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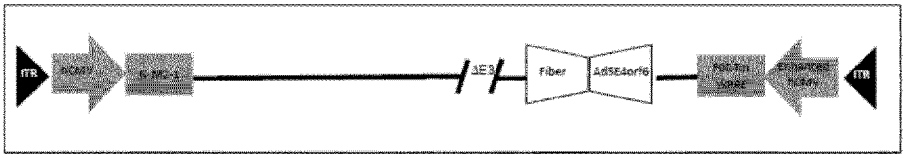
(54) Title: SIMIAN ADENOVIRAL VECTORS WITH TWO EXPRESSION CASSETTES

FIG. 7




(57) Abstract: A simian adenoviral vector comprising two expression cassettes, wherein each expression cassette comprises a transgene and a promoter, and wherein the first expression cassette is inserted in the E1 region of the simian adenoviral vector, and the second expression cassette is inserted in a region of the adenoviral vector that is compatible with vector replication.

WO 2019/076880 A1

# TITLE

## SIMIAN ADENOVIRAL VECTORS WITH TWO EXPRESSION CASSETTES

## SEQUENCE LISTING

The instant application contains a Sequence Listing which has been submitted electronically in ASCII format and is hereby incorporated by reference in its entirety. Said ASCII copy, created on October 11, 2018, is named VU66441A_WO_SL.txt and is 178,926 bytes in size.

## FIELD OF THE INVENTION

This invention is in the field of recombinant adenoviral vectors. The invention relates to an adenoviral vector comprising two expression cassettes. In particular, the invention relates to a simian adenovirus such as a chimpanzee (chimp) adenovirus comprising two expression cassettes.

## BACKGROUND OF THE INVENTION

Recombinant adenoviruses are useful in gene therapy and as vaccines.

Human adenoviruses have been widely used for gene transfer applications due to their large transgene capacity and ability to achieve highly efficient gene transfer in a variety of target tissues.

However, most humans are exposed to and develop immunity to human adenoviruses. Therefore, there is a demand for vectors which effectively deliver molecules to a target and minimize the effect of pre-existing immunity to human adenovirus serotypes. Simian adenoviruses are effective in this regard; they are sufficiently closely related to human viruses to be effective in inducing immunity to delivered exogenous antigens to which humans have little or no pre-existing immunity. Therefore, viral vectors based on simian adenoviruses can provide an alternative to the use of human derived adenoviral vectors for the development of nucleic acid based vaccines.

Replication defective adenoviruses deliver their genome to the interior of a cell and, because they do not replicate, do not amplify the transgene payload. Typically, the E1 gene is replaced with a transgene cassette comprising a promoter of choice and a nucleic acid sequence

corresponding to a gene or genes of interest, resulting in a replication defective recombinant virus.

There is a need in the art for improved recombinant adenoviruses.

## SUMMARY OF THE INVENTION

The invention relates to a simian adenoviral vector comprising two expression cassettes. In particular, the invention relates to a simian adenovirus such as a chimpanzee (chimp) adenovirus comprising two expression cassettes. Examples of suitable chimp adenoviruses include ChAd155 and ChAd83.

The adenoviral vectors of the invention are useful as components of immunogenic compostions for the induction of an immune response in a subject, methods for their use in treatment and processes for manufacture.

The term “vector” refers to an agent (such as a plasmid or virus) that contains or carries genetic material and can be used to introduce exogenous genes into an organism. The adenoviral vector of the present invention is derived from a non-human simian adenovirus, also referred to as a “simian adenovirus”. Preferably, the simian adenoviral vector of the present invention is a simian adenovirus.

Each expression cassette in the adenoviral vector of the invention comprises a transgene and a promoter. A “transgene” is a nucleic acid sequence, heterologous to the vector sequences flanking the transgene, which encodes a polypeptide of interest. The nucleic acid coding sequence is operatively linked to regulatory components in a manner which permits transgene transcription, translation, and/or expression in a host cell. A "promoter" is a nucleotide sequence that permits the binding of RNA polymerase and directs the transcription of a gene. Typically, a promoter is located in a non-coding region of a gene, proximal to the transcriptional start site.

In adenoviral vectors of the invention, the first expression cassette is inserted in the E1 region of the virus, and the second expression cassette is inserted into a second region of the adenoviral vector.

In a simian adenoviral vector comprising two expression cassettes of the invention, the first expression cassette is inserted in the E1 region of the simian adenoviral vector, and the second expression cassette is inserted in a region of the adenoviral vector that is compatible with vector replication. A region of the adenoviral vector genome is considered "compatible with vector replication" if disruption of this region would not affect the ability of the adenoviral vector to replicate.

Preferably, in adenoviral vectors of the invention, the first expression cassette is inserted in the E1 region of the virus, and the second expression cassette is inserted into the E3, HE1 or HE2 region of the adenoviral vector. As is well known in the art, the E3 genes are expressed in the early phase of transduction to prepare the host cell for viral replication. E3 is involved in immune modulation. The term "HE1" is used to describe a site located between the stop codons of L5 and E4. The term "HE2" has been used to define a site located between the end of the ITR and the cap site of E4 mRNA.

For example, in a ChAd155 adenovirus vector:

- HE1 ChAd155: insertion site between bp 34611 and 34612 of SEQ ID NO: 1.
- HE2 ChAd155: insertion site between bp 37662 and 37663 of SEQ ID NO: 1.

In another example, in a ChAd83 adenovirus vector:

- HE1 ChAd83: insertion site between bp 33535 and 33536 of SEQ ID NO: 2.
- HE2 ChAd83: insertion site between bp 36387 and 36388 of SEQ ID NO: 2.

As the first expression cassette is inserted in the E1 region of the adenoviral vector, the native E1 region is deleted. In order to increase the cloning capacity of the vector, the native E3 region can be removed from the adenoviral vector. The native E3 region can be deleted from the adenoviral vector in embodiments of the invention where the second expression cassette is inserted in the E3 region, or in embodiments where the second expression cassette is not inserted into the E3 region. The insertion in HE1 or HE2 site doesn't require deletion of any specific sequence of the vector backbone.

Preferably, the second expression cassette is inserted into the HE1 or HE2 region of the adenoviral vector. Most preferably, the second expression cassette is inserted in the HE2

region of the adenoviral vector. In one embodiment, the native E3 region is deleted from the adenoviral vector to increase the cloning capacity of the vector, and the second expression cassette is inserted in the HE1 or HE2 region of the adenoviral vector.

In embodiments of the invention, the first expression cassette of the adenoviral vector may comprise a human CMV or an enhanced human CMV promoter, and/or the second expression cassette may comprise a human CMV or an enhanced human CMV promoter.

In a preferred embodiment, the first and second expression cassettes comprise different promoters. For example, in one embodiment, the first expression cassette may comprise a human CMV promoter and the second expression cassette an enhanced human CMV promoter (or *vice versa*).

In one aspect of the invention, there is provided an adenoviral vector of the invention, wherein the first expression cassette is inserted in the E1 region of the virus, and the second expression cassette is inserted in a region of the adenoviral vector that is compatible with vector replication, wherein at least one of the first and second expression cassette comprises an enhanced CMV promoter. In some embodiments, the enhanced hCMV promoter can include a nucleic acid sequence having at least about 90%, at least about 95%, at least about 96%, at least about 97%, at least about 98%, at least about 99%, or more, sequence identity to SEQ ID NO: 6. In some embodiments, the promoter comprises or consists of a nucleic acid sequence of SEQ ID NO: 6.

Adenoviral vectors of the invention are derived from a simian adenoviral vector, for example, from chimpanzees (*Pan troglodytes*), bonobos (*Pan paniscus*), gorillas (*Gorilla gorilla*) and orangutans (*Pongo abelii* and *Pongo pygnaeus*). Chimpanzee adenoviruses include, but are not limited to AdY25, ChAd3, ChAd19, ChAd25.2, ChAd26, ChAd27, ChAd29, ChAd30, ChAd31, ChAd32, ChAd33, ChAd34, ChAd35, ChAd37, ChAd38, ChAd39, ChAd40, ChAd63, ChAd83, ChAd155, ChAd15, SadV41, sAd4310A, sAd4312, SAdV31, SAdV-A1337, ChAdOx1, ChAdOx2 and ChAd157. Preferably, the simian adenoviral vector of the invention is a ChAd83 or ChAd155 adenovirus vector, most preferably a ChAd155 adenovirus vector.

Preferably, the adenoviral vector of the invention has a seroprevalence of less than 30%, preferably less than 10% in human subjects and, most preferably, no seroprevalence in human subjects.

In a preferred embodiment, the simian adenoviral vector of the invention is capable of infecting a mammalian cell.

In one embodiment, the first and second expression cassettes of the adenoviral vector of the invention comprise transgenes from respiratory syncytial virus (RSV). For example, in one embodiment, one of the expression cassettes comprises an RSV F antigen, and the other expression cassette comprises RSV M and N antigens. In such emboidments, the vector preferably encodes an RSV F0ΔTM antigen (fusion (F) protein deleted of the transmembrane and cytoplasmic regions), and RSV M2-1 (transcription anti-termination) and N (nucleocapsid) antigens.

The present invention also provides a composition comprising a simian adenoviral vector and a pharmaceutically acceptable excipient.

In addition, the present invention provides a simian adenoviral vector or composition comprising such an adenoviral vector for use as a medicament, a vaccine, and/or for the therapy or prophylaxis of a disease.

The invention also provides a method of inducing an immune response in a subject comprising administering the simian adenoviral vector or composition to the subject.

## DESCRIPTION OF THE FIGURES

FIG. 1: Simian adenoviral constructs with a single expression cassette. Inverted terminal repeats (ITR) flank the 3' and 5' ends; E1 is the early gene 1; CMV is the cytomegalovirus promoter; CASI is the CASI promoter, RG is a model antigen, WPRE is the Woodchuck Hepatitis Postranscriptional Regulatory Element, ΔE3 denotes that the early gene 3 is deleted; fiber denotes the adenoviral gene encoding the fiber protein and E4 is the early gene 4.

Three different simian adenoviral vectors are shown in FIG. 1. The vector of FIG. 1(i) was constructed by inserting a transgene expression cassette in place of the E3 region of the adenoviral genome ("RC1") (top panel), the vector of FIG. 1(ii) was formed by inserting a transgene expression cassette in the HE1 region, *i.e.*, between the stop codons of the fiber gene and the E4 region ("RC3") (middle panel), and the vector of FIG. 1(iii) was made by inserting a transgene expression cassette in the HE2 region, *i.e.*, between the end of the ITR and the cap site of E4 mRNA ("RC2") (bottom panel).

FIG. 2A: Production of ChAd155 and ChAd83 with transgene cassette inserted in E3 and HE2 sites (RC1 and RC2 vectors of FIG. 1) in a primary human cell line.

FIG. 2B: Production of ChAd83 with transgene cassette inserted in E3, HE1 and HE2 (the RC1, RC2 and RC3 vectors of FIG. 1) in a human MRC5 cell line at two and seven days post-infection. Cells were infected at multiplicities of infection of 250 and 1250.

FIG. 3A: Total viral genome copy number of RC1 and RC2 vector (ChAd155 and ChAd83) of FIG. 1 in a primary human cell line.

FIG. 3B: Total viral genome copy number of RC1, RC2 and RC3 versions of ChAd83 vector of FIG. 1 in a human MRC5 cell line at two and seven days post-infection. Cells were infected at multiplicities of infection of 250 and 1250.

FIG. 4: Total viral genome copy number of ChAd155 RC1 and RC2 and ChAd83 RC1 and RC2 vectors of FIG. 1 in a murine cell line (FIG. 4(a), top panel) and in a non-human primate cell line (FIG. 4(b), bottom panel). Cells were infected at multiplicities of infection of 50 and 250.

FIG. 5: Comparison of the expression levels of ChAd155 RC1 and RC2 vectors expressing a model rabies glycoprotein (RG) transgene in a murine cell line, demonstrated by western blot at two and five days post-infection (FIG. 5(a), top panel). Comparison of the expression levels of ChAd155 RC1 and RC2 vectors with ChAd83 RC1 and RC2 vectors expressing a model rabies glycoprotein (RG) transgene in a murine cell line, demonstrated by western blot at two and five days post-infection (FIG. 5(b), bottom panel). Cells were infected at multiplicities of infection of 50, 250 and 1250.

FIG. 5(c): Comparison of the expression levels of ChAd83 RC1, RC2 and RC3 vectors expressing a model rabies glycoprotein (RG) transgene in a human MRC5 cell line, demonstrated by western blot at two and seven days post-infection. Cells were infected at multiplicities of infection of 250 and 1250.

FIG. 6: Another simian adenoviral construct of with a single expression cassette. Inverted terminal repeats (ITR) flank the 3' and 5' ends; human CMV (hCMV) is the cytomegalovirus promoter; FΔTM (F0DTM) and N.M2-1 are RSV antigens; 2A is a self-cleaving linking sequence; ΔE4 denotes that the early gene 4 is deleted; fiber denotes the adenoviral gene encoding the fiber protein. In the vector of FIG. 6, the transgene expression cassette is inserted in place of the E1 region of the adenoviral genome.

FIG. 7: A simian adenoviral construct according to the invention with a dual expression cassette. Inverted terminal repeats (ITR) flank the 3' and 5' ends; human CMV (hCMV) is the cytomegalovirus promoter; Enchanced hCMV is the enhanced cytomegalovirus promoter; N-M2-1 and FΔTM (F0DTM) are the RSV antigens; WPRE is the Woodchuck Hepatitis Postranscriptional Regulatory Element; ΔE3 denotes that the early gene 3 is deleted; fiber denotes the adenoviral gene encoding the fiber protein; and Ad5E4orf6 in a substitute in the early gene 4 (E4) region.

The vector of FIG. 7 was constructed by inserting a first transgene expression cassette in place of the E1 region of the adenoviral genome, and a second transgene expression cassette in the HE2 region, *i.e.*, downstream of the right ITR.

FIG. 8: Comparison of the expression levels of vectors expressing F0ΔTM transgene in a MRC5 cell line, demonstrated by western blot at 48 hours and 96 hours post-infection under non-reducing conditions. Cells were infected at multiplicities of infection of 500 and 1250.

FIG. 9: Comparison of the expression levels of vectors expressing NM2-1 transgene in a MRC5 cell line, demonstrated by western blot at 48 hours post-infection under reducing conditions. Cells were infected at multiplicities of infection of 250 and 1250.

FIG. 10: Comparison of the immunogencity from ChAd155 vectors expressing the RSV antigen F0ΔTM (FΔTm). The data was collected at 4 weeks and 8 weeks after vaccination with a dose of $5x10^8$ virus particles.

FIG. 11: Comparison of the immunogencity from ChAd155 vectors expressing the M2 RSV antigen. The data was collected at 3 weeks after vaccination with a dose of either $10^7$ or $10^6$ virus particles.

FIG. 12A and 12B: Illustrate the results from the experiment of Example 9 to investigate the lung T cell responses from ChAd155 vectors. FIG 12A shows the CD4+ response, and FIG 12B shows the CD8+ response.

Figures 13A and 13B: Show the results from the experiment of Example 9 to investigate the peripheral T cell responses from ChAd155 vectors. FIG 13A shows the PBMC CD4+ response, and FIG 13B shows the PBMC CD8+ response.

FIG 14A and 14B: Also show results from Example 9. FIG. 14A shows the RSV neutralising Ab titres, and Figure 14B illustrates the ratio of the nAb from day D90 to D0.

FIG. 15A. 15B and 15C: Show the results of the immunogencity experiment of Example 10.

FIG. 16A and 16B: Western blots obtained using the expression in HeLa cells of the vectors in Example 11.

FIG. 17: Illustrates the results of the CRPV experiment of Example 12.

FIG. 18: Shows the results of the HPV dual cassette vector characterisation of Example 13.

ANNOTATION OF THE SEQUENCES

SEQ ID NO: 1 – Polynucleotide sequence encoding wild type ChAd155
SEQ ID NO: 2 – Polynucleotide sequence encoding wild type ChAd83
SEQ ID NO: 3 – Polynucleotide sequence encoding the CASI promoter
SEQ ID NO: 4 – Polynucleotide sequence encoding ChAd155/RSV

SEQ ID NO: 5 – RSV F0ΔTM-N-M2-1 amino acid sequence
SEQ ID NO: 6 – Polynucleotide sequence encoding the enhanced hCMV promoter
SEQ ID NO: 7 – Polynucleotide sequence encoding the hCMV NM2 bghpolyA cassette
SEQ ID NO: 8 – NM2 amino acid (protein) sequence
SEQ ID NO: 9 – Polynucleotide sequence encoding the hCMV F0 WPRE bghpolyA cassette
SEQ ID NO: 10 – F0 amino acid (protein) sequence
SEQ ID NO: 11 – Amino acid sequence of a flexible linker
SEQ ID NO: 12 – Amino acid sequence of a flexible linker

## DETAILED DESCRIPTION OF THE INVENTION

*Adenoviruses*

Adenoviruses are nonenveloped icosahedral viruses with a linear double stranded DNA genome of approximately 36 kb. Adenoviruses can transduce numerous cell types of several mammalian species, including both dividing and nondividing cells, without integrating into the genome of the host cell. They have been widely used for gene transfer applications due to their proven safety, ability to achieve highly efficient gene transfer in a variety of target tissues, and large transgene capacity. Human adenoviral vectors are currently used in gene therapy and vaccines but have the drawback of a high worldwide prevalence of pre-existing immunity, following previous exposure to common human adenoviruses.

Adenoviruses have a characteristic morphology with an icosahedral capsid comprising three major proteins, hexon (II), penton base (III) and a knobbed fiber (IV), along with a number of other minor proteins, VI, VIII, IX, IIIa and IVa2. The hexon accounts for the majority of the structural components of the capsid, which consists of 240 trimeric hexon capsomeres and 12 penton bases. The hexon has three conserved double barrels and the top has three towers, each tower containing a loop from each subunit that forms most of the capsid. The base of the hexon is highly conserved between adenoviral serotypes, while the surface loops are variable. The penton is another adenoviral capsid protein; it forms a pentameric base to which the fiber attaches. The trimeric fiber protein protrudes from the penton base at each of the 12 vertices of the capsid and is a knobbed rod-like structure. The primary role of the fiber protein is to tether the viral capsid to the cell surface via the interaction of the knob region with a cellular receptor. Variations in the flexible shaft, as well as knob regions of fiber, are characteristic of the different adenovral serotypes.

