



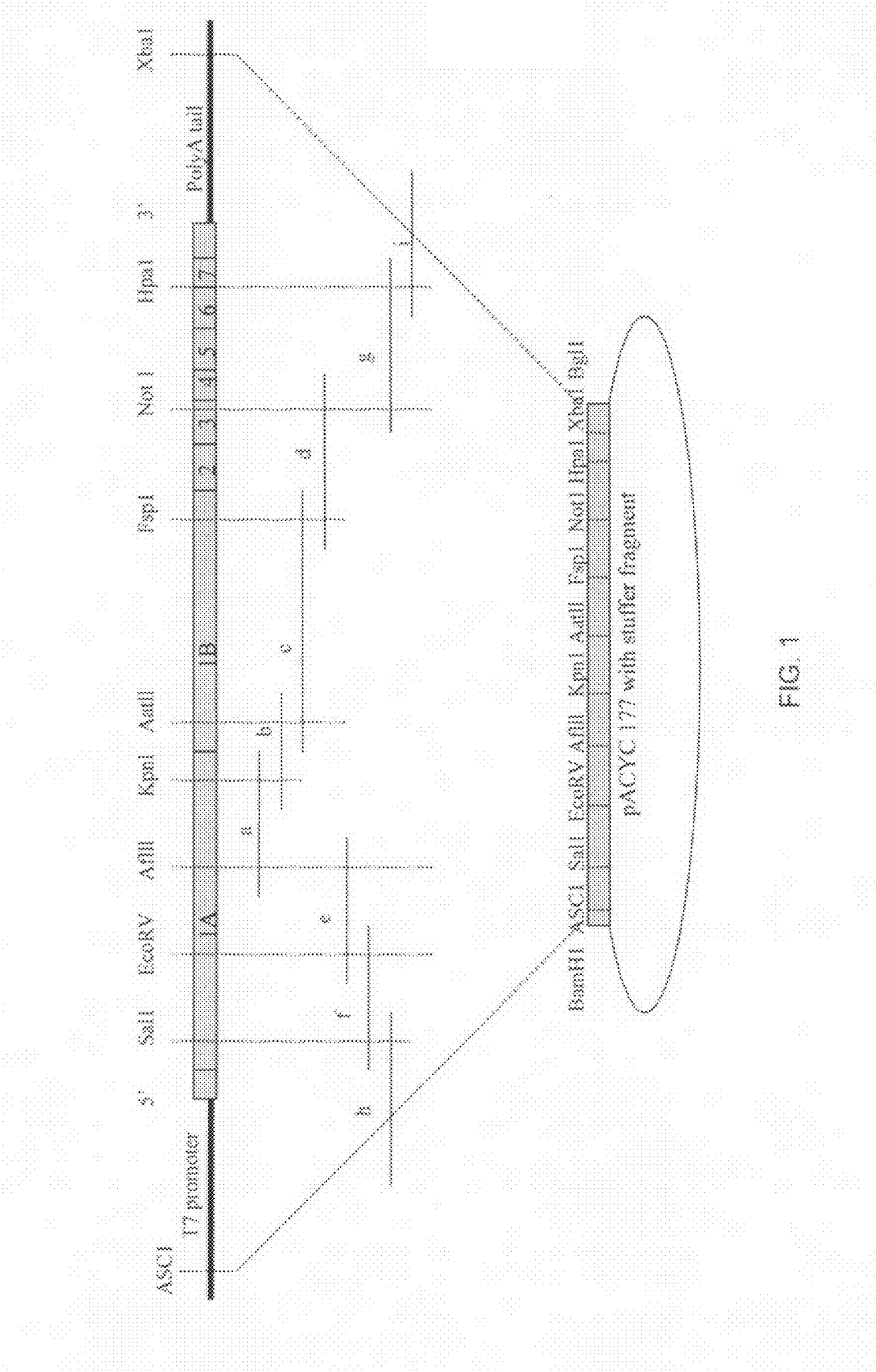
US 20100136047A1

(19) **United States**(12) **Patent Application Publication**
Fang et al.(10) **Pub. No.: US 2010/0136047 A1**(43) **Pub. Date: Jun. 3, 2010**(54) **RECOMBINANT NORTH AMERICAN TYPE 1
PORCINE REPRODUCTIVE AND
RESPIRATORY SYNDROME VIRUS AND
METHODS OF USE**(75) Inventors: **Ying Fang**, Brookings, SD (US);
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25, 2007.**Publication Classification**(51) **Int. Cl.****A61K 39/12** (2006.01)**A61P 31/14** (2006.01)**C12N 7/01** (2006.01)**C12Q 1/70** (2006.01)(52) **U.S. Cl. 424/199.1; 435/235.1; 424/205.1;**
435/5(57) **ABSTRACT**

Porcine reproductive and respiratory syndrome virus (PRRSV) is a major problem in the pork industry worldwide. The inclusion of markers in vaccines will allow for diagnostic differentiation of vaccinated animals from those naturally infected with wild-type virus. Using a cDNA infectious clone of North American Type 1 PRRSV, a recombinant green fluorescent protein (GFP) tagged PRRSV has been made, containing deletion of an immunogenic epitope, ES4, in the nsp2 region. GFP and ES4 epitope-based ELISAs complement the marker identification.



