or similar function, but that have evolved separately in unrelated organisms. The term “orthologs” refers to two polynucleotides or polypeptides from different species, but that have evolved from a common ancestral gene by speciation. Normally, orthologs encode polypeptides having the same or similar functions. The term “paralogs” refers to two polynucleotides or polypeptides that are related by duplication within a genome. Paralogs usually have different functions, but these functions may be related. Analogs, orthologs, and paralogs of a wild-type polypeptide can differ from the wild-type polypeptide by post-translational modifications, by amino acid sequence differences, or by both. In particular, homologs of the invention will generally exhibit at least 80-85%, 85-90%, 90-95%, or 95%, 96%, 97%, 98%, 99% sequence identity, with all or part of the polynucleotide or polypeptide sequences of antigens described above, and will exhibit a similar function.
(54) In one embodiment, the present invention provides a recombinant HVT viral vector comprising one, two or more heterologous polynucleotides coding for and expressing the NDV-F antigen or polypeptide, the IBDV VP2 antigen or polypeptide, the ILTV gD antigen or polypeptide, or a combination thereof. In one aspect of the embodiment, the NDV-F antigen or polypeptide has at least 70%, 75%, 80%, 85%, 90%, 95%, 96%, 97%, 98% or 99% sequence identity to a polypeptide having the sequence as set forth in SEQ ID NO:5 or 22, or a conservative variant, an allelic variant, a homolog or an immunogenic fragment comprising at least eight or at least ten consecutive amino acids of one of these polypeptides, or a combination of these polypeptides. In another aspect of the embodiment, the heterologous polynucleotide encodes an NDV-F antigen or polypeptide having at least 70%, 75%, 80%, 85%, 90%, 95%, 96%, 97%, 98% or 99% sequence identity to a polypeptide having the sequence as set forth in SEQ ID NO:5. In yet another aspect of the embodiment, the heterologous polynucleotide has at least 70%, 75%, 80%, 85%, 90%, 95%,

96%, 97%, 98% or 99% sequence identity to a polynucleotide having the sequence as set forth in SEQ ID NO:3, 4 or 21.
(55) In another aspect of the embodiment, the IBDV VP2 antigen or polypeptide has at least 70%, 75%, 80%, 85%, 90%, 95%, 96%, 97%, 98% or 99% sequence identity to a polypeptide having the sequence as set forth in SEQ ID NO:2, or a conservative variant, an allelic variant, a homolog or an immunogenic fragment comprising at least eight or at least ten consecutive amino acids of one of these polypeptides, or a combination of these polypeptides. In another aspect of the embodiment, the heterologous polynucleotide encodes an IBDV VP2 antigen or polypeptide having at least 70%, 75%, 80%, 85%, 90%, 95%, 96%, 97%, 98% or 99% sequence identity to a polypeptide having the sequence as set forth in SEQ ID NO:2. In yet another aspect of the embodiment, the heterologous polynucleotide has at least 70%, 75%, 80%, 85%, 90%, 95%, 96%, 97%, 98% or 99% sequence identity to a polynucleotide having the sequence as set forth in SEQ ID NO:1.
(56) In another aspect of the embodiment, the ILTV gD antigen or polypeptide has at least 70%, 75%, 80%, 85%, 90%, 95%, 96%, 97%, 98% or 99% sequence identity to a polypeptide having the sequence as set forth in SEQ ID NO:17, or a conservative variant, an allelic variant, a homolog or an immunogenic fragment comprising at least eight or at least ten consecutive amino acids of one of these polypeptides, or a combination of these polypeptides. In another aspect of the embodiment, the heterologous polynucleotide encodes an ILTV gD antigen or polypeptide having at least 70%, 75%, 80%, 85%, 90%, 95%, 96%, 97%, 98% or 99% sequence identity to a polypeptide having the sequence as set forth in SEQ ID NO:17. In yet another aspect of the embodiment, the heterologous polynucleotide has at least 70%, 75%, 80%, 85%, 90%, 95%, 96%, 97%, 98% or 99% sequence identity to a polynucleotide having the sequence as set forth in SEQ ID NO:16.
(57) Variants include allelic variants. The term “allelic variant” refers to a polynucleotide or a polypeptide containing polymorphisms that lead to changes in the amino acid sequences of a protein and that exist within a natural population (e.g., a virus species or variety). Such natural allelic variations can typically result in 1-5% variance in a polynucleotide or a polypeptide. Allelic variants can be identified by sequencing the nucleic acid sequence of interest in a number of different species, which can be readily carried out by using hybridization probes to identify the same gene genetic locus in those species. Any and all such nucleic acid variations and resulting amino acid polymorphisms or variations that are the result of natural allelic variation and that do not alter the functional activity of gene of interest, are intended to be within the scope of the invention.
(58) The term “identity” with respect to sequences can refer to, for example, the number of positions with identical nucleotides or amino acids divided by the number of nucleotides or amino acids in the shorter of the two sequences wherein alignment of the two sequences can be determined in accordance with the Wilbur and Lipman algorithm (Wilbur and Lipman). The sequence identity or sequence similarity of two amino acid sequences, or the sequence identity between two nucleotide sequences can be determined using Vector NTI software package (Invitrogen, 1600 Faraday Ave., Carlsbad, CA). When RNA sequences are said to be similar, or have a degree of sequence identity or homology with DNA sequences, thymidine (T) in the DNA sequence is considered equal to uracil (U) in the RNA sequence. Thus, RNA sequences are within the scope of the invention and can be derived from DNA sequences, by thymidine (T) in the DNA sequence being considered equal to uracil (U) in RNA sequences.
(59) The polynucleotides of the disclosure include sequences that are degenerate as a result of the genetic code, e.g., optimized codon usage for a specific host. As used herein, “optimized” refers to a polynucleotide that is genetically engineered to increase its expression in a given species. To provide optimized polynucleotides coding for NDV-F, IBDV VP2 or ILTV gD polypeptides, the DNA sequence of these genes can be modified to 1) comprise codons preferred by highly expressed genes in a particular species; 2) comprise an A+T or G+C content in nucleotide base composition to that substantially found in said species; 3) form an initiation sequence of said species; or 4)

eliminate sequences that cause destabilization, inappropriate polyadenylation, degradation and termination of RNA, or that form secondary structure hairpins or RNA splice sites. Increased expression of NDV F, IBDV VP2 or ILTV gD protein in said species can be achieved by utilizing the distribution frequency of codon usage in eukaryotes and prokaryotes, or in a particular species. The term “frequency of preferred codon usage” refers to the preference exhibited by a specific host cell in usage of nucleotide codons to specify a given amino acid. There are 20 natural amino acids, most of which are specified by more than one codon. Therefore, all degenerate nucleotide sequences are included in the disclosure as long as the amino acid sequence of the NDV-F, IBDV VP2 or ILTV gD polypeptide encoded by the nucleotide sequence is functionally unchanged.
(60) Successful expression of the heterologous polynucleotides by the recombinant/modified infectious virus requires two conditions. First, the heterologous polynucleotides must be inserted or introduced into a region of the genome of the virus in order that the modified virus remains viable. The second condition for expression of inserted heterologous polynucleotides is the presence of a regulatory sequences allowing expression of the gene in the viral background (for instance: promoter, enhancer, donor and acceptor splicing sites and intron, Kozak translation initiation consensus sequence, polyadenylation signals, untranslated sequence elements).
(61) The insertion site may be any non-essential region of the HVT genome, including, but not limited to, the region between the STOP codon of ORF UL55 and the junction of UL with the adjacent repeat region (intergenic region 1, the IG1 locus, U.S. Pat. No. 5,980,906), the IG2 (intergenic region 2) locus, the IG3 (intergenic region 3) locus, the UL43 locus, the US10 locus, the US2 locus, the SORF3/US2 locus (see FIG. **2**)
(62) In general, it is advantageous to employ a strong promoter functional in eukaryotic cells. The promoters include, but are not limited to, an immediate early (IE) human cytomegalovirus (CMV) (hCMV) promoter, mouse CMV (mCMV) IE promoter, guinea pig CMV (gpCMV) IE promoter, an SV40 promoter, Pseudorabies Virus promoters such as that of glycoprotein X promoter, Herpes Simplex Virus-1 such as the alpha 4 promoter, Marek's Disease Viruses (including MDV-1, MDV-2 and HVT) promoters such as those driving glycoproteins gC, gB, gE, or gI expression, HHV3gB promoter (Human Herpesvirus Type 3 glycoprotein B promoter), Infectious Laryngotracheitis Virus promoters such as those of glycoprotein gB, gE, gI, gD, gC genes, or other herpesvirus promoters.
(63) One embodiment of the invention provides a recombinant HVT vector comprising a first heterologous polynucleotide coding for and expressing the IBDV VP2 antigen or polypeptide and a second polynucleotide coding for and expressing the NDV-F antigen or polypeptide. In one aspect of the embodiment, the NDV-F antigen or polypeptide has at least 70%, 75%, 80%, 85%, 90%, 95%, 96%, 97%, 98% or 99% sequence identity to a polypeptide having the sequence as set forth in SEQ ID NO:5. In another aspect of the embodiment, the IBDV VP2 antigen or polypeptide has at least 70%, 75%, 80%, 85%, 90%, 95%, 96%, 97%, 98% or 99% sequence identity to a polypeptide having the sequence as set forth in SEQ ID NO:2. In another aspect, the polynucleotide encoding the NDV-F polypeptide is operably linked to the SV40 promoter having the sequence as set forth in SEQ ID NO:7 and the expression of NDV-F antigen or polypeptide is regulated by the SV40 promoter. In yet another aspect, the expression of NDV-F antigen or polypeptide is regulated by the SV40 polyA signal having the sequence as set forth in SEQ ID NO:8, or the synthetic polyA signal having the sequence as set forth in SEQ ID NO:9. In another aspect, the expression of IBDV VP2 antigen or polypeptide is regulated by the mCMV-IE promoter having the sequence as set forth in SEQ ID NO:6 and the SV40 polyA signal having the sequence as set forth in SEQ ID NO:8, or the synthetic polyA signal having the sequence as set forth in SEQ ID NO:9.
(64) Another embodiment of the invention provides a recombinant HVT vector comprising a first heterologous polynucleotide coding for and expressing the IBDV VP2 antigen or polypeptide and a second polynucleotide coding for and expressing the NDV-F antigen or polypeptide, and further comprising a sequence which regulates the expression of the second polynucleotide. The regulatory sequences or linkers may be an internal ribosome entry site (IRES), an RNA sequence derived from

Encephalomyocarditis virus (EMCV), or a sequence encoding a self-cleaving porcine teschovirus-1 2A or foot and mouth disease virus (FMDV) peptide (P2A).

(65) In one aspect of the embodiment, the recombinant HVT vector comprises a first polynucleotide encoding the IBDV VP2 antigen and a second polynucleotide encoding the NDV-F antigen, and further comprises the IRES having the sequence as set forth in SEQ ID NO:10. In another aspect of the embodiment, the recombinant HVT comprises a first polynucleotide encoding the IBDV VP2 antigen and a second polynucleotide encoding the NDV-F antigen, and further comprises the P2A encoding polynucleotide having the sequence as set forth in SEQ ID NO:11.

(66) One embodiment of the invention provides a recombinant HVT vector comprising a first heterologous polynucleotide coding for and expressing the NDV F antigen or polypeptide and a second polynucleotide coding for and expressing the ILTV gD antigen or polypeptide, and further comprising a sequence which regulates the expression of the second polynucleotide. The regulatory sequences or linkers may be an internal ribosome entry site (IRES), an RNA sequence derived from Encephalomyocarditis virus (EMCV), or a sequence encoding a self-cleaving porcine teschovirus-1 2A or foot and mouth disease virus (FMDV) peptide (P2A). In one aspect of the embodiment, the ILTV gD antigen or polypeptide has at least 70%, 75%, 80%, 85%, 90%, 95%, 96%, 97%, 98% or 99% sequence identity to a polypeptide having the sequence as set forth in SEQ ID NO:17. In another aspect of the embodiment, the NDV F antigen or polypeptide has at least 70%, 75%, 80%, 85%, 90%, 95%, 96%, 97%, 98% or 99% sequence identity to a polypeptide having the sequence as set forth in SEQ ID NO:5 or 22. In yet another aspect of the embodiment, the recombinant HVT vector comprises a first polynucleotide encoding the NDV F antigen and a second polynucleotide encoding the ILTV gD antigen, and further comprises the IRES having the sequence as set forth in SEQ ID NO:10.

(67) Another embodiment of the invention provides a recombinant HVT vector comprising a first heterologous polynucleotide coding for and expressing the NDV F antigen or polypeptide and a second polynucleotide coding for and expressing the ILTV gD antigen or polypeptide. In one aspect of the embodiment, the ILTV gD antigen or polypeptide has at least 70%, 75%, 80%, 85%, 90%, 95%, 96%, 97%, 98% or 99% sequence identity to a polypeptide having the sequence as set forth in SEQ ID NO:17. In another aspect of the embodiment, the NDV F antigen or polypeptide has at least 70%, 75%, 80%, 85%, 90%, 95%, 96%, 97%, 98% or 99% sequence identity to a polypeptide having the sequence as set forth in SEQ ID NO:5 or 22. In one aspect, the polynucleotide encoding the NDV F polypeptide is operably linked to the SV40 promoter and the expression of NDV F antigen or polypeptide is regulated by the SV40 promoter. In another aspect, the polynucleotide encoding the ILTV gD polypeptide is operably linked to the HHV3gB promoter and the expression of ILTV gD antigen or polypeptide is regulated by the HHV3gB promoter. In yet another aspect, the HHV3gB promoter is in the reverse direction. In yet another aspect, the expressions of the NDV F antigen and ILTV gD antigen are regulated by SV40 promoter and reverse HHV3gB promoter, and are in opposite directions.

(68) Another embodiment of the invention provides a recombinant HVT vector comprising a first heterologous polynucleotide coding for and expressing the IBDV VP2 antigen or polypeptide and a second polynucleotide coding for and expressing the ILTV gD antigen or polypeptide. In one aspect of the embodiment, the ILTV gD antigen or polypeptide has at least 70%, 75%, 80%, 85%, 90%, 95%, 96%, 97%, 98% or 99% sequence identity to a polypeptide having the sequence as set forth in SEQ ID NO:17. In another aspect of the embodiment, the IBDV VP2 antigen or polypeptide has at least 70%, 75%, 80%, 85%, 90%, 95%, 96%, 97%, 98% or 99% sequence identity to a polypeptide having the sequence as set forth in SEQ ID NO:2. In yet another aspect of the embodiment, the recombinant HVT vector comprises a first polynucleotide encoding the IBDV VP2 antigen and a second polynucleotide encoding the ILTV gD antigen, and further comprises the IRES having the sequence as set forth in SEQ ID NO:10.

(69) Another embodiment of the invention provides a recombinant HVT vector comprising a

heterologous polynucleotide coding for and expressing the ILTV gD antigen or polypeptide. In one aspect of the embodiment, the ILTV gD antigen or polypeptide has at least 70%, 75%, 80%, 85%, 90%, 95%, 96%, 97%, 98% or 99% sequence identity to a polypeptide having the sequence as set forth in SEQ ID NO:17. In another aspect of the embodiment, the polynucleotide encoding the ILTV gD polypeptide is operably linked to the SV40 promoter and the expression of ILTV gD antigen or polypeptide is regulated by the SV40 promoter.

(70) In one embodiment, the polynucleotides encoding the IBDV VP2 antigen, and/or NDV-F antigen, and/or ILTV gD antigen may be inserted in one or more locus regions selected from the group consisting of IG1, IG2, US10, US2, SORF3-US2 and gD of HVT genome. In another embodiment, the polynucleotides encoding the IBDV VP2 antigen, and/or NDV-F antigen, and/or ILTV gD antigen are inserted in the same locus, such as IG1 of HVT genome.

(71) In one embodiment, the present invention relates to a pharmaceutical composition or vaccine comprising one or more recombinant HVT vectors of the present invention and a pharmaceutically or veterinarily acceptable carrier, excipient, vehicle or adjuvant. The HVT vector may comprise two heterologous polynucleotides, and wherein the first polynucleotide comprises a polynucleotide encoding a polypeptide selected from the group consisting of an Infectious Bursal Disease Virus (IBDV) VP2 antigen, an Infectious Laryngotracheitis Virus (ILTV) glycoprotein D (gD) antigen and a Newcastle Disease Virus F (NDV-F) antigen, and wherein the second polynucleotide comprises a polynucleotide encoding a polypeptide selected from the group consisting of an Infectious Bursal Disease Virus (IBDV) VP2 antigen, an Infectious Laryngotracheitis Virus (ILTV) glycoprotein D (gD) antigen and a Newcastle Disease Virus F (NDV-F) antigen.