The adenoviral genome has been well characterized. The linear, double-stranded DNA is associated with the highly basic protein VII and a small peptide pX (also termed mu). Another protein, V, is packaged with this DNA-protein complex and provides a structural link to the capsid via protein VI. There is general conservation in the overall organization of the adenoviral genome with respect to specific open reading frames being similarly positioned, *e.g.* the location of the E1A, E1B, E2A, E2B, E3, E4, L1, L2, L3, L4 and L5 genes of each virus. Each extremity of the adenoviral genome comprises a sequence known as an inverted terminal repeat (ITR), which is necessary for viral replication. The 5' end of the adenoviral genome contains the 5' cis-elements necessary for packaging and replication; *i.e.*, the 5' ITR sequences (which can function as origins of replication) and the native 5' packaging enhancer domains, which contain sequences necessary for packaging linear adenoviral genomes and enhancer elements for the E1 promoter. The 3' end of the adenoviral genome includes 3' cis-elements, including the ITRs, necessary for packaging and encapsidation. The virus also comprises a virus-encoded protease, which is necessary for processing some of the structural proteins required to produce infectious virions.

The structure of the adenoviral genome is described on the basis of the order in which the viral genes are expressed following host cell transduction. More specifically, the viral genes are referred to as early (E) or late (L) genes according to whether transcription occurs prior to or after onset of DNA replication. In the early phase of transduction, the E1A, E1B, E2A, E2B, E3 and E4 genes of adenovirus are expressed to prepare the host cell for viral replication. The E1 gene is considered a master switch, it acts as a transcription activator and is involved in both early and late gene transcription. E2 is involved in DNA replication; E3 is involved in immune modulation and E4 regulates viral mRNA metabolism. During the late phase of infection, expression of the late genes L1-L5, which encode the structural components of the viral particles, is activated. Late genes are transcribed from the Major Late Promoter (MLP) with alternative splicing.

HE1 and HE2 sites were identified as potential insertion sites for a transgene since the insertion in these specific points does not interrupt the coding sequences or important regulatory sequences of a chimp adenovirus, such as a Type C or E chimp adenovirus, for example, ChAd155 and ChAd83. The HE1 and HE2 sites can be identified by sequence alignment in

any chimp adenovirus. Therefore, cloning of expression cassettes in the HE1 and HE2 sites of the ChAd genomes doesn't impact the virus replication cycle.

*Adenoviral replication*

Historically, adenovirus vaccine development has focused on defective, non-replicating vectors. They are rendered replication defective by deletion of the E1 region genes, which are essential for replication. Typically, non-essential E3 region genes are also deleted to make room for exogenous transgenes. An expression cassette comprising the transgene under the control of an exogenous promoter is then inserted. These replication-defective viruses are then produced in E1-complementing cells.

The term "replication-defective " or "replication-incompetent" adenovirus refers to an adenovirus that is incapable of replication because it has been engineered to comprise at least a functional deletion (or "loss-of-function" mutation), *i.e.* a deletion or mutation which impairs the function of a gene without removing it entirely, *e.g.* introduction of artificial stop codons, deletion or mutation of active sites or interaction domains, mutation or deletion of a regulatory sequence of a gene etc, or a complete removal of a gene encoding a gene product that is essential for viral replication, such as one or more of the adenoviral genes selected from E1A, E1B, E2A, E2B, E3 and E4 (such as E3 ORF1, E3 ORF2, E3 ORF3, E3 ORF4, E3 ORF5, E3 ORF6, E3 ORF7, E3 ORF8, E3 ORF9, E4 ORF7, E4 ORF6, E4 ORF4, E4 ORF3, E4 ORF2 and/or E4 ORF1). Suitably, E1 and optionally E3 and/or E4 are deleted. If deleted, the aforementioned deleted gene region will suitably not be considered in the alignment when determining percent identity with respect to another sequence.

*Vectors of the Invention*

Viral vectors based on non-human simian adenovirus represent an alternative to the use of human derived vectors for gene therapy and genetic vaccines. Certain adenoviruses isolated from non-human simians are closely related to adenoviruses isolated from humans, as demonstrated by their efficient propagation in cells of human origin. As humans develop little or no immunity to simian adenoviruses, they promise to provide an improved alternative to human adenoviral uses.

"Low seroprevalence" may mean having a reduced pre-existing neutralizing antibody level as compared to human adenovirus 5 (Ad5). Similarly or alternatively, "low seroprevalence" may

mean less than about 30% seroprevalence, less than about 20% seroprevalence, less than about 15% seroprevalence, less than about 10% seroprevalence, less than about 5% seroprevalence, less than about 4% seroprevalence, less than about 3% seroprevalence, less than about 2% seroprevalence, less than about 1% seroprevalence or no detectable seroprevalence. Seroprevalence can be measured as the percentage of individuals having a clinically relevant neutralizing titer (defined as a 50% neutralisation titer >200) using methods as described in Hum. Gene Ther. (2004) 15:293.

The adenoviral vector of the present invention is derived from a nonhuman simian adenovirus, also referred to as a "simian adenovirus." Numerous adenoviruses have been isolated from nonhuman simians such as chimpanzees, bonobos, rhesus macaques, orangutans and gorillas. Vectors derived from these adenoviruses can induce strong immune responses to transgenes encoded by these vectors. Certain advantages of vectors based on nonhuman simian adenoviruses include a relative lack of cross-neutralizing antibodies to these adenoviruses in the human target population, thus their use overcomes the pre-existing immunity to human adenoviruses. For example, some simian adenoviruses have no cross reactivity with preexisting human neutralizing antibodies and cross-reaction of certain chimpanzee adenoviruses with pre-existing human neutralizing antibodies is only present in 2% of the target population, compared with 35% in the case of certain candidate human adenovirus vectors (Sci. Transl. Med. (2012) 4:1).

Adenoviral vectors of the invention are derived from a simian adenovirus, *e.g.*, from chimpanzees (*Pan troglodytes*), bonobos (*Pan paniscus*), gorillas (*Gorilla gorilla*) and orangutans (*Pongo abelii* and *Pongo pygnaeus*). They include adenoviruses from Group B, Group C, Group D, Group E and Group G. Chimpanzee adenoviruses include, but are not limited to AdY25, ChAd3, ChAd19, ChAd25.2, ChAd26, ChAd27, ChAd29, ChAd30, ChAd31, ChAd32, ChAd33, ChAd34, ChAd35, ChAd37, ChAd38, ChAd39, ChAd40, ChAd63, ChAd83, ChAd155, ChAd15, SadV41 and ChAd157 ChAd3, ChAd19, ChAd25.2, ChAd26, ChAd27, ChAd29, ChAd30, ChAd31, ChAd32, ChAd33, ChAd34, ChAd35, ChAd37, ChAd38, ChAd39, ChAd40, ChAd63, ChAd83, ChAd155, ChAd15, SadV41, sAd4310A, sAd4312, SAdV31, SAdV-A1337, ChAdOx1, ChAdOx2 and ChAd157. Alternatively, adenoviral vectors may be derived from nonhuman simian adenoviruses isolated from bonobos, such as PanAd1, PanAd2, PanAd3, Pan 5, Pan 6, Pan 7 (also referred to as C7) and Pan 9. Vectors may include, in whole or in part, a nucleotide encoding the fiber, penton or hexon of a non-human adenovirus.

In an embodiment of the adenoviral vectors of the invention, the adenoviral vector has a seroprevalence of less than 30%, less than 20%, less than 10% or less than 5% in human subjects, preferably no seroprevalence in human subjects and more preferably no seroprevalence in human subjects that have not previously been in contact with a chimpanzee adenoviral vector.

In embodiments of the adenoviral vectors of the invention, the adenoviral DNA is capable of entering a mammalian target cell, *i.e.* it is infectious. An infectious recombinant adenoviral vector of the invention can be used as a prophylactic or therapeutic vaccine and for gene therapy. Thus, in an embodiment, the recombinant adenoviral vector comprises an endogenous molecule for delivery into a target cell. The target cell is a mammalian cell, *e.g.* a bovine cell, a canine cell, a caprine cell, a cervine cell, a chimpanzee cell, a chiroptera cell, an equine cell, a feline cell, a human cell, a lupine cell, an ovine cell, a porcine cell, a rodent cell, an ursine cell or a vulpine cell. The endogenous molecule for delivery into a target cell is an expression cassette.

In an embodiment of the invention, the vector comprises a left ITR region, a deleted E1 region, then a deleted E3 region, and, optionally, additional enhancer elements; these are followed by a fiber region, an E4 region and a right ITR. Translation occurs in the rightward and leftward directions. In this embodiment, the first expression cassette is inserted in the deleted E1 region, and the second expression cassette is insertion in the deleted E3 region. In a further embodiment, the promoters of the two expression cassettes are CMV promoters. In a yet further embodiment, the enhancer element is the Hepatitis B Postranslational Regulatory Element (HPRE) or the Woodchuck Hepatitis Postranslational Regulatory Element (WPRE).

In one embodiment of the invention, the vector comprises left and right ITR regions; a deleted E1 region; at least a partially deleted E3 region; a fiber region; an E4 region; two expression cassettes, each comprising: a promoter and at least one an antigen of interest and, optionally, one or more enhancer elements. The first expression cassette is inserted in the deleted E1 region, and the second expression cassette is inserted at the HE1 site, *i.e.*, between the stop codons of the fiber gene and an E4 region ("the HE1 site"). The ChAd155 HE1 insertion site is between bp 34611 and 34612 of the wild type ChAd155 sequence. The ChAd83 HE1 insertion site is between bp 33535 and 33536 of the wild type ChAd83 sequence. Translation occurs in

the rightward and leftward directions. In a further embodiment, the promoters are CMV promoters. In a preferred embodiment, one promoter is a CMV promoter and the other is a eCMV promoter. In a yet further embodiment, the enhancer element is HPRE or WPRE.

In a further embodiment, the vector comprises left and right ITR regions; a deleted E1 region; at least a partially deleted E3 region; a fiber region; an E4 region; two expression cassettes, each comprising: a promoter, at least one antigen of interest and, optionally, one or more enhancer elements. The first expression cassette is inserted in the deleted E1 region, and the second expression cassette is inserted at the HE2 site, *i.e.*, between the end of the left ITR and the cap site of the E4 mRNA ("the HE2 site"). The ChAd155 HE2 insertion site is between bp 37662 and 37663 of the wild type ChAd155 sequence. The ChAd83 HE2 insertion site is between bp 36387 and 36388 of the wild type ChAd83 sequence. Translation occurs in the rightward and leftward directions. In a further embodiment, the promoters are CMV promoters. In a preferred embodiment, one promoter is a CMV promoter and the other is a eCMV promoter. In a yet further embodiment, the enhancer element is HPRE or WPRE (the enhancer element increases expression of the transgene).

The HE1 and HE2 sites were identified as insertion sites for a transgene, as the insertion in these specific points does not interrupt the coding sequences or regulatory sequences of ChAd155 and ChAd83. Therefore, inserting expression cassettes in the HE1 or HE2 sites of the ChAd genome does not affect the viral replication cycle.

In an embodiment of the invention, the vector is a functional or an immunogenic derivative of an adenoviral vector. By "derivative of an adenoviral vector" is meant a modified version of the vector, *e.g.*, one or more nucleotides of the vector are deleted, inserted, modified or substituted.

*Regulatory Elements*

Regulatory elements, *i.e.*, expression control sequences, include appropriate transcription initiation, termination, promoter and enhancer sequences; efficient RNA processing signals such as splicing and polyadenylation (poly A) signals including rabbit beta-globin polyA; tetracycline regulatable systems, microRNAs, posttranscriptional regulatory elements (*e.g.*, WPRE, posttranscriptional regulatory element of woodchuck hepatitis virus); sequences that stabilize cytoplasmic mRNA; sequences that enhance translation efficiency (*e.g.*, Kozak consensus

sequence); sequences that enhance protein stability; and when desired, sequences that enhance secretion of an encoded product.

A "promoter" is a nucleotide sequence that permits the binding of RNA polymerase and directs the transcription of a gene. Typically, a promoter is located in a non-coding region of a gene, proximal to the transcriptional start site. Sequence elements within promoters that function in the initiation of transcription are often characterized by consensus nucleotide sequences. Examples of promoters include, but are not limited to, promoters from bacteria, yeast, plants, viruses, and mammals, including simians and humans. A great number of expression control sequences, including promoters which are internal, native, constitutive, inducible and/or tissue-specific, are known in the art and may be utilized.

Promoters of the invention will typically be heterologous promoters. Promoters of the invention can be constitutive.

Examples of promoters include, but are not limited to, promoters from bacteria, yeast, plants, viruses, and mammals (including humans).

Examples of promoters include, without limitation, the TBG promoter, the retroviral Rous sarcoma virus LTR promoter (optionally with the enhancer), the cytomegalovirus (CMV) promoter (optionally with the CMV enhancer, see, e.g., Boshart et al, Cell, 41:521-530 (1985)), the CASI promoter, the SV40 promoter, the dihydrofolate reductase promoter, the β-actin promoter, the phosphoglycerol kinase (PGK) promoter, and the EF1a promoter (Invitrogen).

Suitable promoters include the cytomegalovirus (CMV) promoter and the CASI promoter. The CMV promoter is strong and ubiquitously active. It has the ability to drive high levels of transgene expression in many tissue types and is well known in the art. The CMV promoter can be used in vectors of the invention, either with or without a CMV enhancer.

The CASI promoter is a synthetic promoter described as a combination of the CMV enhancer, the chicken beta-actin promoter, and a splice donor and splice acceptor flanking the ubiquitin (UBC) enhancer (US 8865881).

In some embodiments, the CASI promoter can include a nucleic acid sequence having at least about 90%, at least about 95%, at least about 96%, at least about 97%, at least about 98%, at least about 99%, or more, sequence identity to SEQ ID NO: 3. In some embodiments, the promoter comprises or consists of a nucleic acid sequence of SEQ ID NO: 3.

In some embodiments, the enhanced hCMV promoter can include a nucleic acid sequence having at least about 90%, at least about 95%, at least about 96%, at least about 97%, at least about 98%, at least about 99%, or more, sequence identity to SEQ ID NO: 6. In some embodiments, the promoter comprises or consists of a nucleic acid sequence of SEQ ID NO: 6.

Optionally, vectors carrying transgenes encoding therapeutically useful or immunogenic products may also include selectable markers or reporter genes. The reporter gene may be chosen from those known in the art. Suitable reporter genes include, but are not limited to enhanced green fluorescent protein, red fluorescent protein, luciferase and secreted embryonic alkaline phosphatase (seAP), which may include sequences encoding geneticin, hygromicin or purimycin resistance, among others. Such selectable reporters or marker genes (which may or may not be located outside the viral genome to be packaged into a viral particle) can be used to signal the presence of the plasmids in bacterial cells, such as ampicillin resistance. Other components of the vector may include an origin of replication.

A “posttranscriptional regulatory element,” as used herein, is a DNA sequence that, when transcribed, enhances the expression of the transgene(s) or fragments thereof that are delivered by viral vectors of the invention. Postranscriptional regulatory elements include, but are not limited to the Hepatitis B Virus Postranscriptional Regulatory Element (HPRE) and the Woodchuck Hepatitis Postranscriptional Regulatory Element (WPRE). The WPRE is a tripartite cis-acting element that has been demonstrated to enhance transgene expression driven by certain, but not all promoters.

In embodiments of the invention, a ChAd155 vector may comprise one or more of a promoter, an enhancer, and a reporter gene. For example, vectors of the invention may comprise ChAd155-enhanced hCMV-SeAP, ChAd155-CASI-seAP and ChAd155-hCMV-seAP, optionally with a tetracycline on/off transcriptional control and ChAd155–CMV-hFerL-chEF1-seAP with a tetracycline on/off transcriptional control.

In embodiments of the invention, a ChAd83 vector may comprise one or more of a promoter, an enhancer, and a reporter gene. For example, vectors of the invention may comprise ChAd155-enhanced hCMV-SeAP, ChAd83-enhanced hCMV-SeAP, ChAd155-CASI-seAP and ChAd83-hCMV-seAP, optionally with a tetracycline on/off transcriptional control and ChAd83–CMV-hFerL-chEF1-seAP with a tetracycline on/off transcriptional control.

Vectors of the invention are generated using techniques provided herein, in conjunction with techniques known to those of skill in the art. Such techniques include conventional cloning techniques of cDNA such as those described in texts, use of overlapping oligonucleotide sequences of the adenovirus genomes, polymerase chain reaction, and any suitable method which provides the desired nucleotide sequence.

*Transgenes*

A “transgene” is a nucleic acid sequence, heterologous to the vector sequences flanking the transgene, which encodes a polypeptide of interest. The nucleic acid coding sequence is operatively linked to regulatory components in a manner which permits transgene transcription, translation, and/or expression in a host cell. In embodiments of the invention, the vectors express transgenes at a therapeutic or a prophylactic level. A “functional derivative” of a transgenic polypeptide is a modified version of a polypeptide, *e.g.*, wherein one or more amino acids are deleted, inserted, modified or substituted.

The transgene may be used for prophylaxis or treatment, *e.g.*, as a vaccine for inducing an immune response, to correct genetic deficiencies by correcting or replacing a defective or missing gene, or as a cancer therapeutic. As used herein, induction of an immune response refers to the ability of a protein to induce a T cell and/or a humoral antibody immune response to the protein.

The immune response elicited by the transgene may be an antigen specific B cell response, which produces neutralizing antibodies. The elicited immune response may be an antigen specific T cell response, which may be a systemic and/or a local response. The antigen specific T cell response may comprise a CD4+ T cell response, such as a response involving CD4+ T cells expressing cytokines, *e.g.* interferon gamma (IFN gamma), tumor necrosis factor alpha (TNF alpha) and/or interleukin 2 (IL2). Alternatively, or additionally, the antigen specific T cell

response comprises a CD8+ T cell response, such as a response involving CD8+ T cells expressing cytokines, *e.g.*, IFN gamma, TNF alpha and/or IL2.

The composition of the transgene sequence will depend upon the use to which the resulting vector will be put. In an embodiment, the transgene is a sequence encoding a product which is useful in biology and medicine, such as a prophylactic transgene, a therapeutic transgene or an immunogenic transgene, *e.g.*, protein or RNA. Protein transgenes include antigens. Antigenic transgenes of the invention induce an immunogenic response to a disease causing organism.

Transgenes of the invention include, but are not limited to, rabies virus antigens, *e.g.*, rabies glycoprotein (RG), respiratory syncytial virus (RSV) antigens, human immunodeficiency virus (HIV) antigens, or fragments thereof.