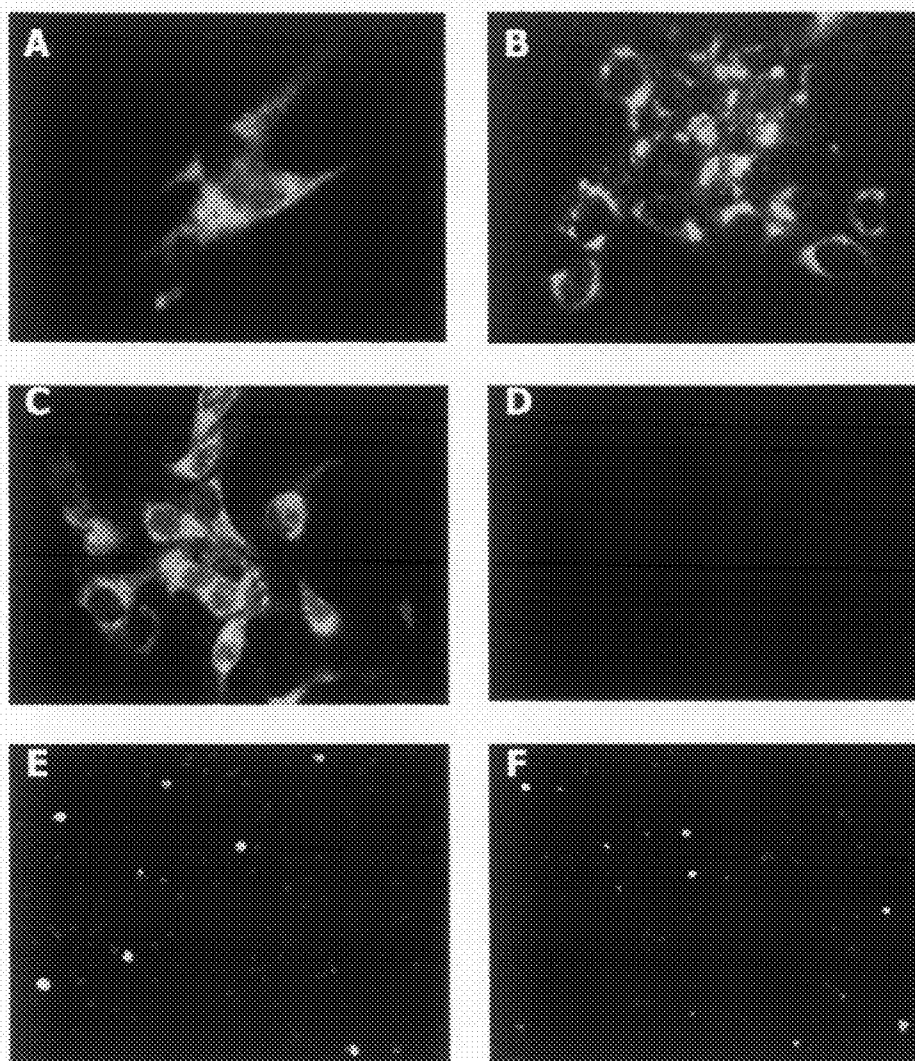


FIG. 2

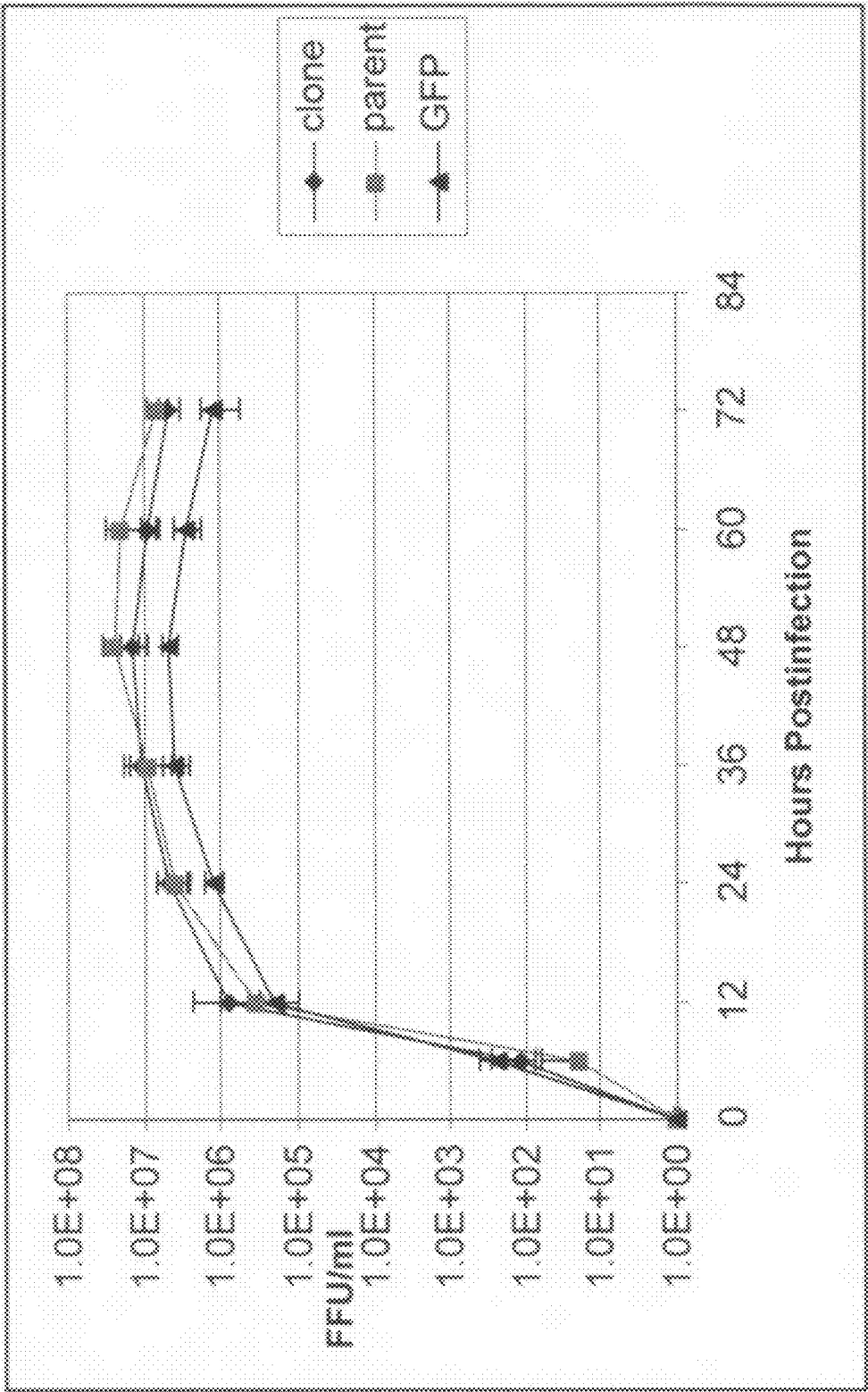


FIG. 3

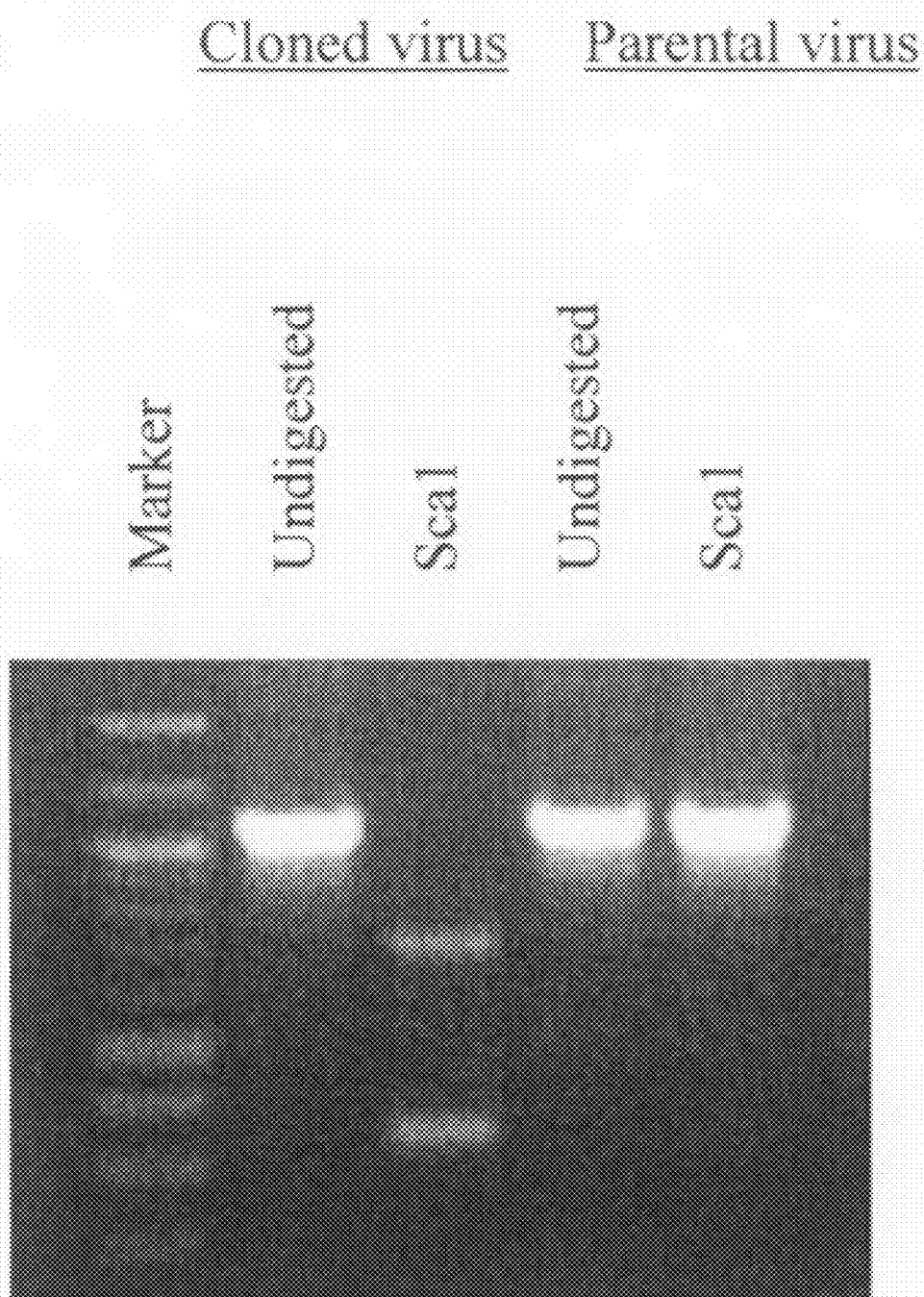


FIG. 4

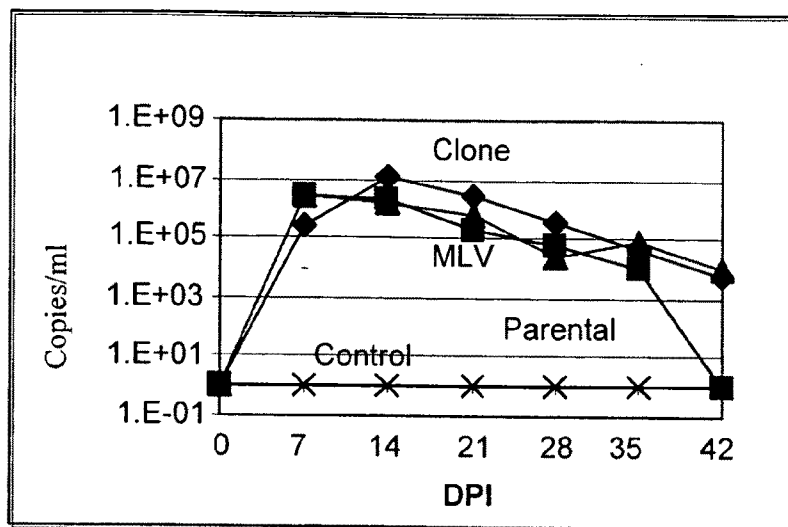


FIG. 5A

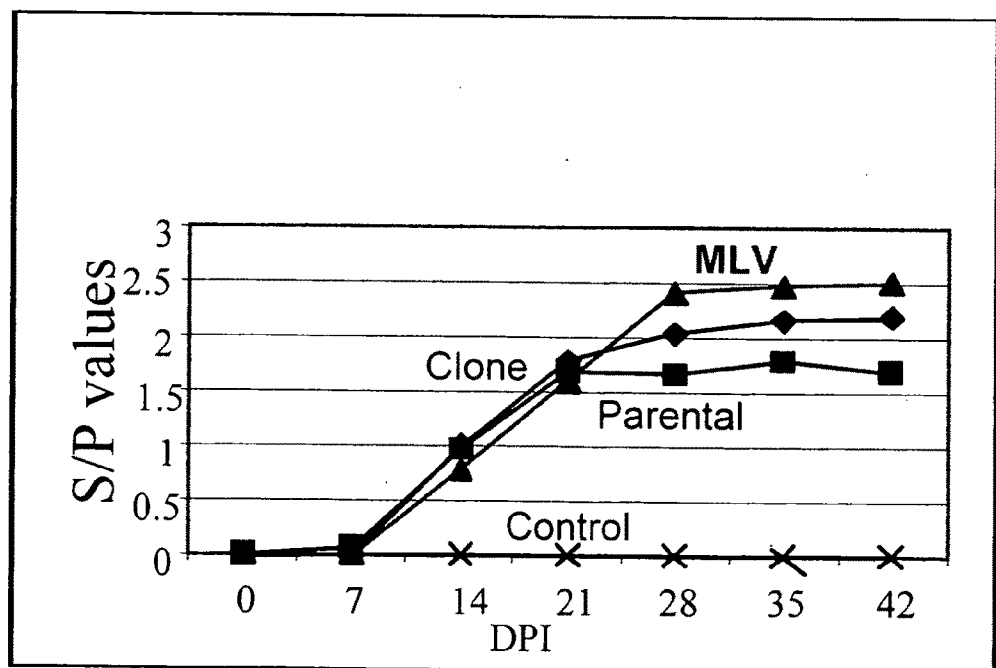


FIG. 5B

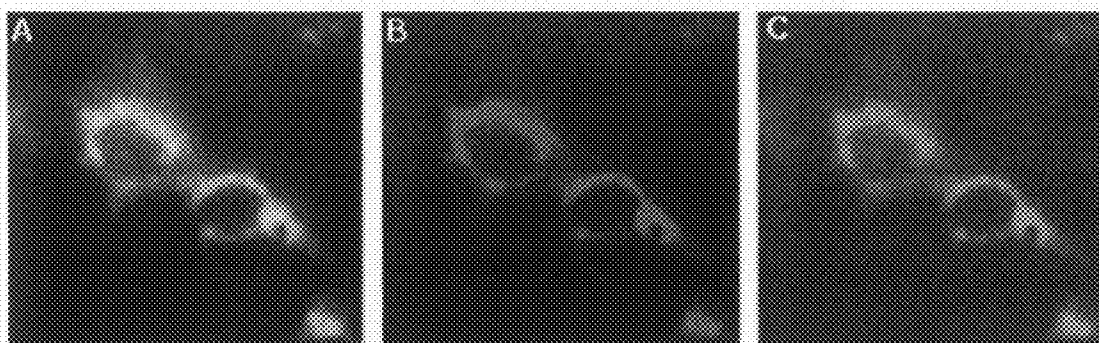


FIG. 6

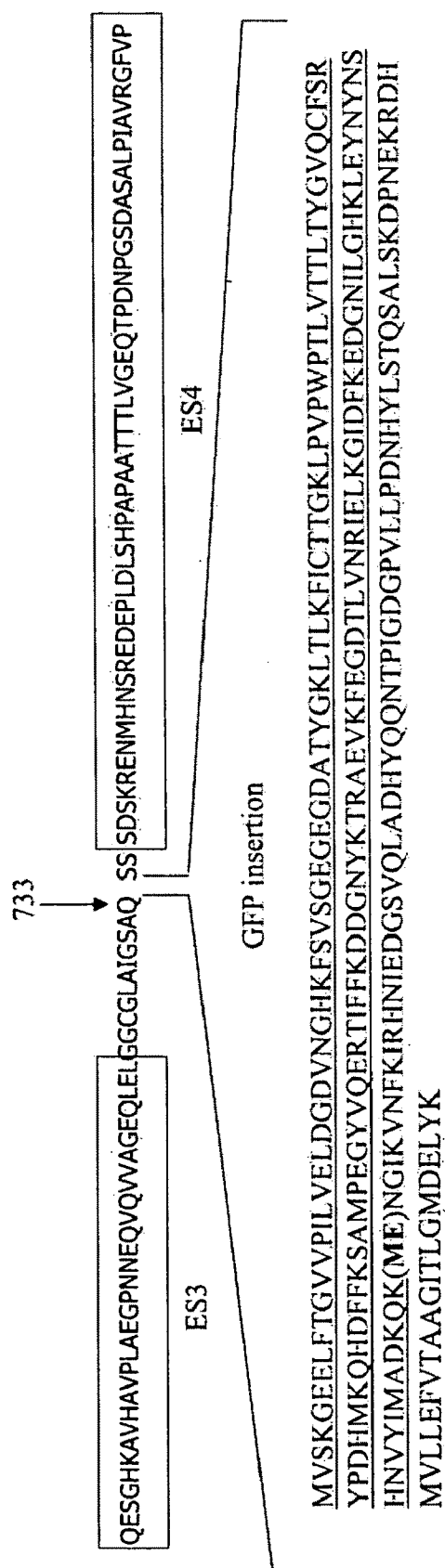


FIG. 7

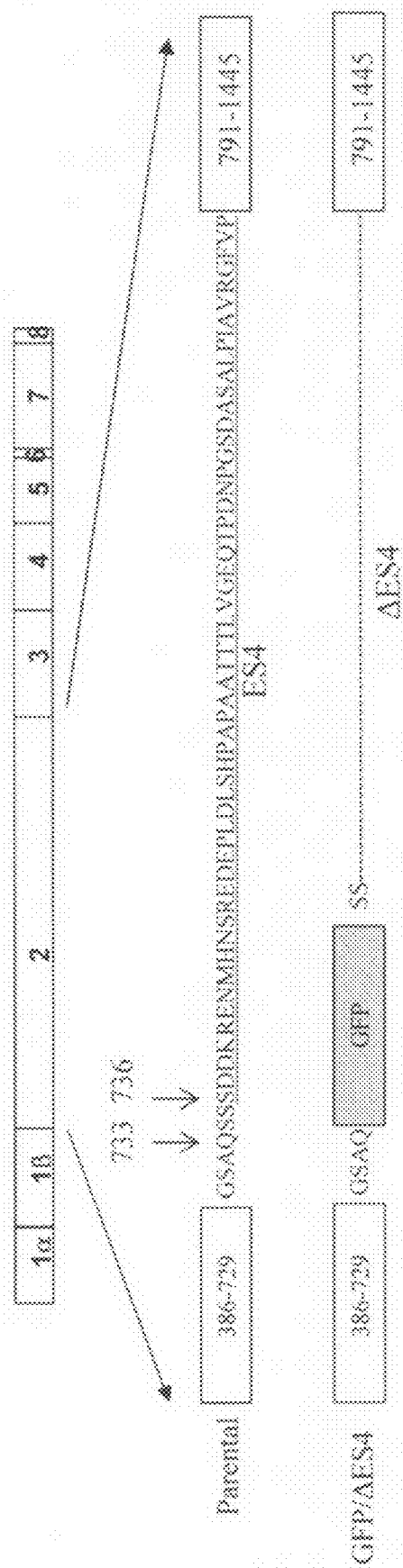


FIG. 8

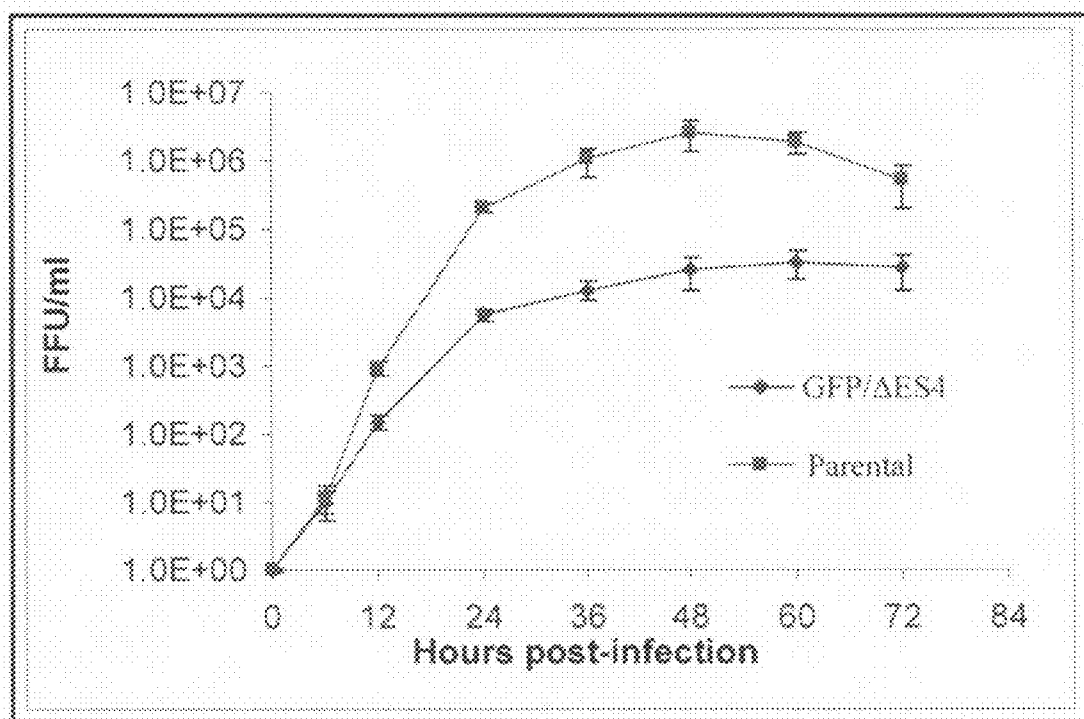
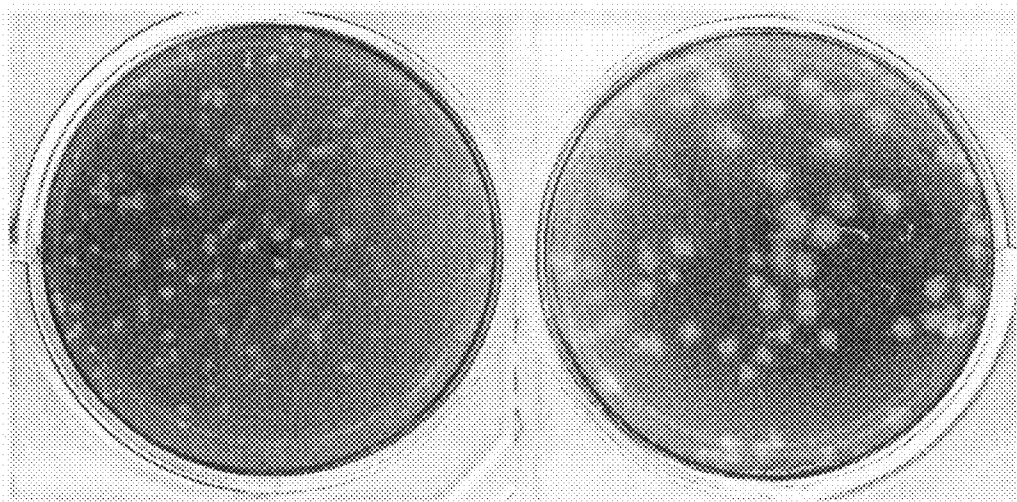