(72) In another embodiment, the present invention provides a composition or vaccine comprising an HVT viral vector comprising: i) a first heterologous polynucleotide coding for and expressing an IBDV VP2 antigen or an NDV-F antigen; ii) a second polynucleotide coding for and expressing an NDV-F antigen or an IBDV VP2 antigen; and iii) optionally a pharmaceutically or veterinarily acceptable carrier, excipient, vehicle or adjuvant. In yet another embodiment, the present invention provides a composition or vaccine comprising an HVT viral vector comprising: i) a first heterologous polynucleotide coding for and expressing an IBDV VP2 antigen or an ILTV gD antigen; ii) a second polynucleotide coding for and expressing an ILTV gD antigen or an IBDV VP2; and iii) optionally a pharmaceutically or veterinarily acceptable carrier, excipient, vehicle or adjuvant. In yet another embodiment, the present invention provides a composition or vaccine comprising an HVT viral vector comprising: i) a first heterologous polynucleotide coding for and expressing an NDV-F antigen or an ILTV gD antigen; ii) a second polynucleotide coding for and expressing an ILTV gD antigen or an NDV-F antigen; and iii) optionally a pharmaceutically or veterinarily acceptable carrier, excipient, vehicle or adjuvant. In yet another embodiment, the present invention provides a composition or vaccine comprising an HVT viral vector comprising a heterologous polynucleotide coding for and expressing an ILTV gD antigen, and optionally a pharmaceutically or veterinarily acceptable carrier, excipient, vehicle or adjuvant. In yet another embodiment, the present invention provides a composition or vaccine comprising an HVT comprising a polynucleotide having at least 70%, 75%, 80%, 85%, 90%, 95%, 96%, 97%, 98% or 99% sequence identity to a polynucleotide having the sequence as set forth in SEQ ID NO:1, 3, 4, 12, 13, 14, 15, 16, 18, 19, 20, 21, 25, 26 or 27. In one embodiment, it is shown that insertion of two or more heterologous polynucleotides in one locus confers better protection and efficacy then insertion in multiple loci. In another embodiment, it is shown that expressing more than one heterologous polynucleotide from a single mRNA through an IRES or P2A provides better protection and efficacy against avian diseases. In yet another embodiment, the experimental data provided by the present invention disclose that constructs comprising IRES elements provided better protection than constructs comprising P2A elements.

(73) The pharmaceutically or veterinarily acceptable carriers or adjuvant or vehicles or excipients are well known to the one skilled in the art. For example, a pharmaceutically or veterinarily

acceptable carrier or adjuvant or vehicle or excipient can be Marek's disease vaccine diluent used for MD vaccines. Other pharmaceutically or veterinarily acceptable carrier or adjuvant or vehicle or excipients that can be used for methods of this invention include, but are not limited to, 0.9% NaCl (e.g., saline) solution or a phosphate buffer, poly-(L-glutamate), the Lactated Ringer's Injection diluent (sodium chloride, sodium lactate, potassium chloride and calcium chloride), or polyvinylpyrrolidone. The pharmaceutically or veterinarily acceptable carrier or vehicle or adjuvant or excipients may be any compound or combination of compounds facilitating the administration of the vector (or protein expressed from an inventive vector in vitro), or facilitating transfection or infection and/or improve preservation of the vector (or protein). Doses and dose volumes are herein discussed in the general description and can also be determined by the skilled artisan from this disclosure read in conjunction with the knowledge in the art, without any undue experimentation.

(74) Optionally other compounds may be added as pharmaceutically or veterinarily acceptable carriers or adjuvants or vehicles or excipients, including, but not limited to, alum; CpG oligonucleotides (ODN), in particular ODN 2006, 2007, 2059, or 2135 (Pontarollo R. A. et al., Vet. *Immunol. Immunopath*, 2002, 84: 43-59; Wernette C. M. et al., Vet. *Immunol. Immunopath*, 2002, 84: 223-236; Mutwiri G. et al., *Vet. Immunol. Immunopath*, 2003, 91: 89-103); polyA-polyU, dimethyldioctadecylammonium bromide (DDA) ("Vaccine Design The Subunit and Adjuvant Approach", edited by Michael F. Powell and Mark J. Newman, *Pharmaceutical Biotechnology*, 6: p. 03, p. 157); N,N-dioctadecyl-N′,N′-bis(2-hydroxyethyl) propanediamine (such as AVRIDINE®) (*Ibid*, p. 148); carbomer, chitosan (see U.S. Pat. No. 5,980,912).

(75) The pharmaceutical compositions and vaccines according to the invention may comprise or consist essentially of one or more adjuvants. Suitable adjuvants for use in the practice of the present invention are (1) polymers of acrylic or methacrylic acid, maleic anhydride and alkenyl derivative polymers, (2) immunostimulating sequences (ISS), such as oligodeoxyribonucleotide sequences having one or more non-methylated CpG units (Klinman et al., 1996; WO98/16247), (3) an oil in water emulsion, such as 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 work, (4) cation lipids containing a quaternary ammonium salt, e.g., DDA (5) cytokines, (6) aluminum hydroxide or aluminum phosphate, (7) saponin or (8) other adjuvants discussed in any document cited and incorporated by reference into the instant application, or (9) any combinations or mixtures thereof.

(76) In one embodiment, the adjuvant may include TS6 TS7, TS8 and TS9 (U.S. Pat. No. 7,371,395), LR2, LR3 and LR4 (U.S. Pat. No. 7,691,368), TSAP (US20110129494), TRIGEN™ (Newport Labs), synthetic dsRNAs (e.g. poly-IC, poly-ICLC [HILTONOL®]), and MONTANIDE™ adjuvants (W/O, W/O/W, O/W, IMS and Gel; all produced by SEPPIC).

(77) In another embodiment, the invention provides for the administration of a therapeutically effective amount of a vaccine or composition for the delivery of recombinant HVT vectors in a target cell. Determination of the therapeutically effective amount is routine experimentation for one of ordinary skill in the art.

(78) Another aspect of the invention relates to a method for inducing an immunological response in an animal against one or more antigens or a protective response in an animal against one or more avian pathogens, which method comprises inoculating the animal at least once with the vaccine or pharmaceutical composition of the present invention. Yet another aspect of the invention relates to a method for inducing an immunological response in an animal to one or more antigens or a protective response in an animal against one or more avian pathogens in a prime-boost administration regimen, which is comprised of at least one primary administration and at least one booster administration using at least one common polypeptide, antigen, epitope or immunogen. The immunological composition or vaccine used in primary administration may be same, may be different in nature from those used as a booster.

(79) The avian pathogens may be Newcastle Disease Virus (NDV), Infectious Bursal Disease Virus (i.e., IBDV or Gumboro Disease virus), Marek's Disease Virus (MDV), Infectious Laryngotracheitis Virus (ILTV), avian encephalomyelitis virus, avian reovirus, avian paramyxovirus, avian metapneumovirus, avian influenza virus, avian adenovirus, fowl pox virus, avian coronavirus, avian rotavirus, avian parvovirus, avian astrovirus and chick anemia virus coccidiosis (*Eimeria* sp.), *Campylobacter* sp., *Salmonella* sp., *Mycoplasma gallisepticum, Mycoplasma synoviae, Pasteurella* sp., *Avibacterium* sp., *E. coli* or *Clostridium* sp.
(80) Usually, one administration of the vaccine in avian is performed either at one day-of-age by the subcutaneous or intramuscular route or in ovo in 17-19 day-old embryo. A second administration can be done within 0-30 days after the first administration.
(81) A variety of administration routes in day-old chicks may be used such as subcutaneously or intramuscularly, intradermally, transdermally. The in ovo vaccination can be performed in the amniotic sac and/or the embryo. Commercially available in ovo and SC administration devices can be used for vaccination.
(82) The composition or vaccine may contain a dose from about 10.sup.2 to about 10.sup.20, about 10.sup.3 to about 10.sup.18, about 10.sup.4 to about 10.sup.16, about 10.sup.5 to about 10.sup.12 VLPs (virus like particles) produced in vitro or in vivo from a viral vector, a plasmid, or baculovirus. The viral vector may be titrated based on any virus titration methods including, but not limited to, FFA (Focus Forming Assay) or FFU (Focus Forming Unit), TCID.sub.50 (50% Tissue Culture Infective Dose), PFU (Plaque Forming Units), and FAID.sub.50 (50% Fluorescent Antibody Infectious Dose), and the VLPs produced in vitro can be titrated by hemagglutination assay, ELISA, and electron microscopy. Other methods may also be applicable depending on the type of VLP.
(83) The composition or vaccine may contain from about 10.sup.2.0 to about 10.sup.7.0 TCID.sub.50 or PFU/dose, from about 10.sup.2.0 to about 10.sup.7.0 TCID.sub.50 or PFU/dose, and from about 10.sup.2.0 to about 10.sup.6.5 TCID.sub.50 or PFU/dose.
(84) The dose volumes can be between about 0.01 and about 10 ml, between about 0.01 and about 5 ml.
(85) The invention will now be further described by way of the following non-limiting examples.
EXAMPLES
(86) Construction of DNA inserts, plasmids and recombinant viral vectors was carried out using the standard molecular biology techniques described by J. Sambrook et al. (Molecular Cloning: A Laboratory Manual, 4th edition, Cold Spring Harbor Laboratory, Cold Spring Harbor, New York., 2014).
Example 1 Construction of Recombinant HVT Vectors Expressing Two Genes
Example 1.1 Construction of Recombinant vHVT309 Expressing IBDV-VP2 and NDV-F
(87) The objective of the study is to construct a recombinant HVT in which an expression cassette containing a mouse cytomegalovirus promoter (mCMV), a gene encoding an infectious bursal disease virus viral protein 2 (VP2), Simian virus 40 poly A tail (SV40 poly A), Simian virus 40 promoter (SV40 promoter), a gene encoding a Newcastle disease virus fusion protein (NDV-F) and synthetic poly A tail (syn poly A tail) is integrated in the intergenic site 1 (IG1).
(88) The parental virus used in the construct is vHVT13 (an HVT vector expressing the IBDV VP2 gene, active ingredient of Merial's VAXXITEK® (HVT+IBD) Vaccine, also known as vHVT17 in U.S. Pat. No. 5,980,906). The vHVT13 vector contains an expression cassette composed of mCMV IE promoter (SEQ ID NO:6), IBDV VP2 gene (SEQ ID NO:1 encoding SEQ ID NO:2), and SV40 poly A tail (SEQ ID NO:8) inserted into the IG1 insertion site. A Newcastle disease virus Fusion Protein (NDV-F) corresponding to genotype VIId sequence was chemically synthesized and codon optimized (GenScript). The F protein cleavage site of this synthetic gene was altered to match a lentogenic F cleavage site sequence and the resultant NDV-F gene sequence has 99% amino acid sequence identity to NDV-F sequence deposited in GenBank (AY337464). Mouse CMV IE

promoter was used for IBD-VP2, and SV40 promoter was used for NDV-F. The insertion locus is intergenic site 1 (IG1) in HVT (FIG. **2**). Donor plasmid pFSV40VP2 (an insertion plasmid containing the VP2/SV40 poly A and flanking arm of IG1+SV40 promoter+NDV-F+synthetic poly A) was constructed as described below. Chicken embryo fibroblast cells (CEF) were used for in vitro recombination.

(89) Donor Plasmid Construction

(90) Synthetic DNA in pUC57 containing the IBDV VP2 gene (SEQ ID NO:1 encoding SEQ ID NO:2), SV40 poly A tail (SEQ ID NO:8), SV40 promoter (SEQ ID NO:7), NDV-F gene (SEQ ID NO:3 encoding SEQ ID NO:5), and synthetic poly A tail (SEQ ID NO:9) was synthesized by GeneScript (FIG. **3**). The plasmid, pFSV40VP2 was transformed using Top10 Oneshot kit (cat #C404002, Invitrogen) and a large scale culture was grown and plasmid extraction was done using Qiagens Maxi Prep kit. Transient expression of the maxi prep was verified using Fugene Transfection Reagent in Chicken Embryo Fibroblast Cells (CEF's) and chicken polyclonal sera against NDV.

(91) Recombinant Generation

(92) A standard homologous recombination procedure was followed by co-electroporation of secondary CEF cells using pFSV40VP2 plasmid and viral DNA isolated from vHVT13 Vaccine. Co-electroporation was performed using 1×10.sup.7 2° CEF in 300 μl Opti-MEM and shocked at 150 volts with 950 capacitance in a 2 mm electroporation cuvette. The transfected cells were seeded into 96-well plate and incubated for 4 days. The cells grown in the 96-well plate were then duplicated into two 96-well plates and incubated for 3 more days. One set of 96-well plates was used for IFA using chicken polyclonal sera against NDV-F to identify positive wells containing recombinants and another set of 96-well plates was used for recovering the infected cells from the positive wells.

(93) The recombinant viral purification methods were performed first by 96-well plate duplication and IFA selection for the wells containing the most IFA positive plaques with the least amount of IFA negative plaques. Wells matching those criteria were then harvested and adjusted to 1 ml in DMEM+2% FBS. From the 1 ml stock, 5-20 ul were removed and mixed with 1×10.sup.7 CEFs in 10 ml DMEM+2% FBS and aliquoted onto a new 96-well plate to have single virus plaques per well. The 96-well plates were duplicated after 5 days of incubation and wells that contained plaques were tested for the presence of double recombinant and absence of vHVT13 parental virus by IFA and PCR. Again the wells that appeared to have more recombinant virus, by comparing the PCR banding results, were harvested and adjusted to 1 ml and aliquoted onto new 96-well plates. After two rounds of purification of virus infected cells, recombinant virus expressing NDV-F protein was isolated and the purity of the recombinant virus was tested by IFA and PCR to confirm the absence of parental virus.

(94) Analysis of Recombinant by PCR

(95) DNA was extracted from a stock virus by phenol/chloroform extraction, ethanol precipitation, and resuspended in 20 mM HEPES. PCR primers (Table 1) were designed to specifically identify the IBDV-VP2 and NDV-F VIId gene, the promoters, the poly As, as well as, the purity of the recombinant virus from Vaxxitek parental virus. The locations of the primer binding sites are shown in FIG. **4**. PCR was performed using 200 μg of DNA template along with the specified primer pairs indicted in Table 1. PCR cycling conditions are as follows: 94° C.-2 min; 30 cycles of 94° C.-30 sec, 60° C.-45 sec, 68° C.-3 min (5 min for MB080+MB081 primer set); 68° C.-5 min (7 min for MB080+MB081 primer set).

(96) TABLE-US-00001 TABLE 1 Expected PCR bands using specific primer sets Primer set Vaxxitek vHVT309 MB080 + MB081 3350 5577 MB010 + NDVFVlldopt.F — 737 MB080 + VP2.F   405 2632 SV40tailR + mCMVF 3021 3021 syntailR + SV40promoterF — 2184

Expression Analysis

(97) For immunofluorescence testing, the recombinant material was diluted 1:100 in media.

Approximately 50 μl of the diluted virus was added to 20 ml of DMEM+2% FBS with 2×10.sup.7 CEFs and then aliquoted onto two 96 well plates (100 μl/well). The plates were incubated for 4 days at 37° C.+5% CO.sub.2 until viral plaques were visible. The plates were fixed with 95% ice-cold acetone for three minutes, allowed to air dry for ten minutes and washed three times with water. Dual immunofluorescent staining was performed for plate #1 using chicken anti-sera against Newcastle Disease virus (NDV Pab) (lot #C0117A, Charles Rivers Laboratories) at 1:500 and HVT L78 monoclonal antibody (HVT Mab) (Lee et al. 1983, J. Immunol. 130 (2) 1003-6; Merial batch) at 1:3000 and the plate was incubated at 37° C. for 1 hour. Dual Immunofluorescent was performed for plate #2 using chicken anti-sera against Infectious Bursal Disease virus (IBDV Pab) at 1:500 (lot #G0117, Charles Rivers Laboratories) and HVT L78 monoclonal antibody (HVT Mab) (Merial) at 1:3000 and the plate was incubated at 37° C. for 1 hour. After one hour incubation, the plates were washed three times with PBS. To both plate #1 and #2 FITC labeled anti-chicken IgG (cat #F8888, Sigma) at 1:500 and TRITC labeled Alex Fluor donkey anti-mouse (cat #A10037, Invitrogen) at 1:300 was added. Again the plates were incubated at 37° C. for 1 hour. After one hour incubation the cells were rinsed three times with PBS and visualized with a fluorescent microscope using fluorescein isothiocyanate (FITC) filter and tetramethyl rhodamine iso-thiocyanate (TRITC) filter.

(98) Results

(99) The nucleotide and amino acid sequences of the donor plasmid pFSV40VP2 are assigned SEQ ID NO as shown in FIG. **1**.

(100) Recombinant Generation and Expression Analyses

(101) Genomic DNA of vHVT13 virus was co-electroporated with pFSV40VP2 donor plasmid to generate recombinant using homologous recombination technique. Recombinant virus was separated from parental Vaxxitek virus by immunofluorescent positive well selection and PCR screening in multiple rounds of plaque purification. A plaque purified recombinant virus expressing the NDV-F protein, designated vHVT309, was scaled up from tissue culture flasks to 5×850 cm.sup.2 roller bottles. After about 72 hrs post infection the infected CEFs were harvested. Aliquots were frozen in liquid nitrogen, each aliquot contained 10% FBS and 10% DMSO. Titrations were performed in triplicate on CEFs and a titer of 1.5×10.sup.5 pfu/ml was obtained for vHVT309.