As a result of the redundancy in the genetic code, a polypeptide can be encoded by a variety of different nucleic acid sequences. Coding is biased to use some synonymous codons, *i.e.*, codons that encode the same amino acid, more than others. By "codon optimized," it is meant that modifications in the codon composition of a recombinant nucleic acid are made without altering the amino acid sequence. Codon optimization has been used to improve mRNA expression in different organisms by using organism-specific codon-usage frequencies.

In addition to, and independently from, codon bias, some synonymous codon pairs are used more frequently than others. This codon pair bias means that some codon pairs are overrepresented and others are underrepresented. Codon pair deoptimization has been used to reduce viral virulence. For example, it has been reported that polioviruses modified to contain underrepresented codon pairs demonstrated decreased translation efficiency and were attenuated compared to wild type poliovirus (Science (2008) 320:1784). Engineering a synthetic attenuated virus by codon pair deoptimization can produce viruses that encode the same amino acid sequences as wild type but use different pairwise arrangements of synonymous codons. Viruses attenuated by codon pair deoptimization generated up to 1000-fold fewer plaques compared to wild type, produced fewer viral particles and required about 100 times as many viral particles to form a plaque.

In contrast, polioviruses modified to contain codon pairs that are overrepresented in the human genome acted in a manner similar to wild type RNA and generated plaques identical in size to

wild type RNA (Coleman et al. (2008) Science 320:1784). This occurred despite the fact that the virus with overrepresented codon pairs contained a similar number of mutations as the virus with underrepresented codon pairs and demonstrated enhanced translation compared to wild type. This observation suggests that codon pair optimized constructs would be expected to act in a manner similar to their non-codon pair optimized counterparts and would not be expected to provide a functional advantage. Without wishing to be constrained by theory, this may be because natural evolution has optimized codon pairing.

A construct of the invention may comprise a codon optimized nucleic acid sequence. Alternatively or additionally, a vector of the invention comprises a codon optimized sequence of a transgene or an immunogenic derivative or fragment thereof. A construct of the invention may comprise a codon pair optimized nucleic acid sequence. Alternatively or additionally, a vector of the invention comprises or consists of a codon pair optimized sequence of a transgene or an immunogenic derivative or fragment thereof.

*Respiratory Syncytial Virus (RSV) Transgenes*

In one embodiment, the present invention provides the use of a recombinant simian-derived adenoviral vector comprising two expression cassettes, wherein each expression cassette comprises an immunogenic transgene derived from human respiratory syncytial virus (RSV), in the treatment or prophylaxis of RSV infection. In one embodiment, the recombinant simian-derived adenoviral vector of the present invention comprises an RSV F antigen in one of the expression cassettes, and another RSV viral antigen in the other expression cassette. Suitable antigens are discussed further below. In one embodiment, the recombinant simian-derived adenoviral vector comprises RSV M and N antigens in the second expression cassette. In such embodiments, the vector preferably encodes an RSV F0ΔTM antigen (fusion (F) protein deleted of the transmembrane and cytoplasmic regions), and RSV M2-1 (transcription anti-termination) and N (nucleocapsid) antigens.

Infection with RSV does not confer full protective immunity. Infection in infancy is followed by symptomatic RSV re-infections which continue throughout adulthood. These re-infections generally go undiagnosed because they usually present as common acute upper respiratory tract infections. In more vulnerable persons (e.g., immunocompromised adults or elderly), re-infections can however also lead to severe disease. Both arms of the immune system (humoral and cellular immunity) are involved in protection from severe disease [Guvenel AK, Chiu C and

Openshaw PJ. Current concepts and progress in RSV vaccine development. *Expert Rev Vaccines*. 2014; 13(3): 333-44.].

The humoral immune response is capable of neutralizing the virus and inhibiting viral replication, thereby playing a major role in protection against lower respiratory RSV infection and severe disease [Piedra PA, Jewell AM, Cron SG, et al., Correlates of immunity to respiratory syncytial virus (RSV) associated-hospitalization: establishment of minimum protective threshold levels of serum neutralizing antibodies. *Vaccine*. 2003; 21(24): 3479-82.]. Passive immunization, in the form of Immunoglobulin G (IgG) RSV-neutralizing monoclonal antibodies (Synagis) given prophylactically, has been shown to prevent RSV disease to some extent in premature infants and newborns with bronchopulmonary dysplasia or underlying cardiopulmonary disease [Cardenas S, Auais A and Piedimonte G. Palivizumab in the prophylaxis of respiratory syncytial virus infection. *Expert Rev Anti Infect Ther*. 2005; 3(5): 719-26].

T cells are also involved in the control of RSV disease. Lethal RSV infections have been described in patients with low CD8 T cells counts, as in the case of severe combined immunodeficiency, bone marrow and lung transplant recipients [Hertz, 1989]. The histopathology of fatal cases of RSV infection of newborns shows that there is a relative paucity of CD8 T cells in the lung infiltrate [Welliver TP, Garofalo RP, Hosakote Y, et al., Severe human lower respiratory tract illness caused by respiratory syncytial virus and influenza virus is characterized by the absence of pulmonary cytotoxic lymphocyte responses. *J Infect Dis*. 2007. 195(8): 1126-36.]. Moreover, the presence of CD8 T cells producing Interferon-gamma (IFN-γ) has been associated with diminished Th2 responses and reduced eosinophilia in animal models of RSV [Castilow EM and Varga SM. Overcoming T cell-mediated immunopathology to achieve safe RSV vaccination. *Future Virol*. 2008; 3(5): 445-454; Stevens WW, Sun J, Castillo JP, et al., Pulmonary eosinophilia is attenuated by early responding CD8(+) memory T cells in a murine model of RSV vaccine-enhanced disease. *Viral Immunol*. 2009; 22(4): 243-51].

Suitable antigens of RSV which are useful as immunogens to immunize a human or non-human animal can be selected from: the fusion protein (F), the attachment protein (G), the matrix protein (M2) and the nucleoprotein (N). The term “F protein” or “fusion protein” or “F protein polypeptide” or “fusion protein polypeptide” refers to a polypeptide or protein having all or part of an amino acid sequence of an RSV Fusion protein polypeptide. Similarly, the term “G protein” or “G protein polypeptide” refers to a polypeptide or protein having all or part of an amino acid

sequence of an RSV Attachment protein polypeptide. The term “M protein” or “matrix protein” or “M protein polypeptide” refers to a polypeptide or protein having all or part of an amino acid sequence of an RSV Matrix protein and may include either or both of the M2-1 (which may be written herein as M2.1) and M2-2 gene products. Likewise, the term “N protein” or “Nucleocapsid protein” or “N protein polypeptide” refers to a polypeptide or protein having all or part of an amino acid sequence of an RSV Nucleoprotein.

Two groups of human RSV strains have been described, the A and B groups, based mainly on differences in the antigenicity of the G glycoprotein. Numerous strains of RSV have been isolated to date, any of which are suitable in the context of the antigens of the immunogenic combinations disclosed herein. Exemplary strains indicated by GenBank and/or EMBL Accession number can be found in US published application number 2010/0203071 (WO2008114149), which is incorporated herein by reference for the purpose of disclosing the nucleic acid and polypeptide sequences of RSV F and G proteins suitable for use in present invention. In an embodiment, the RSV F protein can be an ectodomain of an RSV F Protein (F0ΔTM).

Exemplary M and N protein nucleic acids and protein sequences can be found, e.g., in US published application number 2014/0141042 (WO2012/089833), which are incorporated herein for purpose of disclosing the nucleic acid and polypeptide sequences of RSV M and N proteins suitable for use in present invention.

Suitably, for use with in present invention, transgene nucleic acids encode an RSV F antigen and RSV, M and N antigens. More specifically, the nucleic acids encode an RSV F0ΔTM antigen (fusion (F) protein deleted of the transmembrane and cytoplasmic regions), and RSV M2-1 (transcription anti-termination) and N (nucleocapsid) antigens.

Fusion (F) protein deleted of the transmembrane and cytoplasmic regions (F0ΔTM)

The RSV F protein is a major surface antigen and mediates viral fusion to target cells. The F protein is an antigen which is highly conserved among RSV subgroups and strains. The F protein is a target for neutralizing antibodies, including the prophylactic RSV-neutralizing monoclonal antibody Synagis. Deletion of the transmembrane region and cytoplasmic tail permits secretion of the F0ΔTM protein. Neutralizing antibodies including Synagis, that recognize this soluble form of the F protein, inhibit RSV infectivity in vitro [Magro M, Andreu D,

Gómez-Puertas P, et al., Neutralization of human respiratory syncytial virus infectivity by antibodies and low-molecular-weight compounds targeted against the fusion glycoprotein. *J Virol.* 2010; 84(16): 7970-82].

Nucleocapsid (N) protein

The N protein is an internal (non-exposed) antigen, highly conserved between RSV strains and known to be a source of many T cell epitopes. The N protein is essential for the replication and transcription of the RSV genome. The primary function of the N protein is to encapsulate the virus genome for the purposes of RNA transcription, replication and packaging and protects it from ribonucleases.

Transcription anti-termination (M2-1) protein

The M2-1 protein is a transcription anti-termination factor that is important for the efficient synthesis of full-length messenger RNAs (mRNAs) as well as for the synthesis of polycistronic readthrough mRNAs, which are characteristic of non-segmented negative-strand RNA viruses. M2-1 is an internal (non-exposed) antigen, which is highly conserved between RSV strains and known to be a source of many T cell epitopes.

N-M2-1 Fusion Protein

A polynucleotide encoding a linker is positioned between the polynucleotide encoding an RSV N antigen, or fragment thereof, and the polynucleotide encoding an RSV M2.1 antigen, or fragment thereof. Thus, in certain preferred examples, an expression cassette contains a transgene which encodes a fused RSV viral protein N-linker-M2.1 It is preferred that the linker is a flexible linker, preferably a flexible linker comprising an amino acid sequence according to SEQ ID NO: 11 (Gly-Gly-Gly-Ser-Gly-Gly-Gly) or SEQ ID NO: 12 (Gly-Gly-Gly-Gly-Ser-Gly-Gly-Gly-Gly).

*Papilloma (PV) Transgenes*

In one embodiment, the present invention provides the use of a recombinant simian-derived adenoviral vector comprising two expression cassettes, wherein each expression cassette comprises an immunogenic transgene derived from a papilloma virus (PV), in the treatment or prophylaxis of a papilloma virus induced disease. Suitably, the recombinant simian-derived adenoviral vector of the present invention comprises a modified papilloma virus E1 antigen in

one of the expression cassettes, and a modified papilloma virus E2 antigen in the other expression cassette.

Human Papillomavirus (HPV) are small DNA viruses that infect mucosal and/or cutaneous skin and cause multiple disease conditions, including cervical neoplasia, cervical cancer, and other anogenital cancers. There are over 40 types of HPV known to infect the anogenital tract of humans and about 15 high-risk HPV genotypes are causally associated with human cervical cancers. A majority of HPV infections of the cervical epithelium are subclinal and self-resolving within a two years period. However, persistant infection with high risk HPV types may cause lesions and progress to invasive cancer.

Suitable antigens of HPV which are useful as immunogens are described in WO2018060288 and include in particular HPV E1 and E2proteins.

*Rabies (RG) Transgenes*

*Lyssavirus* is an enveloped, single stranded RNA virus in the *Rhabdoviridae* family. Members of the Lyssavirus genus cause rabies and have the highest fatality rate of all known human viral pathogens. Rabies is transmitted via the saliva of infected mammals. A neurotropic virus, it enters the nervous system of its host, causing an encephalomyelitis that is almost invariably fatal. Currently there are about 60,000 rabies deaths worldwide yearly, mostly caused by dog bites in developing countries in Asia and Africa and by wildlife and bats in North America.

Rabies presents either in a furious or a paralytic form. The incubation period varies between about five days and several years but is typically between about 20 and 90 days. Clinical illness most often starts with prodromal complaints of malaise, anorexia, fatigue, headache and fever followed by pain or parathesia at the site of exposure. Anxiety, agitation or irritability may be prominent during this period, followed by hyperactivity, disorientation, seizures, hydrophobia, hypersalivation and, eventually, paralysis, coma and death.

Rabies antigens may be derived from the rabies viral glycoprotein (RG). For example, rabies glycoprotein may be used as a model antigen.

*Delivery of Adenoviral Vectors*

In some embodiments, the recombinant adenoviral vector of the invention is administered to a subject by epicutaneous administration, intradermal administration, intramuscular injection, intraperitoneal injection, intravenous injection, nasal administration, oral administration, rectal administration, subcutaneous injection, transdermal administration or intravaginal administration.

In an embodiment of the invention, the vectors can be administered intramuscularly (IM), *i.e.*, injection directly into muscle. Muscles are well vascularized and the uptake is typically rapid.

*Adjuvants*

Approaches to establishing strong and lasting immunity to specific pathogens include addition of adjuvants to vaccines. By "adjuvant" is meant an agent that augments, stimulates, activates, potentiates or modulates the immune response to an active ingredient of the composition. The adjuvant effect may occur at the cellular or humoral level, or both. Adjuvants stimulate the response of the immune system to the actual antigen but have no immunological effect themselves. Alternatively or additionally, adjuvented compositions of the invention may comprise one or more immunostimulants. By "immunostimulant" it is meant an agent that induces a general, temporary increase in a subject's immune response, whether administered with the antigen or separately.

A composition of the invention may be administered with or without an adjuvant. Alternatively, or additionally, the composition may comprise, or be administered in conjunction with, one or more adjuvants (*e.g.* vaccine adjuvants), in particular the composition comprises an immunologically effective amount of a vector of the invention encoding a transgene.

*Methods of use/ uses*

Methods are provided for inducing an immune response against a disease caused by a pathogen in a subject in need thereof comprising a step of administering an immunologically effective amount of a construct or composition as disclosed herein. In some embodiments are provided the use of the constructs or compositions disclosed herein for inducing an immune response to a transgenic antigen in a subject in need thereof. Vectors of the invention may be applied for the prophylaxis, treatment or amelioration of diseases due to infection.

Methods of the invention include the use of a vector of the invention in medicine. They include the use of a vector of the invention for the treatment of a disease caused by a pathogen. A vector of the invention can be used in the manufacture of a medicament for treating a disease caused by a pathogen. A vector of the invention can be used in the manufacture of a medicament for the prevention or treatment of a disease, for example, a disease caused by respiratory syncytial virus (RSV).

Effective immunization with adenoviral vectors depends on the intrinsic immnomodulatory capability of the adenoviral vector backbone. Immunologically less potent adenoviruses induce less antigen expression. Effective immunization also depends on the ability of the promoter to drive strong and sustained transgene expression. For example, adenoviral vectors driven by the cytomegalovirus immediate-early (CMV-IE) promoter do not sustain long-term transgene expression because they induce cytokines that dampen expression.

By “subject” is intended a vertebrate, such as a mammal *e.g.* a human or a veterinary mammal. In some embodiments the subject is human.

*General*

Vectors of the invention are generated using techniques and sequences provided herein, in conjunction with techniques known to those of skill in the art. Such techniques include conventional cloning techniques of cDNA such as those described in texts, use of overlapping oligonucleotide sequences of the adenovirus genomes, polymerase chain reaction, and any suitable method which provides the desired nucleotide sequence.

Unless otherwise explained, all technical and scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this disclosure belongs. 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 indicates otherwise. The term "plurality" refers to two or more. Additionally, numerical limitations given with respect to concentrations or levels of a substance, such as solution component concentrations or ratios thereof, and reaction conditions such as temperatures, pressures and cycle times are intended to be approximate. The term “about” used herein is intended to mean the amount ± 10%.

The present invention will now be further described by means of the following non-limiting examples.

## EXAMPLES

Example 1: Construction of Chimpanzee Adenoviruses with a Single Expression Cassette

Wild type chimpanzee adenoviruses type 155 (ChAd155) (WO 2016/198621) and type 83 (ChAd83) (WO 2010/086189) were isolated from healthy chimpanzees using standard procedures and were constructed as described in Sci Transl Med (2012) 4:1 and WO 2010/086189.

In Example 1, the ChAd155 and ChAd 83 vectors were each constructed by inserting a single transgene expression cassette. The expression cassette components used either the classical human CMV promoter or the CASI promoter, rabies glycoprotein as a model antigen and, optionally, a WPRE enhancer. Three different insertion sites were tested for the transgene cassette:

(i) replacing the E3 region with the transgene cassette,
(ii) inserting the transgene cassette between the fiber and the E4 region (site HE1), and
(iii) inserting the transgene cassette downstream of the right ITR (site HE2).

This numbering of these insertion sites corresponds to the illustrations of FIG.1 where:

(i) the top panel illustrates the RC1 vector, in which a transgene cassette replaced the E3 region,
(ii) the middle panel illustrates the RC3 vector, in which a transgene cassette is inserted between the stop codons of the fiber gene and the E4 region (site HE1), and
(iii) the bottom panel illustrates the RC2 vector, in which a transgene cassette is inserted downstream of the right ITR (site HE2).

In the vectors shown in Example 1, the E1 region remains intact in all configurations.

The transgene was inserted by homologous recombination techniques in the following positions of the SEQ ID NO: 1 and of the SEQ ID NO: 2:

HE1 ChAd155: insertion site between bp 34611 and 34612 of SEQ ID NO: 1;
HE2 ChAd155: insertion site between bp 37662 and 37663 of SEQ ID NO: 1;
HE1 ChAd83: insertion site between bp 33535 and 33536 of SEQ ID NO: 2;
HE2 ChAd83: insertion site between bp 36387 and 36388 of SEQ ID NO: 2.

When the transgene cassette was inserted in site HE1, ChAd155 failed to replicate. However, insertion of a transgene cassette into the HE1 site of ChAd83 produced a viable vector.

Example 2: Virus Production, Vector Titer and Expression of Vectors of Example 1

To identify an animal model in which to evaluate vector replication, a type C adenovirus ChAd155 RC2 and a type E adenovirus ChAd83 RC2 vectors of Example 1 were assessed for their ability to replicate, measured by vector titer and genome copy number, in cells of various animal origins. The results are shown in Table 1.