FIG. 9



10-1. Δ ES4/GFP marker virus

10-2. Parental

FIG. 10

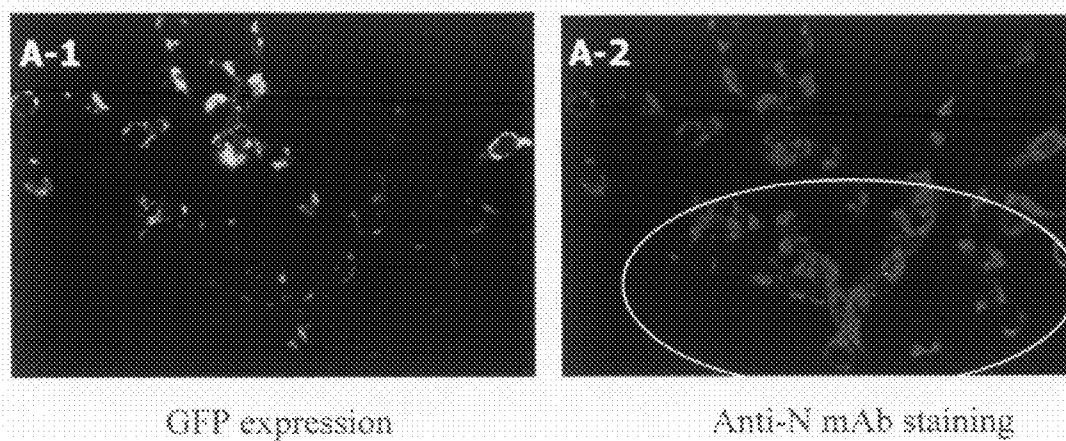


FIG. 11

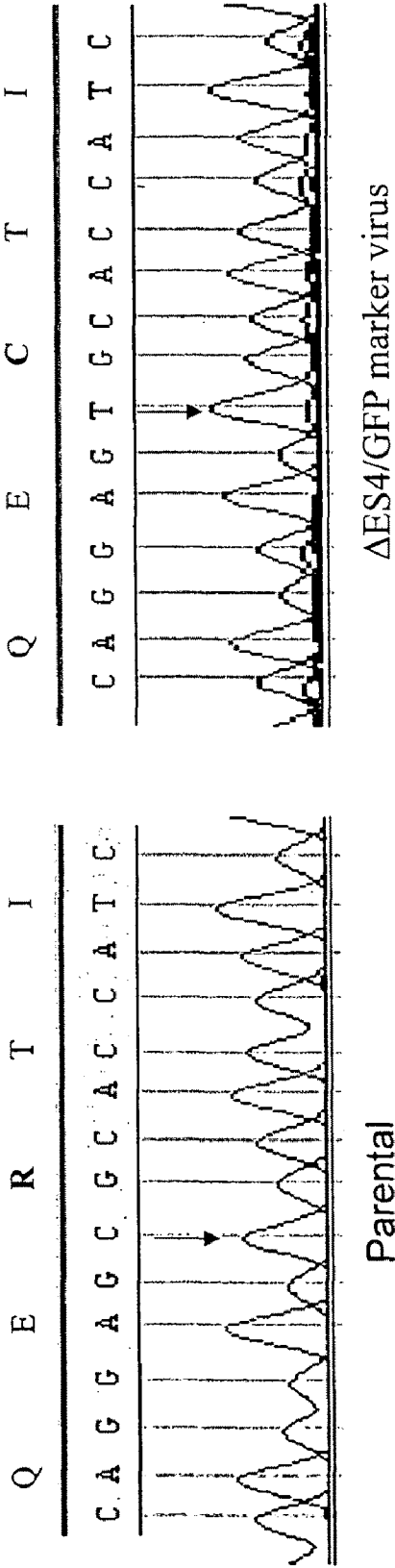


FIG. 12

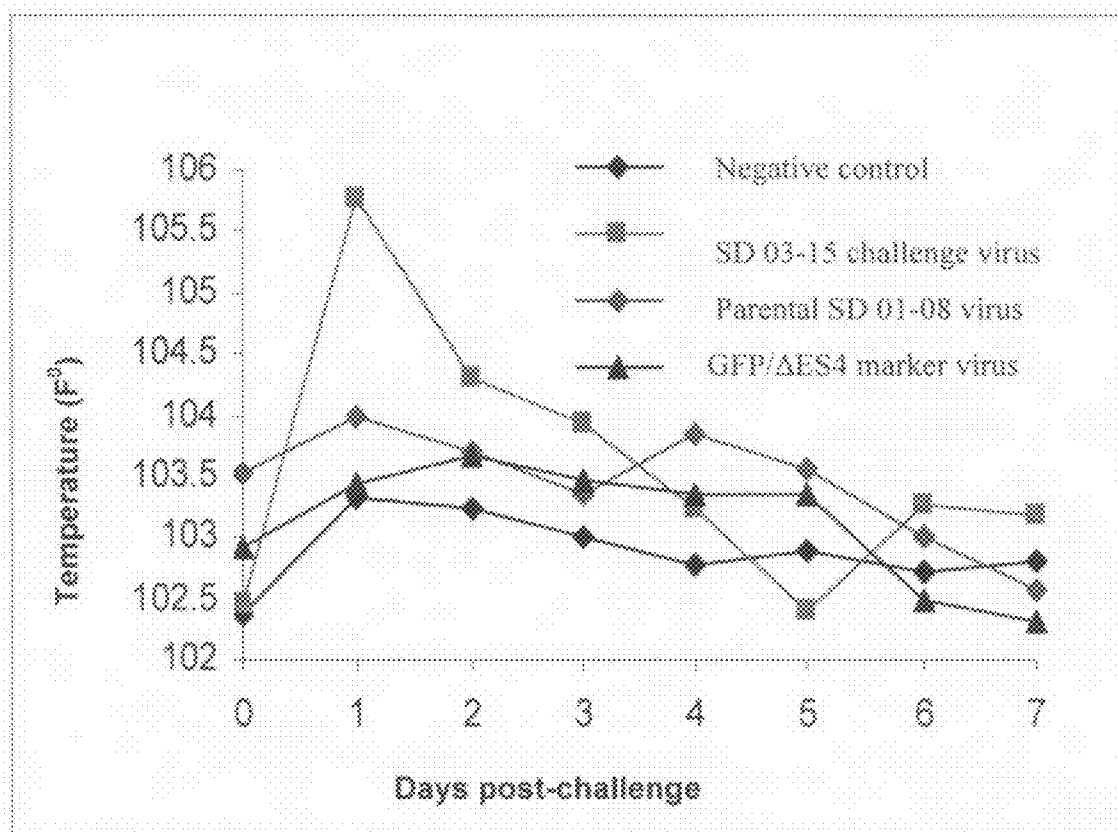


FIG. 13

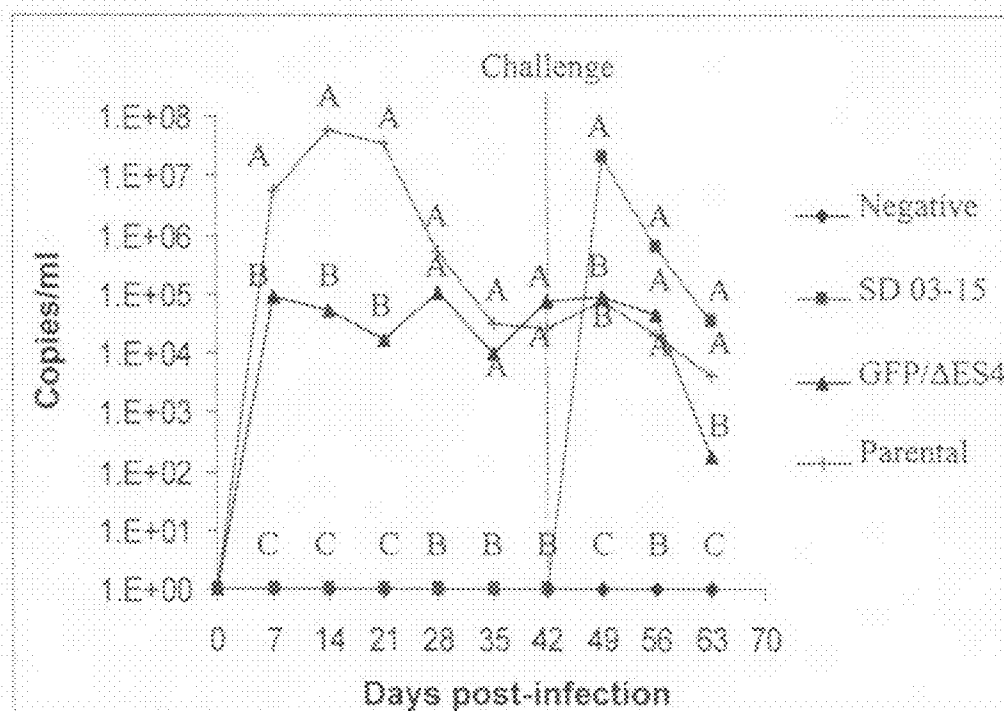


FIG. 14A

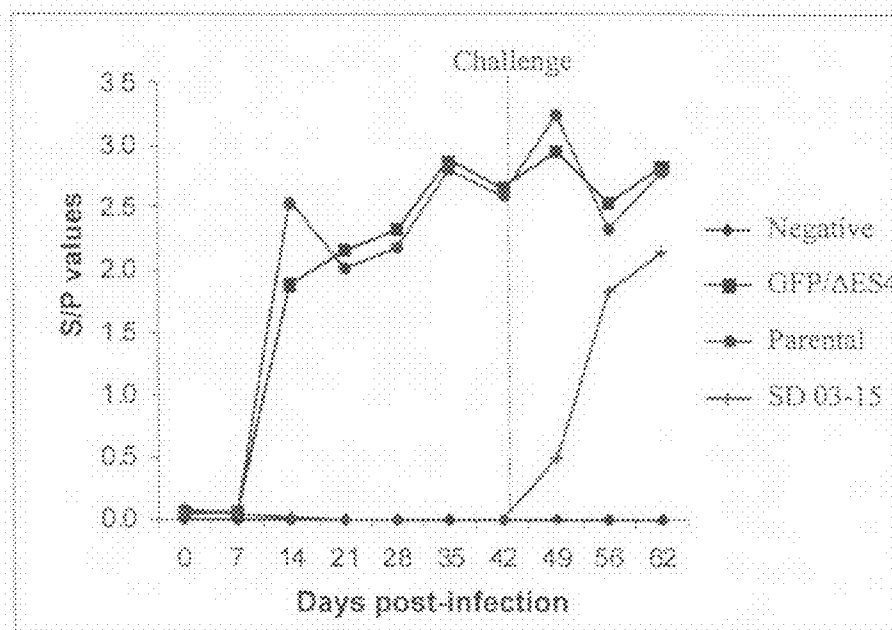


FIG. 14B

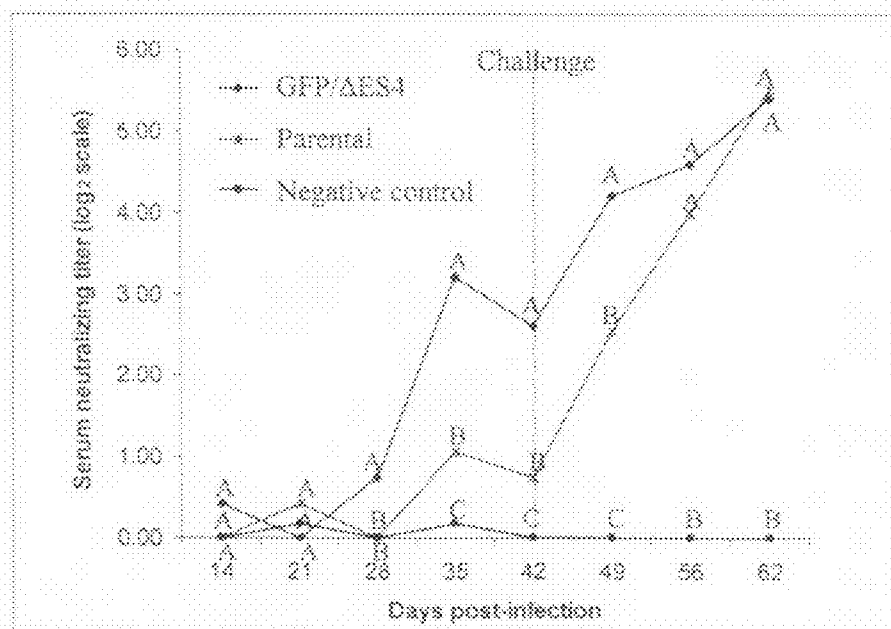


FIG. 14C

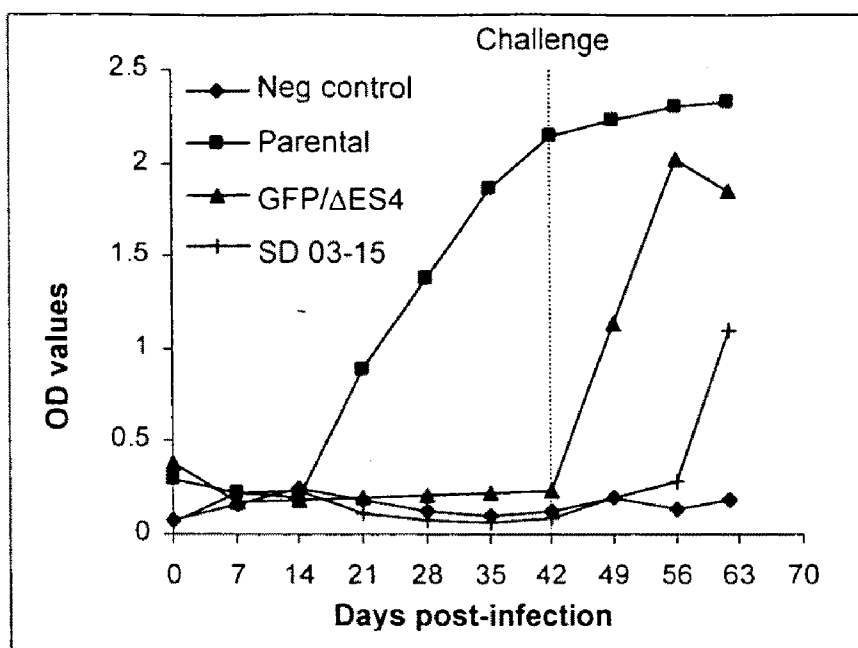


FIG. 15A. ES4 epitope-based ELISA.

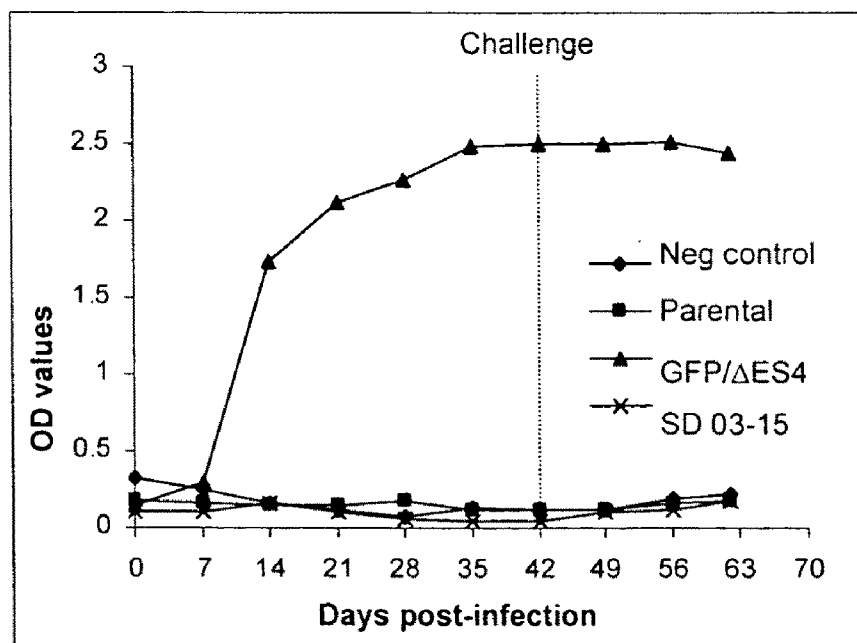


FIG. 15B. GFP antigen-based ELISA.

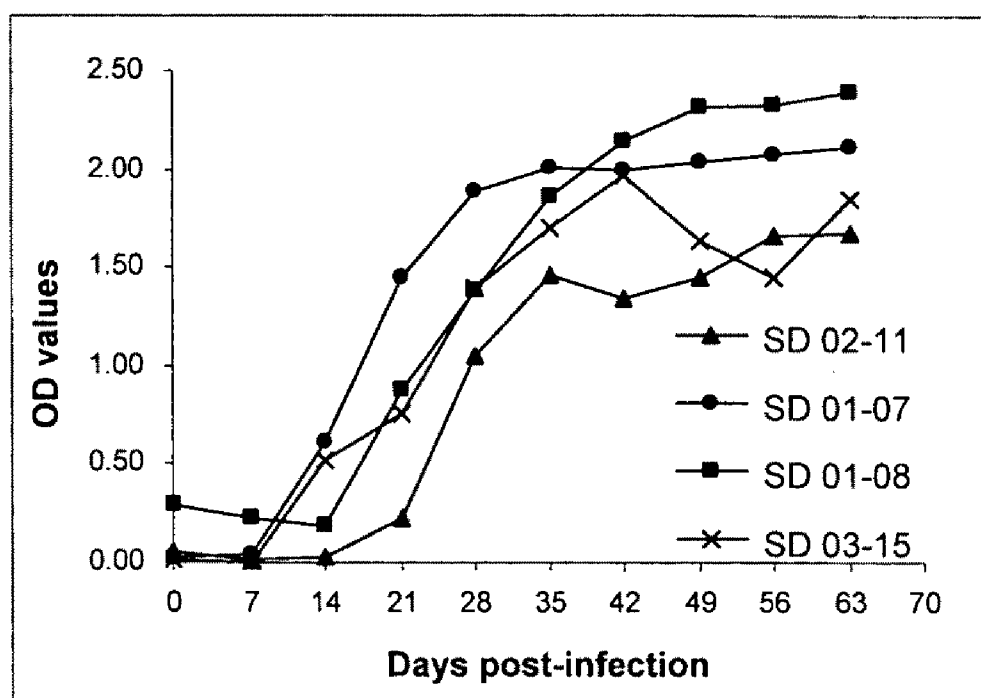


FIG. 15C. ES4 epitope-based ELISA.

RECOMBINANT NORTH AMERICAN TYPE 1 PORCINE REPRODUCTIVE AND RESPIRATORY SYNDROME VIRUS AND METHODS OF USE

[0001] This application claims the benefit of U.S. Provisional Application Ser. No. 60/946,080, filed Jun. 25, 2007.

TECHNICAL FIELD

[0002] This application relates to the field of molecular virology and more particularly to the construction of recombinant nucleic acids encoding Porcine Reproductive and Respiratory Syndrome Virus (PRRSV).

BACKGROUND

[0003] Porcine reproductive and respiratory syndrome (PRRS) is the most economically significant disease of swine worldwide. It is characterized by late term reproductive failure in sows and severe pneumonia in neonatal pigs. The PRRS virus (PRRSV) consists of two major genotypes, European genotype (Type 1) and North American genotype (Type 2), each formerly located on different continents. More recently, Type 1 PRRSV isolates (North American Type 1) have been identified in U.S. swineherds. This group of viruses possesses unique antigenic and genetic characteristics that are distinct from typical North American and European type PRRSV. A unique 51 by deletion has been identified in the immunodominant region of the Nsp2. The etiologic agent of PRRS is a small, enveloped virus containing a single positive-stranded RNA genome. PRRSV belongs to the family Arteriviridae, which includes equine arteritis virus (EAV), lactate dehydrogenase-elevating virus (LDV), and simian hemorrhagic fever virus (SHFV) (Snijder & Meulenberg, 1998). Nucleotide sequence comparisons showed that PRRSV can be divided into distinct European (Type 1) and North American (Type 2) genotypes (Allende et al., 1999; Nelson et al., 1999).

[0004] The PRRSV genome is about 15 kb in length and contains nine open reading frames. The 3' end of the genome encodes four membrane-associated glycoproteins (GP2a, GP3, GP4 and GP5; encoded by sg mRNAs 2-5), two unglycosylated membrane proteins (E and M; encoded by sg mRNAs 6 and 7) and a nucleocapsid protein (N; encoded by sg mRNA 8) (Bautista et al., 1996; Mardassi et al., 1996; Meng et al., 1996; Meulenberg & den Besten, 1996; Meulenberg et al., 1995; Mounir et al., 1995; Wu et al., 2001, 2005). The replicase-associated genes, ORF1a and ORF1b, situated at the 5' end of the genome, represent nearly 75% of the viral genome. The ORF1ab encoded polyprotein pp1ab is predicted to be cleaved at 12 sites to form 13 products: nsp1 α , nsp1 β , and nsp2 to nsp12 (Allende et al., 1999; den Boon et al., 1995; Nelsen et al., 1999; Snijder & Meulenberg, 1998).

[0005] Modified-live attenuated vaccines against PRRSV are currently available for reduction of clinical disease associated with PRRSV (Boehringer-Ingelheim Animal Health, Inc.). However, they cannot be distinguished serologically between pigs that have recovered from a natural infection and those that have been vaccinated. A genetically marked vaccine would allow the differentiation between vaccinated and naturally infected pigs, which is needed for PRRSV control and eradication programs.

SUMMARY

[0006] A recombinant porcine reproductive and respiratory syndrome virus (PRRSV) includes one or more mutations in

open reading frame (ORF) 1a, the mutations being such that the recombinant PRRSV fails to produce at least one functional polypeptide corresponding to ORF1a. The mutation may be a deletion. A deletion may be in the nsp2 region, and may include epitope ES4. In one embodiment, the deletion includes amino acids 736-790 of ORF1a. The mutation may include an insertion of a heterologous DNA sequence. An insertion may be between amino acids 733 and 734 of ORF1a. The insertion may include green fluorescent protein (GFP).

[0007] A recombinant North American PRRS virus is encoded by an isolated polynucleotide molecule including a DNA sequence encoding an infectious RNA molecule encoding a North American PRRS virus, and the DNA sequence is SEQ ID NO: 43 or a sequence homologous thereto.

[0008] A vaccine includes a PRRSV mutant having a mutation in ORF1a, the mutation being such that said PRRSV mutant fails to produce a functional ORF1a polypeptide, and the vaccine includes a pharmaceutically acceptable carrier. The mutation may include a deletion in the nsp2 region, such as a deletion of amino acids 736-790 in the nsp2 region. The mutation may include an insertion of a heterologous DNA sequence. The insertion may be between amino acids 733 and 734 in the nsp2 region.

[0009] A kit includes a vaccine including a PRRSV mutant having a mutation in ORF1a, the mutation being such that said PRRSV mutant fails to produce a functional ORF1a polypeptide, the mutation including an insertion of a heterologous DNA sequence, and a pharmaceutically acceptable carrier. The kit further including one or more first polypeptides encoded by the heterologous DNA sequence, and one or more second polypeptides encoded by the functional ORF1a. The mutation in the PRRSV vaccine may be a deletion in the nsp2 region, such as in an ES4 epitope, and the one or more first polypeptides include GFP and the one or more second polypeptides include the ES4 epitope.

[0010] A method is provided for differentiating an animal vaccinated with a PRRSV marker vaccine from an animal naturally infected with PRRSV, where the PRRSV marker vaccine includes an insertion mutation and a deletion mutation. The method includes the steps of providing a first recombinant PRRSV protein including the insertion mutation, providing a second recombinant PRRSV protein including the deletion mutation, incubating a serum sample from the animal with the first and second recombinant PRRSV proteins, and detecting binding of antibodies in the sample with the first and second recombinant PRRSV proteins. Binding of antibodies in the sample with the first recombinant PRRSV protein is indicative of a vaccinated animal and binding of antibodies in the sample with the second recombinant PRRSV protein is indicative of a naturally infected animal. The first recombinant PRRSV protein may include a GFP insertion, and the second recombinant PRRSV protein may include an ES4 deletion.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] FIG. 1 is a schematic representation of the PRRSV genome and cloning strategy.

[0012] FIGS. 2A-2F depict results of immunofluorescence assays conducted to investigate the infectivity of infectious clone pSD01-08.

[0013] FIG. 3 is a graph showing growth kinetics of cloned virus, parental virus, and GFP-expressing virus.