(102) Dual immunofluorescent staining was performed using chicken anti-sera (Pab) at 1:500 and HVT L78 monoclonal antibody (Mab) at 1:3000 followed by a FITC labeled anti-chicken IgG at 1:500 and TRITC labeled Alex Fluor donkey anti-mouse at 1:300. Plate #1 compares the expression of Newcastle Disease virus with HVT and plate #2 compares the expression of Infectious Bursal Disease virus with HVT. All examined HVT TRITC positive plaques of vHVT309 were found to express NDV-F and IBDV-VP2 proteins.

(103) PCR Analysis of vHVT309

(104) Purity of recombinant virus was verified by PCR using primer pairs that are specific to the HVT flanking arms, the promoters, the NDV-F and IBDV-VP2 genes, and the poly A tails. The PCR results demonstrate that recombinant virus vHVT309 carries the intended expression cassette and the virus stock is free from detectable amounts of parental Vaxxitek virus (Table 1 and FIG. **5**).

(105) Conclusion

(106) Based on PCR testing and immunofluorescence analysis, vHVT309 is a recombinant virus containing an IBDV-VP2 gene under the control of mCMV promoter and a NDV-F gene under the control of an SV40 promoter. The newly generated vHVT309 is free of any detectable parental vHVT13 virus.

Example 1.2 Construction of Recombinant vHVT310 Expressing IBDV-VP2 and NDV-F

(107) The objective of the study is to construct a recombinant HVT in which an expression cassette containing a mouse cytomegalovirus promoter (mCMV), a gene encoding an infectious bursal disease virus viral protein 2 (VP2), internal ribosome entry site (IRES), a gene encoding a

Newcastle Disease virus fusion protein (NDV-F), and Simian virus 40 poly A tail (SV40 poly A) is integrated in the intergenic site 1 (IG1) (FIG. **2**).
(108) The parental virus used in the construct is vHVT13. A Newcastle disease virus Fusion Protein (NDV-F) corresponding to genotype VIId sequence was chemically synthesized and codon optimized (GenScript). The F protein cleavage site of this synthetic gene was altered to match a lentogenic F cleavage site sequence and the resultant NDV-F gene sequence has 99% amino acid sequence identity to NDV-F sequence deposited in GenBank (AY337464). Mouse CMV IE promoter was used for IBD-VP2 (in the parental Vaxxitek virus). IRES, an RNA sequence derived from Encephalomyocarditis virus (EMCV), that allows the initiation of translation within an mRNA immediately downstream from where the IRES is located, was inserted at the end of the VP2 gene to initiate translation of a downstream NDV-F gene. This was the first time that IRES was used in an HVT vector.
(109) The insertion locus is intergenic site 1 (IG1) in HVT (FIG. **2**). Donor plasmid pFIRESVP2 (an insertion plasmid containing the VP2 gene+IRES+NDV-F and SV40 poly A/flanking arm of IG1) was constructed as described below. Chicken embryo fibroblast cells (CEF) were used for in vitro recombination.
(110) Donor Plasmid Construction:
(111) Synthetic DNA in pUC57 containing the IBDV VP2 gene (SEQ ID NO:1 encoding SEQ ID NO:2), IRES (SEQ ID NO:10), NDV-F gene (SEQ ID NO:3 encoding SEQ ID NO:5), and SV40 poly A tail (SEQ ID NO:8) was synthesized by GeneScript (FIG. **6**). The plasmid, pFIRESVP2 was transformed using Top10 Oneshot kit (cat #C404002, Invitrogen) and a large scale culture was grown and plasmid extraction was done using Qiagens Maxi Prep kit.
(112) Recombinant Generation
(113) The homologous recombination procedure as described in Example 1.1 was followed to make recombinant vHVT310.
(114) Analysis of Recombinant by PCR
(115) The PCR analysis procedure as described in Example 1.1 was performed to verify vHVT310.
(116) Expression Analysis
(117) The expression analysis described in Example 1.1 was performed to analyze the expression of vHVT310.
(118) Results
(119) The nucleotide and amino acid sequence of the donor plasmid pFIRESVP2 are assigned SEQ ID NO as shown in FIG. **1**.
(120) Recombinant Generation and Expression Analyses
(121) Genomic DNA of Vaxxitek virus was co-electroporated with pFIRESVP2 donor plasmid to generate recombinant virus using homologous recombination technique. Recombinant virus was separated from parental vHVT13 virus by immunofluorescent positive well selection and PCR screening in multiple rounds of plaque purification. A plaque purified recombinant virus expressing the NDV-F protein, designated vHVT310, was scaled up from tissue culture flasks to 5×850 cm.sup.2 roller bottles. After about 72 hrs post infection the infected CEFs were harvested. Aliquots were frozen in liquid nitrogen, each aliquot contained 10% FBS and 10% DMSO. Titrations were performed in triplicate on CEFs and a titer of 2.0×10.sup.6 pfu/ml was obtained for vHVT310.
(122) Dual Immunofluorescent staining was performed using chicken anti-sera (Pab) at 1:500 and HVT L78 monoclonal antibody (Mab) at 1:3000 followed by a FITC labeled anti-chicken IgG at 1:500 and TRITC labeled Alex Fluor donkey anti-mouse at 1:300. Plate #1 compares the expression of Newcastle Disease virus with HVT and plate #2 compares the expression of Infectious Bursal Disease virus with HVT. All examined HVT TRITC positive plaques of vHVT310 were found to express NDV-F and IBDV-VP2 proteins.
(123) PCR Analysis of vHVT310

(124) Purity of recombinant virus was verified by PCR using primer pairs that are specific to the HVT flanking arms, the promoter, the NDV-F and IBDV-VP2 genes, and the polyA tail. The PCR results demonstrate that recombinant virus vHVT310 carries the intended expression cassette and the virus stock is free from detectable amounts of parental Vaxxitek virus (Table 2 and FIG. **7-8**).
(125) TABLE-US-00002 TABLE 2 Expected PCR bands using specific primer sets Primer set Vaxxitek vHVT310 MB080 + MB081 3350 5586 MB080 + NDVFVlldopt.F — 798 MB080 + VP2.F   405 2641 SV40tailR + mCMVF 3021 5257
Conclusion
(126) Based on PCR testing and immunofluorescence analysis, vHVT310 is a recombinant virus containing an IBDV-VP2 and NDV-F gene under the control of mCMV promoter, where the translation of NDV-F gene is initiated by IRES from EMCV. The newly generated recombinant vHVT310 is free of any detectable parental vHVT13 virus.
Example 1.3 Construction of Recombinant vHVT311 Expressing IBDV-VP2 and NDV-F
(127) The objective of the study is to construct a recombinant HVT in which an expression cassette containing a mouse cytomegalovirus promoter (mCMV), a gene encoding an infectious bursal disease virus viral protein 2 (VP2), self-cleaving porcine teschovirus-1 2A peptide (P2A), a gene encoding a Newcastle Disease virus fusion protein (NDV-F), and Simian virus 40 poly A tail (SV40 poly A) is integrated in the intergenic site 1 (IG1) (FIG. **2**).
(128) The parental virus used in the construct is vHVT13 (an HVT vector expressing the IBDV VP2 gene, Merial's VAXXITEK® (HVT+IBD) Vaccine). The polynucleotide corresponding to wild-type genotype VIId Newcastle disease virus Fusion Protein (NDV-F) sequence was chemically synthesized (GenScript). The F protein cleavage site of this synthetic gene was altered to match a lentogenic F cleavage site sequence and the resultant NDV-F gene sequence has 99% amino acid sequence identity to NDV-F sequence deposited in GenBank (AY337464). Mouse CMV IE promoter was used for IBD-VP2 (in the parental Vaxxitek virus). A self-cleaving porcine teschovirus-1 2A peptide (P2A) that allows co-translational ‘cleavage’ of the upstream and downstream genes, VP2 and F, respectively from a single promoter mCMV, was inserted at the end of the VP2 gene. This is the first time that P2A was used in HVT vectors.
(129) The insertion locus is intergenic site 1 (IG1) in HVT (FIG. **2**). Donor plasmid pFP2AVP2 (an insertion plasmid containing the VP2+P2A+NDV-F and SV40 poly A/flanking arm of IG1) was constructed as described below. Chicken embryo fibroblast cells (CEF) were used for in vitro recombination.
(130) Donor Plasmid Construction
(131) Synthetic DNA in pUC57 containing the IBDV VP2 gene (SEQ ID NO:1 encoding SEQ ID NO:2), P2A encoding DNA (SEQ ID NO:11), NDV-F gene (SEQ ID NO:4 encoding SEQ ID NO:5), and SV40 poly A tail (SEQ ID NO:8) was synthesized by GeneScript (FIG. **9**). The plasmid, pFP2AVP2 was transformed using Top10 Oneshot kit (cat #C404002, Invitrogen) and a large scale culture was grown and plasmid extraction was done using Qiagens Maxi Prep kit.
(132) Recombinant Generation
(133) The homologous recombination procedure as described in Example 1.1 was followed to make recombinant vHVT311.
(134) Analysis of Recombinant by PCR
(135) The PCR analysis procedure as described in Example 1.1 was performed to verify vHVT311.
(136) Expression Analysis
(137) The expression analysis described in Example 1.1 was performed to analyze the expression of vHVT311.
(138) Results
(139) The nucleotide and amino acid sequences of the donor plasmid pFP2AVP2 are assigned SEQ ID NO as shown in FIG. **1**.
(140) Recombinant Generation and Expression Analyses

(141) Genomic DNA of Vaxxitek virus was co-electroporated with pFP2AVP2 donor plasmid to generate recombinant virus using homologous recombination technique. Recombinant virus was separated from parental Vaxxitek virus by immunofluorescent positive well selection and PCR screening in multiple rounds of plaque purification. A plaque purified recombinant virus expressing the NDV-F protein, designated vHVT311, was scaled up from tissue culture flasks to 5×850 cm.sup.2 roller bottles. After about 72 hrs post infection the infected CEFs were harvested. Aliquots were frozen in liquid nitrogen, each aliquot contained 10% FBS and 10% DMSO. Titrations were performed in triplicate on CEFs and a titer of 2.5×10.sup.6 pfu/ml was obtained for vHVT311.
(142) Dual Immunofluorescents was performed using chicken anti-sera (Pab) at 1:500 and a monoclonal antibody (Mab) at 1:3000 followed by a FITC labeled anti-chicken IgG at 1:500 and TRITC labeled Alex Fluor donkey anti-mouse at 1:300. Plate #1 compares the expression of Newcastle Disease virus with HVT and plate #2 compares the expression of Infectious Bursal Disease virus with Newcastle Disease virus. All examined HVT TRITC positive plaques of vHVT311 were found to express NDV-F and all NDV TRITC positive plaques were found to express IBDV-VP2 proteins.
(143) PCR Analysis of vHVT311
(144) Purity of recombinant virus was verified by PCR using primer pairs that are specific to the HVT flanking arms, the promoter, the NDV-F and IBDV-VP2 genes, and the poly A tail. The PCR results demonstrate that recombinant virus vHVT311 carries the intended expression cassette and the virus stock is free from detectable amounts of parental Vaxxitek virus (Table 3 and FIG. **10-11**).
(145) TABLE-US-00003 TABLE 3 Expected PCR bands using specific primer sets Primer set Vaxxitek vHVT311 MB080 + MB081 3350 5101 MB080 + NDVFVlldwt.F — 840 MB080 + VP2.F   405 2156 SV40tailR + mCMVF 3021 4772
Conclusion
(146) Based on PCR testing and immunofluorescence analysis, vHVT311 is a recombinant virus containing an IBDV-VP2 and NDV-F gene under the control of mCMV promoter in which the 2A peptide-mediated cleavage result in co-expression of VP2 and F proteins. The newly generated recombinant vHVT311 is free of any detectable parental vHVT13 virus.
Example 1.4 Construction of Recombinant vHVT317 Expressing IBDV-VP2 and ILTV-gD
(147) The objective of the study is to construct a recombinant HVT in which an expression cassette containing a mouse cytomegalovirus promoter (mCMV), a gene encoding an infectious bursal disease virus viral protein 2 (VP2), internal ribosome entry site (IRES), a gene encoding an Infectious Laryngotracheitis glycoprotein D protein (ILTV-gD), and Simian virus 40 poly A tail (SV40 poly A) is integrated in the intergenic site 1 (IG1) (FIG. **2**).
(148) The parental virus used in the construct is vHVT13. An Infectious Laryngotracheitis virus glycoprotein D (ILTV gD) sequence which was chemically synthesized (GenScript) was used in the construct. Mouse CMV IE promoter was used for IBD-VP2 (in the parental vHVT13 virus). An RNA sequence (IRES) derived from Encephalomyocarditis virus (EMCV), that allows the initiation of translation within an mRNA immediately downstream from where the IRES is located, was inserted at the end of the VP2 gene to initiate translation of a downstream ILTV-gD gene.
(149) The insertion locus is intergenic site 1 (IG1) in HVT (FIG. **2**). Donor plasmid pVP2IRESgD (an insertion plasmid containing the VP2 gene+IRES+ILTV-gD and SV40 poly A/flanking arm of IG1) was constructed as described below. Chicken embryo fibroblast cells (CEF) were used for in vitro recombination.
(150) Donor Plasmid Construction
(151) Synthetic DNA in pUC57 containing the IBDV VP2 gene (SEQ ID NO:1 encoding SEQ ID NO:2), IRES (SEQ ID NO:10), ILTV-gD gene (SEQ ID NO:16 encoding SEQ ID NO:17), and SV40 poly A tail (SEQ ID NO:8) was synthesized by GenScript. The plasmid, pFIRESVP2 was transformed into dcm-/dam-competent cells (New England Biolabs, cat #C2925I) then digested

with HindIII/SalI. The 5 kb fragment was gel extracted. A synthetic DNA in pUC57 containing a partial IRES, ILTV-gD wildtype, and SV40 poly A tail was synthesized by GenScript. The plasmid, Sal-Fse gD-IRES was digested with HindIII/SalI. The 1.9 kb fragment was gel extracted. The two fragments were ligated and transformed using Top10 Oneshot kit (cat #C404002, Invitrogen). Colonies were screen by HindIII/SalI for the correct pattern. The final donor plasmid was sequenced verified and designated pVP2IRESgD (see FIG. **12**).

(152) Recombinant Generation

(153) The homologous recombination procedure as described in Example 1.1 was followed to make recombinant vHVT317.

(154) Analysis of Recombinant by PCR

(155) The PCR analysis procedure as described in Example 1.1 was performed to verify vHVT317.

(156) Expression Analysis

(157) The expression analysis described in Example 1.1 was performed to analyze the expression of vHVT317.

(158) Results

(159) The nucleotide and amino acid sequence of the donor plasmid pVP2IRESgD are assigned SEQ ID NO as shown in FIG. **1**.

(160) Recombinant Generation and Expression Analyses

(161) Dual Immunofluorescents was performed using chicken anti-sera (Polyclonal antibody) at 1:500 and a monoclonal antibody (Mab) at 1:3000 followed by a FITC labeled anti-chicken IgG at 1:500 and TRITC labeled Alex Fluor donkey anti-mouse at 1:300. All examined plaques of vHVT317 were found to express IBDV-VP2 proteins compared to HVT positive plaques and all and plaques were found to express ILTV-gD proteins when compared to IBDV positive plaques.

(162) PCR Analysis of vHVT317

(163) Purity of recombinant virus was verified by PCR using primer pairs that are specific to the HVT flanking arms, the promoter, the ILTV-gD and IBDV-VP2 genes, and the poly A tail. The PCR results demonstrate that recombinant virus vHVT317 carries the intended expression cassette and the virus stock is free from detectable amounts of parental Vaxxitek virus (Table 4 and FIG. **13-14**).

(164) TABLE-US-00004 TABLE 4 Expected PCR bands using specific primer sets Primer set Vaxxitek vHVT317 MB080 + MB081 3350 5101 MB080 + ILTgDwt.F — 825 MB080 + VP2.F 405 2272 SV40tailR + mCMVF 3021 4888

Conclusion

(165) Based on PCR testing and immunofluorescence analysis, vHVT317 is a recombinant virus containing an IBDV-VP2 and ILTV-gD gene under the control of mCMV promoter, where the translation of ILTV-gD gene is initiated by IRES from EMCV. The newly generated recombinant vHVT317 is free of any detectable parental vHVT13 virus.

Example 1.5 Construction of Recombinant vHVT313 Expressing IBDV-VP2 and NDV-F

(166) The objective of the study is to construct a recombinant HVT in which an expression cassette containing a mouse cytomegalovirus promoter (mCMV), a gene encoding an infectious bursal disease virus viral protein 2 (VP2), Simian virus 40 poly A tail (SV40 poly A), Simian virus 40 promoter (SV40 promoter), a gene encoding a wildtype Newcastle disease virus fusion protein (NDV-F) and synthetic poly A tail (syn poly A tail) is integrated in the intergenic site 1 (IG1) (FIG. **2**).

(167) The parental virus used in the construct is vHVT13. A Newcastle disease virus Fusion Protein (NDV-F) corresponding to genotype VIId wildtype sequence chemically synthesized (GenScript). The F protein cleavage site of this synthetic gene was altered to match a lentogenic F cleavage site sequence and the resultant NDV-F gene sequence has 99% amino acid sequence identity to NDV-F sequence deposited in GenBank (AY337464). Mouse CMV IE promoter for IBD-VP2 (in the parental Vaxxitek virus) and SV40 promoter for NDV-F were used.