Table 1. Replication and Expression of RC2 ChAd155 and RC2 ChAd83 of Example 1

| Cell line: Species | Vector | Vector Titer | Genome Copy | Expression | |
|---|---|---|---|---|---|
| | | | | Day 2 | Day 7 |
| MRC5: Human | ChAd155 | +++ | +++ | ++ | ++++ |
| | ChAd83 | +++++ | +++++ | +++ | +++++ |
| PK15: Swine | ChAd155 | +++++ | +++++ | NA | NA |
| | ChAd83 | +++ | ++++ | NA | NA |
| NMuLi: Mouse | ChAd155 | ++ | +++ | +++ | +++ |
| | ChAd83 | ND | + | ++ | ++ |
| Vero: Non-human primate | ChAd155 | ++ | ++++ | +++ | +++ |
| | ChAd83 | ND | + | + | + |

ND = not detected; NA = not available

As shown in Table 1, human MRC5 cells and swine PK15 cells produced high vector titers and high genome copy numbers of both ChAd155 and ChAd83. Murine NMuLi and non-human

primate Vero cells also produced RC ChAd155 but to a lesser extent than the human or swine cells. RC ChAd83 failed to grow well in murine NMuLi cells and, surprisingly, in non-human primate Vero cells.

Human MRC5, mouse NMuLi and non-human primate Vero cells supported the expression of RC ChAd155 through day 7. Human MRC5 cells supported the expression of RC ChAd83 through day 7, as did mouse NMuLi and non-human primate Vero cells, but to a lesser extent than the human cells.

*Virus production*

FIG. 2A shows the amount of virus produced by human primary MRC5 cells infected with either ChAd155 or ChAd83, each comprising either the RC1 or RC2 vector construction of Example 1. The cells were harvested seven days post-infection and the vector titer was evaluated in cell lysates obtained following three freeze-thaw cycles. Vector titers were measured by quantitative PCR (QPCR) analysis with primers designed for the respective promoter regions. The multiplicity of infection (moi) was 1250 virus particles per cell. The virus production is indicated in the number of virus particles per cell (vp/cell) above the bars.

Human MRC5 cells supported production of ChAd155 comprising either RC1 ($2.17 \times 10^3$ vp/cell) or RC2 ($4.40 \times 10^3$ vp/cell) and also supported production of ChAd83 comprising either RC1 ($1.18 \times 10^4$ vp/cell) or RC2 ($1.06 \times 10^5$ vp/cell). As shown in FIG. 2A, ChAd83 was produced at a higher level than ChAd155; the ChAd83 vector comprising RC2 was the most robust of the four viral/vector combinations.

FIG. 2B shows the amount of virus produced by human primary MRC5 cells infected with ChAd83 comprising the RC1, RC2 or RC3 vector construction of Example 1. The cells were harvested two and seven days post-infection. As with FIG. 2A, vector titers were measured by quantitative PCR (QPCR) analysis with primers designed for the respective promoter regions. The multiplicity of infection (moi) was 250 or 1250 virus particles per cell. The virus production is indicated in the number of virus particles per cell (vp/cell) above the bars.

Human MRC5 cells supported production of ChAd83 comprising RC1, RC2 or RC3. As shown in FIG. 2B, there was higher virus production for the RC2 and RC3 ChAd83 vectors than for the

RC1 vector. There was also higher virus production for the ChAd83 RC2 HE2 vector than the RC3 HE1 vector.

*Vector genome copy number*

After infection, the vector is replicated in the cell and the vector genome copy number can be measured by QPCR. Vector DNA replication can occur even in cells not fully permissive for viral replication and propagation. QPCR of vector DNA provides a measure of vector replication within the infected cell, independently of the ability of the virus to complete the replication cycle and be released as mature viral progeny. Vector replication can thus be quantified in animal species, tissue types and cell types which are not permissive for ChAd virus replication or propagation.

Vector genome copy number was measured in parallel with vector titer and the results shown in FIG. 3A and FIG. 3B.

As with the virus production shown in FIG. 2A, Human MRC5 cells were infected with either ChAd155 or ChAd83, each comprising either the RC1 or RC2 vector construction of Example 1. The cells were harvested seven days post-infection, the total DNA extracted, the viral genome quantified by QPCR and the results expressed as vector genome copy per cell. The multiplicity of infection (moi) was 250 virus particles per cell and the numbers of virus particles per cell are indicated above the bars denoting viral genome copies per cell. The copy number is directly proportional to the level of transgene expression.

As shown in FIG. 3A, the amount of viral DNA replication of RC1 ($6.21 \times 10^3$ vp/cell) and RC2 ($6.71 \times 10^3$ vp/cell) by ChAd155 was similar. ChAd83 produced more RC1 ($2.76 \times 10^4$ vp/cell) and RC2 ($9.19 \times 10^4$ vp/cell) viral DNA than ChAd155. The highest level of viral DNA replication was observed by ChAd83 RC2.

As with the virus production shown in FIG. 2B, Human MRC5 cells were infected with ChAd83, comprising the RC1, RC2 or RC3 vector construction of Example 1. The cells were harvested at two and seven days post-infection, the total DNA extracted, the viral genome quantified by QPCR and the results expressed as vector genome copy per cell. The multiplicity of infection (moi) was 250 or 1250 virus particles per cell and the numbers of virus particles per cell are

indicated above the bars denoting viral genome copies per cell. The copy number is directly proportional to the level of transgene expression.

As shown in FIG. 3B, the amount of viral DNA replication was higher for the RC2 and RC3 ChAd83 vectors than for the RC1 vector. There was comparable viral DNA replication between the RC2 and RC3 ChAd83 vectors.

Example 3: Adenoviral Genome Copy Number of Vectors of Example 1

The efficiency of the replication competent adenoviral vectors with the constructs of Example 1, expressed as vector copies per cell, was evaluated in cell cultures derived from both mice and non-human primates.

FIG. 4(a) shows the genome copy number of replication competent vectors grown in murine hepatic NMuLi cells grown in monolayers and infected with ChAd155 RC1, ChAd155 RC2, ChAd83 RC1 or ChAd83 RC2 at a multiplicity of infection of 250 virus particles per cell. Total DNA was extracted at five days post-infection and the vector replication was measured by QPCR using primers annealing to the vector's promoter region.

The results, expressed as vector copies per cell, are shown in FIG. 4(a). ChAd155 amplified both the RC1 and RC2 vector with high efficiency in NMuLi cells. ChAd155 replicated the RC1 ($1.73 \times 10^4$) and RC2 ($1.92 \times 10^4$) vectors to approximately the same degree. ChAd83 was less efficient than ChAd155 in replicating the RC1 and RC2 vectors. ChAd83 replicated the vector DNA only in small amounts in the murine cells. RC1 vector replicated at a level of $5.47 \times 10^2$ copies per cell and the RC2 vector at a level of $6.74 \times 10^2$ copies per cell.

Non-human primate Vero cells were also grown in monolayers and infected with ChAd155 RC1, ChAd155 RC2, ChAd83 RC1 or ChAd83 RC2 (FIG. 4(b)). Two different multiplicities of infection were used: 50 and 250 virus particles per cell. Total DNA was extracted at five days post-infection and the vector replication was measured by QPCR using primers annealing to the vector's promoter region.

The results, expressed as vector copies per cell, are shown in FIG. 4(b). The Vero primate cell line was permissive for ChAd155 RC1 ($3.71 \times 10^3$ copies per cell at an moi of 50 and $4.93 \times 10^4$

copies per cell at an moi of 250) and ChAd155 RC2 ($8.15 \times 10^3$ copies per cell at an moi of 50 and $7.05 \times 10^4$ copies per cell at an moi of 250). The Vero primate cell line was poorly, if at all, permissive for ChAd83 RC1 or ChAd83 RC2. No ChAd83 RC1 or ChAd83 RC2 vectors were detected to be expressed from Vero cells at an moi of 50. At an moi of 250, ChAd83 replicated the RC1 vector at a level of $1.13 \times 10^2$ copies per cell and the RC2 vector at a level of $1.29 \times 10^3$ copies per cell.

Example 4: Transgene Expression from Murine and Non-human Primate Cells of Vectors of Example 1

Western blot analysis was performed to compare the level of transgene expression by ChAd155 RC1 and ChAd155 RC2 in murine NMuLi cells (FIG. 5(a)). The cells were infected with ChAd155 RC1 or ChAd155 RC2 at a multiplicity of infection of 50, 250 or 1250 viral particles per cell. The cells were harvested at two and five days post infection, extracts prepared using standard methods and an equivalent amount of total cell extract loaded onto SDS-PAGE gels. Following electrophoretic separation, the proteins were transferred onto nitrocellulose membranes, which were then probed with a commercially available monoclonal antibody to the rabies glycoprotein transgene.

FIG. 5(a) demonstrates that both ChAd155 RC1 and ChAd155 RC2 express a transgene in murine NMuLi cells. Expression was observed at both two and five days post infection, indicated by the band of about 51 kDa, which corresponds to the expected molecular weight of the rabies glycoprotein (RG). The ChAd155 RC2 vector produced a higher level of transgene expression than the ChAd155 RC1 vector at both two and five days post-infection.

Western blot analysis was then performed to compare the level of transgene expression by ChAd155 RC1, ChAd155 RC2, ChAd83 RC1 and ChAd83 RC2 in murine NMuLi cells (FIG. 5(b)). The cells were infected with ChAd155 RC1, ChAd155 RC2, ChAd83 RC1 or ChAd83 RC2 at a multiplicity of infection of 50, 250 or 1250 viral particles per cell (250 and 1250 for ChAd83 RC1). The cells were processed for western blot. The cells were harvested at two and seven days post infection, extracts prepared using standard methods and an equivalent amount of extract loaded onto SDS-PAGE gels. Following electrophoretic separation, the proteins were transferred onto nitrocellulose membranes, which were then probed with a commercially available monoclonal antibody to the rabies glycoprotein transgene.

FIG. 5(b) demonstrates that ChAd155 RC1, ChAd155 RC2, ChAd83 RC1 and ChAd83 RC2 express a transgene in murine NMuLi cells. Expression was observed at both two and five days post infection, indicated by the band of about 51 kDa, which corresponds to the expected molecular weight of the rabies glycoprotein (RG). ChAd155 demonstrated more efficient expression of the transgene than ChAd83. At two days post-infection, robust transgene expression by ChAd155 RC2 was observed even at the low multiplicity of 50 vp/cell, whereas robust transgene expression by ChAd155 RC1 was first observed at higher mois. Also, RC2 demonstrated more efficient transgene expression than RC1 in both ChAd155 and ChAd83 viral serotypes. RC2 was more robustly expressed than RC1 in each of the direct comparisons.

Western blot analysis was performed to compare the level of transgene expression by ChAd83 RC1, RC2 and RC3 in MRC5 cells (FIG. 5(c)). The cells were infected with ChAd83 RC1, RC2 or RC3 at a multiplicity of infection of 250 or 1250 viral particles per cell. The cells were harvested at two and seven days post infection, extracts prepared using standard methods and an equivalent amount of total cell extract loaded onto SDS-PAGE gels. Following electrophoretic separation, the proteins were transferred onto nitrocellulose membranes, which were then probed with a commercially available monoclonal antibody to the rabies glycoprotein transgene.

FIG. 5(c) demonstrates that all of ChAd83 RC1, RC2 and RC3 express a transgene in MRC5 cells. Expression was observed at both two and seven days post infection, indicated by the band of about 51 kDa, which corresponds to the expected molecular weight of the rabies glycoprotein (RG). The ChAd83 RC2 vector produced a higher level of transgene expression than the ChAd83 RC1 and RC3 vectors at both two and seven days post-infection. There was no rabies glycoprotein detection for the RC1 and RC3 vectors at 7days.

Example 5: Construction of Alternative Chimpanzee Adenoviruses with a Single Expression Cassette

As in Example 1, wild type chimpanzee adenoviruses type 155 (ChAd155) (WO 2016/198621) isolated from healthy chimpanzees using standard procedures were constructed as replication defective viruses as described in Sci Transl Med (2012) 4:1 and WO 2010/086189.

In Example 5, the ChAd155 is constructed by inserting a single transgene expression cassette. This expression cassette comprises the classical human CMV (hCMV) promoter, F0ΔTM, N and M2-1 RSV antigens and, optionally, a WPRE enhancer. This vector is shown in FIG. 6. The expression cassette is inserted into the E1 region of the adeno virus (after the E1 region has been deleted).

The ChAd155 shown in FIG. 6 comprises a transgene encoding all of the RSV F0ΔTM, M2-1 and N antigens, wherein a self-cleavage site ("2A") is included between the RSV F0ΔTM antigen and the composite RSV N.M2-1 antigen, in which a flexible linker is included between the RSV M2-1 and N antigens.

The ChAd155 RSV vector of Example 5 compises the polynucleotide of SEQ ID NO: 4 and encodes the polypeptide of SEQ ID NO: 5.

Example 6: Construction of a Chimpanzee Adenoviruses with a Dual Expression Cassette

Again, wild type chimpanzee adenoviruses type 155 (ChAd155) (WO 2016/198621) isolated from healthy chimpanzees using standard procedures were constructed as replication defective viruses as described in Sci Transl Med (2012) 4:1 and WO 2010/086189.

The ChAd155 of Example 6 is constructed by inserting two transgene expression cassettes into two different locations in the adenovirus:

(1) The first expression cassette components comprise the classical human CMV (hCMV) promoter and N.M2-1 RSV composite antigen. This first expression cassette is inserted into the E1 region of the adenovirus (after the E1 region has been deleted).

(2) The second expression cassette comprises an enhanced classical human CMV (enhanced hCMV) promoter, the F0ΔTM RSV antigen and a WPRE enhancer. This first expression cassette is inserted into the HE2 region of the adenovirus (after the HE2 region has been deleted).

This vector comprising a dual expression cassette is shown in FIG. 7.

In the construct of FIG. 7, Ad5E4orf6 has been substituted into the early gene 4 (E4) region. The substitution is necessary to increase the productivity in HEK 293 cells.

Example 7: Transgene expression from the Dual Expression Cassette of Example 6

Western blot analysis was performed to compare the level of transgene expression in the ChAd155 vector of Example 6 (labelled "Dual" or "Dual cassette" in the figures) in MRC5 cells with:

(i) a vector comprising a single F expression cassette (ChAd155-F0ΔTM, labelled "F0ΔTm"),

(ii) a vector comprising a single NM2 expression cassette (ChAd155-NM2, labelled "NM2-1"), and

(iii) the vector of Example 5 comprising a single expression cassette containing the F and N.M2-1 RSV antigens (ChAd155-F0ΔTM.NM2, also labelled "RSV")

The western blot analysis is shown in FIG. 8 and FIG. 9.

As shown in FIG. 8, the cells were infected with ChAd155-F0ΔTM, ChAd155-F0ΔTM.NM2 ("RSV") or the ChAd155 dual cassette of Example 6 at a multiplicity of infection of 500 viral particles per cell. In addition, cells were infected with ChAd155-F0ΔTM.NM2 ("RSV") at a multiplicity of infection of 500 or 1250 viral particles per cell. The cells were harvested at 48 hours and 96 hours post infection, extracts prepared using standard methods and an equivalent amount of total cell extract loaded onto SDS-PAGE gels.

FIG. 8 shows that the ChAd155 dual cassette provides an expression level of the F antigen which is comparable to ChAd155F0ΔTM and higher than ChAd155-FΔTM.NM2 in MRC5 cells.

As shown in FIG. 9, the cells were infected with ChAd155-NM2, ChAd155-F0ΔTM.NM2 ("RSV") or the ChAd155 dual cassette of Example 6 at a multiplicity of infection of 250 and 1250 viral particles per cell. The cells were harvested at 48 hours post infection, extracts prepared using standard methods and an equivalent amount of total cell extract loaded onto SDS-PAGE gels.

In FIG. 9, the ChAd155 dual cassette provides NM2-1 expression level at least comparable to the ChAd155-NM2 single vector and higher than ChAd155-FΔTM.NM2 ("RSV") in MRC5 cells.

Example 8: Immunogencity of the Dual Expression Cassette of Example 6

The immunogenicity of the dual expression cassette of Example 6 was evaluated in CD1 outbred mice (10 per group). The experiment was performed by injecting $5x10^8$ viral particles intramuscularly into the mice. The B-cell response was measured at 4 and 8 weeks after the immunization by measuring the RSV neutralising titres. Each dot represents the response in a single mouse, and the line corresponds to the mean for each dose group. The results of this analysis are shown in FIG. 10.

FIG. 10 shows that the ChAd155 dual cassette provides a B-cell response comparable to ChAd155F0ΔTM and higher than that produced by ChAd155-F0ΔTM.NM2 ("RSV").

The immunogenicity of the dual expression cassette of Example 6 was also evaluated in BALB/c inbred mice (48, 11 or 8 per group). The experiment was performed by injecting $10^7$ or $10^6$ viral particles intramuscularly. The T-cell response was measured 3 weeks after the immunization by ex vivo IFN-gamma enzyme-linked immunospot (ELISpot) using a M2 peptide T cell epitope mapped in BALB/c mice. The results are shown in Figure 11, expressed as IFN-gamma Spot Forming Cells (SFC) per million splenocytes. Each dot represents the response in a single mouse, and the line corresponds to the mean for each dose group. Injected dose in number of virus particles are shown on the x axis. The results are shown in FIG. 11.
FIG. 11 shows that the ChAd155 dual cassette provides a T-cell response higher than that produced by the single cassette ChAd155-F0ΔTM.NM2 ("triple RSV", the results for which are obtained from historical data). This difference in response is greater for the $10^6$ vp dose.

FIG. 11 refers to "#positive mice", i.e. the number of mice which responded to the vaccine.

Example 9: Immunogencity of the Dual Expression Cassette of Example 6 in cows

The study design is detailed in Table 2 below:

| Group | No. Cows | Vaccine | Route | Dose | Immunization | End of Study |
|---|---|---|---|---|---|---|
| **Gp1** | 4 | ChAd155 single RSV | Intramuscular (IM) | $1x10^{11}$ | D0 | D90 |
| **Gp2** | 4 | ChAd155 dual RSV | Intramuscular (IM) | $1x10^{11}$ | D0 | D90 |
| **Gp3** | 4 | Saline | Intramuscular (IM) | N/A | D0 | D90 |

The "ChAd155 single RSV" is the ChAd155 of Example 5, and the "ChAd155 dual RSV" is the ChAd155 of Example 6.

A total of 12 adult cows were enrolled in the study. The cows ranged in age from 2.7 years to 7.8 years and had a mean range of 4.8 years.

Before they were enrolled in the study, the cows were pre-screened for bovine RSV (BRSV) antibodies by ELISA. This allowed study groups to be established that had a similar distribution and mean BRSV Ab titer (so as to not bias any of the groups).

Samples were collected from the cows before vaccination (D-5 or D0) and after vaccination (D7,10,14,28,60,90). In this study, the cows were vaccinated with 1x10^11 viral particles of one of the two vaccines or with saline on day zero (D0).