[0014] FIG. 4 depicts restriction endonuclease fragment patterns of the RT-PCR products of cloned and parental virus SD01-08.

[0015] FIGS. 5A and 5B are graphs showing in vivo characterization of cloned virus.

[0016] FIGS. 6A-6C depict the results of immunofluorescence assays conducted to investigate GFP-expressing PRRSV.

[0017] FIG. 7 is a schematic representation of the pSD01-08-GFP construct.

[0018] FIG. 8 is a schematic representation of the pSD01-08-GFP/ Δ ES4 construct.

[0019] FIG. 9 is a graph showing growth kinetics of GFP/ Δ ES4 marker viruses.

[0020] FIG. 10 depicts plaque morphology of GFP/ Δ ES4 marker viruses and parental viruses.

[0021] FIG. 11 depicts the stability of GFP expression.

[0022] FIG. 12 depicts a comparison of the wild-type GFP gene to an Arg-97 mutated GFP gene.

[0023] FIG. 13 is a graph depicting in vivo characteristics of the GFP/ Δ ES4 marker virus.

[0024] FIGS. 14A-14C are graphs depicting virological and immunological properties of the GFP/ Δ ES4 marker virus.

[0025] FIGS. 15A-15C depict GFP and ES4 epitope-based ELISA results.

DETAILED DESCRIPTION

[0026] A full-length cDNA clone, SD01-08, of a North American Type 1 PRRSV isolate was developed. When compared to Lelystad virus, SD01-08 shares 94.1% identity at the nucleotide level (GenBank accession number DQ489311). An important distinction between SD01-08 and LV is the growth properties in PAMs and monkey kidney cells. Results reported by Meulenberget al (15) showed that wild-type and cloned LV viruses grew well in PAMs, but to low levels in the MA-104 derived cell line, CL2621. Parental and cloned SD01-08 grew equally well on PAMs and MARC-145 cells, another MA-104 derived cell line. The titer of SD01-08 cloned viruses peaked at 48 hpi, while LV cloned viruses grow to lower titers and had not peaked even at 96 hpi. Therefore, the SD01-08 infectious clone replicates well in the continuous cell line. Another difference between LV and SD01-08 is in the level of virulence. In PAMs, the LV cloned virus reached high titers at $10^{7.1}$ to $10^{7.9}$ TCID₅₀/ml and peaked around 32 hpi. The SD01-08 cloned virus reached the same titer as its parental virus in PAMs, but their titers were both lower than that of LV, reaching only about 10^4 TCID₅₀/ml and peaked later, around 72 hpi. This result suggests that SD01-08 cloned virus is less virulent than the LV cloned virus. This conclusion is supported by field observations and an experimental animal challenge study. SD01-08 did not cause significant clinical signs, and only mild pathological lesions observed in the experimental infected pigs. In contrast, LV was reported to cause significant respiratory problems in pigs and abortions in sows (34).

[0027] One of the major applications of the infectious clone is to use it as viral backbone for constructing genetically engineered vaccines. Current PRRSV vaccines in the U.S. mainly target the North American Type 2 isolates. The emergence of the North American Type 1 PRRSV requires that vaccines be effective for both genotypes of PRRSV. An essential requirement for any live virus vaccine is that it be low virulence, inducing no or at most very mild disease manifes-

tations. The parental virus, SD01-08 was isolated from a group of pigs showing no clinical signs. Pathogenesis studies confirmed that SD01-08 possesses low virulence properties at the acute phase of the disease, which suggested that the pSD01-08 infectious clone is a potential low virulent strain and suitable for vaccine construction.

[0028] One of the key steps in vaccine development is to include markers for the diagnostic differentiation of vaccinated animals from those that are naturally infected with wild-type virus. Marker vaccines are important in programs aimed at controlling or eradicating virus infections in food animals, as well as in companion animals (Babiuk, 1999; Babiuk et al., 1999, 2002; van Oirschot, 2001). Herpesvirus marker vaccines were among the first proved to be effective in the field (Bosch et al., 1996; van Oirschot et al., 1996), followed by various genetically modified RNA viruses, such as classical swine fever virus (Widjoatmodjo et al., 2000; van Gennip et al., 2002) and Rinderpest virus (Walsh et al., 2000). In EAV eradication programs, since horses are actively involved in international trade and traffic, a marker vaccine is required by some legislative authorities. Discrimination between vaccination and infection is becoming a ruling issue (Castillo-Olivares et al., 2003). Similarly, with a PRRSV elimination program, the international trade in pigs and pork will likely require a marker vaccine in the future. Furthermore, as the world is progressively moving toward elimination of PRRSV, serosurveillance is an essential tool to verify the disease status. The currently available conventional vaccines are unable to allow differentiation between wild-type infection and vaccination. Thus, serosurveillance is impossible in the face of ongoing vaccination or for several months after vaccination has ceased. Clearly, a marked vaccine would be of great benefit.

[0029] An infectious clone of North American Type 1 PRRSV, pSD01-08 was used to create a recombinant PRRSV. Compared to a European Lelystad virus (LV) infectious clone, pSD01-08 possesses several distinct biological properties: (1) the pSD01-08 infectious clone was derived from a parental strain isolated in the U.S. in 2001, which represents a North American Type 1 PRRSV; (2) the parental strain SD01-08 was isolated from a group of 8-week-old pigs showing no clinical signs; and (3) SD01-08 possesses a unique 51 by deletion in the immunodominant region of Nsp2 (Fang et al., 2004).

[0030] The nsp2 plays a role in the viral replication. The nsp2 contains a cysteine protease domain residing in the N-terminal. This domain induces nsp2/3 cleavage, and also functions as a co-factor with nsp4 serine protease to process the other cleavage products (Snijder et al., 1994, 1995; Wasenaar et al., 1997). Besides its function in viral replication, cysteine proteases of EAV and PRRSV nsp2 have been shown to belong to the ovarian tumor (OTU) protease superfamily. The OTU protease is capable of deconjugating both ubiquitin and ISG15 from cellular proteins, which inhibits Ub- and ISG15-dependent innate immune response (Frias-Staheli et al., 2007).

[0031] The development of the marker vaccine is based on the manipulation of cDNA infectious clones, from where a foreign antigen can be inserted (positive marker) or an immunogenic epitope can be deleted (negative marker). The antibody response to the foreign antigen or viral epitope can be used to differentiate vaccinated animals from naturally infected animals. The PRRSV nsp2 is an excellent candidate site for marker modification. The most important property of

nsp2 related to marker engineering is the ability of nsp2 to tolerate large deletions and insertions. Nucleotide sequence insertions/deletions have been reported within the central region of the protein (Gao et al., 2004; Shen et al., 2000; Tian et al., 2007; Han et al., 2007). Another property related to marker engineering is the presence of several immunodominant epitopes in this region. Six linear B-cell epitope sites (ES) in the nsp2 region of a Danish Type 1 virus (ES2 to ES7) have been identified (Oleksiewicz et al., 2001). In Type 2 virus, the nsp2 has been found to contain the highest frequency of immunodominant epitopes when compared to structural proteins (de Lima et al., 2006).

[0032] Marker modifications in the nsp2 region of a US Type 1 PRRSV infectious clone were prepared. A positive marker, GFP, was inserted into the nsp2 region, but the GFP gene was not stable. Next, a highly immunogenic epitope, ES4, located in the nsp2 region (amino acid 736 to 790 of ORF1a) was deleted and replaced with the GFP gene (at amino acid 733/734 of ORF1a) using reverse genetics, to create a negative marker. The resulting recombinant virus' in vitro replication features and in vivo biological properties were characterized to determine its potential use as marker vaccine against PRRSV infection. The GFP antigen and ES4 peptide antigen-based ELISAs were tested to determine their sensitivity and specificity as companion diagnostic assays for the marker detection and differentiation.

I. Positive Marker GFP

[0033] Cells and viruses. A North American Type 1 PRRSV isolate, SD01-08, was originally isolated in 2001 from a group of 8-week-old pigs in the U.S., which were showing no clinical signs of PRRS. Baby hamster kidney cells (BHK-21 C13: American Type Culture Collection) were used for initial transfection for recovery of virus from in vitro transcribed RNA. MARC-145 cells were used for virus rescue and subsequent experiments (Fang et al., 2006). Porcine alveolar macrophages (PAM) cells were obtained by lung lavage of specific-pathogen-free piglets free of PRRSV.

[0034] RNA extraction, RT-PCR and sequencing: MARC-145 cells were infected with plaque purified viruses at an MOI of approximately 0.1. After three days, the culture supernatant was layered onto a 0.5 M sucrose cushion and centrifuged at 100,000×g for 14 h in a SW41 rotor (Beckman). RNA was extracted from the pellet using a QIAamp viral RNA kit (Qiagen). To obtain the full-length genome sequence of the parental virus, SD01-08, RT-PCR was performed using a series of primers (Ropp et al., 2004). Each RT-PCR product was directly sequenced at least two times from both directions to obtain the consensus sequences. To construct the infectious clone, nine overlapping fragments (FIG. 1) covering the full-length viral genome flanked by unique restriction enzyme sites were amplified by RT-PCR. The forward and reverse oligonucleotides for the RT-PCR amplification were designed initially based on the sequence of LV (GenBank accession number M96262; 18) and later modified to match SD01-08 sequence (Table 1). RT-PCR was performed (Fang et al., 2004). These RT-PCR amplified fragments were gel purified and cloned in the PCR-Blunt II-Topo vector (Invitrogen). Three clones of each fragment were sequenced and the clone containing the consensus sequence was used for infectious clone assembly.

TABLE 1

<u>Primers used for RT-PCR amplification</u>		
Primers	Sequences	Genome Position in SD01-08
<u>Fragment a</u>		
E4849F	5' gca tgg ctc tta agg cag ac SEQ ID NO. 1	4849-4868
E7227R	5' cag ctt caa ggc agt tgt ca SEQ ID NO. 2	7208-7227
<u>Fragment b</u>		
E7139F	5' tgt tgt gat cgg cgg tat ta SEQ ID NO. 3	7139-7158
E8297R	5' cgg cgc ggg cac aca ttt cgt caa ttt SEQ ID NO. 4	8271-8297
<u>Fragment c</u>		
E8090F	5' tac gac cta tcc acc caa gg SEQ ID NO. 5	8090-8109
E10275R	5' gaa tct atg gtt atc gca gag c SEQ ID NO. 6	10254-10275
<u>Fragment d</u>		
E9946F	5' cct cga tga ggc tgg ata tt SEQ ID NO. 7	9946-9965
E12929R	5' gca cca acc agg agg aaa aaa gc SEQ ID NO. 8	12907-12929
<u>Fragment e</u>		
E3173F	5' cat tct tgc gtc cct caa at SEQ ID NO. 9	3173-3192
E5352R	5' cga cag tct ttc tgc cat caa tg SEQ ID NO. 10	5330-5352
<u>Fragment f</u>		
E2229F	5' gct gct gtt gtc ctg tgt t SEQ ID NO. 11	2229-2247
E3397R	5' ccg tcg aag ggg gtg gca tcc SEQ ID NO. 12	3377-3397
<u>Fragment g</u>		
E12482F	5' tca ttc gag ctg acc atc aa SEQ ID NO. 13	12482-12501
E14651R	5' ctt tat cat tgc acc cag caa SEQ ID NO. 14	14631-14651
<u>Fragment h</u>		
E1GF	5' ggc gcg cct aat acg act cac tat aga tga tgt gta ggg tat SEQ ID NO. 15	1-16

TABLE 1-continued

Primers used for RT-PCR amplification		
Primers	Sequences	Genome Position in SD01-08
E2968R	5' cgc ggg cgc ctg agt tcg aca aat t SEQ ID NO. 16	2944-2968
Fragment i		
E14059F	5' caa cga tcc tac cgc cgc aca a SEQ ID NO. 17	14059-14080
018 Poly AR	5' ggc gat cgg gcg tct agg aat tct aga (T) ₄₁ aat ttc ggc cac SEQ ID NO. 18	15036-15047
018 3' R	5' ggc gat cgg gcg tct agg aat tc SEQ ID NO. 19	After polyA
Unique restriction enzyme site construction in ORF7		
E14059F	5' caa cga tcc tac cgc cgc aca a SEQ ID NO. 20	14059-14080
YFp503R	5' ggc ccc agt gct gca atg ata c SEQ ID NO. 21	After polyA
Sca1F *	5' aga aga aaa aga aaa gta c tg ctc caa tgg g SEQ ID NO. 22	14569-14599
Sca1R *	5' ccc cat tgg agc agt act ttt ctt ttt ctt SEQ ID NO. 23	14571-14600
GFP insertion in Nsp2 region		
gfpF	5' gct cag atg gtg agc aag ggc gag gag c SEQ ID NO. 24	
gfpR	5' gag tct gaa gag gac ttg tac agc tcg tcc a SEQ ID NO. 25	
Nsp2F1	5' tgc tga ctt tct tgc tga tcc acc tcc t SEQ ID NO. 26	1895-1922
Nsp2R1	5' cct tgc tca cca tct gag cac tcc cg SEQ ID NO. 27	2408-2420
Nsp2F2	5' gct gta caa gtc ctc ttc aga ctc caa ga SEQ ID NO. 28	2419-2439
Nsp2R2	5' gcg gac cca gcc agg atc aga c SEQ ID NO. 29	2732-2753

* The nucleotide mutated for creating Sca1 restriction enzyme site is in bold and italics.

[0035] The 5' and 3' ends of the genome sequences were determined using a GeneRACER kit (Invitrogen) following the manufacture's instructions. The fragment representing the 5' terminus of the viral genome was prepared using RT-PCR with primers, E1GF and E2968R (Table 1), which integrates a T7 RNA polymerase site immediately preceding the authentic 5' terminal nucleotides and an AscI restriction enzyme site. The fragment containing the 3' end sequence was constructed by reverse transcription of RNA with primer 018 polyA, which is flanking the 41 poly A residues and XbaI site. The reverse transcription reaction was followed by PCR with primers E14059F and 018 3'R (Table 1).

[0036] Construction of a full-length cDNA clone of a North American Type 1 PRRSV and determination of its infectivity. A full-length genomic cDNA clone of a North American Type 1 PRRSV, pSD01-08 was constructed using the strategy shown in FIG. 1. A low copy number plasmid pACYC177 (GenBank Accession #X06402) was modified by replacing the fragment between the BamHI and BglI sites with a stuffer fragment, which was prepared as a synthetic gene containing the restriction enzyme sites as shown in FIG. 1. Each of the viral fragments was excised from PCR-Blunt II-Topo using restriction enzymes and ligated into the pACYC177 plasmid, which was digested with the same restriction enzymes. After each ligation step, the pACYC177 construct was transformed into *E. coli* DH5 α cells and grown overnight at 37° C. in the presence of Kanamycin. The completely assembled full-length cDNA clone was sequenced, and the full-length genome sequence was deposited in GenBank under the accession number DQ489311.

[0037] To create the ScaI restriction enzyme site, the silent mutation (G to T mutation) at nucleotide 42 of ORF7 (nucleotide 14588 of SD01-08 genome) was generated using site directed mutagenesis. Site directed mutagenesis was achieved by an overlapping extension PCR technique (Ho et al., 1989; Jespersen et al., 1997) using primer pairs E14059F/Sca1R and Sca1F/YFp503R. The mutated product was confirmed by DNA sequencing analysis.

[0038] This construct contains a bacteriophage T7 RNA polymerase promoter at the 5' terminus of the viral genome, one additional guanosine residue introduced between the T7 promoter and the first nucleotide of the viral genome, the 15047 nucleotides full-length genome of SD 01-08 and a poly (A) tail of 41 residues incorporated at the 3' end of the genome. Compared to the genome sequence of the parental virus, the DNA sequence of pSD0'-08 contained six nucleotide differences (Table 2).

TABLE 2

Nucleotide differences between the parental SD 01-08 isolate and the full-length cDNA clone.				
Nucleotide position within SD01-08 genome	Nucleotide in parental virus	Nucleotide in cDNA clone	Amino acid change	Gene position
1331	T	C	Silent	Nsp1 β
6158	T	C	Silent	Nsp5
8191	A	G	Silent	Nsp9
9492	C	T	P to L	Nsp10
11261	T	C	Y to H	Nsp11
14588	G	T	Silent	ORF7

[0039] Four of these differences were silent mutations. The mutation at nucleotide 14588 was introduced to create a unique ScaI restriction enzyme site into ORF7 for differentiating the cloned virus from parental virus. Two of the nucleotide mutations resulted in amino acid changes, which included the substitution of a C to T at nucleotide 9492 (amino acid P to L) located at Nsp10, and a T to C at nucleotide 11261 (amino acid Y to H) located at Nsp11.

[0040] The plasmid pSD01-08 was linearized by restriction enzyme XbaI and used for in vitro transcription by T7 RNA polymerase to synthesize capped RNAs. The in vitro transcribed capped RNA was transfected into BHK-21 cells. At 48 hours post-transfection, cells were examined for the expression of N protein by fluorescent antibody staining with

mAb SDOW17 (FIG. 2A). Results in FIG. 2A showed that about 5% of the transfected cells expressed the N protein. Supernatants from the transfected cells were passaged onto MARC-145 cells. After 72 hours, MARC-145 cells were stained using the SD01-08 specific, anti-Nsp2 mAb, ES3-4 58-46 (FIG. 2B), and anti-N mAb SDOW17 (FIG. 2C). A North American Type 2 PRRSV specific, anti-N mAb, MR39 (FIG. 2D), was incorporated as a negative control. The results showed that both Nsp2 and N proteins were detected in MARC-145 cells inoculated with supernatant from the pSD01-08 transfected BHK-21 cells. Upon further passage of the supernatant onto fresh MARC-145 cells (passage 2 on MARC-145 cells), cytopathic effects (CPE) were observed within 48 to 72 hours post infection (hpi). Titration of virus from passage 2 on MARC-145 cells showed an average titer of 3.6×10^7 FFU/ml. These results indicate that viable and infectious North American Type 1 PRRSV was rescued from the cells transfected with in vitro transcribed RNA.