(168) The insertion locus is intergenic site 1 (IG1) (FIG. **2**). Donor plasmid pFwtSV40VP2 (an insertion plasmid containing the VP2/SV40 poly A and flanking arm of IG1+SV40 promoter+NDV-F+synthetic poly A) was constructed as described below. Chicken embryo fibroblast cells (CEF) were used for in vitro recombination.
(169) Donor Plasmid Construction
(170) Synthetic DNA in pUC57 containing the IBDV VP2 gene (SEQ ID NO:1 encoding SEQ ID NO:2), SV40 poly A tail (SEQ ID NO:8), SV40 promoter (SEQ ID NO:7), NDV-F gene (SEQ ID NO:4 encoding SEQ ID NO:5), and synthetic poly A tail (SEQ ID NO:9) was synthesized by GeneScript.
(171) The plasmid, pFSV40VP2 was then digested with SbfI/AvrII and the 5.6 kb fragment was gel extracted. A plasmid, pHM103NDVFwtsyn was also digested with SbfI/AvrII and the 1.9 kb fragment was gel extracted. The fragments were then ligated together and transformed using Top10 Oneshot kit (cat #C404002, Invitrogen). Colonies were screened with PstI for the correct pattern. Transient expression of the maxi prep was verified using Fugene Transfection Reagent in Chicken Embryo Fibroblast Cells (CEF's) and chicken polyclonal sera against NDV. The final donor plasmid was sequenced verified and designated pFwtSV40VP2 (see FIG. **15**).
(172) Recombinant Generation
(173) The homologous recombination procedure as described in Example 1.1 was followed to make recombinant vHVT313.
(174) Analysis of Recombinant by PCR
(175) The PCR analysis procedure as described in Example 1.1 was performed to verify vHVT313.
(176) Expression Analysis
(177) The expression analysis described in Example 1.1 was performed to analyze the expression of vHVT313.
(178) Results
(179) The nucleotide and amino acid sequence of the donor plasmid pFwtSV40VP2 are assigned SEQ ID NO as shown in FIG. **1**.
(180) Recombinant Generation and Expression Analyses
(181) Dual Immunofluorescents was performed using chicken anti-sera (Pab) and an anti-HVT monoclonal antibody (Mab) followed by a FITC labeled anti-chicken IgG and TRITC labeled Alex Fluor donkey anti-mouse. All examined TRITC positive plaques of vHVT313 were found to express NDV-F and IBDV-VP2 proteins.
(182) PCR Analysis of vHVT313
(183) Purity of recombinant virus was verified by PCR using primer pairs that are specific to the HVT flanking arms, the promoters, the NDV-F and IBDV-VP2 genes, and the poly A tails. The PCR results demonstrate that recombinant virus vHVT313 carries the intended expression cassette and the virus stock is free from detectable amounts of parental Vaxxitek virus (Table 5 and FIG. **16**-**17**).
(184) TABLE-US-00005 TABLE 5 Expected PCR bands using specific primer sets Primer set Vaxxitek vHVT313 MB080 + MB081 3350 5574 MB080 + 312P6 — 556 MB080 + VP2.F 405 2629 SV40tailR + mCMVF 3021 3021 SyntailR + SV40promoterF — 2181
Conclusion
(185) Based on PCR testing and immunofluorescence analysis, vHVT313 is a recombinant virus containing an IBDV-VP2 gene under the control of mCMV promoter and a NDV-F wildtype gene under the control of an SV40 promoter. The newly generated vHVT313 is free of any detectable parental Vaxxitek virus.
Example 1.6 Construction of Recombinant vHVT316 Expressing IBDV-VP2 and NDV-F
(186) The objective of the study is to construct a recombinant HVT in which an expression cassette containing a mouse cytomegalovirus promoter (mCMV), a gene encoding an infectious bursal disease virus viral protein 2 (VP2), internal ribosome entry site (IRES), a gene encoding a wildtype

Newcastle Disease virus fusion protein (NDV-F), and Simian virus 40 poly A tail (SV40 poly A) is integrated in the IG1 locus (FIG. **2**).
(187) The parental virus used in the construct is vHVT13. A Newcastle disease virus Fusion Protein (NDV-F) corresponding to genotype VIId wildtype sequence chemically synthesized (GenScript). The F protein cleavage site of this synthetic gene was altered to match a lentogenic F cleavage site sequence and the resultant NDV-F gene sequence has 99% amino acid sequence identity to NDV-F sequence deposited in GenBank (AY337464). Mouse CMV IE promoter was used for IBD-VP2 (in the parental Vaxxitek virus). IRES was inserted at the end of the VP2 gene to initiate translation of a downstream NDV-F gene.
(188) The insertion locus is IG1 (FIG. **2**). Donor plasmid pVP2IRESFwt (an insertion plasmid containing the VP2 gene+IRES+NDV-F and SV40 poly A/flanking arm of IG1) was constructed as described below. Chicken embryo fibroblast cells (CEF) were used for in vitro recombination.
(189) Donor Plasmid Construction
(190) Synthetic DNA in pUC57 containing the IBDV VP2 gene (SEQ ID NO:1 encoding SEQ ID NO:2), IRES(SEQ ID NO:10), NDV-F gene (SEQ ID NO:4 encoding SEQ ID NO:5), and SV40 poly A tail (SEQ ID NO:8), was synthesized by GenScript. The plasmid, pFIRESVP2 was transformed into dcm-/dam-competent cells (New England Biolabs, cat #C2925I) then digested with HindIII/SalI. The 5 kb fragment was gel extracted. A synthetic DNA in pUC57 containing a partial IRES, NDV-F wildtype, and SV40 poly A tail was synthesized by GenScript. The plasmid, Sal-Hind-Fwt+ was digested with HindIII/SalI. The 2.2 kb fragment was gel extracted. The two fragments were ligated and transformed using Top10 Oneshot kit (cat #C404002, Invitrogen). The final donor plasmid was sequenced verified and designated pVP2IRESFwt (see FIG. **18**).
(191) Recombinant Generation
(192) The homologous recombination procedure as described in Example 1.1 was followed to make recombinant vHVT316.
(193) Analysis of Recombinant by PCR
(194) The PCR analysis procedure as described in Example 1.1 was performed to verify vHVT316.
(195) Expression Analysis
(196) The expression analysis described in Example 1.1 was performed to analyze the expression of vHVT316.
(197) Results
(198) The nucleotide and amino acid sequence of the donor plasmid pVP2IRESFwt are assigned SEQ ID NO as shown in FIG. **1**.
(199) Recombinant Generation and Expression Analyses
(200) Dual Immunofluorescent staining was performed using chicken anti-sera (Pab) and a monoclonal antibody (Mab) followed by a FITC labeled anti-chicken IgG and TRITC labeled Alex Fluor donkey anti-mouse. All examined plaques of vHVT316 were found to express IBDV-VP2 proteins compared to HVT positive plaques and all and plaques were found to express IBDV-VP2 proteins when compared to NDV positive plaques.
(201) PCR Analysis of vHVT316
(202) Purity of recombinant virus was verified by PCR using primer pairs that are specific to the HVT flanking arms, the promoter, the NDV-F and IBDV-VP2 genes, and the poly A tail. The PCR results demonstrate that recombinant virus vHVT316 carries the intended expression cassette and the virus stock is free from detectable amounts of parental Vaxxitek virus (Table 6 and FIG. **19-20**).
(203) TABLE-US-00006 TABLE 6 Expected PCR bands using specific primer sets Primer set Vaxxitek vHVT316 MB080 + MB081 3350 5574 MB080 + 312P6 — 604 MB080 + VP2.F 405 2629 SV40tailR + mCMVF 3021 5245
Conclusion
(204) Based on PCR testing and immunofluorescence analysis, vHVT316 is a recombinant virus containing an IBDV-VP2 and NDV-F gene under the control of mCMV promoter, where the

translation of NDV-F gene is initiated by IRES from EMCV. The newly generated recombinant vHVT316 is free of any detectable parental Vaxxitek virus.

Example 1.7 Construction of Recombinant vHVT407 Expressing IBDV-VP2 and ILTV-gD

(205) The objective of the study is to construct a recombinant HVT in which an expression cassette containing an SV40 promoter, ILTV glycoprotein D, and synthetic poly A into the SORF3-US2 site of vHVT13.

(206) The parental virus used in the construct is vHVT13. An Infectious Laryngotracheitis virus glycoprotein D (ILTV gD) sequence which was chemically synthesized (GenScript) was used in the construct. SV40 promoter was used for ILTV gD. The insertion locus is SORF3-US2 for ILTV gD and IG1 for IBDV VP2 from vVHT13 (FIG. **2**). Donor plasmid HVT US2SVgDwtsyn containing SORF3-US2 arms, SV40 promoter (SEQ ID NO:7), gene encoding ILTV wild-type gD (SEQ ID NO:16 encoding SEQ ID NO:17), and synthetic polyA (SEQ ID NO:9) was constructed (see FIG. **22**). Chicken embryo fibroblast cells (CEF) were used for in vitro recombination.

(207) Recombinant Generation

(208) The homologous recombination procedure as described in Example 1.1 was followed to make recombinant vHVT407.

(209) Analysis of Recombinant by PCR

(210) The PCR analysis procedure as described in Example 1.1 was performed to verify vHVT407.

(211) Expression Analysis

(212) The expression analysis described in Example 1.1 was performed to analyze the expression of vHVT407.

(213) Results

(214) The nucleotide and amino acid sequence of the donor plasmid HVT US2SVgDwtsyn are assigned SEQ ID NO as shown in FIG. **1**.

(215) Recombinant Generation and Expression Analyses

(216) Dual Immunofluorescent staining was performed using chicken anti-sera (Pab) and a monoclonal antibody (Mab) followed by a FITC labeled anti-chicken IgG and TRITC labeled Alex Fluor donkey anti-mouse. All examined plaques of vHVT407 were found to express IBDV-VP2 and ILTV gD proteins.

(217) PCR Analysis of vHVT407

(218) Purity of recombinant virus was verified by PCR using primer pairs that are specific to the HVT flanking arms, the promoter, the ILTV gD and IBDV-VP2 genes, and the poly A tail. The PCR results demonstrate that recombinant virus vHVT407 carries the intended expression cassette and the virus stock is free from detectable amounts of parental vHVT13 virus.

(219) Conclusion

(220) Based on PCR testing and immunofluorescence analysis, vHVT407 is a recombinant virus containing IBDV-VP2 and ILTV gD genes. The newly generated recombinant vHVT407 is free of any detectable parental vHVT13 virus.

Example 1.8 Construction of Recombinant vHVT308 Expressing NDV-F and ILTV-gD in Opposite Directions

(221) The objective of the study is to construct an insertion plasmid for the Intergenic region I site that will contain a Synthetic poly A tail, NDV F, SV40 promoter, HHV3gB promoter, ILTV gD, and SV40 poly A tail for homologous recombination into HVT FC126.

(222) The parental virus used in the construct is HVT FC126. A synthetic Newcastle disease virus Fusion Protein (NDV-F) (SEQ ID NO:21 encoding SEQ ID NO:22) corresponding to genotype V sequence was chemically synthesized and codon optimized (GenScript). The F protein cleavage site of this synthetic gene was altered to match a lentogenic F cleavage site sequence. A synthetic wildtype ILTV glycoprotein D (SEQ ID NO:16 encoding SEQ ID NO:17) was chemically synthesized. Donor plasmid pHVTIG1gDCaFopt containing the HHV3gB promoter (Human Herpesvirus Type 3 glycoprotein B promoter) in the reverse orientation driving ILTV-gD+SV40

poly A tail, and SV40 promoter driving Newcastle fusion protein+synthetic poly A tail was constructed (see FIG. **23**). Chicken embryo fibroblast cells (CEF) were used for in vitro recombination.
(223) Recombinant Generation
(224) The homologous recombination procedure as described in Example 1.1 was followed to make the recombinant vHVT308. Serial passaging was performed to pre-MSV+13.
(225) Analysis of Recombinant by PCR
(226) The PCR analysis procedure as described in Example 1.1 was performed to verify the recombinant vHVT308.
(227) Expression Analysis
(228) The expression analysis described in Example 1.1 was performed to analyze the expression of the recombinant vHVT308.
(229) Results
(230) The nucleotide and amino acid sequence of the donor plasmid pHVTIG1gDCaFopt are assigned SEQ ID NO as shown in FIG. **1**.
(231) Recombinant Generation and Expression Analyses
(232) Dual Immunofluorescent staining was performed using chicken anti-sera (Pab) and a monoclonal antibody (Mab) followed by a FITC labeled anti-chicken IgG and TRITC labeled Alex Fluor donkey anti-mouse. All examined plaques of vHVT308 were found to express NDV-F and ILTV-gD proteins.
(233) PCR Analysis of vHVT308
(234) Purity of recombinant virus was verified by PCR using primer pairs that are specific to the HVT flanking arms, the promoters, the NDV-F and ILTV-gD genes, and the poly A tails. The PCR results demonstrate that recombinant virus vHVT308 carries the intended expression cassette and the virus stock is free from detectable amounts of parental HVT virus (Table 6.1 and FIGS. **24** and **25**).
(235) TABLE-US-00007 TABLE 6.1 Expected PCR bands using specific primer sets Primer set HVT FC126 vHVT308 MB080 + MB081 323 bp 4697 bp syntailR + SV40promoterF — 2196 bp CAoptF.RP + 404P12 — 2056 bp HHV3gBF + SV40tailR — 2043 bp
(236) PCR reactions with all primer pairs resulted in the expected PCR products and banding patterns. As shown above, there is no evidence of parental HVT virus in vHVT308 and vHVT308 is stable at pre-MSV+13 passages.
(237) Conclusion
(238) Based on PCR testing and immunofluorescence analysis, vHVT308 is a recombinant HVT virus containing an NDV-F gene under the control of an SV40 promoter and an ILTV-gD gene under the control of an HHV3gB promoter. vHVT308 is free of any detectable parental HVT virus.
Example 1.9 Construction of Recombinant vHVT322 Expressing NDV-F and ILTV-gD
(239) The objective of the study is to construct a recombinant HVT in which an expression cassette containing an mCMV promoter, Newcastle Disease virus fusion protein (NDV-F), internal ribosome entry site (IRES), Infectious Laryngotracheitis glycoprotein D (ILTV-gD), and Simian virus 40 poly A tail (SV40 poly A) will homologously recombine with the flanking arms in the intergenic region 1 (IG1) of vHVT13 (HVT+IBD).
(240) The parental virus used in the construct is vHVT13. A Newcastle disease virus Fusion Protein (NDV-F) corresponding to the wildtype genotype VIId sequence (SEQ ID NO:4 encoding SEQ ID NO:5) was chemically synthesized (GenScript). The F protein cleavage site of this synthetic gene was altered to match a lentogenic F cleavage site sequence and the resultant NDV-F gene sequence has 99% nucleotide as well as amino acid sequence identity to NDV-F sequence deposited in GenBank (AY337464). A synthetic wildtype ILTV glycoprotein D (SEQ ID NO:16 encoding SEQ ID NO:17) was chemically synthesized. Donor plasmid_pFwaRESgD contained the left flanking arm of IG1, mCMV (mouse CMV IE) promoter, NDV-F, IRES, ILTV-gD, SV40 poly A, and the

right flanking arm of IG1 (see FIG. **26**). Chicken embryo fibroblast cells (CEF) were used for in vitro recombination.

(241) Recombinant Generation

(242) The homologous recombination procedure as described in Example 1.1 was followed to make the recombinant vHVT322. Serial passaging was performed to pre-MSV+13.

(243) Analysis of Recombinant by PCR

(244) The PCR analysis procedure as described in Example 1.1 was performed to verify the recombinant vHVT322.

(245) Expression Analysis

(246) The expression analysis described in Example 1.1 was performed to analyze the expression of the recombinant vHVT322.

(247) Results

(248) The nucleotide and amino acid sequence of the donor plasmid pFwtIRESgD are assigned SEQ ID NO as shown in FIG. **1**.

(249) Recombinant Generation and Expression Analyses

(250) Dual Immunofluorescent staining was performed using chicken anti-sera (Pab) and a monoclonal antibody (Mab) followed by a FITC labeled anti-chicken IgG and TRITC labeled Alex Fluor donkey anti-mouse. All examined TRITC positive plaques of vHVT322 were found to express NDV-F and ILTV-gD proteins.

(251) PCR Analysis of vHVT322

(252) Purity of recombinant virus was verified by PCR using primer pairs that are specific to the HVT flanking arms, the promoter, the NDV-F and ILTV-gD genes, and the poly A tail. The PCR results demonstrate that recombinant virus vHVT322 carries the intended expression cassette and the virus stock is free from detectable amounts of parental vHVT13 (Table 6.2 and FIGS. **27** and **28**).

(253) TABLE-US-00008 TABLE 6.2 Expected PCR bands using specific primer sets Primer set vHVT13 vHVT322 MB080 + MB081 3350 bp 5804 bp MB080 + ILTgDwtF — 1653 bp MB080 + 312P6 — 2485 bp mCMVF + SV40PolyA.R1 3021 bp 5105 bp

(254) PCR reactions with all primer pairs resulted in the expected PCR products and banding patterns. As shown above, there is no evidence of parental vHVT13 virus in vHVT322.