A Bronchoalveolar lavage (BAL) was performed at day -5, 7, 10 or 28 after vaccination to isolate T cells in the lungs of the cow. Then IFN-gamma cytokine production of the CD4+ and CD8+ T cells upon stimulation with RSV antigens (in the form of peptide pools) encoded in the vaccines was detected using intracellular cytokine staining (ICS) (i.e. IFNɣ ICS was used to detect the lung T cell responses in the animals). The results of this experiment are shown in Figures 12A and 12B. It can be concluded from this experiment that the ChAd155-dual RSV induces consistent RSV-specific CD4+ and CD8+ responses in Bronchoalveolar lavage (BAL).

Blood samples were also taken from the cows on day 0, 14, 28, 60 and 90 after vaccination in order for IFN-gamma cytokine production of the RSV-specific CD4+ and CD8+ responses of the peripheral blood mononuclear cells (PBMC) to be detected using intracellular cytokine staining

(ICS) (i.e. IFNγ ICS was used to detect the peripheral T cell responses). The results of this experiment are shown in Figures 13A and 13B. Based on these results, it can be concluded that the ChAd155-dual RSV consistently expand the pre-existing RSV-specific CD4+ and CD8+ responses in PBMC.

The blood samples were also used to detect neutralising antibodies (nAbs) for RSV in the serum (i.e. the peripheral humoral response was detected). The results of this experiment are shown in Figures 14A and 14B. These results show that the ChAd155-dual RSV boosts RSV nAbs in serum which are maintained at levels higher than baseline 3 months after vaccination.

Example 10: Immunogenicity of ChAd155 dual encoding rabies G and RSV NM2 proteins

Three different ChAd155 vectors used constructed in this experiment:

- ChAd155 encoding both rabies G (RG) and RSV NM2 proteins (called "ChAd155 dual" in this example, and ChAd155 dual hCMV NM 2-1 – CASI RG WPRE);
- ChAd155 encoding just the rabies G (RG) protein (called "ChAd155 RG" in this example, and ChAd155(ΔE4)CASI RG WPRE); and
- The ChAd155 vector shown in FIG. 6, i.e. the vector with transgene encoding all of the RSV F0ΔTM, M2-1 and N antigens (called "ChAd155 RSV" ).

Three different doses of the ChAd155 dual adenovirus were administered to mice: a highest dose of $10^7$ viral particles, and a middle dose of $10^6$ viral particles, and a lowest dose of $10^5$ viral particles.

Two different doses of the ChAd155 RG and ChAd155 RSV vectors were administered to mice. For the ChAd155 RSV, this was a higher dose of $10^7$ vaccine particles, and a lower dose of $10^6$ vaccine particles. For the ChAd155 RG, this was a higher dose of $10^6$ vaccine particles, and a lower dose of $10^5$ vaccine particles. Mice were sacrificed 3 weeks later and splenocytes tested by IFNγ ELISpot for T cell response to the vaccine encoded antigens.

The results of this experiment are shown in FIG. 15A, 15B and 15C. As can be seen from FIG. 15A,15B and 15C, the ChAd155 dual RG-NM2 vector shows overall comparable immune responses to the vectors encoding each of the RG and NM2 antigens alone.

FIG. 15C compares the cumulative response to all encoded antigens at the common $10^6$ vp dosage used for all three different vectors. The rabies G protein is listed twice (G1 and G2) as two pools of overlapping peptides were used to cover the whole sequence of the protein

Therefore, placing the two antigens in the same vector still produces a comparable immune response while allowing antigens for different pathogens to be provided in the same vector.

Example 11: Expression of ChAd155 dual encoding rabies G and RSV NM2 proteins in HeLa cells

In the experiments of Example 11, HeLa cells were infected with the purified "ChAd155 dual", "ChAd155 RG" and "ChAd155 RSV" used in Example 10.

Multiplicities of infection (MOI) of 50, 250 and 1250 were used in this experiment.

In order to obtain the Western Blot shown in FIG. 16A (obtained under reduicing conditions), the cell lysate was harvested 48 hours post-infection. The estimated size of the NM2-1 is 65 kDa. FIG. 16A shows a comparable expression level for ChAd155 dual cassette and ChAd155 NM2-1. In addition, the NM2-1 expression level was higher for the ChAd155 dual cassette than the ChAd155 RSV vector.

To obtain the Western Blot shown in FIG. 16B, the supernatent was harvested 48 hours post-infection. The estimated size of the rabies glycoprotein is 57.6 kDa. FIG. 16B shows a comparable expression level for the ChAd155 dual and ChAd155 RG adenoviruses.

In addition, infectivity data was also collected using the four different vectors. The infectivity of purified virus was evaluated in adherent Procell 92 cells by Hexon Immunostaining. The results are given in Table 3 below (vp = virus particle, ifu = infectious unit, and R is the ratio between these two numbers). The infectivity results indicate that all of the vectors have similar infectivity. In addition, as all of the R values were below 300, the infectivity of all vectors was deemed to be within the range of acceptability.

Table 3:

| | Vp/ml | Ifu/ml | R (vp/ifu) |
|---|---|---|---|
| ChAd155 hCMV NM 2-1 – CASI RG WPRE | 5,51E+11 | 4,53E+09 | 122 |
| ChAd155(ΔE4)hCMV-RSV | 1.12E+11 | 1.05E+09 | 107 |
| ChAd155(ΔE4)hCMV NM2-1 | 5.68E+11 | 4.26E+09 | 133 |
| ChAd155(ΔE4)CASI RG WPRE | 3.48E+11 | 3.35E+09 | 104 |

Example 12: Immunogenicity of ChAd155 dual encoding CRPV E2 and E1 proteins

Two different ChAd155 vectors were constructed in this experiment:

- ChAd155 encoding a modified CRPV E2 protein in a first expression cassette, and a modified CRPV E1 protein in a second expression cassette (called “CRPV Dual”); and
- ChAd155 encoding a fusion of the modified CRPV E2 and E1 proteins in a single expression cassette (called “CRPV Fusion”)

Two different doses of the two adeno vectors were administered to mice: a higher dose of $10^7$ viral particles, and a lower dose of $10^6$ viral particles. The results of this experiment are shown in FIG. 17. FIG. 17 is a IFNγ ELISpot on splenocytes 3 weeks post vaccination. A statistical analysis was performed on the results and the differences between the response from the different vectors was not deemed to be statistically significant. However, as can be seen from FIG. 17, the ChAd155 CRPV Dual vectors show increased frequency of responding mice at lowest dosage than the CRPV Fusion vectors (6/6 positive responding mice for the $10^6$ dose of the CRPV dual vector, but only 4/6 positive responding mice for the $10^6$ dose of the CRPV fusion vector.

Example 13: Expression of ChAd155 dual encoding CRPV E2 and E1 proteins

The two different ChAd155 vectors used in Example 12 were also used in Example 13.

Multiplicities of infection (MOI) of 250 and 1250 were used in this experiment. The cell lysate was harvested 48 hours post-infection. The estimated size of the modified E1 protein is 48 kDa, the modified E2 protein is 35 kDa, and the fusion protein containing both the modified E1 and E2 proteins is 88 kDa.

FIG. 18 shows a Western blot (obtained under reducing conditions) illustrating that there was better expression of the modified E1 and E2 proteins by the CRPV dual vector than the CRPV fusion vector. The "Pvj" columns shown in FIG. 18 are the controls used.

In addition, infectivity data was collected using the two different vectors. The infectivity of purified virus was evaluated in adherent Procell 92 cells by Hexon Immunostaining. The results are given in Table 4 below (vp = virus particle, ifu = infectious unit, and R is the ratio between these two numbers). The infectivity results indicate that the two vectors have similar infectivity. In addition, as all of the R values were below 300, the infectivity of all vectors was deemed to be within the range of acceptability.

Table 4:

| | Vp/ml | Ifu/ml | R (vp/ifu) |
|---|---|---|---|
| ChAd155 hCMV CRPV DE2DE1 Fusion HA WPRE "CRPV Fusion" | 4.52E+11 | 2.97E+09 | 153 |
| ChAd155 hCMV CRPV DE2 HA WPRE – Enh.CMV CRPV DE1 HA WPRE "CRPV Dual" | 6.20E+11 | 4.39E+09 | 143 |

## DESCRIPTION OF THE SEQUENCES

**SEQ ID NO: 1 Polynucleotide sequence encoding wild type ChAd155**

CATCATCAATAATATACCTTATTTTGGATTGAAGCCAATATGATAATGAGATGGGCGGCGCGGGGCGGGAG
GCGGGTCCGGGGGCGGGCCGGCGGGCGGGGCGGTGTGGCGGAAGTGGACTTTGTAAGTGTGGCGGATGTGACTTGCT
AGTGCCGGGCGCGGTAAAAGTGACGTTTTCCGTGCGCGACAACGCCCACGGGAAGTGACATTTTTCCCGCGGTTTTT
ACCGGATGTTGTAGTGAATTTGGGCGTAACCAAGTAAGATTTGGCCATTTTCGCGGGAAAACTGAAACGGGGAAGTG
AAATCTGATTAATTTCGCGTTAGTCATACCGCGTAATATTTGTCGAGGGCCGAGGGACTTTGGCCGATTACGTGGAG
GACTCGCCCAGGTGTTTTTTGAGGTGAATTTCCGCGTTCCGGGTCAAAGTCTCCGTTTTATTATTATAGTCAGCTGA
CGCGGAGTGTATTTATACCCTCTGATCTCGTCAAGTGGCCACTCTTGAGTGCCAGCGAGTAGAGTTTTCTCCTCTGC
CGCTCTCCGCTCCGCTCCGCTCGGCTCTGACACCGGGGAAAAAATGAGACATTTCACCTACGATGGCGGTGTGCTCA
CCGGCCAGCTGGCTGCTGAAGTCCTGGACACCCTGATCGAGGAGGTATTGGCCGATAATTATCCTCCCTCGACTCCT
TTTGAGCCACCTACACTTCACGAACTCTACGATCTGGATGTGGTGGGGCCCAGCGATCCGAACGAGCAGGCGGTTTC
CAGTTTTTTTCCAGAGTCCATGTTGTTGGCCAGCCAGGAGGGGGTCGAACTTGAGACCCCTCCTCCGATCGTGGATT
CCCCCGATCCGCCGCAGCTGACTAGGCAGCCCGAGCGCTGTGCGGGACCTGAGACTATGCCCCAGCTGCTACCTGAG
GTGATCGATCTCACCTGTAATGAGTCTGGTTTTCCACCCAGCGAGGATGAGGACGAAGAGGGTGAGCAGTTTGTGTT
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GTGGAGTGCATTGAGGACTTGCTTTTTGATTCACAGGAACCTTTGGACTTGAGCTTGAAACGCCCCAGGCATTAAAC
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TTCCAGGAGAAGGTCATCAGGACTTTGGATTTTTCCACACCGGGGCGCATTGCAGCCGCGGTTGCTTTTCTAGCTTT
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GAGCATGGATCAGACACAAGAACAGGCTGCAACTGTTGTCTTCCGTCCGCCCGTTGCTGATTCCGGCGGAGGAGCAA
CAGGCCGGGTCAGAGGACCGGGCCCGTCGGGATCCGGAGGAGAGGGCACCGAGGCCGGGCGAGAGGAGCGCGCTGAA
CCTGGGAACCGGGCTGAGCGGCCATCCACATCGGGAGTGAATGTCGGGCAGGTGGTGGATCTTTTTCCAGAACTGCG
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AATTGTGCCAATGAGTTGGATCTGTTGGGTCAGAAGTATAGCATAGAGCAGCTGACCACTTACTGGCTGCAGCCGGG
TGATGATCTGGAGGAAGCTATTAGGGTGTATGCTAAGGTGGCCCTGCGGCCCGATTGCAAGTACAAGCTCAAGGGGC
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GGGGCCCAACTTTAACGGCACGGTGTTTTTGGGGAACACCAACCTGGTCCTGCACGGGGTGAGCTTCTATGGGTTTA
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ACCATCCATGTAACCAGCCACAGCCGGAAGGCCTGGCCCGTGTTCGAGCACAACTTGCTGACCCGCTGCTCCTTGCA
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GGTGAGTGGGCGTGGCCTGGGGTGGTCATGAAAATATATAAGTTGGGGGTCTTAGGGTCTCTTTATTTGTGTTGCAG
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**SEQ ID NO: 2 Polynucleotide sequence encoding wild type ChAd83**

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ACCAAAAGTTTGAGGTATATTATTGATGATG

**SEQ ID NO: 3 Polynucleotide sequence encoding the CASI promoter**

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**SEQ ID NO: 4 Polynucleotide sequence encoding ChAd155/RSV**

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ATGATG

**SEQ ID NO: 5 RSV F0ΔTM-N-M2-1 amino acid sequence**

MELLILKANAITTILTAVTFCFASGQNITEEFYQSTCSAVSKGYLSALRTGWYTSVITIELSNIKENKCNGTDA
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KLAAGDRSGLTAVIRRANNVLKNEMKRYKGLLPKDIANS
FYEVFEKYPHFIDVFVHFGIAQSSTRGGSRVEGIFAGLFMNAYGAGQVMLRWGVLAKSVKNIMLGHASVQ
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AAKAYAEQLKENGVINYSVLDLTAEELEAIKHQLNPKDNDVELGGGGSGGGGMSRRNPCKFEIRGHCLNG
KRCHFSHNYFEWPPHALLVRQNFMLNRILKSMDKSIDTLSEISGAAELDRTEEYALGVVGVLESYIGSINNIT
KQSACVAMSKLLTELNSDDIKKLRDNEELNSPKIRVYNTVISYIESNRKNNKQTIHLLKRLPADVLKKTIKN
TLDIHKSITINNPKESTVSDTNDHAKNNDTT

**SEQ ID NO: 6 Polynucleotide sequence encoding the enhanced hCMV promoter**

CCATTGCATACGTTGTATCCATATCATAATATGTACATTTATATTGGCTCATGTCCAACATTACCGCCATGTTG
ACATTGATTATTGACTAGTTATTAATAGTAATCAATTACGGGGTCATTAGTTCATAGCCCATATATGGAGTTCC
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ACGTATGTTCCCATAGTAACGCCAATAGGGACTTTCCATTGACGTCAATGGGTGGAGTATTTACGGTAAACTGC
CCACTTGGCAGTACATCAAGTGTATCATATGCCAAGTACGCCCCCTATTGACGTCAATGACGGTAAATGGCCCG
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**SEQ ID NO: 7 Polynucleotide sequence encoding the hCMV NM2 bghpolyA cassette**

**CCATTGCATACGTTGTATCCATATCATAATATGTACATTTATATTGGCTCATGTCCAACATTACCGCCATGTTG**
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**GCGTTACATAACTTACGGTAAATGGCCCGCCTGGCTGACCGCCCAACGACCCCCGCCCATTGACGTCAATAATG**
**ACGTATGTTCCCATAGTAACGCCAATAGGGACTTTCCATTGACGTCAATGGGTGGAGTATTTACGGTAAACTGC**
**CCACTTGGCAGTACATCAAGTGTATCATATGCCAAGTACGCCCCCTATTGACGTCAATGACGGTAAATGGCCCG**
**CCTGGCATTATGCCCAGTACATGACCTTATGGGACTTTCCTACTTGGCAGTACATCTACGTATTAGTCATCGCT**
**ATTACCATGGTGATGCGGTTTTGGCAGTACATCAATGGGCGTGGATAGCGGTTTGACTCACGGGGATTTCCAAG**
**TCTCCACCCCATTGACGTCAATGGGAGTTTGTTTTGGCACCAAAATCAACGGGACTTTCCAAAATGTCGTAACA**
**ACTCCGCCCCATTGACGCAAATGGGCGGTAGGCGTGTACGGTGGGAGGTCTATATAAGCAGAGCTCTCCCTATC**
**AGTGATAGAGATCTCCCTATCAGTGATAGAGATCGTCGACGAGCTCGTTTAGTGAACCGTCAGATCGCCTGGAG**
**ACGCCATCCACGCTGTTTTGACCTCCATAGAAGACACCGGGACCGATCCAGCCTCCGCGGCCGGGAACGGTGCA**
**TTGGAACGCGGATTCCCCGTGCCAAGAGTGA**GATCTTCCGTTTATCTAGGTACCAGATATCGCCACC*ATGGCCC*
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*AGCACCGGCGACAGCATCGATACCCCCAACTACGACGTGCAGAAGCACATCAACAAGCTGTGCGGCATGCTGCT*
*GATCACAGAGGACGCCAACCACAAGTTCACCGGCCTGATCGGCATGCTGTACGCCATGAGCCGGCTGGGCCGGG*
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*CAGGACATCAACGGCAAAGAAATGAAGTTCGAGGTGCTGACCCTGGCCAGCCTGACCACCGAGATCCAGATCAA*
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*CGCCAGCGTGCAGGCCGAGATGGAACAGGTGGTGGAGGTGTACGAGTACGCCCAGAAGCTGGGCGGAGAGGCCG*
*GCTTCTACCACATCCTGAACAACCCTAAGGCCTCCCTGCTGTCCCTGACCCAGTTCCCCCACTTCTCCAGCGTG*
*GTGCTGGGAAATGCCGCCGGACTGGGCATCATGGGCGAGTACCGGGGCACCCCCAGAAACCAGGACCTGTACGA*
*CGCCGCCAAGGCCTACGCCGAGCAGCTGAAAGAAAACGGCGTGATCAACTACAGCGTGCTGGACCTGACCGCTG*
*AGGAACTGGAAGCCATCAAGCACCAGCTGAACCCCAAGGACAACGACGTGGAGCTGGGAGGCGGAGGATCTGGC*
*GGCGGAGGCATGAGCAGACGGAACCCCTGCAAGTTCGAGATCCGGGGCCACTGCCTGAACGGCAAGCGGTGCCA*
*CTTCAGCCACAACTACTTCGAGTGGCCCCCTCATGCTCTGCTGGTGCGGCAGAACTTCATGCTGAACCGGATCC*
*TGAAGTCCATGGACAAGAGCATCGACACCCTGAGCGAGATCAGCGGAGCCGCCGAGCTGGACAGAACCGAGGAA*

*TATGCCCTGGGCGTGGTGGGAGTGCTGGAAAGCTACATCGGCTCCATCAACAACATCACAAAGCAGAGCGCCTG*
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*ACAGCCCCAAGATCCGGGTGTACAACACCGTGATCAGCTACATTGAGAGCAACCGCAAGAACAACAAGCAGACC*
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*GACCCTGGAAGGTGCCACTCCCACTGTCCTTTCCTAATAAAATGAGGAAATTGCATCGCATTGTCTGAGTAGGT*
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**CMV Promoter sequence: bold**