[0041] GFP insertion: The pSD01-08-GFP clone was constructed by inserting the GFP gene sequence (Clontech) into the Nsp2 region (nucleotide 2420/2421) of the viral genome in the plasmid pSD01-08. The GFP gene was amplified from the pEGFP-N1 plasmid (Clontech) with forward primer gfpF and reverse primer gfpR. GFP was inserted by overlapping extension PCR technique (Ho et al.; 1989, Jespersen et al., 1997) using primer pairs of Nsp2F1/Nsp2R1 and Nsp2F2/Nsp2R2. The PCR product was digested with RsrI and AclI restriction enzymes and ligated into the pSD01-08 plasmid, which was digested with the same restriction enzymes.

[0042] In vitro transcription and rescue of PRRSV: The plasmid, pSD 01-08 or pSD01-08-GFP was linearized with restriction enzyme XbaI. Capped RNA was transcribed with T7 RNA polymerase using the mMessage Machine kit (Ambion) and transfected to BHK-21 cells using DMRIE-C reagent (Invitrogen) following the manufacturer's instructions. To rescue the virus, cell culture supernatant obtained 48 hours posttransfection was serially passaged on MARC-145 cells. Rescue of infectious virus was confirmed by indirect immunofluorescent assay (IFA) (Ropp et al., 2004). Monoclonal antibodies (MAbs) were developed for use in the IFA test, including MAb ES3-4 58-46, which specifically recognizes Nsp2 of SD01-08 (Fang et al., Conf. Res. Work. Anim. Dis., abstr. 78, 2004). MAb MR39 specifically recognizes the N protein of the North American Type 2 PRRSV and MAb SDOW17 recognizes the N protein of both genotypes of PRRSV (Nelson et al., 1993; Ropp et al., 2004). For rescue of GFP virus, the expression of GFP was also visualized directly under a fluorescent microscope.

[0043] Growth kinetics were examined by infecting MARC-145 cells with cloned virus and parental virus at a MOI of 0.1. Infected cells were collected at 0, 6, 12, 24, 36, 48, 60 and 72 hours post infection, and the virus titers were determined by IFA on MARC-145 cells and quantified as fluorescent focus unit per ml (FFU/ml). Plaque morphology between the cloned virus and parental virus was compared by plaque assay on MARC-145 cells. Confluent cell monolayers were infected with 0.1 MOI of viruses. After 2 hours, cell culture supernatant was removed and an agar overlay was applied. Plaques were detected after five days at 37° C., and stained by using 0.1% crystal violet.

[0044] In vitro characterization of cloned virus. The parental virus and cloned virus (passage 2 on MARC-145 cells) were titrated on porcine alveolar macrophages (PAMs). Immunofluorescent staining using anti-N mAb showed that

both viruses replicated in PAMs (FIGS. 2E and 2F) and produced the similar virus yield (2.1 - 2.8×10^4 FFU/ml) at 72 hpi.

[0045] To further compare the growth properties of the cloned and parental viruses, MARC-145 cells were infected with each of the viruses at a MOI of 0.1 and harvested at 6, 12, 24, 36, 48, 60, and 72 hpi. Growth curve results showed that cloned virus possessed similar growth kinetics with that of parental virus (FIG. 3). Titers peaked at 48 hpi for both viruses. The peak titer of the cloned virus was 1.39×10^7 FFU/ml, versus 2.34×10^7 FFU/ml for the parental virus. Plaque morphology of these viruses was also determined, the plaque size produced by cloned virus was similar to that of parental virus (data not shown). These results indicate that the cloned virus possesses in vitro properties similar to the parental wild-type virus.

[0046] To differentiate cloned virus from the parental virus, we engineered a ScaI restriction enzyme site at nucleotide 42 of ORF7. As shown in FIG. 4, a 1054 bp RT-PCR fragment derived from amplifying the nucleotides 13875 to 14928 was cleaved by ScaI in the cloned virus. In contrast, the RT-PCR fragment derived from the parental virus was not cleaved by ScaI.

[0047] Pathogenic and immunological properties of cloned virus derived from pSD 01-08 in a pig model. An in vivo study of the replication properties of virus derived from the infectious clone using a nursery pig model was performed. Twenty-one 4 week-old, PRRSV naïve pigs from a certified PRRSV-negative herd were obtained and randomly divided into 4 groups housed separately in isolation facilities. After a 4 day acclimation period, pigs from each group (n=6 for cloned virus infected group; n=5 for the remaining groups) were inoculated intranasally with 1 ml 10^5 TCID₅₀ of cloned virus (group 1) or parental virus (group 2). The third group of animals was inoculated with the current modified live virus (MLV) Ingelvac® PRRSV vaccine. The negative control group (group 4) animals were mock-challenged with MARC-145 cell culture supernatant.

[0048] Pigs were observed daily for clinical signs and body temperatures taken for the first 7 days after infection. Blood samples were obtained from all pigs on days 0, 7, 14, 21, 28, 35, and 42. Serum samples were stored at -80° C. for further tests. Two pigs from each group were euthanized at 21 days post inoculation (dpi) for post-mortem analysis of acute infection. The remaining three pigs from each group were euthanized at 42 dpi. Lung lesions of the study animals were evaluated using a previously developed system based on the approximate volume that each lobe contributes to the entire lung: the left and right apical lobes, the left and right cardiac lobes, and the intermediate lobe each contribute 10% of the total lung volume, the left and right caudal lobes each contribute 25%. These scores were then used to calculate the total lung lesion score based on the relative contribution of each lobe (Halbur et al., 1995).

[0049] For the detection of viral RNA and determination of viral load, serum samples from 0, 7, 14, 21, 28, 35, and 42 dpi were examined using a real-time, quantitative PCR (Tetracore VetAlert PRRS; Wasilk et al., 2004), which is routinely performed at the South Dakota Animal Disease Research and Diagnostic Laboratory (SDSU-ADRDL). All serum samples were evaluated for anti-PRRSV antibodies using the IDXXX HerdChek® PRRS 2XR ELISA and virus neutralization assay (VN). These tests are also routinely performed at SDSU-ADRDL under strict quality assurance guidelines.

[0050] All pigs that received viruses became infected, which was evident by positive RT-PCR results for the presence of viral RNA in serum and by serology. Virus in serum peaked at about 14 days post-infection (dpi) (FIG. 5A; Table 3). At 14 dpi, 5 of 6 pigs in the cloned virus group, 4 of 5 pigs in the parental virus group, and all 5 pigs in the vaccine groups had seroconverted (FIG. 5B; Table 3). Four of the 6 pigs in the cloned virus challenged group had detectable neutralizing antibody titers at 21 dpi, while 1 of the 5 pigs in the parental challenged group developed neutralizing antibodies by 21 dpi. Two of the pigs from the MLV vaccine challenged group developed detectable neutralizing antibody titers at 42 dpi (Table 3).

[0052] Introduction of green fluorescent protein into the Nsp2 region of the infectious clone. We explored the potential of using this infectious clone for foreign gene expression. Previous studies showed that Nsp2 is an excellent candidate site for foreign gene insertion. The C-terminal region of Nsp2 for both Type 1 and Type 2 contains hypervariable domains, including amino acid insertions and deletions (7, 8, 27). One of the major differences between the SD01-08 and LV, the prototypic member of European Type 1 viruses, is the presence of a 17 amino acid deletion in the Nsp2, which is located between amino acids 734 to 750 in ORF1 of LV. We inserted a green fluorescent protein (GFP) into this unique deletion site of Nsp2 (at amino acids 733/734 of SD01-08 ORF1a,

TABLE 3

Summary of serological and PCR results in serum of inoculated pigs at different days post infection (dpi).									
dpi	Parental virus			Cloned virus			MLV vaccine		
	PCR ^a	ELISA ^b	VN ^c	PCR ^a	ELISA ^b	VN ^c	PCR ^a	ELISA ^b	VN ^c
0	0/5	0/5	0/5	0/6	0/6	0/6	0/5	0/5	0/5
7	4/5	1/5	0/5	5/6	0/6	0/6	5/5	0/5	0/5
14	4/5	4/5	0/5	6/6	5/6	0/6	5/5	5/5	0/5
21*	5/5	5/5	1/5	6/6	5/6	4/6	5/5	5/5	0/5
28	2/3	3/3	2/3	4/4	4/4	2/4	3/3	3/3	0/3
35	1/3	3/3	2/3	2/4	4/4	2/4	3/3	3/3	0/3
42	0/3	3/3	3/3	1/4	4/4	2/4	2/3	3/3	2/3

^aPCR: number of pigs with a PCR positive/total number of pigs in each group determined by the real time PCR;

^bELISA: number of seropositive pigs/total number of pigs in each group determined by IDEXX HerdChek ® PRRS 2XR ELISA;

^cVN: number of pigs developing neutralizing antibody response/total number of pigs, determined by fluorescent focus neutralization assay. Results interpreted as 90% reduction of the viral infection.

*Two pigs euthanized at day 21 for analysis of acute infection.

[0051] All mock-infected pigs remained RT-PCR and PRRSV antibody negative throughout the study period. No significant clinical signs were observed in any of the infected pigs. Only mild pathological lung lesions characteristic of PRRSV, such as minor interstitial pneumonia, were observed in 3 of 6 pigs from the cloned virus group, 5 of 5 pigs from the parental virus group and 2 of 5 pigs from the vaccine group. The rest of the pigs did not show gross lung lesions (Table 4). Interestingly, in comparing to the pathological lesions among the pigs from different groups, the lesion scores appear slightly higher in pigs infected with parental virus.

TABLE 4

Percentage of lung with gross pneumonia lesions in infected pigs.				
Pig number	Gross lung lesion score (%) [*]			
	Cloned virus	Parental virus	MLV vaccine	Mock control
#1	0	0.6	0.7	0
#2	1.0	0.5	0	0
#3	0.9	10.5	0	0
#4	0	2.1	0.3	0
#5	0	3.25	0	0
#6	1.5	N/A	N/A	N/A

^{*}Gross lung pathology was assessed by using a gross pig lung lesion scoring system where each lobe of the lung was evaluated for % pneumonia, and the % pneumonia of each lobe was added for entire lung (10).

FIG. 7). The construct, pSD01-08-GFP was in vitro transcribed and transfected into BHK-21 cells. Live cells were examined directly under a fluorescence microscope after 48 hours post-transfection. The cell culture supernatant from transfected BHK cells was passaged onto MARC-145 cells, resulting in the appearance of GFP-expressing cells, which could be clearly visualized as early as 6 hours after infection (FIG. 6A). To confirm the expression of GFP-Nsp2 fusion protein, at 48 hours post-infection, cells were fixed and stained with an Nsp2 specific mAb ES3-4 58-46. ES3-4 58-46 was generated by immunizing mice with synthetic peptide made from ES3 epitope sequence, which is located immediately up-stream of the GFP insertion site (FIG. 7). A red fluorescent Cy3-conjugated goat anti-mouse IgG was used as secondary antibody. Confocal microscopy showed the perinuclear localization of both GFP and Nsp2, similar to Nsp2 localization of the parental virus (FIGS. 6B and 6C). To determine if the expression of GFP affected virus replication, the growth characteristics of the GFP virus were compared to the parental wild-type and cloned viruses. The replication cycle of the pSD01-08-GFP virus was similar to the other viruses, including peak viral titers at 48 hpi; however, the peak titer for the GFP virus infection was approximately 10 fold reduced (FIG. 3).

[0053] To investigate the stability of GFP expression over multiple rounds of virus replication, the GFP virus was serially passaged eight times on MARC-145 cells. By the seventh passage, there appeared a subpopulation of non-GFP express-

ing virus, which was counted as 15% of the total virus population. The loss of GFP was also analyzed by RT-PCR. Total cellular RNA was isolated from cells infected with the seventh passage of the GFP virus, and RNA was used as a template in a RT-PCR reaction with primers that amplified the GFP insertion region. The RT-PCR product was cloned and sequenced. The results revealed that the N-terminal amino acids 1-159 of GFP were deleted (FIG. 7). More interestingly, while the amino acids 1-159 were deleted, two amino acids, methionine (M) and glutamic acid (E) were inserted by the virus before the GFP amino acid 160 (FIG. 7). Therefore, the selection of viral genome encoding the deletion in the GFP gene accounted for the decline in the percentage of infected cells expressing GFP. Taken together, these results indicate that the Nsp2 region can tolerate the introduction of a foreign gene. However, inserting a foreign gene reduces the level of viral replication. The positive marker, GFP gene was thus not stable.

II. Negative Marker Virus GFP/ΔES4

[0054] GFP/ΔES4 negative marker vaccine virus construction. In order to obtain a potential negative marker vaccine virus, the B-cell epitope, ES4, that is located downstream of the GFP (at nucleotide 2427 to 2591 of SD01-08 viral genome) was deleted by overlapping extension PCR techniques (Hayashi et al., 1994) using primer pairs ΔES4F/E3448R and E1895F/ΔES4R (Table 5). The PCR product was digested with RsrII and EcoRV restriction enzymes and ligated into the pSD01-08-GFP plasmid, which was digested with the same restriction enzymes. The resulting plasmid construct is designated as pSD01-08-GFP/ΔES4 (FIG. 8).

TABLE 5

Primers used for ES4 epitope deletion and ELISA antigen expression.			Genome position in SD01-08@
Primer name	Sequence*		
ΔES4F	5' caa gtc ctc tac agg gcc cat act c SEQ ID NO. 32	2421-2426 2592-2606	
ΔES4R	5' ggc cct gta gag gac ttg tac agc tc SEQ ID NO. 33	2421-2426 2592-2599	
E1895F	5' ctt gct gat cc acct cct cag g SEQ ID NO. 34	1905-1926	
E3448R	5' ccg tcg gag ggg gtg gca tcc SEQ ID NO. 35	3377-3397	
Nsp2-2144F	5' gtc tgt gtc ctt gga cga gtg SEQ ID NO. 36	2144-2164	
Nsp2-2694R	5' cca agc ggc caa gga tag atc SEQ ID NO. 37	2694-2714	
pET-EGFP-F	5' cgg gat cca tgg tga gca agg gcg agg agc SEQ ID NO. 38	—	

TABLE 5-continued

Primers used for ES4 epitope deletion and ELISA antigen expression.			Genome position in SD01-08@
Primer name	Sequence*		
pET-EGFP-R	5' cct <u>aaq ctt</u> cct tgt aca gct cgt cca tgc cg SEQ ID NO. 39	—	
pET-ES4F1	5' gc <u>aga tct</u> tca gac tcc aag aga gaa SEQ ID NO. 40	2427-2444	
pET-ES4F2	5' gc <u>agatct</u> ggt ggt ggt ggt tcc tca gac tcc aag aga gaa SEQ ID NO. 41	2427-2444	
pET-ES4R	5' at ccc <u>aaq ctt</u> gcg <u>ggg</u> <u>atc ccg</u> gga caa atc ctc g SEQ ID NO. 42	2577-2591	

*Nucleotides of GFP are bolded, restriction enzyme sites are italicized and underlined; @Numbers correspond to nucleotide positions within the SD01-08 genome.

[0055] FIG. 8 is a schematic diagram of the pSD01-08-GFP/ΔES4 construct. The GFP was inserted between amino acids 733 and 734 of ORF1a, and the immunogenic B-cell epitope, ES4, located downstream of GFP (at amino acid 736 to 790) was deleted from SD01-08 virus. Direct transfection of this plasmid DNA into BHK-21 cells initiates a full cycle of virus replication. Cell culture supernatants from BHK-21 cells obtained 48 hours post-transfection were passaged onto MARC-145 cells, infectious progeny virus was recovered, and the resulting virus was designated as GFP/ΔES4 marker virus. The parental virus, SD01-08, was generated in parallel from the pSD01-08 cDNA clone. Passage two of the viruses from MARC-154 cells was used for in vitro and in vivo characterization.

[0056] Growth kinetics study showed that GFP/ΔES4 marker viruses replicated with slightly slower kinetics, reaching maximal titer several hours later than the parental virus, SD01-08. The peak viral titer of the marker virus (3.34×10^4 FFU/ml) was approximately two logs lower titer than that of the parental virus (2.56×10^6 FFU/ml) (FIG. 9). FIG. 9 depicts growth kinetics of GFP/ΔES4 marker viruses. MARC-145 cells were infected in parallel at MOI of 0.1 with the passage three of GFP/ΔES4 marker virus and parental virus. At 0, 6, 12, 24, 36, 48, 60, and 72 hours post infection, cells were harvested and the virus titers were determined by IFA on MARC-145 cells. The results were mean values from three replications of the experiment, and viral titers were expressed as fluorescence focus units per milliliter (FFU/ml). Plaque morphology between the marker virus and parental virus was compared by plaque assay on MARC-145 cells. Viral plaques formed by GFP/ΔES4 marker virus were drastically reduced in size, and most plaques were of pinpoint size (FIG. 10), suggesting a negative effect of the GFP insertion/ES4 deletion on the rate of cell-to-cell spread during infection. FIG. 10 shows plaque morphology of GFP/ΔES4 marker viruses (10-1) and parental viruses (10-2). Confluent cell culture monolayers were infected with viruses at a MOI of 0.1. After 2 hours infection, cell culture supernatant was removed and an

agar overlay was applied. Plaques were detected after 5 days at 37° C. and stained by using 0.1% crystal violet.

[0057] In vitro stability of the GFP insertion or ES4 deletion in the recombinant viruses was followed for 10 serial passages (72 hours incubation for each passage) in MARC-145 cells. The GFP/ Δ ES4 region of the virus at passage 10 was sequenced. Surprisingly, unlike the previous SD01-08-GFP virus which experienced a deletion of the N-terminal 159 amino acids, the GFP in the GFP/ Δ ES4 marker virus remained intact as a full-length gene, and the ES4 deletion was still present. This result indicates that deletion of the ES4 epitope region improved the stability of the inserted foreign gene, GFP. A small population of the infected cells was identified that lost the GFP-associated fluorescence (FIG. 11). GFP expression in MARC-145 cells infected with passage 10 of the GFP/ Δ ES4 marker viruses is shown in 11-1. The same viral focus stained with AlexiFluor-labeled anti-nucleocapsid monoclonal antibody, SDOW17 (Nelson et al., 1993) is shown in 11-2. The population of viruses that lost GFP fluorescence is shown in the circle.