(255) Conclusion

(256) Based on PCR testing and immunofluorescence analysis, vHVT322 is a recombinant HVT virus containing an NDV-F and ILTV-gD gene under the control of mCMV promoter. vHVT322 is free of any detectable parental vHVT13 virus.

Example 1.10 Construction of Recombinant vHVT406 Expressing ILT-gDwt

(257) The objective of the study is to construct a recombinant HVT of which the SORF3-US2 site contains the SV40 promoter, Infectious Larygotracheitis gD, and synthetic poly A tail for homologous recombination into HVT FC126.

(258) The parental virus used in the construct is HVT FC126. A synthetic Infectious Laryngotracheitis Virus (ILTV) wildtype glycoprotein D (gDwt) was chemically synthesized. Donor plasmid pHVTUS2SVgDwtsyn contained the SORF3 and US2 arms of HVT FC126, SV40 promoter, ILTV gDwt (SEQ ID NO:16 encoding SEQ ID NO:17) and synthetic poly A (see FIG. **29**). Chicken embryo fibroblast cells (CEF) were used for in vitro recombination.

(259) Recombinant Generation

(260) The homologous recombination procedure as described in Example 1.1 was followed to make the recombinant vHVT406. Serial passaging was performed to pre-MSV+13 (x+12).

(261) Analysis of Recombinant by PCR

(262) The PCR analysis procedure as described in Example 1.1 was performed to verify the recombinant vHVT406.

(263) Expression Analysis

(264) The expression analysis described in Example 1.1 was performed to analyze the expression of the recombinant vHVT406.
(265) Results
(266) The nucleotide and amino acid sequence of the donor plasmid pHVTUS2SVgDwtsyn are assigned SEQ ID NO as shown in FIG. **1**.
(267) Recombinant Generation and Expression Analyses
(268) Genomic DNA of HVT virus was co-electroporated with pHVTUS2SVgDwtsyn donor plasmid to generate recombinant HVT using homologous recombination technique. Recombinant virus was separated from parental HVT virus by immunofluorescent positive well selection and PCR screening in multiple rounds of plaque purification. A plaque purified recombinant HVT virus expressing the ILTV-gD protein was designated vHVT406.
(269) Recombinant vHVT406 viral plaques were visualized using both the TRITC and FITC filters for the dual staining. The FITC showed the ILTV-gDwt expression and the TRITC showed the HVT expression. Because of the small wells of the 96 well plates, each well was recorded with the plaques first counted with the TRITC filter and then recounted with the FITC filter. A combined 600+ plaques were counted between the pre-MSV and pre-MSV+13 passage. All the plaques were positive for both the FITC and TRITC for both passages.
(270) PCR Analysis of vHVT406
(271) PCR analysis of vHVT406 was performed using the PCR primers listed in Table 6.3 (see FIG. **30**). As shown in FIG. **31**, the sizes of PCR products after gel electrophoresis correspond well with the expected sizes and the banding patterns. There is no evidence of the parental HVT FC126 virus in vHVT406.
(272) TABLE-US-00009 TABLE 6.3 Expected PCR bands using specific primer sets primer HVT FC126 pHVTUS2SVgDwtsyn vHVT406 SORF3.FP + 0.334 2.218 2.218 US2.RP SORF3.FP + — 0.733 0.733 404P12 SV40promoterF + — 1.829 1.829 syntailR MB080 + 0.323 — 0.323 MB081 primer SB-1 pHVTUS2SVgDwtsyn vHVT406 SB1SORF4 + SB1US2R 0.989 — —
Conclusion
(273) Based on PCR testing and immunofluorescence analysis, vHVT406 is a recombinant HVT virus containing an SV40 promoter, ILTV-gDwt gene, and synthetic poly A tail in the SOrf3-US2 site. vHVT406 is free of any detectable parental HVT virus.
Example 1.11 In Vitro Stability Study of the HVT Vectors
(274) The HVT vectors constructed above were tested for genomic/expression stability after multiple in vitro passages in Chicken embryo fibroblast cells (CEF). The HVT vectors expressing two genes were stable after multiple passages. Contrary to the common knowledge that HVT with multiple inserts are less stable, the results demonstrated surprisingly that the HVT vectors of the present invention are stable and express two genes efficiently.
Example 2 Newcastle Disease (ND) Efficacy Induced at D28 by vHVT306, vHVT309, vHVT310 & vHVT311 in SPF Chicks
(275) The aim of the study was to assess the efficacy of four HVT recombinant constructs (vHVT306, vHVT309, vHVT310 & vHVT311) expressing the IBDV VP2 gene and NDV F gene administered to one-day-old SPF chickens against Newcastle disease challenges (Texas GB strain) performed on D28.
(276) The characteristics of these vaccine candidates are described in Table 7 below.
(277) TABLE-US-00010 TABLE 7 Characteristics of the vectors used in the challenge study Parental Promoter/ Name virus gene linker Poly-A Locus vHVT306* vHVT13** IBDV VP2 mCMV IE SV40 Poly A IG1 NDV F SV40 Synthetic PolyA SORF3-US2 vHVT309 vHVT13 IBDV VP2 mCMV IE SV40 poly A IG1 NDV F SV40 Synthetic PolyA IG1 vHVT310 vHVT13 IBDV VP2 mCMV IE N/A IG1 NDV F IRES SV40 poly A IG1 vHVT311 vHVT13 IBDV VP2 mCMV IE N/A IG1 NDV F P2A SV40 poly A IG1 vHVT306*: the vHVT vector expressing IBDV VP2 and NDV F (see U.S. Pat. No. 9,114,108), used as a control. vHVT13** is the active

ingredient of the licensed VAXXITEK HVT-IBD vaccine based on an HVT vector expressing the IBDV VP2 gene (described as vHVT17 in U.S. Pat. No. 5,980,906 and EP 0 719 864).
(278) Ninety five one-day-old specific pathogen free (SPF) chicks were assigned to 5 groups as shown in Table 8. All birds from groups 1 to 4 (20 birds/group) were vaccinated by the subcutaneous (SC) route with 0.2 mL of different HVT-IBD+ND constructs at the dose indicated (see Table 8). The 15 birds from group 5 were left unvaccinated. Twenty eight (D28) days post-vaccination, the birds in each group were challenged with NDV Texas GB strain by the intramuscular (IM) route (10.sup.4.0 egg infectious dose 50% (EID50) in 0.1 mL/bird). Birds were observed for clinical signs during 14 days after challenge. Birds that did not show any ND clinical signs (including central nervous, or respiratory signs and/or death) for up to 14 days post-challenge were considered as protected.
(279) Results of protection are shown in Table 8. All control birds of group 5 died after the challenge. Protection in the vaccinated groups reached at least 90%.
(280) TABLE-US-00011 TABLE 8 ND efficacy induced by different HVT-IBD + ND double constructs in SPF chicks Dose ND protection after Group Vaccine (PFU) D 28 challenge 1 vHVT306* 1580 95% (19/20) 2 vHVT309 1680 90% (18/20) 3 vHVT310 2840 95% (19/20) 4 vHVT311 2980 90% (18/20) 5 — — 0% (0/15) vHVT306*: used as a control
Example 3 IBD Efficacy Induced by vHVT309, vHVT310, vHVT311 and vHVT407 Against a Standard IBDV Challenge at D35
(281) The aim of the study was to assess the efficacy of three HVT recombinant constructs (vHVT309, vHVT310 & vHVT311) expressing the IBDV VP2 gene and NDV F gene and one construct (vHVT407) expressing the IBDV VP2 gene and ILTV gD gene administered to one-day-old SPF chickens against standard IBDV challenge performed on D35.
(282) One-day-old specific pathogen free (SPF) chicks were assigned to 4 groups as shown in Table 9. All birds from groups 1 to 4 (20 birds/group) were vaccinated by the subcutaneous (SC) route with 0.2 mL of different HVT-IBD+ND or HVT-IBD+ILT constructs at the dose indicated. The 20 birds from group 5 were left unvaccinated. Thirty five days after vaccination (at D35), all birds were challenged with the infectious bursal disease virus (IBDV) classical STC strain by the intraocular (TO) route (10.sup.2.0 EID50 in 0.03 mL/bird). Four days post-challenge (at D39) all birds were terminated and necropsied to examine for gross bursal lesions.
(283) Results of protection are shown in Table 9. All vaccinated birds (except two vHVT311-vaccinated birds) were protected against IBD, whereas none of the control birds were protected.
(284) TABLE-US-00012 TABLE 9 IBD efficacy induced by different HVT-IBD + ND or HVT-IBD + ILT double constructs in SPF chicks after challenge at D 35 with STC IBDV strain Dose IBD STC protection after Group Vaccine (PFU) D 35 challenge 1 vHVT309 2180 100% (20/20) 2 vHVT310 3980 100% (20/20) 3 vHVT311 3180 90% (18/20) 4 vHVT407 1220 100% (20/20) 5 — — 0% (0/20)
Example 4 IBD Efficacy Induced by vHVT309, vHVT310, vHVT311 and vHVT407 Against a Variant IBDV Challenge at D35
(285) The aim of the study was to assess the efficacy of three HVT recombinant constructs (vHVT309, vHVT310 & vHVT311) expressing the IBDV VP2 gene and NDV F gene and one construct (vHVT407) expressing the IBDV VP2 gene and ILTV gD gene administered to one-day-old SPF chickens against a variant (Delaware E) IBDV challenge performed on D35.
(286) One-day-old specific pathogen free (SPF) chicks were assigned to 6 groups as shown in Table 10. All birds from groups 1 to 4 (19-20 birds/group) were vaccinated by the subcutaneous (SC) route with 0.2 mL of different HVT-IBD+ND or HVT-IBD+ILTconstructs at the dose indicated. Birds from group 5 (19 birds) and group 6 (18 birds) were left unvaccinated. At D35, all birds from groups 1 to 5 were challenged with the infectious bursal disease virus (IBDV) variant Delaware E strain by the intraocular (TO) route (10.sup.3.0 EID50 in 0.03 mL/bird). Birds from group 6 were left unchallenged. At D46, body weight and bursal weight of all birds were measured.

The B/B wt. ratios (bursa weight/body weight ratio×100) were calculated for all groups.
(287) Results of protection are shown in Table 10. Vaccinated birds from groups 1 and 2 had a mean B/B wt. ratio similar as that of non-vaccinated non-challenged controls (group 6) and greater than those of non-vaccinated challenged controls (group 5). Birds of group 3 were not protected and birds of group 4 were partially protected. Surprisingly, vHVT310 which contains IRES provided better protection than vHVT311 which contains P2A.
(288) TABLE-US-00013 TABLE 10 IBD efficacy induced by different HVT-IBD + ND or HVT-IBD + ILT double constructs in SPF chicks after challenge at D 35 with variant E IBDV strain Dose Number IBDV challenge Mean B/B Group Vaccine (PFU) of birds at D 35 wt. ratio 1 vHVT309 2180 20 Yes 0.43 2 vHVT310 3980 20 Yes 0.50 3 vHVT311 3180 20 Yes 0.18 4 vHVT407 1220 19 Yes 0.32 5 — — 19 Yes 0.13 6 — — 18 No 0.45
Example 5 IBD Efficacy Induced by vHVT306, vHVT309 & vHVT310 Against a vvIBDV Challenge at D28 in Broilers
(289) The aim of the study was to assess the efficacy of three HVT recombinant constructs (vHVT306, vHVT309 & vHVT310) expressing the IBDV VP2 gene and NDV F gene administered to one-day-old broiler chickens against vvIBDV challenge performed on D28.
(290) Seventy one-day-old broiler chicks (Hubbard JA957 line) were assigned to 5 groups as shown in Table 11. All birds from groups 2 to 5 (about 15 birds/group) were vaccinated by the subcutaneous (SC) route with 0.2 mL of different HVT-IBD+ND constructs at the dose indicated. Ten birds from group 1 were left unvaccinated. Twenty eight days after vaccination (at D28), all birds were challenged with the very virulent IBDV (vvIBDV) 91-168 strain by the intraocular (TO) route (10.sup.4.3 EID50 in 0.05 mL/bird). Ten days post-challenge (at D38) all birds were terminated and necropsied to examine for gross bursal lesions. Bursal and body were weighted and histopathology was performed on the bursa. Histological lesions of the bursa were scored from 0 to 5 according to the following scale: 0—No lesion, normal bursa; 1—1% to 25% of the follicles show lymphoid depletion (i.e., less than 50% of depletion in 1 affected follicle), influx of heterophils in lesions; 2—26% to 50% of the follicles show nearly complete lymphoid depletion (i.e., with more than 75% of depletion in 1 affected follicle), the affected follicles show necrosis lesions and severe influx of heterophils may be detected; 3—51% to 75% of the follicles show lymphoid depletion; affected follicles show necrosis lesions and a severe influx of heterophils is detected; 4—76% to 100% of the follicles show nearly complete lymphoid depletion; hyperplasia and cyst structures are detected; affected follicles show necrosis lesions and severe influx of heterophils is detected; and 5—100% of the follicles show nearly complete lymphoid depletion; complete loss of follicular structure; thickened and folded epithelium; fibrosis of bursal tissue. Birds were considered as protected if they did not show clinical signs post-challenge and if their histology score was ≤2.
(291) There were some early mortalities in the first week in this batch of broilers likely due to colibacillosis. The dose of the tested vaccines was lower than expected (2000 PFU). Results of protection are shown in Table 11. Partial protection was induced by vaccination which shows vHVT310 being higher than vHVT306 and vHVT309.
(292) TABLE-US-00014 TABLE 11 IBD efficacy induced by different HVT-IBD + ND double constructs in broiler chicks after challenge at D 28 with vvIBDV strain Protection based on Dose Mean Bursal/body histopathology Group Vaccine (PFU) weight ratio (*1000) score 1 — — 0.75 0% 2 vHVT306 955 1.07 20% 3 vHVT309 741 0.89 20% 4 vHVT310 708 1.38 53% 5 vHVT13* 2000 1.99 80% vHVT13*: used as a control.
Example 6 ND Efficacy Induced by vHVT306, vHVT309 & vHVT310 Against a Velogenic NDV Challenge at D42 in Broilers
(293) The aim of the study was to assess the efficacy of three HVT recombinant constructs (vHVT306, vHVT309 & vHVT310) expressing the IBDV VP2 gene and NDV F gene administered to one-day-old broiler chickens against velogenic NDV challenge performed on D42.

(294) One-day-old broiler chicks (Hubbard JA957 line) were assigned to 4 groups as shown in Table 12. All birds from groups 2 to 4 (16-20 birds/group) were vaccinated by the subcutaneous (SC) route with 0.2 mL of different HVT-IBD+ND constructs at the dose indicated. Twelve birds from group 1 were left unvaccinated. Forty two days after vaccination (at D42), all birds were challenged with the velogenic NDV Herts 33 strain by the intramuscular (IM) route (10.sup.5.0 EID50 in 0.2 mL/bird). All birds were observed for clinical signs during 14 days post-challenge. Birds were considered as protected if they did not die or show ND clinical signs.
(295) There were some early mortalities in the first week in this batch of broilers likely due to colibacillosis. The dose of the tested vaccines was lower than expected (2000 PFU). Results of protection are shown in Table 12. Best protections were induced by vaccination with vHVT309 & vHVT310, followed by vHVT306.
(296) TABLE-US-00015 TABLE 12 ND efficacy induced by different HVT-IBD + ND double constructs in broiler chicks after challenge at D 42 with velogenic NDV strain Dose Protection against Protection against Group Vaccine (PFU) mortality mortality & morbidity 1 — — 8.3% 0% 2 vHVT306 955 68.8%.sup. 62.5%.sup. 3 vHVT309 741 85% 85% 4 vHVT310 708 85% 80%
Example 7 ND Efficacy Induced by vHVT306, vHVT309 & vHVT310 Against a Velogenic NDV Challenge at D42 in Broilers
(297) The aim of the study was to re-assess the efficacy of three HVT recombinant constructs (vHVT306, vHVT309 & vHVT310) expressing the IBDV VP2 gene and NDV F gene administered to one-day-old broiler chickens against velogenic NDV challenge performed on D42.
(298) One-day-old broiler chicks (Hubbard JA957 line) were assigned to 4 groups as shown in Table 13. All birds from groups 2 to 4 (16-20 birds/group) were vaccinated by the subcutaneous (SC) route with 0.2 mL of different HVT-IBD+ND constructs at 2000 PFU. Nineteen birds from group 1 were left unvaccinated. Forty two days after vaccination (at D42), all birds were challenged with the velogenic NDV Herts 33 strain by the intramuscular (IM) route (10.sup.5.0 EID50 in 0.2 mL/bird). All birds were observed for clinical signs during 14 days post-challenge. Birds were considered as protected if they did not die or show ND clinical signs.
(299) Results of protection are shown in Table 13. Overall, the levels of protection were higher than the previous study (see example 6), but they follow the same trend: best protections were induced by vaccination with vHVT309 & vHVT310, followed by vHVT306.
(300) The results showed that vHVT309 is more efficacious than vHVT306 against ND challenges in SPF as well as broilers (Tables 12 &13), suggesting that inserting heterologous polynucleotides in one locus have less negative impact on the overall fitness of the virus than inserting in multiple loci.
(301) TABLE-US-00016 TABLE 13 ND efficacy induced by different HVT-IBD + ND double constructs in broiler chicks after challenge at D 42 with velogenic NDV strain Dose Protection against Protection against Group Vaccine (PFU) mortality mortality & morbidity 1 — — 0% 0% 2 vHVT306 955 75% 75% 3 vHVT309 741 94% 89% 4 vHVT310 708 94% 94%
Example 8 IBD Efficacy Induced by vHVT306, vHVT309 & vHVT310 Against a Standard IBDV Challenge at D14 in SPF Chicks
(302) The aim of the study was to assess the efficacy of three HVT recombinant constructs (vHVT306, vHVT309 & vHVT310) expressing the IBDV VP2 gene and NDV F gene administered to one-day-old SPF chickens against standard IBDV challenge performed at D14.
(303) One-day-old specific pathogen free (SPF) chicks were assigned to 4 groups as shown in Table 14. All birds from groups 1 to 3 (21-22 birds/group) were vaccinated by the subcutaneous (SC) route with 0.2 mL of different HVT-IBD+ND constructs at the dose indicated. The 22 birds from group 4 were left unvaccinated. Fourteen days after vaccination (at D14), all birds were challenged with the infectious bursal disease virus (IBDV) classical STC strain by the intraocular (TO) route (10.sup.1.4 EID50 in 0.03 mL/bird). Four days post-challenge (at D18) all birds were

terminated and necropsied to examine for gross bursal lesions.