*Transgene sequence NM2: Italic*

*bghpolyA PolyA signal: italic+ underline*

**SEQ ID NO: 8 NM2 protein sequence**

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**SEQ ID NO: 9 Polynucleotide sequence encoding the hCMV F0 WPRE bghpolyA cassette**

**CCATTGCATACGTTGTATCCATATCATAATATGTACATTTATATTGGCTCATGTCCAACATTACCGCCATGTTG**
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**GCGTTACATAACTTACGGTAAATGGCCCGCCTGGCTGACCGCCCAACGACCCCCGCCCATTGACGTCAATAATG**
**ACGTATGTTCCCATAGTAACGCCAATAGGGACTTTCCATTGACGTCAATGGGTGGAGTATTTACGGTAAACTGC**
**CCACTTGGCAGTACATCAAGTGTATCATATGCCAAGTACGCCCCCTATTGACGTCAATGACGGTAAATGGCCCG**
**CCTGGCATTATGCCCAGTACATGACCTTATGGGACTTTCCTACTTGGCAGTACATCTACGTATTAGTCATCGCT**
**ATTACCATGGTGATGCGGTTTTGGCAGTACATCAATGGGCGTGGATAGCGGTTTGACTCACGGGGATTTCCAAG**

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**AGGTAAGTCCGGCCTCCGCGCCGGGTTTTGGCGCCTCCCGCGGGCGCCCCCCTCCTCACGGCGAGCGCTGCCAC**
**GTCAGACGAAGGGCGCAGCGAGCGTCCTGATCCTTCCGCCCGGACGCTCAGGACAGCGGCCCGCTGCTCATAAG**
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**TTCTTTCCAGAGAGCGGAACAGGCGAGGAAAAGTAGTCCCTTCTCGGCGATTCTGCGGAGGGATCTCCGTGGGG**
**CGGTGAACGCCGATGATGCCTCTACTAACCATGTTCATGTTTTCTTTTTTTTTCTACAGGTCCTGGGTGACGAA**
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*CTGCTTCGCCAGCGGCCAGAACATCACCGAGGAATTCTACCAGAGCACCTGTAGCGCCGTGAGCAAGGGCTACC*
*TGAGCGCCCTGAGAACCGGCTGGTACACCAGCGTGATCACCATCGAGCTGAGCAACATCAAAGAAAACAAGTGC*
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*GCTGCTGATGCAGAGCACCCCCGCCACCAACAACCGGGCCAGACGGGAGCTGCCCCGGTTCATGAACTACACCC*
*TGAACAACGCCAAAAAGACCAACGTGACCCTGAGCAAGAAGCGGAAGCGGCGGTTCCTGGGCTTTCTGCTGGGC*
*GTGGGCAGCGCCATTGCCAGCGGCGTGGCCGTGTCTAAGGTGCTGCACCTGGAAGGCGAAGTGAACAAGATCAA*
*GAGCGCCCTGCTGAGCACCAACAAGGCCGTGGTGTCCCTGAGCAACGGCGTGAGCGTGCTGACCAGCAAGGTGC*
*TGGATCTGAAGAACTACATCGACAAGCAGCTGCTGCCCATCGTGAACAAGCAGAGCTGCAGCATCAGCAACATC*
*GAGACAGTGATCGAGTTCCAGCAGAAGAACAACCGGCTGCTGGAAATCACCCGGGAGTTCAGCGTGAACGCCGG*
*CGTGACCACCCCTGTGTCCACCTACATGCTGACCAACAGCGAGCTGCTGAGCCTGATCAACGACATGCCCATCA*
*CCAACGACCAGAAAAAGCTGATGAGCAACAACGTGCAGATCGTGCGGCAGCAGAGCTACTCCATCATGTCCATC*
*ATCAAAGAAGAGGTGCTGGCCTACGTGGTGCAGCTGCCCCTGTACGGCGTGATCGACACCCCCTGCTGGAAGCT*
*GCACACCAGCCCCCTGTGCACCACCAACACCAAAGAGGGCAGCAACATCTGCCTGACCCGGACCGACAGAGGCT*
*GGTACTGCGACAACGCCGGCAGCGTGTCATTCTTTCCACAGGCCGAGACATGCAAGGTGCAGAGCAACCGGGTG*
*TTCTGCGACACCATGAACAGCCTGACCCTGCCCTCCGAAGTGAACCTGTGCAACGTGGACATCTTCAACCCCAA*
*GTACGACTGCAAGATCATGACCTCCAAGACCGACGTGTCCAGCTCCGTGATCACCTCCCTGGGCGCCATCGTGT*
*CCTGCTACGGCAAGACCAAGTGCACCGCCAGCAACAAGAACCGGGGCATCATCAAGACCTTCAGCAACGGCTGC*
*GACTACGTGTCCAACAAGGGGGTGGACACCGTGTCCGTGGGCAACACCCTGTACTACGTGAACAAACAGGAAGG*
*CAAGAGCCTGTACGTGAAGGGCGAGCCCATCATCAACTTCTACGACCCCCTGGTGTTCCCCAGCGACGAGTTCG*
*ACGCCAGCATCAGCCAGGTGAACGAGAAGATCAACCAGAGCCTGGCCTTCATCCGGAAGTCCGACGAGCTGCTG*
*CACAATGTGAATGCCGGCAAGTCCACCACCAAC*TGATGAGCGGCCATCTAA**TCAACCTCTGGATTACAAAATTT**
**GTGAAAGATTGACTGGTATTCTTAACTATGTTGCTCCTTTTACGCTATGTGGATACGCTGCTTTAATGCCTTTG**
**TATCATGCTATTGCTTCCCGTATGGCTTTCATTTTCTCCTCCTTGTATAAATCCTGGTTGCTGTCTCTTTATGA**
**GGAGTTGTGGCCCGTTGTCAGGCAACGTGGCGTGGTGTGCACTGTGTTTGCTGACGCAACCCCCACTGGTTGGG**
**GCATTGCCACCACCTGTCAGCTCCTTTCCGGGACTTTCGCTTTCCCCCTCCCTATTGCCACGGCGGAACTCATC**
**GCCGCCTGCCTTGCCCGCTGCTGGACAGGGGCTCGGCTGTTGGGCACTGACAATTCCGTGGTGTTGTCGGGGAA**

**ATCATCGTCCTTTCCTTGGCTGCTCGCCTGTGTTGCCACCTGGATTCTGCGCGGGACGTCCTTCTGCTACGTCC**
**CTTCGGCCCTCAATCCAGCGGACCTTCCTTCCCGCGGCCTGCTGCCGGCTCTGCGGCCTCTTCCGCGTCTTCGC**
**CTTCGCCCTCAGACGAGTCGGATCTCCCTTTGGGCCGCCTCCCCGCCT**GCGGCCGCGATCTG*CTGTGCCTTCTA*
*GTTGCCAGCCATCTGTTGTTTGCCCCTCCCCCGTGCCTTCCTTGACCCTGGAAGGTGCCACTCCCACTGTCCTT*
*TCCTAATAAAATGAGGAAATTGCATCGCATTGTCTGAGTAGGTGTCATTCTATTCTGGGGGGTGGGGTGGGGCA*
*GGACAGCAAGGGGGAGGATTGGGAAGACAATAGCAGGCATGCTGGGGATGCGGTGGGCTCTATGG*

**Enhanced CMV Promoter sequence: bold**

*Transgene sequence F0: Italic*

**WPRE sequence: underlined bold**

*bghpolyA PolyA signal: italic+ underline*

**SEQ ID NO: 10 F0 protein sequence**

MELLILKANAITTILTAVTFCFASGQNITEEFYQSTCSAVSKGYLSALRTGWYTSVITIELSNIKENKCNGTDA
KVKLIKQELDKYKNAVTELQLLMQSTPATNNRARRELPRFMNYTLNNAKKTNVTLSKKRKRRFLGFLLGVGSAI
ASGVAVSKVLHLEGEVNKIKSALLSTNKAVVSLSNGVSVLTSKVLDLKNYIDKQLLPIVNKQSCSISNIETVIE
FQQKNNRLLEITREFSVNAGVTTPVSTYMLTNSELLSLINDMPITNDQKKLMSNNVQIVRQQSYSIMSIIKEEV
LAYVVQLPLYGVIDTPCWKLHTSPLCTTNTKEGSNICLTRTDRGWYCDNAGSVSFFPQAETCKVQSNRVFCDTM
NSLTLPSEVNLCNVDIFNPKYDCKIMTSKTDVSSSVITSLGAIVSCYGKTKCTASNKNRGIIKTFSNGCDYVSN
KGVDTVSVGNTLYYVNKQEGKSLYVKGEPIINFYDPLVFPSDEFDASISQVNEKINQSLAFIRKSDELLHNVNA
GKSTTN

**SEQ ID NO: 11 Amino acid sequence of a flexible linker**

Gly-Gly-Gly-Ser-Gly-Gly-Gly

**SEQ ID NO: 12 Amino acid sequence of a flexible linker**

Gly-Gly-Gly-Gly-Ser-Gly-Gly-Gly-Gly

# CLAIMS

1. A simian adenoviral vector comprising two expression cassettes, wherein each expression cassette comprises a transgene and a promoter, and wherein the first expression cassette is inserted in the E1 region of the simian adenoviral vector, and the second expression cassette is inserted in a region of the adenoviral vector that is compatible with vector replication.

2. A simian adenoviral vector comprising two expression cassettes, wherein each expression cassette comprises a transgene and a promoter, and wherein the first expression cassette is inserted in the E1 region of the simian adenoviral vector, and the second expression cassette is inserted in the E3 region, between the stop codons of L5 and E4 (the “HE1” region) or between the end of the ITR and the cap site of E4 mRNA (the “HE2” region) of the simian adenoviral vector.

3. The simian adenoviral vector of Claim 2, wherein the second expression cassette is inserted in the E3 region of the simian adenoviral vector.

4. The simian adenoviral vector of Claim 2, wherein the second expression cassette is inserted in the HE1 region of the simian adenoviral vector.

5. The simian adenoviral vector of Claim 2, wherein the second expression cassette is inserted in the HE2 region of the simian adenoviral vector.

6. The simian adenoviral vector of any preceeding claim, wherein the vector is a chimpanzee adenoviral vector.

7. The simian adenoviral vector of any preceeding claim, wherein the vector is an adenovirus.

8. The simian adenoviral vector of Claim 7, wherein the vector is ChAd155.

9. The simian adenoviral vector of Claim 7, wherein the vector is ChAd83.

10. The simian adenoviral vector of any preceeding claim, wherein the first expression cassette comprises a human CMV or an enhanced human CMV promoter.

11. The simian adenoviral vector of any preceeding claim, wherein the second expression cassette comprises a human CMV or an enhanced human CMV promoter.

12. The simian adenoviral vector of Claim 10 or 11, wherein the enhanced hCMV promoter has a nucleic acid sequence having at least about 90%, at least about 95%, at least about 96%, at least about 97%, at least about 98%, at least about 99% sequence identity to SEQ ID NO: 6.

13. The simian adenoviral vector of any one of Claims 10 to 12, wherein, the promoter comprises or consists of a nucleic acid sequence of SEQ ID NO: 6.

14. The simian adenoviral vector of any preceeding claim, wherein the first and second expression cassettes comprise different promoters.

15. The simian adenoviral vector of any preceeding claim, wherein the adenoviral vector is capable of infecting a mammalian cell.

16. The simian adenoviral vector of any preceeding claim, wherin the first and/or second expression cassette further comprises a posttranscriptional regulatory element.

17. The simian adenoviral vector of claim 16, wherein the posttranscriptional regulatory element is a Woodchuck Hepatitis Postranscriptional Regulatory Element.

18. A composition comprising a simian adenoviral vector of any preceding claim and a pharmaceutically acceptable excipient.

19. A simian adenoviral vector or composition according to any preceding claim for use as a medicament.

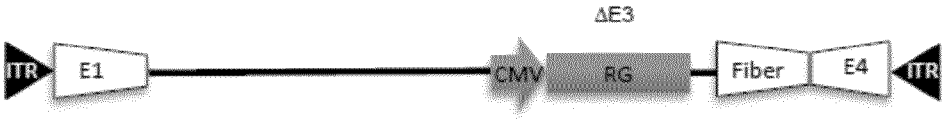
20. A simian adenoviral vector or composition according to any preceding claim for use as a vaccine.

21. A simian adenoviral vector or composition according to any preceding claim for the therapy or prophylaxis of a disease.

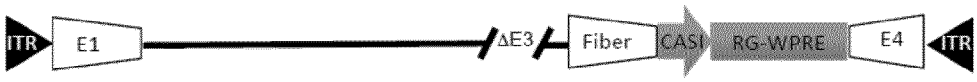
22. A method of inducing an immune response in a subject comprising administering the simian adenoviral vector or composition according to any preceding claim to the subject.

FIG. 1

(i) RC1




(ii) RC3:




(iii) RC2:

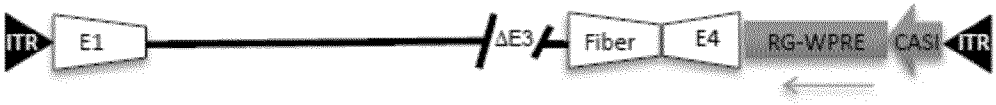


FIG. 2A

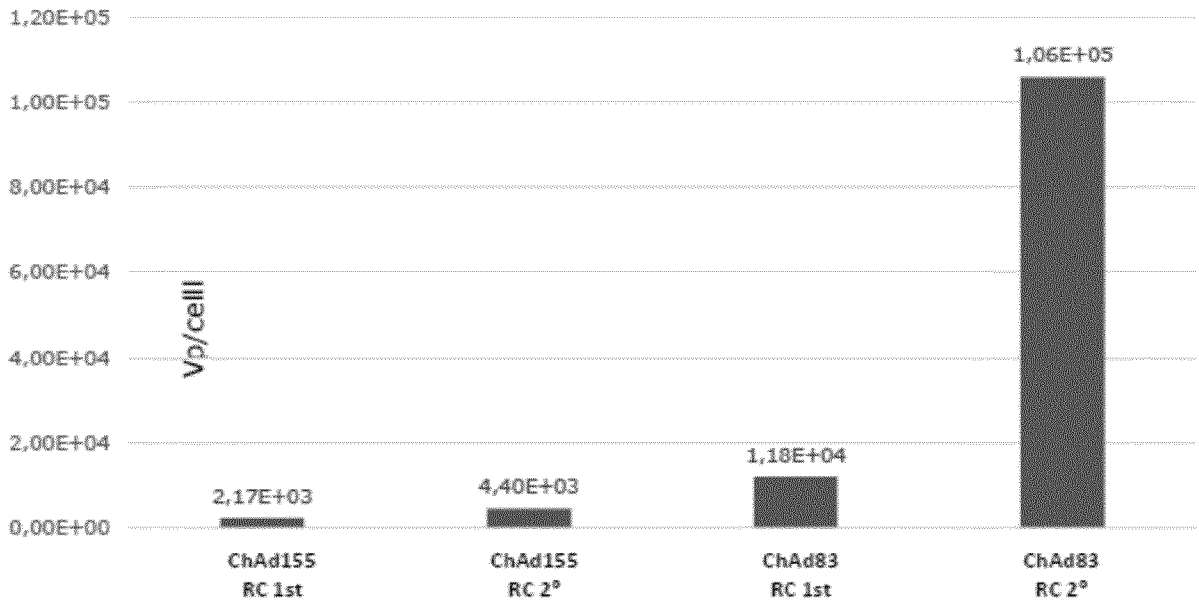

1,20E+05
1,00E+05
8,00E+04
6,00E+04
4,00E+04
2,00E+04
0,00E+00
Vp/cell
2,17E+03
4,40E+03
1,18E+04
1,06E+05
ChAd155 RC 1st
ChAd155 RC 2°
ChAd83 RC 1st
ChAd83 RC 2°

FIG. 2B

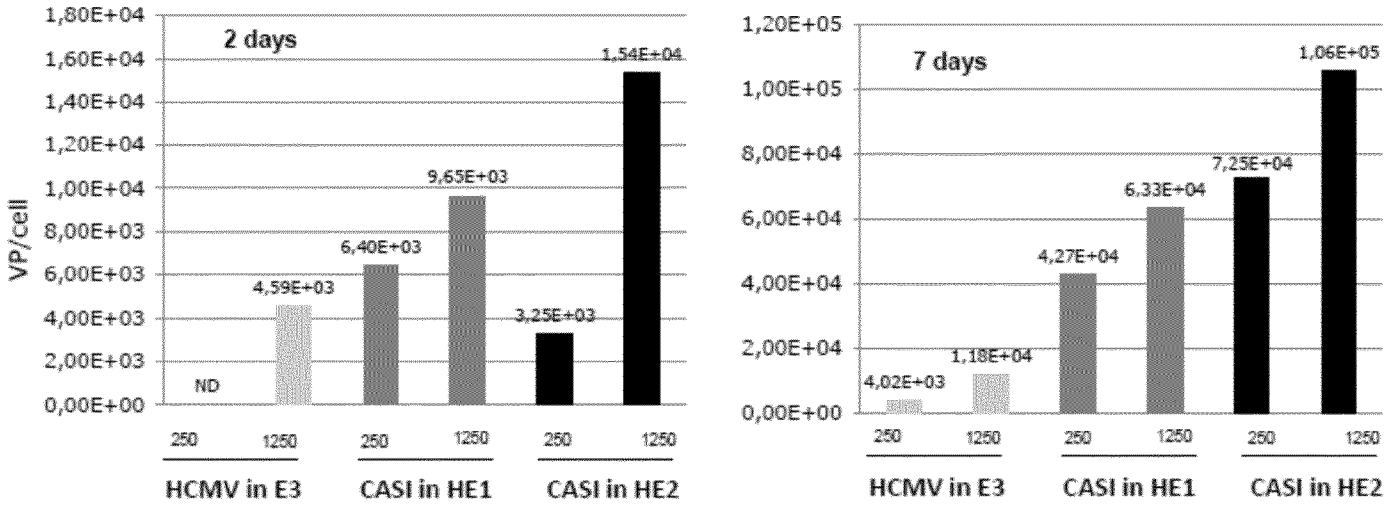

2 days
VP/cell
1,80E+04
1,60E+04
1,40E+04
1,20E+04
1,00E+04
8,00E+03
6,00E+03
4,00E+03
2,00E+03
0,00E+00
ND
4,59E+03
6,40E+03
9,65E+03
3,25E+03
1,54E+04
250
1250
HCMV in E3
CASI in HE1
CASI in HE2
7 days
1,20E+05
1,00E+05
8,00E+04
6,00E+04
4,00E+04
2,00E+04
0,00E+00
4,02E+03
1,18E+04
4,27E+04
6,33E+04
7,25E+04
1,06E+05