[0058] For the GFP/ Δ ES4 region, we performed three independent repeats of PCR and sequencing (both forward and reverse directions). Therefore, a total six sequences were obtained. In one of the sequences, a nucleotide C-289 to T-289 mutation was identified, which caused the amino acid mutation of arginine to cysteine at position 97 of the GFP, which may correspond to the small population of infected cells that lost the GFP-associated fluorescence (FIG. 12). No mutation was detected on the other five sequences. FIG. 12 depicts an electrophoregram of the wild-type GFP gene in comparison to the Arg-97 mutated GFP gene. The GFP insertion region was sequenced from cell culture passage 10 of the GFP/ Δ ES4 marker viruses. Amino acids are presented in a single letter code, and the bold letter indicates mutated amino acid from CGC (Arg) to TGC (Cys).

[0059] ES4 and GFP antigens expression. The ES4 antigen was expressed as tandem repeat ES4 epitopes using a modified method described previously (Sun et al., 2004). Briefly, three copies of the ES4 epitope (amino acid 736-790 of ORF1a of SD01-08), were constructed in protein expression vector, pET-28a (+) (Novagen). A flexible peptide linker, GGTGGTGGTGGTTCC, was added between the epitopes to help display the epitopes. There were two forward primers. Forward primer 1, pET-ES4F1 contained a BglII restriction site, but without a linker sequence, whereas the forward primer 2, pET-ES4F2 contained not only a BglII restriction site, but also the linker sequence. The ES4 gene fragment was first amplified with the forward primer 1 and reverse primer, pET-ES4R. The PCR product was digested with BglII and HindIII, and then cloned into pET-28a that was digested with BamHI and HindIII. This clone was designated as pET-28a-ES4 (+1). The second copy of ES4 was PCR amplified by forward primer 2 and reverse primer, pET-ES4R. The PCR product was digested with BglII and HindIII, and then cloned into pET-28a-ES4 (+1) that was digested with BamHI and HindIII. The third copy of the ES4 was inserted using the same strategy as the second copy. The final construct was designated as pET-28a-ES4 (+3). The GFP gene was amplified from the pEGFP-N1 plasmid (Clontech) with primer pair pET-EGFP-F/pET-EGFP-R. The PCR product was digested by BamHI and HindIII restriction enzymes and ligated to the pET-28a vector that was digested with the same enzymes. Recombinant proteins were expressed in *E. coli* BL21 (DE3) to produce a fusion protein with six histidine residues at the

N-terminal. The proteins were purified by nickel-affinity chromatography and analyzed by SDS-PAGE as described in our previous publication (Ferrin et al., 2004).

[0060] In vivo characterization of GFP/ Δ ES4 marker virus. The in vivo characteristics of the GFP/ Δ ES4 marker virus were studied in a nursery pig disease model. Eighteen four-week-old pigs were purchased from a PRRSV-free herd. The animals were randomly separated into three groups (n=6/group) and housed under BL2 isolation conditions with an acclimation period of 7 days before starting experimental inoculations. Group 1 pigs were infected with GFP/ Δ ES4 marker virus, the group 2 pigs were infected with parental SD01-08 virus as the positive control, and group 3 pigs were mock-infected with the cell culture medium. Group 1 and group 2 pigs were inoculated through both intranasal and intramuscular sites with 1×10^6 50% tissue culture infective doses (TCID₅₀) of the virus (1 ml at each site). On 42 days post infection (dpi), group 1 and group 2 pigs were challenged with a heterologous Type 1 strain, SD03-15 virus.

[0061] The SD03-15 is another US Type 1 strain, which was isolated from clinical samples submitted to our diagnostic laboratory in 2003. In field reports, pigs infected with SD03-15 were experiencing a pre-weaning mortality of 80-90% for a 3-week period. Decreased performance continued through the finisher phase. In the adult sow population, there was a mild abortion storm, compared to previous US PRRSV outbreaks. Our previous experimental animal study also demonstrated the pathogenic nature of this virus (Lawson et al., Proc. Conf. Res. Work. Anim. Dis., abstr. 99, 2005).

[0062] Three pigs from group 3 were challenged with SD03-15 virus, and the other three pigs remained as mock-infected controls. Pigs were observed daily for clinical signs and body temperatures for the first 7 days after infection and the first 7 days after challenge. Mean temperature responses between different challenge groups were compared. Rectal temperatures were taken one day before challenge, and 7 days after challenge. No temperature increase was detected in any pigs after initial infection and no clinical signs were observed. After challenge, rectal temperatures were elevated in those three challenged pigs from Group 3 (initially mock infected) at one and two days post challenge (FIG. 13). Clinical signs (coughing and nasal discharge) were also observed in these three pigs. The rest of the pigs remained asymptomatic. Blood samples were obtained once per week from all pigs. Pigs were euthanized at 21 days post challenge. Gross lung lesions of the study animal were evaluated using a previously developed system based on the approximate volume that each lobe contributes to the entire lung: the left and right apical lobes, the left and right cardiac lobes, and the intermediate lobe each contribute 10% of the total lung volume, and the left and right caudal lobes each contribute 25%. These scores were then used to calculate the total lung lesion score based on the relative contributions of each lobe (Halbur et al., 1995). At necropsy, gross pathologic lesions were not observed in Group 1, Group 2, and the three strict negative control pigs. In contrast, mild gross pathologic lung lesions characteristic of PRRSV were observed in those three pigs from Group 3 that were initially mock infected and then challenged with SD03-15.

[0063] Virological and immunological properties. In vivo virological and immunological properties of the marker virus were determined. Pigs were challenged at 42 dpi, shown as a vertical dotted line in FIGS. 14A-14C. The duration and height of viremia was determined by real-time PCR, and the

result was interpreted as RNA copy numbers per ml. At each day post-infection, mean viral load with different capital letters (A, B or C) differ significantly ($P < 0.05$). In comparison to Group 2 pigs infected with parental viruses (peak mean viral titer = 5.9×10^7 copies/ml), pigs that were infected with the GFP/ Δ ES4 marker virus had lower peak viral load (peak mean viral titer = 2.08×10^5 copies/ml, FIG. 14A). At day 7 post-challenge, the viral load was two to three logs lower for the pigs vaccinated than those pigs initially mock infected and then challenged with SD03-15 virus. By day 21 post-challenge, GFP/ Δ ES4 marker virus infected-group pigs had a 10-fold lower viral load in comparison to the parental group, and $\frac{3}{5}$ pigs had eliminated the virus in the serum (FIG. 14A; Table 6).

TABLE 6

Viral load in serum measured by quantitative PCR at 21 days post-challenge with a genetically different strain, SD03-15.				
Viral load in serum (copies/ml)				
Pig numbers	GFP/ Δ ES4	Parental	Negative/challenged*	Negative
1	0	2.7E+02	N/A	0
2	7.4E+02	0	N/A	0
3	0	1.2E+04	N/A	0
4	N/A	0	3.6E+04	N/A
5	0	2.6E+03	3.3E+04	N/A
6	1.7E+02	1.1E+04	3.6E+04	N/A
Mean	1.8E+02	4.3E+03	3.5E+04	0

*Three of the pigs in negative group challenged with the heterologous strain, SD 03-15 at 42 dpi.

[0064] By 14 dpi, all of the pigs in infected groups had seroconverted. PRRSV-specific serum antibodies were measured by an IDEXX HerdChek® PRRSV ELISA 2XR kit. S/P ratios of greater than 0.4 are considered positive. The antibody response reached similar levels after 21 dpi (FIG. 14B).

[0065] Viral neutralizing antibody response was determined by fluorescent focus neutralization assay (FIG. 14C). Results were interpreted as a 90% reduction of the viral infection, and the neutralizing antibody titers were presented as mean value ($n=6$) and expressed on a $\log_2$ scale. The parental SD01-08 virus was used for the viral neutralizing assay. At each day post-infection, means with different capital letters (A, B or C) differ significantly ($P < 0.05$). Further measurement of the serum neutralizing (SN) antibody levels showed that in pigs infected with the parental virus, SN antibodies were detected from one of the six pigs by 21 days post-infection, and $\frac{3}{5}$ pigs developed detectable SN titer that reached an average geometric mean titer (GMT) of 2 by 35 days post-infection. In contrast, neutralizing antibody responses developed faster and higher in pigs infected with GFP/ Δ ES4 marker virus. SN antibodies were detected from one of the six pigs by 14 days post-infection, and SN titers were detected from all of the pigs in this group, which reached an average GMT of 9.2 by 35 days post-infection. After challenge with SD03-15, an increased effect was observed, with the GMT of 18.4 from the GFP/ Δ ES4 marker virus infected group compared to the GMT of 5.7 from the parental virus infected group at 49 dpi (one week after challenge). Both groups reached similar SN titers at 62 dpi (three weeks after challenge) (FIG. 14C). These data suggest that on the

initial infection, pigs infected with GFP/ Δ ES4 marker virus generated higher neutralizing antibody titers than pigs infected with parental virus.

[0066] Virus isolation and sequencing. Serum samples from 7, 14, 21, and 28 dpi were used for virus isolation as described previously (Wasilk et al., 2004). The presence of virus was confirmed by IFA with PRRSV specific antibody, SDOW17 (Nelson et al., 1993). To determine the stability of the GFP insertion and ES4 epitope deletion, viral RNA was extracted from the serum-isolated virus using QIAamp Viral RNA mini kit (Qiagen) following the manufacture's instruction. The RT-PCR was performed using previously described methods (Fang et al., 2004). The RT-PCR amplified fragment was gel purified, and the sequence was determined at the Iowa State University sequencing facility (Ames, Iowa). Primer pair nsp2-2144F/nsp2-2694R (Table 5) was used for RT-PCR and sequencing, and amplifies the nucleotide region (2144 to 2694 of SD01-08 genome) containing the GFP insertion and ES4 deletion. The full length sequence of the GFP/ Δ ES4 marker virus is provided in SEQ ID NO. 43 (Table 7).

[0067] In vivo stability of the GFP/ Δ ES4 marker. To determine stability of the GFP/ Δ ES4 markers, serum samples from 7 to 28 dpi were used for virus isolation on MARC-145 cells. Viruses were recovered from the serum samples collected on 7, 14, and 21 dpi, and no virus was isolated from the serum samples collected from 28 dpi. In cell culture, we only observed a small population of infected cells showing weak GFP fluorescence with the viruses isolated from 7 and 14 dpi, no GFP fluorescence was observed in infected cells with the viruses isolated from 21 dpi. However, immunofluorescent staining using nucleocapsid protein specific monoclonal antibody, SDOW17 confirmed the presence of a large population of viruses, similar to that observed in the in vitro study (FIG. 11). The stability of the GFP insertion/ Δ ES4 deletion was determined by sequencing the corresponding regions. The results confirmed the presence of the ES4 deletion, and the GFP remained intact as a full-length gene. However, sequencing results revealed two point mutations that were located at nucleotide 144 (C to T) and nucleotide 289 (C to T) of the GFP. The nucleotide 144 mutation was silent, but the nucleotide 289 mutation caused amino acid mutation of arginine (R) to cysteine (C) at position 97 of the GFP, which is consistent with our in vitro sequencing analysis (FIG. 12). Interestingly, there was still a small population of the non-mutated GFP gene detected in the viruses isolated from 7 and 14 dpi. For each dpi, we have sequenced viruses isolated from three pigs, and sequencing was performed using both forward and reverse primers, resulting in a total of six sequences for each dpi. For the viruses isolated from 7 dpi, $\frac{1}{6}$ sequences was found to have no mutation at position 97, and the other five sequences were determined to contain the R to C mutation. For the viruses isolated from 14 dpi, $\frac{2}{6}$ sequences identified no mutations, and these two sequences were from two different pigs. The other four sequences were also identified to contain the R to C mutation. All the sequences generated from viruses of 21 dpi contained the R to C mutation. This data was consistent with a previous report (Kim et al., 2007) that the loss of GFP fluorescence is due to the R to C mutation. The presence of small population of the non-mutated GFP would account for the weakly fluorescing cells observed in the cell culture. These results suggest that the selection may have gradually occurred to generate the mutation in favor of improved viral replication.

[0068] GFP and ES4 epitope-based ELISA. ELISAs were performed using Immulon II HB 96-well microtiter plates (Thermo LabSystems, Franklin, Mass.). The recombinant protein was diluted in coating buffer (15 mM sodium carbonate-35 mM sodium bicarbonate, pH 9.6), and the plates were coated with 100 μ l of the diluted antigen in columns 1, 3, 5, 7, 9, and 11. Columns 2, 4, 6, 8, 10, and 12 were treated with 100 μ l of coating buffer as a background control. Plates were incubated at 37° C. for 1 hour, and then excess protein binding sites were blocked with 10% milk in PBST buffer (1 $\times$ PBS with 0.05% Tween 20) at 4° C. overnight. The test sera were applied at 1:5 dilutions in PBST buffer with 5% milk. After 1 hour incubation at 37° C., plates were washed with PBST and horseradish peroxidase-conjugated goat anti-swine IgG (Kirkegaard & Perry Laboratories, Gaithersburg, Md.) was added to bind to any PRRSV serum antibodies that bound to the antigen on the plates. Plates were incubated at 37° C. for another hour, washed, and the peroxidase substrate ABTS (Kirkegaard & Perry Laboratories, Gaithersburg, Md.) was added for color development. The color development was quantified by reading at 405 nm with an EL800 microplate reader (BioTek Instruments Inc., Winooski, Vt.) controlled by XChck Software (IDEXX Laboratories).

[0069] A companion differential diagnostic assay was developed to differentiate animals that were vaccinated with the marker vaccine from those naturally infected with the field viruses. Because two markers, the GFP insertion (positive marker) and ES4 deletion (negative marker), were used, we developed both GFP and ES4 epitope-based ELISA assays for marker detection. Both GFP and ES4 epitopes were expressed as soluble recombinant proteins. We evaluated these two ELISA tests for detecting the specific antibodies. FIG. 15A shows results from the ES4 epitope-based ELISA, and FIG. 15B shows results from the GFP antigen-based ELISA. Pigs were challenged at day 42 post-infection shown as a dotted vertical line in FIG. 15A. As expected, the infection of Group 1 pigs with GFP/ Δ ES4 marker virus did not induce a detectable antibody response against the deleted ES4 epitope (FIG. 15A), but induced a strong antibody response against the GFP antigen, starting from 14 dpi and continuing for the duration of the study to 62 dpi (FIG. 15B). In contrast, the Group 2 pigs that were infected with parental virus, antibody specific to ES4 recombinant protein could be detected at 21 dpi, and also lasted to 62 dpi (FIG. 15A), while no specific antibody response was detected against GFP antigen (FIG. 15B). After challenged with 03-15, the Group 1 pigs showed a detectable antibody response to the ES4 epitope one week after challenge, since 03-15 virus contains the ES4 epitope (FIG. 15A). No specific antibody response was detected on both GFP and ES4 epitope-based ELISAs for the serum samples from the three strict negative control pigs (FIGS. 15A and 15B).

[0070] Serum samples from other Type 1 and Type 2 PRRSV infected animals. A basic requirement for the negative marker is that the antigenic region should be able to react with a broad array of field viruses. To ensure that the ES4 epitope can be reactive in various viral strains, we used serum samples from pigs infected with each of four representative strains of the US Type 1 virus, SD01-07, SD01-08, SD02-11, and SD03-15 (Lawson et al., Proc. Conf. Res. Work. Anim. Dis., abstr. 99, 2005). The SD01-07 and SD01-08 isolates were obtained from herds showing no clinical disease and SD02-11 and SD03-15 were from herds with substantial morbidity and mortality in young pigs. These four isolates also

group into different branches of the phylogenetic tree developed for Type 1 PRRSV isolates of US origin (Fang et al., 2007). Serum samples from experimental pigs infected with Type 2 virus, VR2332 were obtained from the shared reagent resource of the PRRSV Cooperative Agriculture Project (CAP). As shown in FIG. 15C, the ES4 epitope reacted with anti-sera from all of the pigs infected with these four viral strains. The results are presented as mean values (n=6). The antibody response was detected by 14 dpi, and lasted more than 62 dpi. However, further testing of serum samples from a group of experimental pigs infected with Type 2 prototypic strain, VR2332 showed no reactivity with the ES4 epitope on the ELISA (data not shown). Therefore, another serological test will be required to differentiate animals infected with Type 1 viruses from those animals infected with Type 2 viruses.

III. Discussion

[0071] Two genetic markers in the nsp2 region of the PRRSV virus have been constructed. The positive marker (GFP insertion) will allow detection of the animals that have been vaccinated, while the negative marker (ES4 epitope deletion) will allow detecting the presence of wild-type virus in the animals. In comparison to the MLV prepared by traditional multiple cell culture passage techniques, vaccines constructed using this type of precisely defined attenuating deletions/insertions and the use of reverse genetics technology reduces the potential risk of reversion to virulent wild-type viruses.