(304) Results of protection are shown in Table 14 Similar levels of IBD protection were induced by the 3 experimental vaccines, whereas all but one control birds was infected.

(305) TABLE-US-00017 TABLE 14 IBD efficacy induced by different HVT-IBD + ND double constructs in SPF chicks after challenge at D 14 with STC IBDV strain Dose IBD STC protection after D 14 Group Vaccine (PFU) challenge (infected/total) 1 vHVT306 2061 68.2% (7/22) 2 vHVT309 1476 76.2% (5/21) 3 vHVT310 1970 68.2% (7/22) 4 — — 4.5% (21/22)

Example 9 IBD Efficacy Induced by vHVT306, vHVT309 & vHVT310 in SPF Chicks after Variant IBD Challenge at D14

(306) The aim of the study was to assess the efficacy of three HVT recombinant constructs (vHVT306, vHVT309 & vHVT310) expressing the IBDV VP2 gene and NDV F gene administered to one-day-old SPF chickens against variant IBDV challenge performed at D14.

(307) One-day-old specific pathogen free (SPF) chicks were assigned to 5 groups as shown in Table 15. All birds from groups 1 to 3 (20 birds/group) were vaccinated by the subcutaneous (SC) route with 0.2 mL of different HVT-IBD+ND constructs at the dose indicated. Birds from group 4 and group 5 (19-20 birds/group) were left unvaccinated. At D14, all birds from groups 1 to 4 were challenged with the infectious bursal disease virus (IBDV) variant Delaware E strain by the intraocular (TO) route (10.sup.2.2 EID50 in 0.03 mL/bird). Birds from group 5 were left unchallenged. At D25, body weight and bursal weight of all birds were measured. The B/B wt. ratios (bursa weight/body weight ratio×100) were calculated for all groups.

(308) Results of protection are shown in Table 15. Partial protection was induced at D14 by the 3 vaccines, protection being higher for vHVT309 and vHVT310.

(309) Recombinant vHVT306 and vHVT309 have two independent expression cassettes (two mRNAs). The constructs expressing two genes through an IRES or P2A (for example, vHVT310, vHVT317, vHVT311, vHVT316, vHVT322) are not only in one insertion site, but also the genes are expressed from a single mRNA. Comparing all the data presented in Tables 11 to 19, it shows that one insertion site recombinants vHVT309 and vHVT310 are more efficacious than two insertion site recombinant vHVT306, indicating that HVT recombinants carrying more than one heterologous polynucleotides in one insertion locus are biologically more fit than HVT recombinants carrying heterologous polynucleotides in multiple insertion loci. Furthermore, surprisingly, expressing more than one heterologous polynucleotides from a single mRNA expressed through an IRES has less negative impact on IBD efficacy, particularly in broilers (see results on Table 11).

(310) TABLE-US-00018 TABLE 15 IBD efficacy induced by different HVT-IBD + ND double constructs in SPF chicks after challenge at D 14 with variant E IBDV strain Dose Number IBDV challenge Mean B/B Group Vaccine (PFU) of birds at D 14 wt. ratio 1 vHVT306 2061 20 Yes 0.18 2 vHVT309 1476 20 Yes 0.33 3 vHVT310 1970 20 Yes 0.27 4 — — 19 Yes 0.13 5 — — 20 No 0.64

Example 10 IBD Efficacy Induced by vHVT306, vHVT309 & vHVT310 Against a Standard IBDV Challenge at D28 in SPF Chicks

(311) The aim of the study was to assess the efficacy of three HVT recombinant constructs (vHVT306, vHVT309 & vHVT310) expressing the IBDV VP2 gene and NDV F gene administered to one-day-old SPF chickens against standard IBDV challenge performed at D28.

(312) One-day-old specific pathogen free (SPF) chicks were assigned to 4 groups as shown in Table 16. All birds from groups 1 to 3 (20-22 birds/group) were vaccinated by the subcutaneous (SC) route with 0.2 mL of different HVT-IBD+ND constructs at the dose indicated. The 22 birds from group 4 were left unvaccinated. Twenty eight days after vaccination (at D28), all birds were challenged with the infectious bursal disease virus (IBDV) classical STC strain by the intraocular (TO) route (10.sup.2.0 EID50 in 0.03 mL/bird). Four days post-challenge (at D32) all birds were terminated and necropsied to examine for gross bursal lesions.

(313) Results of protection are shown in Table 16. Full protection was induced by vHVT310 whereas only a few birds were not protected for the other vaccine candidates.

(314) TABLE-US-00019 TABLE 16 IBD efficacy induced by different HVT-IBD + ND double constructs in SPF chicks after challenge at D 28 with STC IBDV strain Dose IBD STC protection after D 28 Group Vaccine (PFU) challenge (infected/total 1 vHVT306 2061 86.4% (3/22) 2 vHVT309 1476 95.0% (1/20) 3 vHVT310 1970 100% (0/22) 4 — — 4.5% (21/22)

Example 11 IBD Efficacy Induced by vHVT306, vHVT309 & vHVT310 in SPF Chicks after Variant IBD Challenge at D28

(315) The aim of the study was to assess the efficacy of three HVT recombinant constructs (vHVT306, vHVT309 & vHVT310) expressing the IBDV VP2 gene and NDV F gene administered to one-day-old SPF chickens against variant IBDV challenge performed at D28.

(316) One-day-old specific pathogen free (SPF) chicks were assigned to 5 groups as shown in Table 17. All birds from groups 1 to 3 (20 birds/group) were vaccinated by the subcutaneous (SC) route with 0.2 mL of different HVT-IBD+ND constructs at the dose indicated. Birds from group 4 and group 5 (18-19 birds/group) were left unvaccinated. At D28, all birds from groups 1 to 4 were challenged with the infectious bursal disease virus (IBDV) variant Delaware E strain by the intraocular (TO) route (10.sup.2.2 EID50 in 0.03 mL/bird). Birds from group 5 were left unchallenged. At D39, body weight and bursal weight of all birds were measured. The B/B wt. ratios (bursa weight/body weight ratio×100) were calculated for all groups.

(317) Results of protection are shown in Table 17. The B/B wt ratio for group 5 (unchallenged group) could not be obtained since this group was unexpectedly infected with the STC IBDV strain. Protection induced by vHVT310 was higher than that induced by vHVT306 and vHVT309.

(318) TABLE-US-00020 TABLE 17 IBD efficacy induced by different HVT-IBD + ND double constructs in SPF chicks after challenge at D 28 with variant E IBDV strain Dose Number IBDV challenge Mean B/B Group Vaccine (PFU) of birds at D 28 wt. ratio 1 vHVT306 2061 20 Yes 0.21 2 vHVT309 1476 20 Yes 0.26 3 vHVT310 1970 20 Yes 0.37 4 — — 19 Yes 0.11 5 — — 20 No ND* *Not done due to standard IBDV exposure in this group

Example 12 Newcastle Disease (ND) Efficacy Induced at D21 and D28 by vHVT306, vHVT309 & vHVT310 in SPF Chicks

(319) The aim of the study was to assess the efficacy of three HVT recombinant constructs (vHVT309, vHVT310 & vHVT311) expressing the IBDV VP2 gene and NDV F gene administered to one-day-old SPF chickens against Newcastle disease challenges (Texas GB strain) performed on D21 and D28.

(320) One-day-old specific pathogen free (SPF) chicks were assigned to 4 groups as shown in Table 18. All birds from groups 1 to 3 (50 birds/group) were vaccinated by the subcutaneous (SC) route with 0.2 mL of different HVT-IBD+ND constructs at the dose indicated. The 30 birds from group 4 were left unvaccinated. Twenty one (D21) days post-vaccination, 20 birds from groups 1-3 and 15 birds from group 4 were challenged with NDV Texas GB strain by the intramuscular (IM) route (10.sup.4.2 egg infectious dose 50% (EID50) in 0.1 mL/bird). Twenty eight (D28) days post-vaccination, 30 birds from groups 1-3 and 15 birds from group 4 were challenged with NDV Texas GB strain by the intramuscular (IM) route (10.sup.4.3 egg infectious dose 50% (EID50) in 0.1 mL/bird). Birds were observed for clinical signs during 14 days after challenge. Birds that did not show any ND clinical signs (including central nervous, or respiratory signs and/or death) for up to 14 days post-challenge were considered as protected.

(321) Results of protection are shown in Table 18. All control birds of group 4 died after the challenge. Protection induced by vHVT310 was the best followed by vHVT306 and vHVT309.

(322) TABLE-US-00021 TABLE 18 ND efficacy at D 21 and D 28 induced by different HVT-IBD + ND double constructs in SPF chicks ND protection ND protection after D 21 after D 28 Dose challenge challenge Group Vaccine (PFU) (protected/total) (protected/total) 1 vHVT306* 2248 80% (16/20) 90% (27/30) 2 vHVT309 1765 60% (12/20) 86.2% (25/29) 3 vHVT310 2106 85%

(17/20) 100% (29/29) 4 — — 0% (0/15) 0% (0/15) vHVT306*: used as a control

Example 13 Marek's Disease (MD) Efficacy Induced by vHVT306, vHVT309 & vHVT310 in SPF Chicks

(323) The aim of the study was to assess the efficacy of three HVT recombinant constructs (vHVT309, vHVT310 & vHVT311) expressing the IBDV VP2 gene and NDV F gene administered to one-day-old SPF chickens against Marek's disease challenges (GA strain, 2 batches & 2 dilutions).

(324) One-day-old specific pathogen free (SPF) chicks were assigned to 4 groups as shown in Table 19. All birds from groups 1 to 3 (20 birds/group) were vaccinated by the subcutaneous (SC) route with 0.2 mL of different HVT-IBD+ND constructs at the dose indicated. The 20 birds from group 4 were left unvaccinated. Four days post-vaccination (D4), 18-20 birds from groups 1-4 were challenged with two dilutions (1:5 and 1:640) of two different batches (#1 and #2) of the vMDV GA22 strain by the SC route. Birds were observed for clinical signs attributable to Marek's disease during 46-50 days post-hatch. At D46-D50, all remaining birds were necropsied and checked for Marek's disease lesions. Birds that did not show any MD clinical signs or lesions were considered as protected.

(325) Results of protection are shown in Table 19. Infectivity in control birds of group 4 varied between 75-90%. Overall, protection induced by vHVT310 was the best followed closely by vHVT306 and then vHVT309.

(326) TABLE-US-00022 TABLE 19 MD efficacy induced by different HVT-IBD + ND double constructs in SPF chicks against 2 different lots of GA22 challenge either diluted 1:5 or 1:640 MD protect. MD protect. MD protect. MD protect. Dose GA22 lot #1 GA22 lot #1 GA22 lot #2 GA22 lot #2 Group Vaccine (PFU) 1:5 dil. 1:640 dil. 1:5 dil. 1:640 dil. 1 vHVT306* 2420 75% (15/20) 85% (17/20) 26.3% (5/19) 70% (14/20) 2 vHVT309 1893 50% (10/20) 72.2% (13/18) 55% (11/20) 70% (14/20) 3 vHVT310 2127 80% (16/20) 84.2% (16/19) 40% (8/20) 90% (18/20) 4 — — 25% (5/20) 10% (2/20) 10% (2/20) 20% (4/20) vHVT306*: used as a control

Example 14 IBD Efficacy Induced by vHVT306 and vHVT407 Against a Classical IBDV Challenge at D21 in SPF Chicks

(327) The aim of the study was to assess the efficacy of two HVT recombinant constructs, one (vHVT306) expressing the IBDV VP2 gene and NDV F gene and the other (vHVT407) expressing the IBDV VP2 gene and ILTV gD gene administered to one-day-old SPF chickens against a classical IBDV challenge performed on D21.

(328) Forty one-day-old SPF chicks (white Leghorn) were assigned to 3 groups as shown in Table 20. All birds from groups 2 & 3 (about 15 birds/group) were vaccinated by the subcutaneous (SC) route with 0.2 mL of vHVT306 or vHVT407 construct at the dose indicated. Ten birds from group 1 were left unvaccinated. Twenty one days after vaccination (at D21), all birds were challenged with the classical 52/70 Faragher IBDV strain by the intraocular (TO) route (10.sup.2.0 EID50 in 0.05 mL/bird). Eleven days post-challenge (at D32) all birds were terminated and necropsied to examine for gross bursal lesions. Bursal and body were weighted to calculate the bursal on body weight ratio. Birds were considered as protected if they did not show clinical signs or bursal lesion post-challenge.

(329) Results of protection are shown in Table 20. Complete IBD protection was induced by vaccination with vHVT306 or vHVT407.

(330) TABLE-US-00023 TABLE 20 IBD efficacy induced by two HVT constructs expressing two genes in SPF chicks after challenge at D 21 with Faragher IBDV strain Clinical Mean % with Dose signs Bursal/body gross (log10 #dead/ weight ratio bursal Group Vaccine PFU) #sick/total (*1000) lesion 1 — — 3/4/10 1.6 ± 0.7** 100% 2 vHVT306* 3.1 0/0/15 6.1 ± 1.1 0% 3 vHVT407 3.1 0/0/15 6.3 ± 1.1 0% vHVT306*: used as a control. **mean ± standard deviation

Example 15 ILT Efficacy Induced by vHVT407 Against an ILTV Challenge at D21 in SPF Chicks

(331) The aim of the study was to assess the efficacy of two vHVT407 recombinant construct

expressing the IBDV VP2 gene and the ILTV gD gene administered to one-day-old SPF chickens against an ILTV challenge performed on D21.

(332) Twenty four one-day-old SPF chicks (white Leghorn) were assigned to 2 groups as shown in Table 21. All birds (about 12 birds/group) were vaccinated by the subcutaneous (SC) route with 0.2 mL of vHVT13 (used as a negative control) or vHVT407 construct at the dose indicated. Twenty one days after vaccination (at D21), all birds were challenged with the ILT-96-3 ILTV strain by the intratracheal (IT) route (10.sup.3.6 EID50 in 0.5 mL/bird). The birds were observed for clinical signs for 11 days post-challenge. On Study Days 25-29 and 32 all the birds were observed for clinical signs including breathing pattern, conjunctivitis, depression and mortality. On Study Day 32, all the remaining birds were terminated. Birds were considered as protected if they did not show ILT clinical signs such as respiratory distress associated with coughing, sneezing, rales, depression, gasping and/or bloody mucous exudates, including mortality.

(333) Results of protection are shown in Table 21. Significant ILT protection was induced by vaccination with vHVT407 in these challenge conditions.

(334) TABLE-US-00024 TABLE 21 ILT efficacy induced by vHVT407 construct in SPF chicks after challenge at D 21 with ILT-96-3 ILTV strain Dose Clinical signs Clinical Group Vaccine (PFU) #dead/#sick/total Protection 1 vHVT13* 3420 6/2/11 27% 2 vHVT407 2880 2/0/12 83% vHVT13*: used as a negative control.

Example 16 ILT Efficacy Induced by vHVT407, a Commercial HVT-ILT and a Commercial Chicken Embryo Origin (CEO) Vaccine Against an ILTV Challenge at D21 in Broiler Chicks

(335) The aim of the study was to assess the efficacy of vHVT407 recombinant construct expressing the IBDV VP2 gene and the ILTV gD gene administered to one-day-old broiler chickens compared to a commercial HVT-ILT vaccine (INNOVAX® ILT) against an ILTV challenge performed on D21.