FIG. 3A

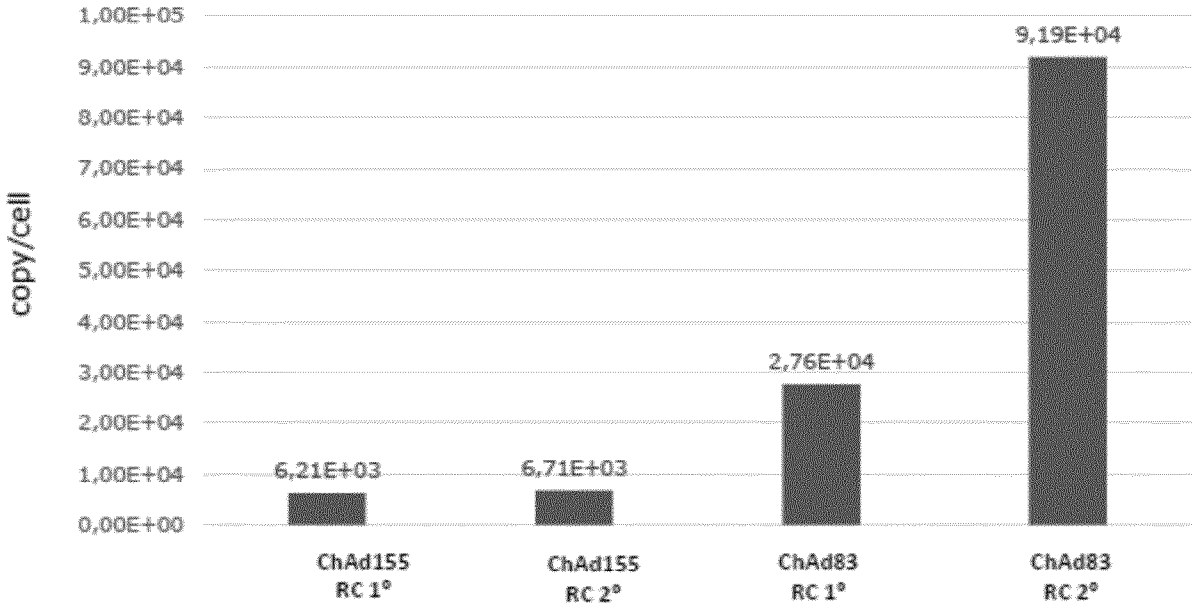

copy/cell
1,00E+05
9,00E+04
8,00E+04
7,00E+04
6,00E+04
5,00E+04
4,00E+04
3,00E+04
2,00E+04
1,00E+04
0,00E+00
6,21E+03
6,71E+03
2,76E+04
9,19E+04
ChAd155 RC 1°
ChAd155 RC 2°
ChAd83 RC 1°
ChAd83 RC 2°

FIG. 3B

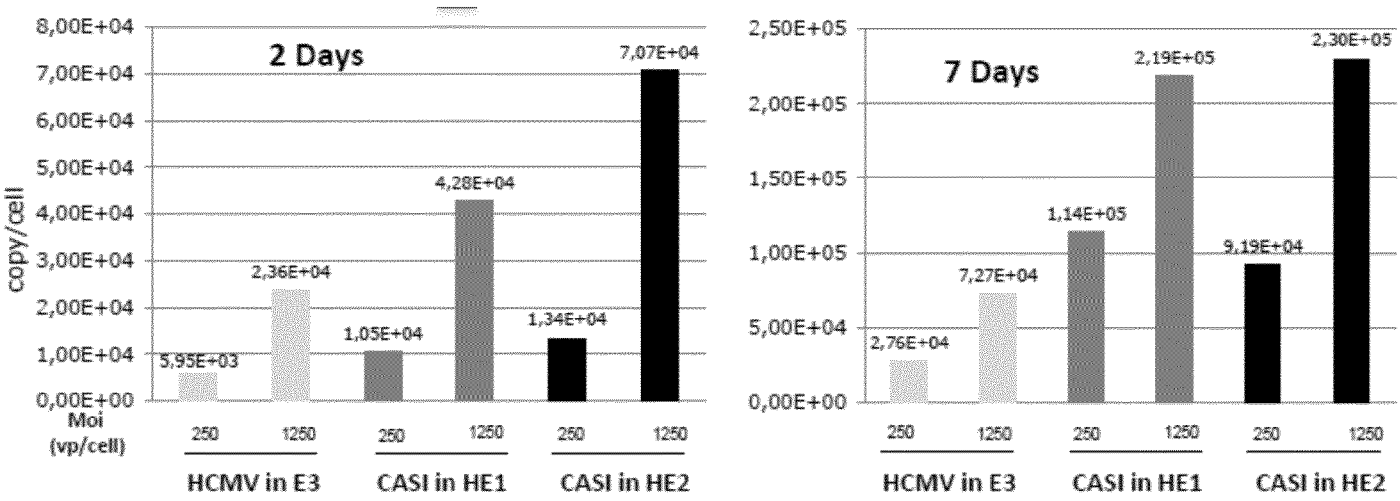
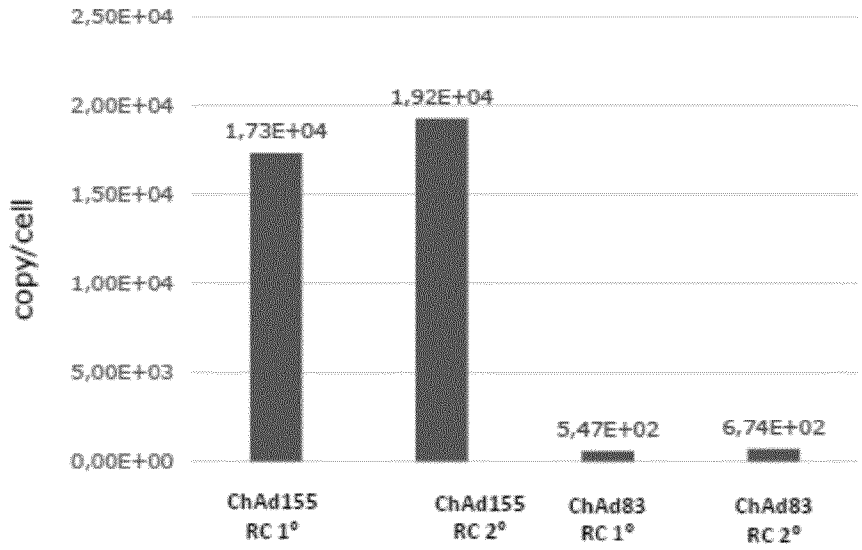

2 Days
copy/cell
8,00E+04
7,00E+04
6,00E+04
5,00E+04
4,00E+04
3,00E+04
2,00E+04
1,00E+04
0,00E+00
5,95E+03
2,36E+04
1,05E+04
4,28E+04
1,34E+04
7,07E+04
Moi
(vp/cell)
250
1250
250
1250
250
1250
HCMV in E3
CASI in HE1
CASI in HE2
7 Days
2,50E+05
2,00E+05
1,50E+05
1,00E+05
5,00E+04
0,00E+00
2,76E+04
7,27E+04
1,14E+05
2,19E+05
9,19E+04
2,30E+05
250
1250
250
1250
250
1250
HCMV in E3
CASI in HE1
CASI in HE2

FIG. 4

(a)


2,50E+04
2,00E+04
1,50E+04
1,00E+04
5,00E+03
0,00E+00
copy/cell
1,73E+04
1,92E+04
5,47E+02
6,74E+02
ChAd155 RC 1°
ChAd155 RC 2°
ChAd83 RC 1°
ChAd83 RC 2°

(b)

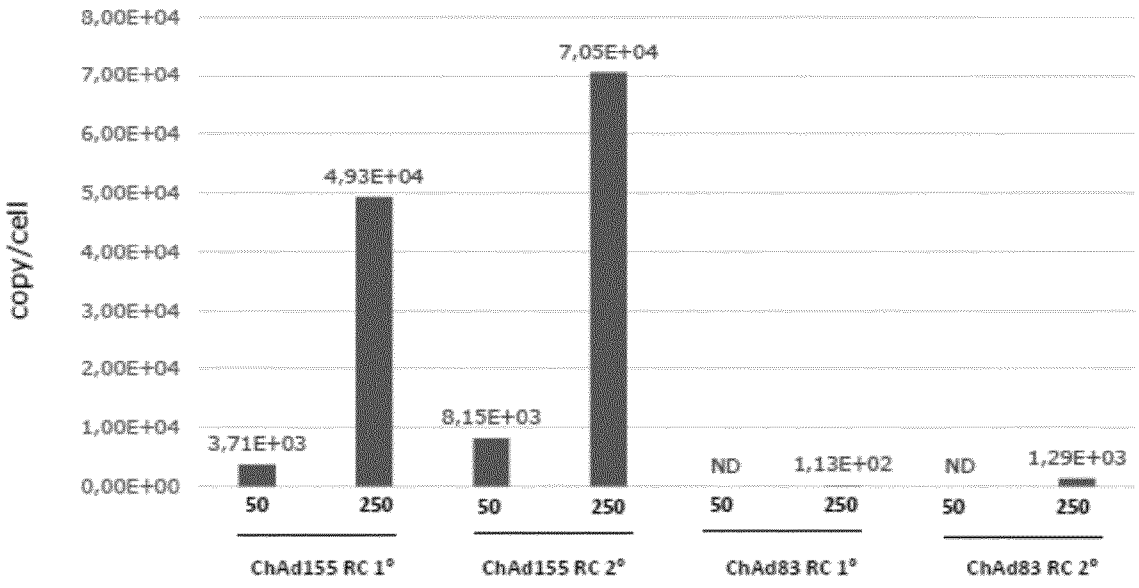

8,00E+04
7,00E+04
6,00E+04
5,00E+04
4,00E+04
3,00E+04
2,00E+04
1,00E+04
0,00E+00
copy/cell
3,71E+03
4,93E+04
8,15E+03
7,05E+04
ND
1,13E+02
ND
1,29E+03
50
250
ChAd155 RC 1°
ChAd155 RC 2°
ChAd83 RC 1°
ChAd83 RC 2°

FIG. 5

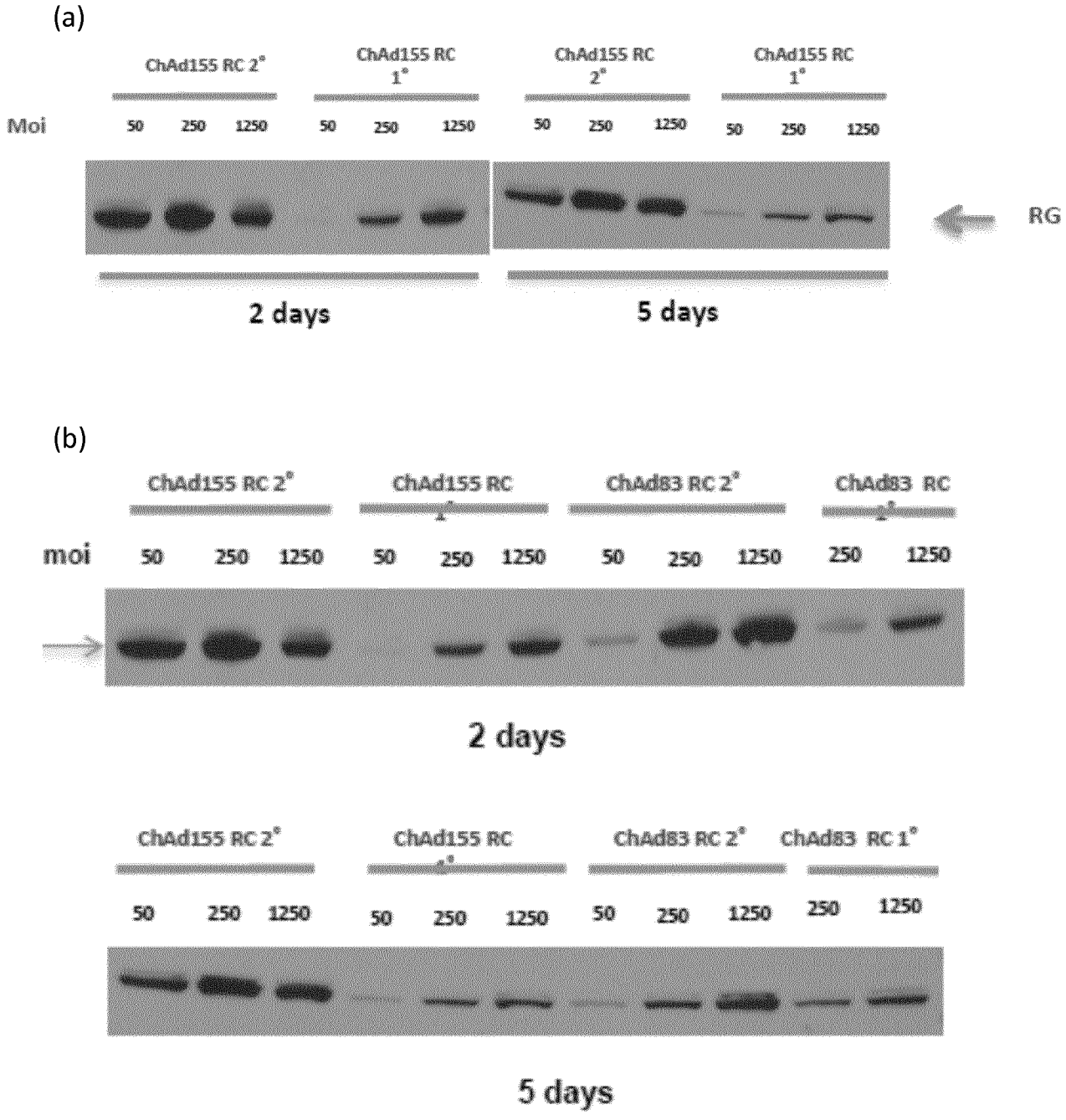
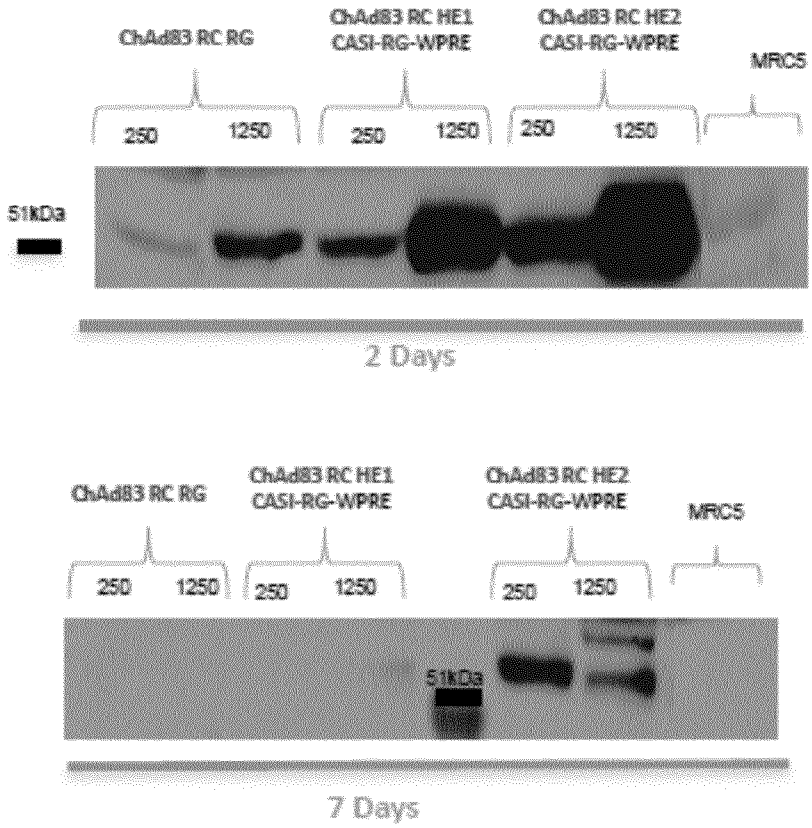

(a)
ChAd155 RC 2°
ChAd155 RC 1°
ChAd155 RC 2°
ChAd155 RC 1°
Moi
50 250 1250 50 250 1250 50 250 1250 50 250 1250
RG
2 days
5 days
(b)
ChAd155 RC 2°
ChAd155 RC 1°
ChAd83 RC 2°
ChAd83 RC 1°
moi
50 250 1250 50 250 1250 50 250 1250 250 1250
2 days
ChAd155 RC 2°
ChAd155 RC 1°
ChAd83 RC 2°
ChAd83 RC 1°
50 250 1250 50 250 1250 50 250 1250 250 1250
5 days

FIG. 5

(c)


ChAd83 RC RG
ChAd83 RC HE1 CASI-RG-WPRE
ChAd83 RC HE2 CASI-RG-WPRE
MRC5
250
1250
250
1250
250
1250
51kDa
2 Days
ChAd83 RC RG
ChAd83 RC HE1 CASI-RG-WPRE
ChAd83 RC HE2 CASI-RG-WPRE
MRC5
250
1250
250
1250
250
1250
51kDa
7 Days