[0072] Marker vaccines are only useful if suitable tests (companion diagnostic tests) are available to monitor the vaccination levels and to follow the spatial course of the infection. The GFP antigen-based ELISA detected a high level of the anti-GFP response in the group of pigs infected with the marker virus. The ES4 epitope-based ELISA also detected a high level of antibody response in the group of pigs infected with the parental virus, but appeared to develop slower than that of the anti-GFP response. A high level, robust anti-GFP response can be detected by 14 dpi in marker virus infected pigs, while anti-ES4 antibody response was detected by 21 dpi and reached higher levels by 28 dpi in pigs infected with wild-type virus. The ES4 epitope possesses the highest hydrophilic values (Hopp & Woods, 1981) among the six B-cell epitopes identified on the nsp2 of Type 1 virus (Oleksiewicz et al., 2001). Analysis of the currently available nsp2 amino acid sequences of Type 1 PRRSV (Meulenberg et al., 1993; Fang et al., 2007) showed that this region possesses 63.6% to 100% amino acid sequence identity within the Type 1 genotype. Protein sequence analysis showed that the ES4 epitope region, AA736-AA790, actually contains seven small B-cell epitopes (PepTool, BioTools, Inc., Edmonton, Alberta, Canada). Epitope AA745-AA754 and AA768-AA780 are well conserved within the Type 1 genotype. Our ES4 ELISA data was consistent with the protein sequence analysis, showing that the ES4 epitope can react with sera samples from animals infected with four representative field strains of Type 1 PRRSV. However, ES4 epitope does not react with serum samples from animals infected with Type 2 isolates. In comparison of the identified B-cell epitopes on nsp2 region (Oleksiewicz et al., 2001; de Lima et al., 2006), none of the epitopes identified in the nsp2 region was conserved between Type 1 and Type 2 isolates. Therefore, another diagnostic assay is required to differentiate pigs vaccinated with the ES4 epitope deletion mutant from those pigs infected with Type 2 field strains.

[0073] The ES4 epitope in the nsp2 region appears to be non-essential for PRRSV replication but may play an important role in viral attenuation and pathogenesis in vivo. Insertion of the GFP alone did not substantially reduce the in vitro growth properties of the virus, however, when the ES4 epitope downstream of the GFP was deleted, viral titer was reduced at least two-logs in comparison to that of parental viruses. Plaque morphology also demonstrated negative effects of the markers in virus growth. In vivo characterization further demonstrated that the GFP/ Δ ES4 marker virus was attenuated with a lower level of viremia and higher level of neutralizing antibody response than that of wild-type virus. Protein sequence analysis has showed that the ES4 epitope region contains the highest hydrophilic value on the nsp2 (Hopp & Woods, 1981).

[0074] Surprisingly, the ES4 epitope deletion improved the stability of the GFP insertion in the nsp2. Another interesting observation is the loss of GFP fluorescence in vitro and in vivo although the GFP gene remained intact. Sequence analysis identified the Arg-97 to Cys mutation in the GFP. The Arg-97 to Cys mutation is exactly the same amino acid mutation identified on GFP that was inserted into the nsp2 region

of a Type 2 virus (Kim et al., 2007). As indicated by Kim et al (2007) that Arg-97 plays a key role in the chromophore formation of GFP, which suggests that the chromophore formation may affect nsp2 function. In addition, since Cys is the amino acid normally involved in forming the disulfide-bond in the protein, the additional disulfide-bond may be required in maintaining the correct conformation of nsp2 in order to function. Nevertheless, the GFP retains its immunogenicity in vivo, and functions as an excellent positive marker for differentiation between vaccinated and wild-type virus infected animals.

[0075] All publications and patent applications in this specification are indicative of the level of ordinary skill in the art to which this invention pertains. All publications and patent applications are herein incorporated by reference to the same extent as if each individual publication or patent application was specifically and individually indicated by reference.

[0076] The invention has been described with reference to various embodiments and techniques. However, it should be understood that many variations and modifications may be made while remaining within the spirit and scope of the invention.

TABLE 7

Full length sequence of the GFP/-ES4 marker virus (SEQ ID NO: 43).		
atgatgtgta gggatcccc cctacatata caacactttt tgtgtttgtg tactttggag		60
gcgtgggtac agcccccgcc cacccttgg ccctgttct agcccaacag gtatccttct		120
ccctcggggc gagtgcgcc cctgtgtct ccttgcaagt ggaaggacct ccgagattt		180
tccggagagc acctgcttta cgggatctcc accctttaac catgtctggg acgttctccc		240
ggtgcatgtg caccgccgct gcccggtat tttggaacgc cggccaagtc tttgacacac		300
ggtgtctcag tgcgcggcct cttctctctc cggaacttca ggacactgac ctcggtgtag		360
ttggattgtt ttacaagcct aaggacaaga ttacttgaa agttcctatc ggcatctctc		420
aggtggagtg tactccatcc ggggtgtgct ggctctcagc cgtattccct ttggcgcgca		480
tgacttcggg taatcacaa ctcctccaac gacttgtaa ggttgctgat gttttgtatc		540
gcgatgggtg ctggcgcct cgacacctcc gtgaactcca agtttacgag cgcggttgta		600
gctggtaccc aattacgggg ccctgacctg gaatgggttt gtttgcaac tccatgcacg		660
tgtctgacca gccgttcctt ggtgccaccc atgtgttgac taactcgctt ctgcctcagc		720
gggcgtgccg gcagccgttc tgctcatttg aggaagctca ttctgacgtt tacagggtgga		780
agaaatttgt gatatttacg gactcctctc ccaacggtcg atttcgcatg atgtggacgc		840
cggaatccga tgactcagcc gccctggagg tgetgccgcc cgagtttaga cgtcaggtcg		900
agatcctcac tcggagtttt ccgctcatc accctataca cctagctgac tgggagctca		960
ctgagtcctc tgagaacggt tttctttctg gcacgtccca ttcttgccgc cacatcgctc		1020
agaaccccaa cgtgtttgac ggcaagtgtt ggctcacctg ctttttgggc caatcggtcg		1080
aagtgtgcta ccacaggaa catctagcta acgcctcgg ttaccaaacc aagtggggcg		1140
tgcatggtaa gtacctcaa cgcaggcttc aagtcgcgg catgctgtct gtggctgac		1200
ctgacggccc tattcacgtt gaagcgtgt cttgtctcca gtcttggtc aggcacctga		1260
ctctgaataa tgatgtcacc ccaggattcg ttgcctgac atccatccgc attgtgtcca		1320
acacagaacc caccgcttcc cggatcttcc ggtttggagc acataagtgg tatggcgctg		1380

TABLE 7-continued

Full length sequence of the GFP/-ES4 marker virus (SEQ ID NO: 43).		
ccggcaaacg ggctcgtgcc aaacgtgcc ccaaaagtgg gaaggattcg gccctcgctc	1440	
ccaagattgc cccaccggtc cccacctgtg gaatcaccac ctactctcca ccgacagacg	1500	
ggtcttgtgg ttggcacgtt cttgccgcca tagtgaatcg gatgataaac ggtgacttta	1560	
cgccccccct gcctcagtag aacagaccag aggatgattg ggcttctgat tatgatcttg	1620	
ctcaggcgat tcaatgttta caactgcctg ccaccgtggt tcggaatcgc gcctgtccta	1680	
acgccaagta cctcataaag ctaaacgggg ttactcggga agtagagggt agatctggaa	1740	
tggtcctcgc ttccctttct cgtgaatgtg tagttggcgt ttgctctgaa ggctgtgtcg	1800	
caccgcctta tccagcggac gggcttccta aacgtgcact cgaggccttg gcgtctgcct	1860	
acagactacc ctcagattgt gttagctctg gtattgctga ctttcttgct gatccacctc	1920	
ctcaggaatt ctggactctc gacaaaatgt tgacctcccc gtcaccggag cgttccggct	1980	
tctccagctt gtataaatga ctcttagagg ttgttccgca aaaatgtggt gctacggaag	2040	
gggctttcgt ctatgctgtt gagaggatgt taaaggactg tccgagcccc gaacaggcca	2100	
tgcccttctt ggcaaaaatt aaagttccat cctcaaaggc cccgtctgtg tcttggacg	2160	
agtgttttcc tgcgggtggt ccagccgact tcgagccagc atttcaggaa aggccccaaa	2220	
gtcccgggtg tgctgtgcc ctgtgttcac cggacgcaaa agggttcgag ggaacagcct	2280	
cgaagaagc tcaagagagt ggccataagg ccgtccacgc tgtacctctt gccgaaggtc	2340	
ccaataatga acaggtacag gtggttgctg gtgagcagct agagctcggc ggttgtggtt	2400	
tggaatcgg gagtgctcag atggtgagca agggcgagga gctgttcacc ggggtggtgc	2460	
ccatcctggt cgagctggac ggcgacgtaa acggccacaa gttcagcgtg tccggcgagg	2520	
gcgagggcga tgccacctac ggcaagctga cctgaagtt catctgcacc accggcaagc	2580	
tgcccggtgc ctggcccacc ctcgtgacca cctgacctc cggcgtgcag tgcttcagcc	2640	
gtacccccga ccacatgaag cagcagcact tcttcaagtc cgccatgccc gaaggctacg	2700	
tccaggagcg caccatcttc ttcaaggacg acggcaacta caagaccgc gccgaggtga	2760	
agttcgaggg cgacacctg gtgaaccgca tcgagctgaa gggcatcgac ttcaaggagg	2820	
acggcaacat cctggggcac aagctggagt acaactacaa cagccacaac gtctatatca	2880	
tgcccgacaa gcagaagaac ggcataaagg tgaacttcaa gatccgccac aacatcgagg	2940	
acggcagcgt gcagctcgcc gaccactacc agcagaacac ccccatcggc gacggccccg	3000	
tgctgctgcc cgacaaccac tacctgagca ccagtcctgc cctgagcaaa gacccaacg	3060	
agaagcgcga tcacatggtc ctgctggagt tcgtgaccgc cgccgggatc actctcgga	3120	
tggaagagct gtacaagtcc tctacagggc ccatactcgc tcattgtgag cactgcggca	3180	
cagagtcagg cgacagcagt tcgcctttgg atctgtcttt tgcgcaaacg ttggaccagc	3240	
ctttagatct atccttggcc gcttggccgg tgaaggccac cgctctgat cctggctggg	3300	
tccgcggtag gtgcgagcct gtctttttta agcctcgaa agctttctct gatggcgatt	3360	
cggcccttca gttcggggag ctttctgagt ccagctctgt catcgagttt gaccagacaa	3420	
aagatactct ggtggctgac gcccctgttg acttgacgac ttcgaacgag gccctctctg	3480	
cagtcgaccc ttccgaattt gtcgaaacta ggcccccgg tcattccgca caagccttaa	3540	
ttgaccgagg cgttccactt gctgatgtcc atgcgaaaat aaagaaccgg gtgtatgaac	3600	

TABLE 7-continued

Full length sequence of the GFP/-ES4 marker virus (SEQ ID NO: 43).		
agtgcctcca agcttgtgag cctggtagtc gtgcaacccc agccaccagg gagtggctcg	3660	
acaaaatgtg ggataggggtg gacatgaaaa cttggcgctg cacttcacag ttccaggccg	3720	
gtcgcattct tgcgtccctc aaatttcttc ctgacatgat tcaagacacg ccgcctcctg	3780	
ttcccaagaa gaaccgagct agtgacagtg ccggtcagac cgtccctccg cctacggata	3840	
tccagcaaga ggatgccacc ccctccgacg ggttatccca tgcacggat ttttctagtc	3900	
gagtgcagc gagctggagt tggaaaggcc ttatgctttc cggcaccctg ctgcgggggt	3960	
ctgctgggtca gcgcctcatg acatgggttt ttgaagttaa ctcccatctc ccagctttta	4020	
tactcacact tttctgcgcg cggggctcta tggctccagg cgattgggtg tttgcaggtg	4080	
ttgttttact tgctctcttg ctctgtcgtt cttacccaat actcggtgc cttcccttac	4140	
tgggtgtctt ctctggttct ttgcggcggt ttcgtctggg tgtttttggg tcttggtg	4200	
cttttgcgtg atttttatc tcgactccat ccaaccagc cggttcttct tgtgaccacg	4260	
attcgccgga atgtcatgct gagcttttgg ctcttgagca gcgccaaact tgggaacctg	4320	
tgcgcggcct tgtggttggc ccctcaggtc tcttatgtgt catccttggc aagtactc	4380	
gtgggtcacg tcatctctgg catgttatcc tacgtttatg catgcttaca gatttggccc	4440	
tttctcttgt ttatgtgggt tcccaagggc gttgtcacia gtgttgggga aagtgtataa	4500	
ggacagctcc tgctgaggtg gctctcaatg tatttcttt ctgcgcgcgc actcgcaact	4560	
ctctcacatc cttgtgtgat cggttccaaa ctctaaagg agttgatccc gtgcaacttg	4620	
caacgggttg gcgcgggtgt tggcgtgggt agagtcccat ccatcaacca caccaaaagc	4680	
ccatagctta tgccaatttg gatgaaaaga aaatatctgc tcaaacgggtg gttgctgtcc	4740	
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ttccaaaagt tccagtaaac ccagattgca ggattgtggg ggattcagat acttttgtgg	4920	
ctgcagtcgg ctgcgggttac tcgacagcac aactgggtcct aggcgggggc aactttgcca	4980	
agttgaatca gacccccctt agggactctg cctccaccaa aacgactggg ggggcctctt	5040	
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tgcactcatt cttggtgttt tgtatgccag cagccggcat cctctcacta gggataactg	5520	
gccttctctg gccagttggc cgctttaccc aggttgccgg aattattaca ctttatgaca	5580	
ttccaccagta taactctggg ccacgcgggt cagccgctgt agccacagcc ccagaaggca	5640	
cttatatggc cgcgcctcgg agagctgctt taactggacg aactttgatc ttcacccctg	5700	
ctgcggctcg atccctctt gaaggtgctt tcaggactca taaacctgc cttaacaccg	5760	
tgaatgttgt gggttcttcc cttggttctg gaggggtttt taccattgat ggcagaaaga	5820	

TABLE 7-continued

Full length sequence of the GFP/-ES4 marker virus (SEQ ID NO: 43).		
ccgtcgtcac	tgctgctcat	gtgttgaacg gcgacacagc tagagttacc ggcgactcct 5880
acaaccgcat	gcacactttt	aagaccagtg gcgattatgc ctgggtcccat gctgatgact 5940
ggcagggcgt	tgccctctg	gtcaagggtg cgaaggggta tcgcggctcg gcctactggc 6000
aaacatcaac	cgggtgcgaa	cccggcgctca ttggggaagg gttcgcttc tgtttcacca 6060
actgtggcga	ttcgggggtca	cccgtcatct cagaatctgg tgatctcatc ggaatccata 6120
ccggttcaaa	caaacctcgt	tctggtcttg tgacgacccc tgaaggggaa acctgcgcca 6180
tcaaagaaac	caagctctct	gaccttccca gacattttgc gggcccgagc gtccctcttg 6240
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ctacgctcct	agcttccgct	cctgtaattg aaggcggcct ctcgaccgtt caacttctgt 6360
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gcttcttttt	gctgaatgaa	attcttccag cagttttggt ccgagccgtg ttttcctttg 6480
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tcattggtgg	actccatgcc	ctcgggtgta ttctgtggtt gttcaaatac cggtgccctc 6780
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ctgctctagc	ttgcaagtg	tcgcaggctg accttgactt tttgtccagc ttaacgaact 6960
tcaagtgcct	tgtatctgct	tcaaactga aaaatgctgc cggccagtat attgaagcag 7020
cgtatgccaa	ggccctgcgc	caagagttgg cctccctagt tcagggtgac aaaatgaaag 7080
gaattttgct	taagcttgag	gcctttgctg aaacagccac tccgtccctt gacgcagggtg 7140
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tttgactgtg	cgtgtccaac	acaccgtgg acgccttaac tggcatccca ctccagacac 7320
caaccctct	ttttgagaat	ggtccgcgtc accgtggtga ggaagacgat cttagagtcg 7380
agaggatgaa	gaaacactgt	gtgtccctcg gcttcacaaa catataggc aaagtttact 7440
gcaaaatttg	ggacaagtcc	accggtgata ccttttatac cgatgattcc cggtagaccc 7500
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aaaccgcccc	ccaacagggc	tttgatccaa agtctgaaac ccctattggc actgtggtga 7620
tcggcggtat	cacgtataac	aggtacctga tcaaaggtaa ggaggtcttg gttcccaagc 7680
ctgacaacgt	ccttgaagct	gccaaagctg cccttgagca agctctcgct gggatggggc 7740
aaacttgcca	ccttacagct	gccgaggtgg aaaagttgag gcgcattcatt agccagctcc 7800
aaggtttgac	cactgaacag	gctttaaact gttagccgcc agcggcttga cccgctgtgg 7860
ccgcggcggc	ttagttgtaa	ctgaaacagc ggtaaaaatc gtaaaagtacc acagcagaac 7920
tttcacccta	ggccctctgg	acctgaaagt cacctccgag gctgaggtaa agaaatcaac 7980
tgagcagggc	cacgctgttg	tggcaaaact atgttctggt gtcattctga tgagacctca 8040