(336) Forty eight one-day-old commercial broiler chicks were assigned to 3 groups as shown in Table 22. All birds (about 12 birds/group) of groups 1-3 were vaccinated by the subcutaneous (SC) route with 0.2 mL of vHVT13 (used as a negative control), vHVT407 or INNOVAX® ILT (used as a positive control) constructs at the dose indicated. Twenty one days after vaccination (at D21), all birds were challenged with the ILT-96-3 ILTV strain by the intratracheal (IT) route (10.sup.4.2 EID50 in 0.5 mL/bird). The birds were observed for clinical signs for 12 days post-challenge. On Study Days 25-29 and 32-33 all the birds were observed and scored for clinical signs including breathing pattern, conjunctivitis, depression and mortality. On Study Day 34, all the remaining birds were terminated. Birds were considered as protected if they did not show ILT clinical signs such as respiratory distress associated with coughing, sneezing, rales, depression, gasping and/or bloody mucous exudates, including mortality.

(337) Results of protection are shown in Table 22. ILT protection was induced by vaccination with vHVT407, which was higher than that induced by INNOVAX ILT.

(338) TABLE-US-00025 TABLE 22 ILT efficacy induced by vHVT407 and INNOVAX ILT constructs in broiler chicks after challenge at D 21 with ILT-96-3 ILTV strain Clinical signs Clinical Group Vaccine Dose #dead/#sick/total Protection 1 vHVT13* 2200 PFU 5/7/12 0% 2 vHVT407 1860 PFU 1/4/11 55% 3 INNOVAX ILT** 2240 PFU 0/10/12 17% vHVT13*: used as a negative control. **INNOVAX ® ILT used as a positive control

Example 17 Newcastle Disease (ND) Efficacy Induced at D14, D21 and D32 by vHVT310 & vHVT316 in SPF Chicks

(339) The aim of the study was to compare the onset of ND immunity of two HVT recombinant constructs (vHVT310 & vHVT316) expressing the IBDV VP2 gene and NDV F gene administered to one-day-old SPF chickens against Newcastle disease challenges (Texas GB strain) performed on D14, D21 and D32.

(340) One-day-old specific pathogen free (SPF) chicks were assigned to 3 groups as shown in Table 23. All birds from groups 1 to 2 (59-70 birds/group; see table) were vaccinated by the

subcutaneous (SC) route with 0.2 mL of different HVT-IBD+ND constructs at the dose indicated. The 45 birds from group 3 were left unvaccinated. At D14, D21 and D32, 15-30 birds (see table) from groups 1-3 were challenged with NDV Texas GB strain by the intramuscular (IM) route (10.sup.4.0 EID50/bird) in 0.1 mL/bird). Birds were observed for clinical signs during 14 days after challenge. Birds that did not show any ND clinical signs (including central nervous, or respiratory signs and/or death) for up to 14 days post-challenge were considered as protected.

(341) Results of protection are shown in Table 23. All control birds of group 3 died after the challenge. Protection levels induced by both vHVT310 and vHVT316 were similar, with a possible earlier onset of immunity induced by vHVT316.

(342) TABLE-US-00026 TABLE 23 ND efficacy at D 14, D 21 and D 32 induced by different HVT-IBD + ND double constructs in SPF chicks ND protection ND protection ND protection after D 14 after D 21 after D 32 Dose challenge challenge challenge Group Vaccine (PFU) (protected/total) (protected/total) (protected/total) 1 vHVT310 2473 30% (6/20) 80% (16/20) 97% (29/30) 2 vHVT316 2367 45% (9/20) 80% (16/20) 100% (19/19) 3 — — 0% (0/15) 0% (0/15) 0% (0/15)

Example 18 ILTV Efficacy Induced by HVT Vectors Expressing ILTV gD and IBDV VP2 or Expressing ILTV gD and NDV F

(343) The aim of the study is to assess the efficacy of the HVT recombinant constructs expressing ILTV gD and IBDV VP2 (such as vHVT317 and vHVT407) or expressing ILTV gD and NDV F genes (such as vHVT308 and vHVT322) administered to chickens against ILTV challenges.

(344) Chickens are assigned to different groups. Birds are vaccinated by the subcutaneous (SC) route with 0.2 mL of different HVT constructs. The birds from one group are left unvaccinated. Birds are challenged with ILTV by the intratracheal (IT) or the infraorbital sinus route. Birds are observed for clinical signs during 11-14 days after challenge. Birds that do not show any ILTV clinical signs (including respiratory distress associated with coughing, sneezing, rales, depression, gasping and/or bloody mucous exudates and/or death) for up to 14 days post-challenge are considered as protected.

(345) The results show that the HVT vectors provide protection against ILTV infection.

Example 19 IBD Efficacy Induced by HVT Vectors Expressing ILTV gD and IBDV VP2

(346) The aim of the study is to assess the efficacy of the HVT recombinant constructs expressing ILTV gD and IBDV VP2 (such as vHVT317 and vHVT407) administered to chickens against IBD challenges.

(347) Chickens are assigned to different groups. Birds are vaccinated by the subcutaneous (SC) route with 0.2 mL of different HVT constructs. The birds from one group are left unvaccinated. Birds are challenged with IBD by the intraocular (TO) route. Birds are observed for clinical signs during 4 to 10 days after challenge. Birds that do not show any IBD clinical signs (including depression and/or death) and that do not show bursal lesions and/or atrophy for up to 10 days post-challenge are considered as protected.

(348) The results show that the HVT vectors provide protection against IBD infection.

Example 20 NDV Efficacy Induced by HVT Vectors Expressing ILTV gD and NDV F

(349) The aim of the study is to assess the efficacy of the HVT recombinant constructs expressing ILTV gD and NDV F genes (such as vHVT308 and vHVT322) administered to chickens against NDV challenges.

(350) Chickens are assigned to different groups. Birds are vaccinated by the subcutaneous (SC) route with 0.2 mL of different HVT constructs. The birds from one group are left unvaccinated. Birds are challenged with NDV by the intramuscular (IM) route. Birds are observed for clinical signs during 14 days after challenge. Birds that do not show any ND clinical signs (including central nervous, or respiratory signs and/or death) for up to 14 days post-challenge are considered as protected.

(351) The results show that the HVT vectors provide protection against NDV infection.

Example 21 IBD Efficacy Induced by vHVT316 & vHVT317 Against a Standard IBDV Challenge at D28 in SPF Chicks

(352) The aim of the study was to assess the efficacy of two HVT recombinant constructs (vHVT316 & vHVT317) expressing either the IBDV VP2 gene and NDV F gene (vHVT316) or the IBDV VP2 gene and ILTV gD gene (vHVT317) administered to one-day-old SPF chickens against standard IBDV challenge performed at D28.

(353) One-day-old specific pathogen free (SPF) chicks were assigned to 3 groups as shown in Table 24. All birds from groups 1 & 2 (15 birds/group) were vaccinated by the subcutaneous (SC) route with 0.2 mL of vHVT316 & vHVT317 at the dose indicated. The 15 birds from group 3 were left unvaccinated. Twenty eight days after vaccination (at D28), all birds were challenged with the infectious bursal disease virus (IBDV) classical STC strain by the intraocular (TO) route (10.sup.2.0 EID50 in 0.03 mL/bird). Four days post-challenge (at D32), all birds were terminated and necropsied to examine for gross bursal lesions.

(354) Results of protection are shown in Table 24. 100% and 80% protection were induced by vHVT316 and vHVT317, respectively; however, the dose administered of vHVT317 was nearly 3 times lower than that of vHVT316.

(355) TABLE-US-00027 TABLE 24 IBD efficacy induced by HVT-IBD + ND (vHVT316) and HVT-IBD + ILT (vHVT317) double constructs in SPF chicks after challenge at D 28 with STC IBDV strain Dose IBD STC protection after D 28 Group Vaccine (PFU) challenge (infected/total) 1 vHVT316 2910 100% (0/15) 2 vHVT317 1030 80.0% (3/15) 3 — — 6.7% (14/15)

Example 22 IBD Efficacy Induced by vHVT310, vHVT316 & vHVT317 in SPF Chicks after Variant IBD Challenge at D28

(356) The aim of the study was to assess the efficacy of three HVT recombinant constructs (vHVT310, vHVT316 & vHVT317) expressing either the IBDV VP2 gene and NDV F gene (vHVT310 & vHVT316) or the IBDV VP2 gene and ILTV gD gene (vHVT317) administered to one-day-old SPF chickens against variant IBDV challenge performed at D28.

(357) One-day-old specific pathogen free (SPF) chicks were assigned to 5 groups as shown in Table 25. All birds from groups 1 to 3 (15 birds/group) were vaccinated by the subcutaneous (SC) route with 0.2 mL of vHVT310, vHVT316 & vHVT317 at the dose indicated. Birds from group 4 and group 5 (15 birds/group) were left unvaccinated. At D28, all birds from groups 1 to 4 were challenged with the infectious bursal disease virus (IBDV) variant Delaware E strain by the intraocular (TO) route (10.sup.3.0 EID50 in 0.03 mL/bird). Birds from group 5 were left unchallenged. At D39, body weight and bursal weight of all birds were measured. The B/B wt. ratios (bursa weight/body weight ratio×100) were calculated for all groups.

(358) Results of protection are shown in Table 25. Protection was observed in all vaccinated groups. Protection with vHVT317 was slightly higher than that induced by vHVT310 and vHVT316 despite its lower dose.

(359) TABLE-US-00028 TABLE 25 IBD efficacy induced by different HVT constructs with double inserts in SPF chicks after challenge at D 28 with variant E IBDV strain Dose Number IBDV challenge Mean B/B Group Vaccine (PFU) of birds at D 28 wt. ratio 1 vHVT310 2260 15 Yes 0.34 2 vHVT316 2910 15 Yes 0.33 3 vHVT317 1030 15 Yes 0.40 4 — — 15 Yes 0.12 5 — — 15 No 0.43

Example 23 ILT Efficacy Induced by vHVT317 Against a ILTV Challenge at D28 in SPF Chicks

(360) The aim of the study was to assess the efficacy of the vHVT317 recombinant construct expressing the IBDV VP2 gene and the ILTV gD gene administered to one-day-old SPF chickens against an ILTV challenge performed on D28.

(361) Thirty six one-day-old SPF chicks (white Leghorn) were assigned to 2 groups as shown in Table 26. All birds (about 18 birds/group) were either vaccinated by the subcutaneous (SC) route with 0.2 mL of vHVT317 or left unvaccinated. Twenty eight days after vaccination (at D28), all birds were challenged with the ILT-96-3 ILTV strain by the intratracheal (IT) route (10.sup.3.0

EID50 in 0.2 mL/bird). The birds were observed for clinical signs and mortality at D32, D36 & D39. Clinical signs included breathing pattern, conjunctivitis, depression and mortality. On Study Day 32, all the remaining birds were terminated. Evaluation of protection was used using 3 different criteria: (1) Any bird exhibiting any clinical signs for three consecutive days or that died after challenge is considered as ILT positive; (2) Any bird exhibiting any moderate or severe clinical signs in any category for any day or that died after challenge is considered as ILT positive; and (3) Any bird exhibiting any moderate or severe clinical signs in any category for two consecutive days or that died after challenge is considered as ILT positive.
(362) Results of protection based on the 3 different criteria are shown in Table 26. The ILT challenge was severe since it killed (or birds were euthanized when they show very severe clinical signs for ethical reason) 86.7% of non-vaccinated birds. High levels of ILT protection were induced by vaccination with vHVT317 in these challenge conditions.
(363) TABLE-US-00029 TABLE 26 ILT efficacy induced by vHVT317 construct in SPF chicks after challenge at D 28 with ILT-96-3 ILTV strain % Protection Dose Number % based on Group Vaccine (PFU) of birds Mortality criteria 1/2/3 1 vHVT317 1030 15 0% 100%/86.7%/100% 2 — — 15 86.7% 6.7%/6.7%/6.7%
Example 24 ILT Efficacy Induced by vHVT317, a Commercial HVT-ILT and a Commercial Chicken Embryo Origin (CEO) Vaccine Against an ILTV Challenge at D21 in Broiler Chicks
(364) The aim of the study was to assess the efficacy of vHVT317 recombinant construct expressing the IBDV VP2 gene and the ILTV gD gene administered to one-day-old broiler chickens compared to a commercial HVT-ILT vaccine (INNOVAX® ILT, Merck Animal Health) against an ILTV challenge performed on D28.
(365) Fifty one one-day-old commercial broiler chicks were assigned to 3 groups as shown in Table 27. All birds (17 birds/group) were either vaccinated by the subcutaneous (SC) route with 0.2 mL of vHVT317 or INNOVAX® ILT (used as a positive control) at the dose indicated or left unvaccinated. At D26, the number of birds per group was reduced to 15 and each bird was weighed. Twenty eight days after vaccination (at D28), all birds were challenged with the 63140 ILTV strain by the infraorbital route (10.sup.4.3 EID50 in 0.2 mL/bird). On Study Days 31 to 35, and Study Day 38, all birds were individually observed for clinical signs. On Study Day 38, all the remaining birds were individually weighed and terminated. Evaluation of protection was performed using 3 different criteria: (1) Any bird exhibiting any clinical signs for three consecutive days or that died after challenge is considered as ILT positive; (2) Any bird exhibiting any moderate or severe clinical signs in any category for any day or that died after challenge is considered as ILT positive; and (3) Any bird exhibiting any moderate or severe clinical signs in any category for two consecutive days or that died after challenge is considered as ILT positive. The body weight was also compared at D26 and D38.
(366) Results of protection using the 3 criteria are shown in Table 27. All controls were considered non-protected for the 3 criteria. Both tested vaccines induced high and similar ILT protection. There were no significant difference between body weight at D26 (before challenge); however, after challenge, body weights of vaccinated birds were significantly (p<0.0001) higher than those of non-vaccinated birds indicating protection against weight loss.
(367) TABLE-US-00030 TABLE 27 ILT efficacy induced by vHVT317 and INNOVAX ILT (positive control) constructs in broiler chicks after challenge at D 28 with 63140 ILTV strain % Protection Dose Number based on criteria Body weight Body weight Group Vaccine (PFU) of birds 1/2/3 at D 26* at D 38* 1 vHVT317 3820 15 86.7%/86.7%/86.7% 1544 ± 61 2931 ± 63 1 INNOVAX 3700 15 100%/93.3%/93.3% 1491 ± 61 2839 ± 61 2 — — 15 0%/0%/0% 1461 ± 61 2433 ± 63 *mean ± standard deviation in g
Example 25 IBD Efficacy Induced by the in Ovo Administration of vHVT317 after Variant IBD Challenge at 28 Day-of-Age in SPF Chicks
(368) The aim of the study was to assess the efficacy of vHVT317 expressing the IBDV VP2 gene

and ILTV gD gene administered in ovo to 18-19 day-old embryos from SPF chickens against variant IBDV challenge performed at 28 day-of-age (31 days post-vaccination).
(369) 18-19 day-old embryos from specific pathogen free (SPF) chickens were assigned to 3 groups as shown in Table 28. All birds from groups 1 & 2 (about 30 eggs/group) were vaccinated by the in ovo (SC) route with 0.05 mL of vHVT317 at the dose indicated. Embryonated eggs from group 3 were sham-inoculated with 0.05 mL of Marek's vaccine diluent. At hatch, 22 chicks per group were kept and, before challenge, all 3 groups were reduced to 20 birds. Thirty one days after vaccination (at 28 day-of-age), birds from all 3 groups were challenged with the infectious bursal disease virus (IBDV) variant Delaware E strain by the intraocular (TO) route (target dose of 10.sup.3.0 EID50 in 0.03 mL/bird). Birds from group 5 were sham challenged with TPB (tryptose phosphate broth, 0.03 mL/bird). Eleven days post-challenge, body weight and bursal weight of all birds were measured. The B/B wt. ratios (bursa weight/body weight ratio×100) were calculated for all groups.
(370) Results of protection are shown in Table 28. A clear bursal atrophy was observed in all non-vaccinated challenged birds. Protection was observed in vHVT317-vaccinated groups at the 2 tested doses.
(371) TABLE-US-00031 TABLE 28 IBD efficacy induced by vHVT317 administered in ovo after challenge at 28 day-of-age with variant E IBDV strain in SPF chicks Dose Number IBDV Mean B/B Group Vaccine (PFU) of birds challenge wt. ratio 1 vHVT317 2250 20 Yes 0.41 2 vHVT317 3225 20 Yes 0.60 3 — — 20 Yes 0.13 4 — — 20 No 0.69
Example 26 ILT Efficacy Induced by vHVT317 Administered by the in Ovo Route Against a ILTV Challenge at D28 in SPF Chicks
(372) The aim of the study was to assess the efficacy of the vHVT317 recombinant construct expressing the IBDV VP2 gene and the ILTV gD gene administered by the in ovo route to 18-19 day-old embryos against an ILTV challenge performed on D28 (at 25 day-of-age) in SPF chickens.
(373) 18-19 day-old embryos from specific pathogen free (SPF) chickens were assigned to 2 groups as shown in Table 29. All birds from groups 1 (about 30 eggs/group) were vaccinated by the in ovo (SC) route with 0.05 mL of vHVT317 at the dose indicated. Embryonated eggs from group 2 were sham-inoculated with 0.05 mL of Marek's vaccine diluent. At hatch, 22 chicks per group were kept and, one day before challenge, both groups were reduced to 20 birds. Twenty five days after vaccination (at D28), birds from both groups were challenged with the 63140 ILTV strain administered in the infraorbital sinus (10.sup.47 EID50 in 0.2 mL/bird). The birds were observed for clinical signs and mortality on D28 to D38. On Study Day 38, all the remaining birds were terminated. Efficacy against ILT challenge was determined by the absence of typical ILT clinical signs such as: depression, respiratory distress associated with coughing, sneezing, rales, gasping with extended neck, with or without bloody and/or mucous discharge; dyspnea and mouth breathing; infra-orbital sinuses swelling, with or without drainage; and/or swollen conjunctiva with partial or complete closure of the eyes. Any mortality post-challenge, except due to trauma, or any clear condition that excludes the bird from the study, were considered positive for ILT.
(374) Results of ILT protection are shown in Table 29. The results showed that most vHVT317 vaccinated birds were protected.
(375) TABLE-US-00032 TABLE 29 ILT efficacy induced by vHVT317 administered by the in ovo route after infraorbital sinus challenge at D 28 with 63140 ILTV strain in SPF chicks Dose Number % Protection (number Group Vaccine (PFU) of birds protected/total) 1 vHVT317 2300 20 85% (17/20) 2 — — 20 5% (1/20)
Example 29 ND Efficacy Induced by vHVT309 & vHVT310 Against a Velogenic NDV Challenge at D21 in SPF Chickens
(376) The aim of the study was to assess the efficacy of two HVT recombinant constructs (vHVT309 & vHVT310) expressing the IBDV VP2 gene and NDV F gene administered to one-day-old SPF chickens against velogenic NDV challenge performed on D21.

(377) One-day-old SPF chicks (white leghorn) were assigned to 3 groups of birds as shown in Table 30. All birds from groups 2 and 3 were vaccinated by the subcutaneous (SC) route with 0.2 mL of vHVT309 (14 birds; group 2) or vHVT310 (15 birds; group 3) at a target dose of 2000 PFU. Birds from group 1 (5 birds) were left unvaccinated. Two birds of group 2 died on D5 for unknown reason. Twenty one days after vaccination (at D21), the blood of 10 birds from group 3 was collected for serology; then, all birds from all 3 groups were challenged with the velogenic NDV Herts 33 strain by the intramuscular (IM) route (10.sup.5.0 EID50 in 0.2 mL/bird). All birds were observed for clinical signs during 14 days post-challenge. Birds were considered as protected if they did not die or show ND clinical signs.
(378) Results of protection are summarized in Table 30. All non-vaccinated birds of group 1 died after challenge; all vaccinated birds were protected. The vHVT310 construct induced significant anti-NDV (mean of 3.7±0.3 (standard deviation) log 10 by ELISA (ID Screen Newcastle Disease Indirect kit from ID-VET) and mean of 3.9±0.7 log 2 by HI test) and anti-IBDV (mean of 3.7 log 10±0.2 log 10 by ELISA (ProFLOK IBD Plus ELISA kit from Zoetis) antibodies in all the 10 G3-bird serums sampled on D21.
(379) TABLE-US-00033 TABLE 30 ND efficacy induced by different HVT-IBD + ND double constructs in broiler chicks after challenge at D 21 with velogenic NDV strain Number of Dose Number Dead & sick Group Vaccine (PFU) of birds birds Protection 1 — — 5 5 & 0   0% 2 vHVT309 2000 12 0 & 0 100% 3 vHVT310 2000 15 0 & 0 100%
Example 28 IBD Efficacy Induced by vHVT309 and vHVT310 Against a Classical IBDV Challenge at D21 in SPF Chicks
(380) The aim of the study was to assess the efficacy of two HVT recombinant constructs (vHVT309 & vHVT310) expressing the IBDV VP2 gene and NDV F gene administered to one-day-old SPF chickens against a classical IBDV challenge performed on D21.
(381) One-day-old SPF chicks (white Leghorn) were assigned to 3 groups as shown in Table 31. All birds from groups 2 & 3 (about 15 birds/group) were vaccinated by the subcutaneous (SC) route with 0.2 mL of vHVT309 (group 2) or vHVT310 (group 3) construct at a target dose of 2000 PFU. Ten birds from group 1 were left unvaccinated. Two unspecific early deaths were recorded in group 2. Twenty one days after vaccination (at D21), all birds were challenged with the classical 52/70 Faragher IBDV strain by the intraocular (TO) route (10.sup.2.0 EID50 in 0.05 mL/bird). Eleven days post-challenge (at D32) all birds were terminated and necropsied to examine for gross bursal lesions. Bursal and body were weighted to calculate the bursal on body weight ratio. The bursa was then stored in formaldehyde for histology. Histological lesions of the bursa were scored according to the scale presented in Table 32. The severity of the challenge was validated if (1) at least 50% of the challenge controls died or showed characteristic signs of the disease, especially apathy/ruffled feathers during more than 2 days or prostration, and (2) 100% of the surviving challenge controls showed histology scores of the Bursa of Fabricius ≥3. The efficacy of the vaccine candidates was demonstrated if at least 90% of the chickens were protected. The chickens were considered protected if (1) they survived and did not show notable clinical signs of the disease, especially no apathy/ruffled feathers during more than 2 days or absence of prostration, and (2) they showed a histology score of the Bursa of Fabricius <3.
(382) Results of protection are shown in Table 31. All controls were positive for IBD infection. Complete IBD protection was induced by vaccination with vHVT309 or vHVT310.
(383) TABLE-US-00034 TABLE 31 IBD efficacy induced by two HVT constructs expressing two genes in SPF chicks after challenge at D 21 with Faragher IBDV strain Clinical Mean Dose signs Bursal/body (log10 #dead/ weight ratio Group Vaccine PFU) #sick/total (*1000) Protection 1 — — 4/1/10   1.7 ± 0.6**   0% 2 vHVT309 3.3 0/0/14 5.4 ± 1.2 100% 3 vHVT310 3.3 0/0/15 5.5 ± 0.7 100% **mean ± standard deviation
(384) TABLE-US-00035 TABLE 32 Scoring scale of histological lesions of the bursa of Fabricius* Score Histology observation/lesions 0 No lesion, normal bursa 1 1% to 25% of the follicles show

lymphoid depletion (i.e. less than 50% of depletion in 1 affected follicle), influx of heterophils in lesions 2 26% to 50% of the follicles show nearly complete lymphoid depletion (i.e. more than 75% of depletion in 1 affected follicle), affected follicles show necrosis and severe influx of heterophils may be detected 3 51% to 75% of the follicles show lymphoid depletion; affected follicles show necrosis lesions and a severe influx of heterophils is detected 4 76% to 100% of the follicles show nearly complete lymphoid depletion; hyperplasia and cyst structures are detected; affected follicles show necrosis and severe influx of heterophils is detected 5 100% of the follicles show nearly complete lymphoid depletion; complete loss of follicular structure, thickened and folded epithelium, fibrosis of bursal tissue *sourced from Monograph No. 04/2013: 0587 of European Pharmacopoeia “Avian Infectious Bursal Disease vaccine (live)

Example 29 Impact of in Ovo Administration of vHVT317 on Hatchability of SPF Chicks

(385) The aim of the study was to assess the safety of vHVT317 on hatchability when administered by the in ovo route.

(386) The results are a compilation of data from several studies including those described in examples 23, 24, 25, and 26. Embryonated eggs at 18-19 days of incubation were inoculated either with vHVT317 at a target dose of 2000 or 3000 PFU or with Marek's disease vaccine diluent. The percentage of hatchability was evaluated for each group. Results are summarized in Table 33 and showed excellent levels of hatchability in vaccinated eggs.

(387) TABLE-US-00036 TABLE 33 Hatchability after in ovo administration of vHVT317 Target Number of Number of Dose vaccinated eggs % Group Vaccine (PFU) eggs hatched hatchability 1 Diluent — 150 149 99.3% 2 vHVT317 2000 139 135 97.1% 3 vHVT317 3000 80 78 97.5%

Example 30 ILT Efficacy Induced by vHVT406 Against ILTV Challenges

Example 30.1 ILT Efficacy Induced by vHVT406 Against an ILTV Challenge at D28

(388) The aim of the study is to assess and compare the efficacy of vHVT406 recombinant construct expressing the ILTV gD gene and a commercial HVT-ILT vectored vaccine against ILT challenge.

(389) Twelve (12) one-day-old SPF birds were assigned to each group. The birds in Groups 1-2 were vaccinated SQ with 0.2 ml per bird. After vaccination, all birds were placed into their respective units. On Day 28, all birds were challenged via the intratracheal (IT) route with Infectious Laryngotracheitis Virus (ILT), ILT-93-3 EP2. All birds were observed for 11 days post-challenge for clinical signs due to the challenge. On Day 32, tracheal and conjunctival swabs were collected from all remaining birds. Swabs were processed for q-PCR analysis. On Day 39, all remaining birds were terminated.

(390) Results are shown in Table 34 below. The results showed that all vHVT406 vaccinated birds were protected. Surprisingly, the results also showed that good protection (100% protection) was achieved in vHVT406 group when lower dose (6,960 pfu/0.2 ml) was used when compared to the higher dose (10,340 pfu/0.2 ml) used for the commercial product Innovax HVT-ILT.

(391) TABLE-US-00037 TABLE 34 Number of Birds Positive for ILT and Percent Positive by Group.sup.1 # Positive/ # Total # % Protection % Found % Total Group Vaccine Dose/SQ.sup.2 Birds Birds (% Infection) Dead Mortality 1 vHVT406   6,960 pfu/ 11.sup.3 0/11 100 0 0 0.2 ml HVT 2 Innovax 10,340 pfu/ 12   0/12 100 0 0 HVT-ILT.sup.4 0.2 ml HVT .sup.1Birds were considered positive if they showed clinical signs for three consecutive days, including mortality or mortality after swabbing. .sup.2Plaque forming units (pfu)-Subcutaneous administration (SQ); 0.20 ml per dose. .sup.3One bird in vHVT406 group was excluded from the study due to paralysis. .sup.4Commercial product of MSD Animal Health

Example 30.2 ILT Efficacy Induced by vHVT406 Against an ILTV Challenge at D21

(392) The goal of the study is to assess and compare the efficacy of the vHVT406 and two commercial HVT-ILT vectored vaccines against ILT challenge.

(393) Twelve (12) one-day-old SPF birds were assigned to each group. The randomization also assigned the isolation units where the birds were placed (12 birds per unit, one unit per group).

Birds in Groups 1-3 were vaccinated SQ with 0.2 ml per bird. On Day 21, all birds in Groups 1-2 were challenged via the intratracheal (IT) route with Infectious Laryngotracheitis Virus (ILT), ILT-96-3 EP2. The birds were observed for 11 days post-challenge for clinical signs due to the challenge. On Day 25, tracheal and conjunctival swabs were collected on all remaining birds. Swab samples were processed for q-PCR. On Day 32, all remaining birds were terminated.

(394) Results are shown in Table 35 below. The results showed that all but one vHVT406 vaccinated birds were protected. Surprisingly, the results also showed that good protection (91.7% protection) was achieved in vHVT406 group when lower dose (810 pfu/0.2 ml) was used when compared to the higher dose (1590 pfu/0.2 ml) used for the commercial product Innovax HVT-ILT to achieve the same protection level (91.7%). Further, vHVT406 provided better protection (91.7%) when used at a lower dose than the commercial product Vectormune HVT-ILT which only provided 75% protection.

(395) TABLE-US-00038 TABLE 35 Number of Birds Positive for ILT and Percent Positive by Group.sup.1 # Positive/ # Total # % Protection % Found % Total Group Vaccine Dose/SQ.sup.2 Birds Birds (% Infection) Dead Mortality 1 vHVT406 810 pfu/ 12 1/12 91.7 0 0 0.2 ml 2 Innovax 1590 pfu/ 12 1/12 91.7 0 0 HVT-ILT 0.2 ml 3 Vectormune 39,000 pfu/ 12 3/12 75 25 25 HVT-ILT.sup.3 0.2 ml .sup.1Birds were considered positive if they showed clinical signs for three consecutive days, including mortality or mortality after swabbing. .sup.2Plaque forming units (pfu)-Subcutaneous administration (SQ); 0.20 ml per dose. .sup.3Commercial product of Ceva

(396) Having thus described in detail preferred embodiments of the present invention, it is to be understood that the invention defined by the above examples is not to be limited to particular details set forth in the above description as many apparent variations thereof are possible without departing from the spirit or scope of the present invention.

(397) All documents cited or referenced herein (“herein cited documents”), and all documents cited or referenced in herein cited documents, together with any manufacturer's instructions, descriptions, product specifications, and product sheets for any products mentioned herein or in any document incorporated by reference herein, are hereby incorporated herein by reference, and may be employed in the practice of the invention.

Claims

1. A vaccine comprising a recombinant herpesvirus of turkeys (HVT) vector, wherein the HVT vector comprises a first heterologous polynucleotide coding for and expressing an Infectious Bursal Disease Virus (IBDV) viral protein 2 (VP2) antigen and a second heterologous polynucleotide coding for and expressing a Newcastle Disease Virus Fusion Protein (NDV-F) antigen, wherein the IBDV VP2 antigen has at least 85% sequence identity to a polypeptide having the sequence as set forth in SEQ ID NO:2, and wherein the NDV-F antigen has at least 85% sequence identity to a polypeptide having the sequence as set forth in SEQ ID NO:5; wherein the two heterologous polynucleotides are inserted into one locus in a non-essential region of the HVT genome selected from the group consisting of intergenic region 1 locus, intergenic region 2 locus, intergenic region 3 locus, UL43 locus, US10 locus, US2 locus, and SORF3/US2 locus; wherein the two heterologous polynucleotides are linked by internal ribosome entry site (IRES); and wherein the expression of the two heterologous polynucleotides is driven by a mouse cytomegalovirus (mCMV) immediate early (IE) promoter or human cytomegalovirus (hCMV) IE promoter.
2. The vaccine of claim 1, wherein the first heterologous polynucleotide is operably linked to mCMV IE promoter at the 5′ end, and the IRES at the 3′ end.
3. The vaccine of claim 1, wherein the non-essential region is the IG1 locus of the HVT genome.
4. The vaccine of claim 1, wherein the IBDV VP2 antigen has at least 90%, 95%, 96%, 97%, 98% or 99% sequence identity to a polypeptide having the sequence as set forth in SEQ ID NO:2.
5. The vaccine of claim 1, wherein the IBDV VP2 antigen has the polypeptide sequence as set forth

in SEQ ID NO: 2.

6. The vaccine of claim 1, wherein the first heterologous polynucleotide encoding the IBDV VP2 antigen has at least 70%, 75%, 80%, 85%, 90%, 95%, 96%, 97%, 98% or 99% sequence identity to a polynucleotide having the sequence as set forth in SEQ ID NO:1.

7. The vaccine of claim 1, wherein the first heterologous polynucleotide encoding the IBDV VP2 antigen has the sequence as set forth in SEQ ID NO: 1.

8. The vaccines of claim 1, wherein the NDV-F antigen has at least 90%, 95%, 96%, 97%, 98% or 99% sequence identity to a polypeptide having the sequence as set forth in SEQ ID NO:5.

9. The vaccines of claim 1, wherein the NDV-F antigen has the polypeptide sequence as set forth in SEQ ID NO: 5.

10. The vaccine of claim 1, wherein the second heterologous polynucleotide encoding the NDV-F antigen has at least 70%, 75%, 80%, 85%, 90%, 95%, 96%, 97%, 98% or 99% sequence identity to a polynucleotide having the sequence as set forth in SEQ ID NO:3.

11. The vaccine of claim 1, wherein the second heterologous polynucleotide encoding the NDV-F antigen has the sequence as set forth in SEQ ID NO: 3.

12. The vaccines of claim 1, wherein the expression of the NDV-F antigen is regulated by the Simian virus 40 (SV40) poly A signal having the sequence as set forth in SEQ ID NO: 8.

13. The vaccine of claim 1, wherein the IRES has the sequence as set forth in SEQ ID NO: 10.

14. The vaccine of claim 1, wherein the first heterologous polynucleotide has the sequence as set forth in SEQ ID NO: 1, and wherein the second heterologous polynucleotide has the sequence as set forth in SEQ ID NO: 3; wherein the non-essential region is the IG1 locus of the HVT genome; wherein the first heterologous polynucleotide is operably linked to a mCMV IE promoter at the 5′ end, and the IRES at the 3′ end, and wherein the IRES has the sequence as set forth in SEQ ID NO: 10; and wherein the expression of the NDV-F antigen is regulated by the SV40 poly A signal having the sequence as set forth in SEQ ID NO: 8.

15. The vaccine of claim 1, further comprising a pharmaceutically or veterinarily acceptable carrier, excipient, vehicle or adjuvant.

16. A method of inducing an immunological response in an animal against one or more antigens or a protective response in an animal against one or more avian pathogens, comprising inoculating the animal at least once with the vaccine of claim 15.

17. The method of claim 16, wherein the animal is an avian.

18. The method of claim 16, wherein the avian pathogen is selected from the group consisting of Newcastle Disease Virus (NDV) and Infectious Bursal Disease Virus (IBDV).

19. The method of claim 16, wherein the vaccine is administered to one-day old chicks subcutaneously or intramuscularly.

20. The method of claim 16, wherein the vaccine is administered to an avian in ovo in 17-19 day-old embryos.