TABLE 7-continued

Full length sequence of the GFP/-ES4 marker virus (SEQ ID NO: 43).						
cccaccgtcc	cttgttgatg	tctctctgaa	acccggaactt	gacacaaaac	ccggcattca	8100
accagggcat	ggggccggga	atatgggcgt	agacggctct	acttgggatt	ttgaaaccgc	8160
accacaaaag	gcagaacttg	agttgtccaa	acaaataatt	caagcatgtg	aagttaggcg	8220
cggggacgcc	ccgaacctcc	aactccctta	caagctctat	cctgttagag	gggatcctga	8280
gcggcatggg	ggccgcctta	tcaataccag	gtttggagat	ctatcttaca	aaaccctca	8340
agacaccaag	tccgaatcc	atgcggcttg	ttgcctgcac	cccaacgggg	cccctgtgtc	8400
tgatggtaag	tcaacactag	gtaccaccct	tcaacatggt	ttcgaacttt	atgtcccccac	8460
tgtgccctat	agtgtcatgg	agtacctcga	ttcacgccct	gacacccctt	tcatgtgcac	8520
taaacatggt	acttccaagg	ctgctgcaga	agacctccaa	aaatacgacc	tatctactca	8580
aggatttgtc	ctgccggggg	tcttacgcct	tgtacgcaga	ttcatctttg	gccatattgg	8640
taaggcaccg	ccattgttcc	tcccgctcaac	ctatcccgtc	aaaaattcta	tggcaggggat	8700
caatggccag	aggttcccaa	caaaggacgt	ccagagcata	cctgaaattg	acgaaatgtg	8760
tgcccgcgcc	gtcaaggaga	attggcaaac	tgtgacacct	tgtaccctca	agaaacagta	8820
ctgttccaag	cccaaaacca	ggaccatcct	gggcaccaac	aactttattg	ccctggctca	8880
ccgatcggcg	ctcagtgggt	tcaccaggcc	attcatgaag	aaggcttgga	agtccccgat	8940
tgccttggga	aaaaacaaat	tcaaggagct	gcattgcact	gtcgcgggca	ggtgtcttga	9000
agccgacttg	gcctcctgtg	accgcagcac	ccccgccatt	gtgaggtggg	tcgtcgccaa	9060
cctcctgtat	gaacttgcag	gatgtgaaga	gtacttgctt	agctatgtgc	ttaactgctg	9120
ccatgacctt	gtggcaaacac	aggatgggtc	cttcacaaaa	cgcgggtggc	tgtcgtccgg	9180
ggacccccgtc	accagtgtgt	ctaacaccgt	atattcactg	ataatctatg	cccagcacat	9240
ggtgttgctg	gccttaaaaa	tgggtcatga	aatcgggtctc	aagttcctcg	aggaacagct	9300
caaatcgcag	gacctcctcg	aaatccagcc	tatgttggtc	tattctgatg	accttgtctt	9360
gtacgctgaa	aggcccaact	ttcctaatta	tcactggtgg	gtcgagcacc	ttgacctaat	9420
gctgggtttc	agaacgggacc	caaagaagac	agtcataact	gataaaccca	gcttcctcgg	9480
ctgcagaatt	gaggcggggc	gacagctggg	ccctaatacgc	gaccgcatcc	tggtgtctct	9540
cgcatatcac	atgaaggcgc	agaacgcctc	agagtattat	gcgtctgctg	ccgcaatcct	9600
gatggattca	tgtgcttgca	ttgatcatga	ccctgagtgg	tatgaggacc	tcactctcgg	9660
tatcgcccca	tgcgccccgc	aggatgggta	tagtttccca	ggccccgcat	ttttcatgtc	9720
catgtgggaa	aagctgagaa	gtcacaatga	agggaagaaa	tttcgacact	gcggcatctg	9780
cgacgccaaa	gcgaccatg	catccgcctg	tgggcttgat	ttgtgtttgt	tccactcaca	9840
ctttcatcaa	cactgccccg	tcactctgag	ctgtgggtcat	catgccgggt	caagggaatg	9900
ttcgcagtgt	cagtcacctg	ttggggctgg	cagatctcct	cctgatgccg	tgctaaaaaca	9960
aatcctgtac	aaacctcctc	gtacagtcac	catgaagggtg	ggtaacaaaa	caacggccct	10020
cgatccgggg	aggtagcagt	cccgtcgagg	tcttggttga	gtcaagaggg	gtattgcagg	10080
caatgaagtt	gatcttcctg	atgggggacta	ccaagtagtg	cctcttttac	caacttgtaa	10140
agacataaac	atggtaaagg	tggcttgcaa	tgtactactc	agtaagttca	tagtggggcc	10200
accaggttcc	ggaagaccca	cctgggttact	gagtcaagtc	caggacgatg	atgtcattta	10260

TABLE 7-continued

Full length sequence of the GFP/-ES4 marker virus (SEQ ID NO: 43).			
cacacccacc	catcagacca	tgtttgatat	agtcagtgtc
ctcaaagttt	gcaggatttc	10320	
tattccagga	gcctcaggac	ttcctttccc	accacctgcc
aggtccgggc	cgtgggtag	10380	
gctcgtggcc	agcgggcacg	tccccggcgg	aacatcatac
ctcgatgagg	ctggatattg	10440	
taatcatctg	gacattctca	gactgctttc	caaaacaccc
ctcgtgtgtt	tgggtgacct	10500	
tcaacaactt	cacctgtcgg	gctttgactc	ctactgttat
gtgtttgatc	agatgcctca	10560	
aaagcaactg	accactattt	atagatttgg	ccctaacatc
tgcgcagcca	tccagccttg	10620	
ttacagggag	aagcttgaat	ctaaggctag	gaacaccagg
gtggtcttta	ccacctggcc	10680	
tgtggccttt	ggtcagggtc	tgacaccata	ccataaagat
cgcacgcgct	ctgcgataac	10740	
catagactca	tcccaggggg	ccactttcga	cattgtgaca
ttgcatctac	catcaccaaa	10800	
gtccctaagt	aaatcccag	cacttgtagc	catcactcgg
gcaagacacg	ggttggtcat	10860	
ttatgacctt	cacaaccagc	tccaggagtt	tttcaacctg
atccctgagc	gcactgattg	10920	
caaccttggt	ttcagccgtg	gggatgatct	ggtagtctct
agtcgggaca	atgcagtcac	10980	
aactgtagcg	aaggccctag	ggacagggtc	atctcgattt
cgagtatcag	acccgagggtg	11040	
caagtctctc	ttagctgctt	gttcggccag	tctggagggg
agctgtatgc	cactaccaca	11100	
agtggcacat	aacctggggt	tttacttctc	cccagacagt
ccagcatttg	cacctctgcc	11160	
aaaggagtta	gcccacatt	ggccagtggt	tactcaccag
aacaatcggg	cgtggcccga	11220	
tcgacttgct	gctagtatgc	gcccatttga	tgcccgtac
agcaagccaa	tggtcgggtg	11280	
agggtagtgt	gtcgggcccgt	ccacctttct	tggtactcct
ggtgtagtgt	catactacct	11340	
cacgctatac	atcaggggtg	agccccaggc	cttgccagag
acactcgttt	caacaggacg	11400	
catagccact	gactgcgggg	agtatctcga	cgcggctgag
gaagaggcag	caaaagaact	11460	
ccccacgca	ttcattggcg	atgtcaaagg	taccacggtc
gggggggtgc	accacatcac	11520	
atcaaaaatac	ctaccaggga	ccctgcctaa	ggactctggt
gctgtagttg	gagtaagctc	11580	
gcccggcagg	gctgctaaag	ccatgtgcac	tctcactgat
gtgtatctcc	ccgaactccg	11640	
gccatacctg	caacctgaga	cggcgctcga	atgctggaaa
ctcaaattag	acttcaggga	11700	
cgtccgacta	atggctctgga	aaggagccac	cgcctatttc
cagttggaag	gacttacatg	11760	
gtcagcgctg	cctgactatg	ccaggtttat	tcagcttccc
aaggacgccg	ttgtgtacat	11820	
tgatccgtgt	ataggaccgg	caacagccaa	ccgcaaggtc
gtgcgaacca	cagactggcg	11880	
ggccgacctg	gcagtgacac	cgtatgatta	cgggtcccag
aacattttga	caacagcctg	11940	
gttcgaggac	ctcgggccgc	agtggaagat	tttgggggtg
cagcccttca	ggcgggcatt	12000	
tggttttgaa	aatactgagg	attgggcaat	ccttgcacgc
cgtatgagtg	acggcaaaga	12060	
ctacactgac	tacaactggg	attgtgttcg	agaacgccc
cacgccatct	acgggcgtgc	12120	
tcgtgaccat	acatacatt	ttgcccccg	cacggaattg
caggtagagc	tgggtaaacc	12180	
ccggctgccg	cctggacgag	agccgtaaac	ttggagtgat
gcaatgggggt	cactgtggag	12240	
taaaatcagc	cagctgtttc	tggatgcctt	cactgagttt
cttgtcagtg	tggttgatat	12300	
tgatcatttt	cttgccatac	tgtttgggtt	caccgtcgca
ggatgggttat	tggctcttct	12360	
tctcagagtg	gtttgtctcg	cgtctctccg	ttcgcgtctc
gccattcact	ctcccgaact	12420	
atcgaaggtc	ctatgaaagc	ttgttgccca	actgcaggcc
ggatgtccca	caatttgcat	12480	

TABLE 7-continued

Full length sequence of the GFP/-ES4 marker virus (SEQ ID NO: 43).		
ttaagcacc	attgggtata	ctttggcaca
tgcgagtttc	ccacctgatt	gatgagatgg
12540		
tctctcgccg	catttaccag	accatggaac
attcaggtca	agcggcctgg	aaatatgtgg
12600		
tcggtgaggc	cactctcacg	aagctatcaa
agcttgatat	agttaactcat	ttccaacatc
12660		
tgcccgagc	agaggcggat	tcttgccgct
ttctcagctc	acgactcgtg	atgctaaaaa
12720		
atcttgccgt	tggcaatgtg	agcctacagt
acaacaccac	gttggatcgc	gttgaactca
12780		
ttttccccc	gccaggtacg	aggcccaagt
tgaccgactt	cagacaatgg	ctcatcagtg
12840		
tgcatgcttc	catttttttc	tctgtggctt
catctgttac	cttgttcata	gtgctttggc
12900		
tgcaattcc	agctctacgc	tatgtttttg
gtttccattg	gcccacggca	acacatcatt
12960		
cgagctgacc	atcaattata	ccatatgcat
gccctgtctt	accagtcaag	cagctcgcca
13020		
aaggctcgag	cccggctcga	acatgtgggt
cagaataggg	catgataggt	gtgaggagcg
13080		
tgaccatgat	gagttgttaa	tgtccatccc
gtccgggtac	gacaacctca	aacttgaggg
13140		
atattatgct	tggctggctt	ttttgtcctt
ttcctacgcg	gcccatttcc	atccggagct
13200		
gttcgggata	gggaatgtgt	cgcgcgtctt
cgtggacaag	cgacaccagt	ttatttgtgc
13260		
cgagcatggt	ggactcaatt	caaccttata
taccgagcac	aatatctccg	catttatatgc
13320		
ggtattatta	caccacaaaa	tagacggggg
taattgggtc	catttggaat	ggctgcggcc
13380		
gcttttttcc	tcctggttgg	tgtctaacat
atcatggttt	ctgaggcggt	cgctgttaag
13440		
ccctgtttct	cgacgcctct	atcagatatt
aagaccaaca	cgaccgcggc	tgccggtttc
13500		
atggtccttc	agaacatcaa	ttgttcccgg
cctcacgagg	cctcagcaac	gcaagggtcaa
13560		
gttccttcca	gaaagtcgtc	ccaatgccgt
gaagccgtcg	gtgttcccca	atacatcacg
13620		
ataacggcca	acgtgaccga	cgaatcatat
ttgtacaacg	cggacttgct	gatgctttct
13680		
gcgtgccttt	tctacgcttc	ggaaatgagc
gagaaaggct	ttaaagttaa	ctttgggaat
13740		
gtctctggcg	ttgtttctgc	ttgtgtcaat
ttcacagatt	atgtggccca	tgtgacccaa
13800		
cataccagc	agcatcatct	ggtgattaat
cacatccggt	tactgcactt	cctgacacca
13860		
tctgcaatga	ggtgggctac	aaccattgct
tgtctgttcg	ccattctctt	ggcgatatga
13920		
aatgttctca	caaattgggg	cattccttga
ctccgcactc	ttgcttcttg	tggttttttt
13980		
tgctgtgtac	cggcttgtcc	tggtcctttg
ccgatggcaa	cggcaacaac	tcgacatacc
14040		
aatacatata	taatttgagc	atatgcgagt
tgaatgggac	caattggctg	tccggccatt
14100		
ttgaatgggc	agttgagacc	tttgtgcttt
acccggttgt	cactcatatc	ctctcactgg
14160		
gttttctcac	gacaagtcat	ttttttgacg
cgtccggtct	cggcgctgta	tccactgcag
14220		
gatttgcctg	agggcggtat	gtacttagca
gcgtctacgg	cgttgtgtct	ttegcagcgt
14280		
tcgtatgctt	cgtcatccgt	gctgctaaaa
attgcatggc	ctgccgtat	gcccgtaccc
14340		
ggttcaccaa	cttcatttgt	gacgacgggg
ggggagttca	tagatggaag	tctccaatag
14400		
tggtagaaaa	actgggcaaa	gccgaaattg
gcggcaacct	tgteaccatc	aaacatgtcg
14460		
tcctcgaagg	ggttaaagct	caacccttga
cgagaacttc	ggccgagcaa	tgggaggcct
14520		
agataatttt	tgcaacgata	ctaccgccgc
acaaaagata	gtgctagcct	tcagcatcac
14580		
atacacacct	ataatgatata	acgccottaa
ggtgtcacgc	ggccgactcc	tggggctggt
14640		
gcacatccta	atatttctga	actgttcctt
tacattcgga	tacatgacat	atgtgcattt
14700		

TABLE 7-continued

Full length sequence of the GFP/-ES4 marker virus (SEQ ID NO: 43).	
tcattctacc caccgtgtcg cacttacccct gggggctgtt gtcgcccttt tgtgggggtgt	14760
ctacagcctc acagagtcac ggaagtttat cacttccaga tgcagattgt gttgcctcgg	14820
ccggcgatac attctggccc ctgcccatca cgtagaaagt gctgcaggtc tccattcaat	14880
ctcagcgtct ggtaaccgag catacgctgt gagaaagccc ggactaacat cagtgaacgg	14940
cactctagta ccaggacttc ggagcctcgt gctggggcggc aaacgagctg ttaaaccgagg	15000
agtggttaac ctgcgtcaagt atggccggta aaaatcagag ccagaagaaa aagaaaagta	15060
cggtcctaat ggggaatggc cagccagtca atcaactgtg ccagttgctg ggtgcaatga	15120
taaagtccca gcgccagcaa cctaggggag gacaggctaa aaagaaaaag cctgagaagc	15180
cacattttcc cctggctgca gaagatgaca tccggcacca cctcacccaa actgaacgct	15240
ccctctgctt gcaatcgatc cagacggctt tcaatcaagg cgcaggaact gcgtcgcttt	15300
catccagcgg gaaggtcagt ttccaggttg agtttatgct gccggttgct catacagtgc	15360
gcctgattcg cgtgacttct acatccgcca gtcagggtgc aaattaattt gacagtcagg	15420
tgaatggcgg cgattggcgt gtggcctctg agtcacctat tcaattaggg cgatcacatg	15480
ggggtcatac ttaatcaggc aggaaccatg tgaccgaaat t	15521

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What is claimed is:

1. A recombinant North American Type 1 porcine reproductive and respiratory syndrome virus (PRRSV), comprising one or more mutations in open reading frame (ORF) 1a, wherein said mutations are such that the recombinant PRRSV fails to produce at least one functional polypeptide corresponding to ORF1a.

2. The recombinant PRRSV of claim 1, wherein the mutation comprises a deletion.

3. The recombinant PRRSV of claim 2, wherein the deletion is in the nsp2 region.

4. The recombinant PRRSV of claim 3, wherein the deletion includes epitope ES4.

5. The recombinant PRRSV of claim 4, wherein the deletion includes amino acids 736-790 of ORF1a.

6. The recombinant PRRSV of claim 3, wherein the mutation comprises an insertion of a heterologous DNA sequence.

7. The recombinant PRRSV of claim 6, wherein the insertion is between amino acids 733 and 734 of ORF1a.

8. The recombinant PRRSV of claim 6, wherein the insertion is green fluorescent protein (GFP).

9. A recombinant North American PRRS virus encoded by an isolated polynucleotide molecule comprising a DNA sequence encoding an infectious RNA molecule encoding a North American PRRS virus, wherein said DNA sequence is SEQ ID NO: 43.

10. A North American Type 1 PRRSV vaccine comprising a recombinant PRRSV having a mutation in ORF1a, said mutation including a deletion, an insertion, or both, in ORF1a, and a pharmaceutically acceptable carrier.

11. The vaccine of claim 10, wherein said mutation comprises a deletion in the nsp2 region.

12. The vaccine of claim 11, wherein said deletion is of amino acids 736-790 in the nsp2 region.

13. The vaccine of claim **11**, wherein said mutation further comprises an insertion of a heterologous DNA sequence.

14. The vaccine of claim **13**, wherein said insertion is between amino acids 733 and 734 in the nsp2 region.

15. A kit comprising:

a vaccine comprising a PRRSV mutant having a mutation in ORF1a, said mutation being such that said PRRSV mutant fails to produce a functional ORF1a polypeptide, said mutation including an insertion of a heterologous DNA sequence, and a pharmaceutically acceptable carrier;

one or more first polypeptides encoded by the heterologous DNA sequence; and

one or more second polypeptides encoded by the functional ORF1a.

16. The kit of claim **15**, wherein the mutation in the PRRSV vaccine is a deletion in the nsp2 region.

17. The kit of claim **16**, wherein the deletion is an ES4 epitope, wherein the one or more first polypeptides include GFP and the one or more second polypeptides include the ES4 epitope.

18. A method of differentiating an animal vaccinated with a PRRSV marker vaccine from an animal naturally infected

with PRRSV, wherein the PRRSV marker vaccine includes an insertion mutation and a deletion mutation, the method comprising:

providing a first recombinant PRRSV protein including the insertion mutation;

providing a second recombinant PRRSV protein including the deletion mutation;

incubating a serum sample from the animal with the first and second recombinant PRRSV proteins; and

detecting binding of antibodies in the sample with the first and second recombinant PRRSV proteins;

wherein binding of antibodies in the sample with the first recombinant PRRSV protein is indicative of a vaccinated animal and binding of antibodies in the sample with the second recombinant PRRSV protein is indicative of a naturally infected animal.

19. The method of claim **18**, wherein the first recombinant PRRSV protein includes a GFP insertion.

20. The method of claim **18**, wherein the second recombinant PRRSV protein includes an ES4 deletion.

* * * * *