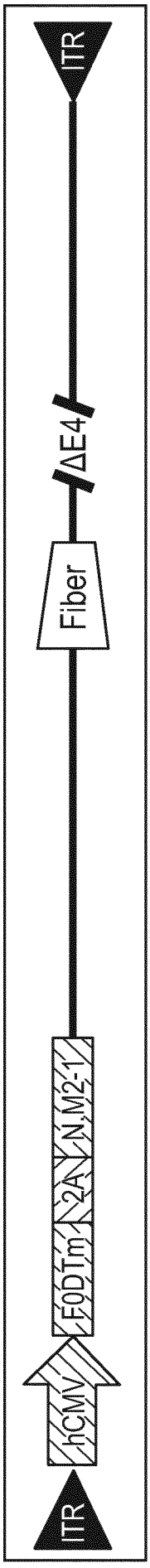



FIG. 6

FIG. 7

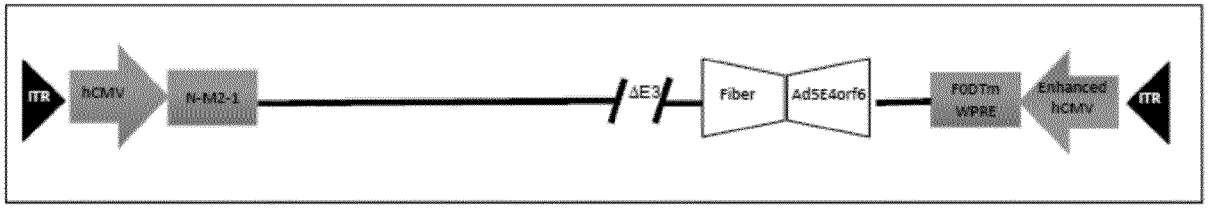

ITR
hCMV
N-M2-1
ΔE3
Fiber
Ad5E4orf6
F0DTm
WPRE
Enhanced
hCMV
ITR

FIG. 8

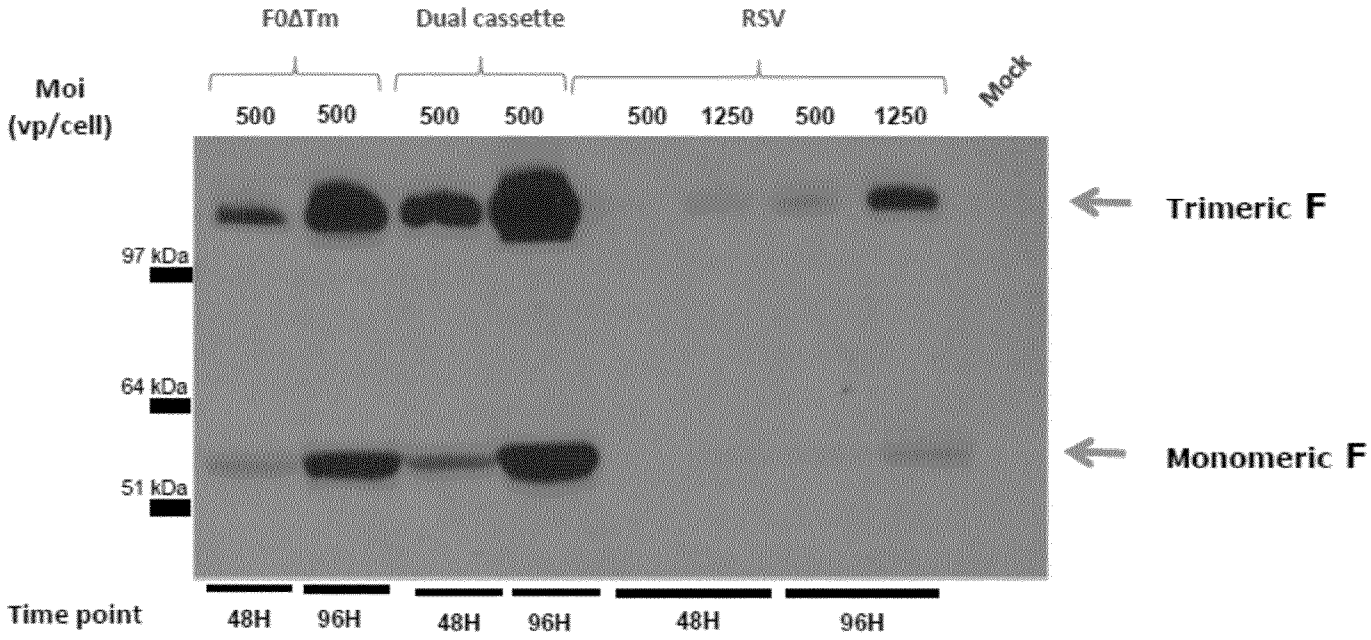

F0ΔTm
Dual cassette
RSV
Moi
(vp/cell)
500
500
500
500
500
1250
500
1250
Mock
97 kDa
64 kDa
51 kDa
Trimeric F
Monomeric F
Time point
48H
96H
48H
96H
48H
96H

FIG. 9

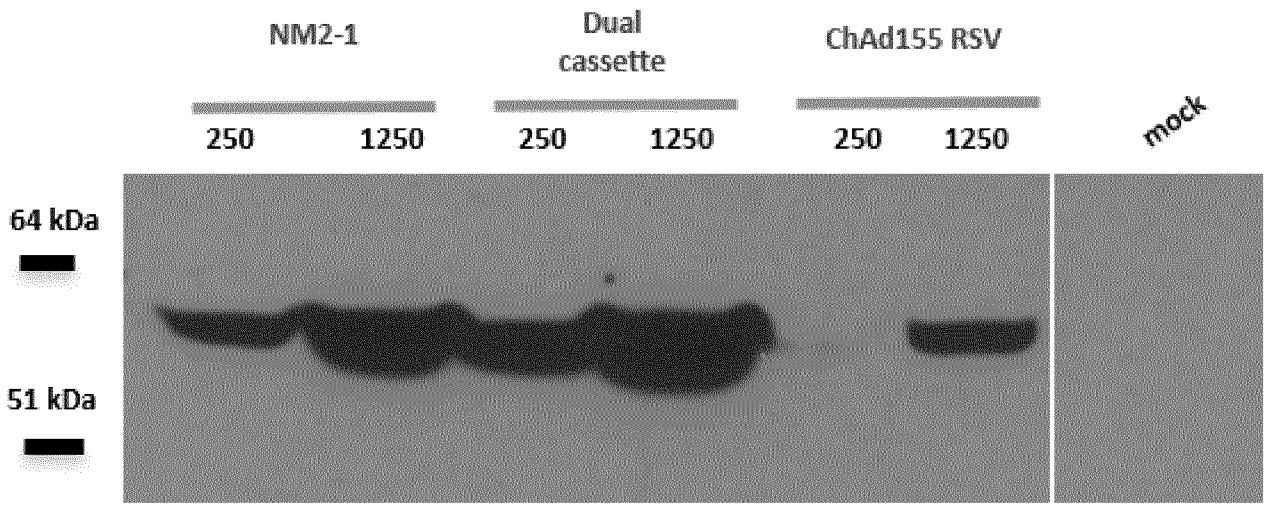

NM2-1
Dual cassette
ChAd155 RSV
250
1250
250
1250
250
1250
mock
64 kDa
51 kDa

FIG. 10

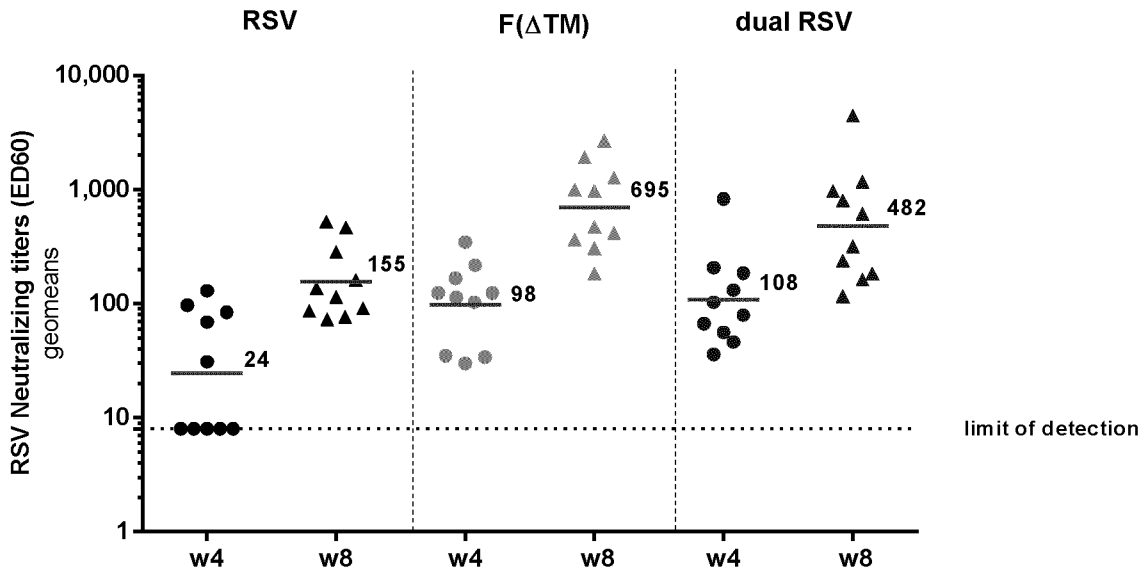

RSV
F(ΔTM)
dual RSV
RSV Neutralizing titers (ED60)
geomeans
10,000
1,000
100
10
1
24
155
98
695
108
482
limit of detection
w4
w8
w4
w8
w4
w8

FIG. 11

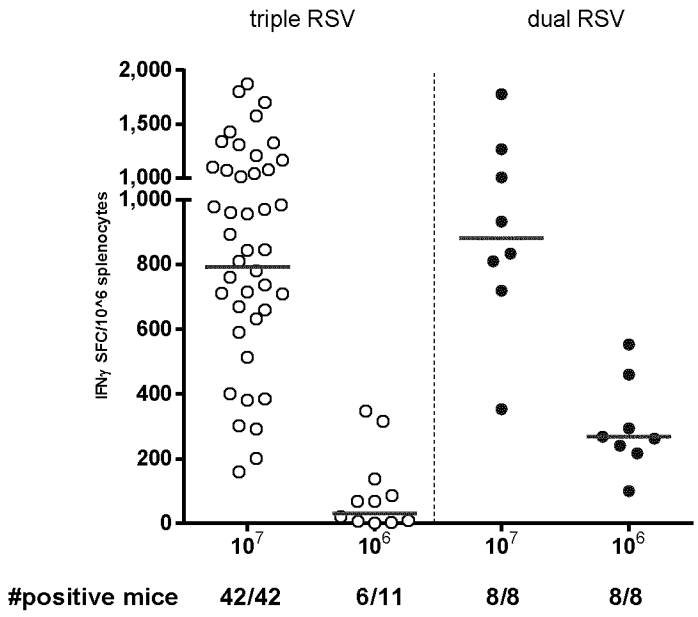

triple RSV
dual RSV
2,000
1,500
1,000
1,000
800
600
400
200
0
IFNγ SFC/10^6 splenocytes
10^7
10^6
10^7
10^6
#positive mice
42/42
6/11
8/8
8/8

FIG. 12A

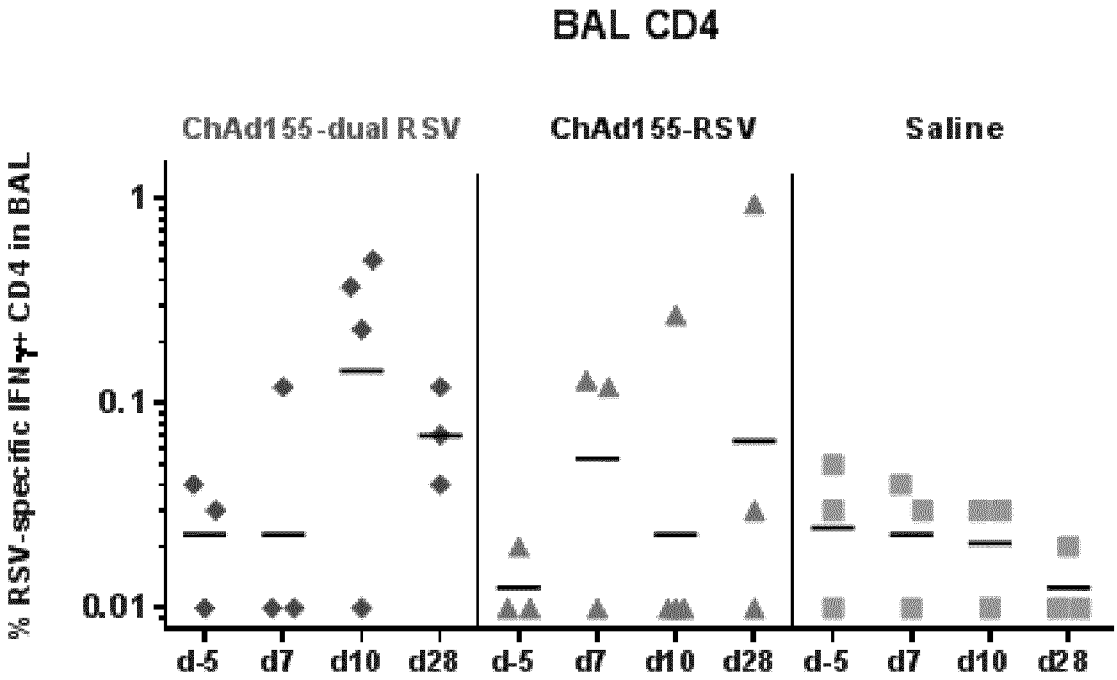

BAL CD4
ChAd155-dual RSV
ChAd155-RSV
Saline
% RSV-specific IFNγ+ CD4 in BAL
1
0.1
0.01
d-5
d7
d10
d28
d-5
d7
d10
d28
d-5
d7
d10
d28

FIG. 12B

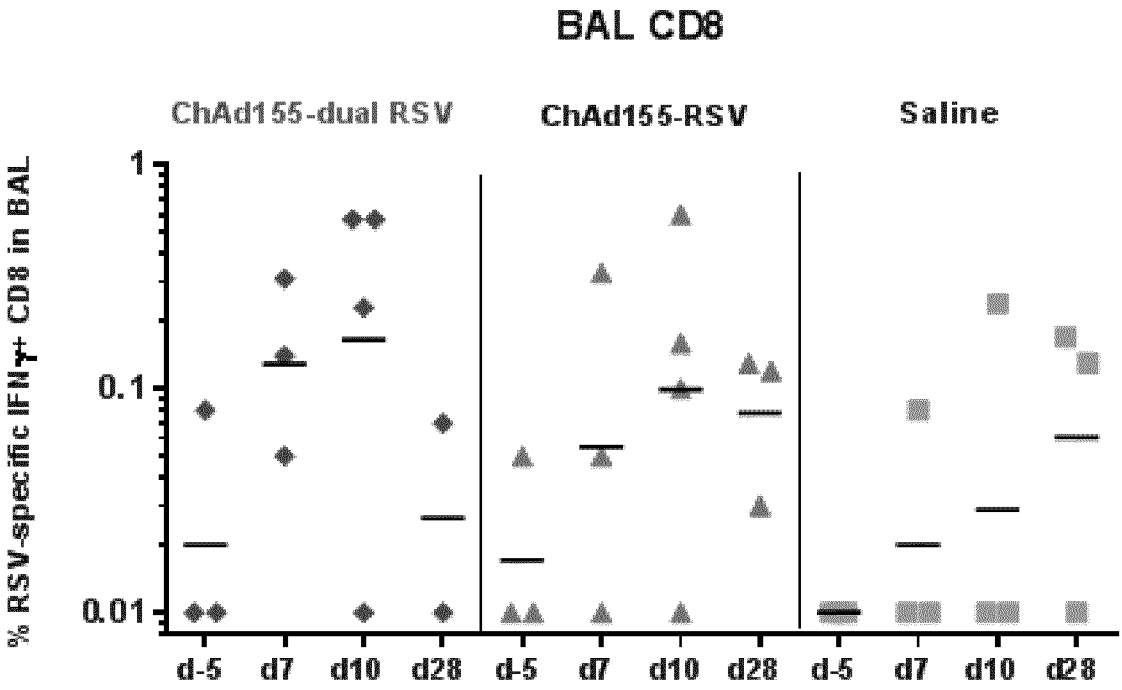

BAL CD8
ChAd155-dual RSV
ChAd155-RSV
Saline
% RSV-specific IFNγ+ CD8 in BAL
1
0.1
0.01
d-5
d7
d10
d28
d-5
d7
d10
d28
d-5
d7
d10
d28

FIG. 13A

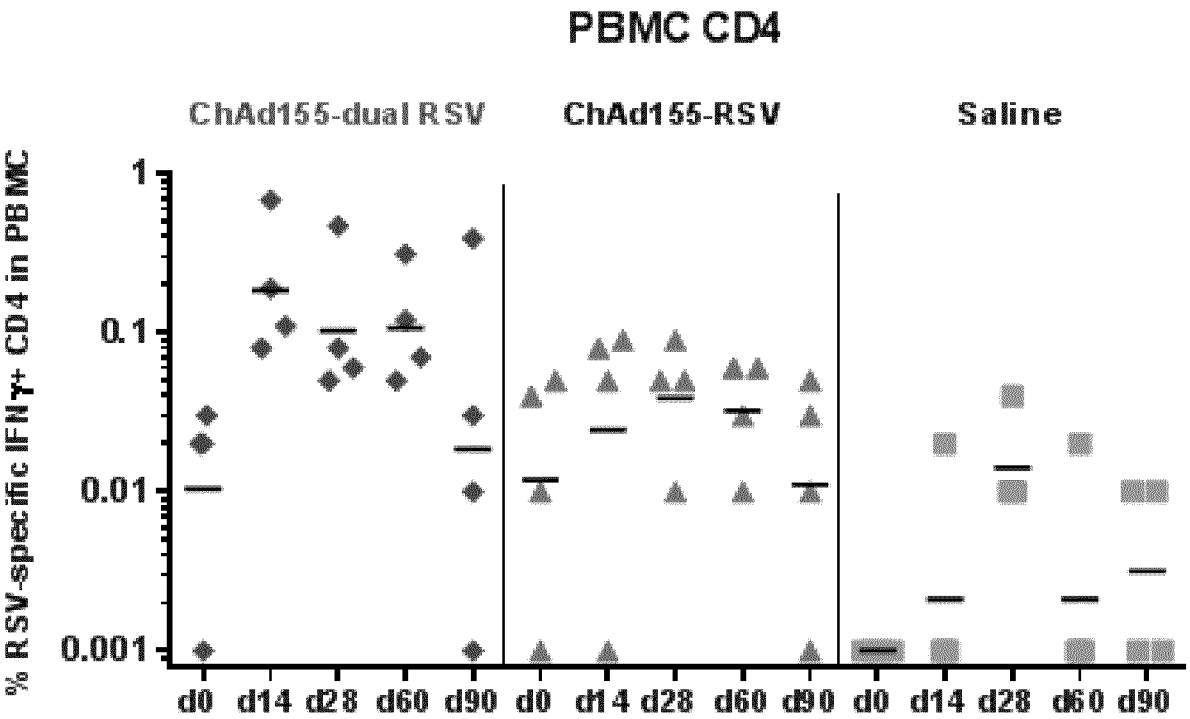

PBMC CD4
ChAd155-dual RSV
ChAd155-RSV
Saline
% RSV-specific IFNγ+ CD4 in PBMC
1
0.1
0.01
0.001
d0
d14
d28
d60
d90

FIG. 13B

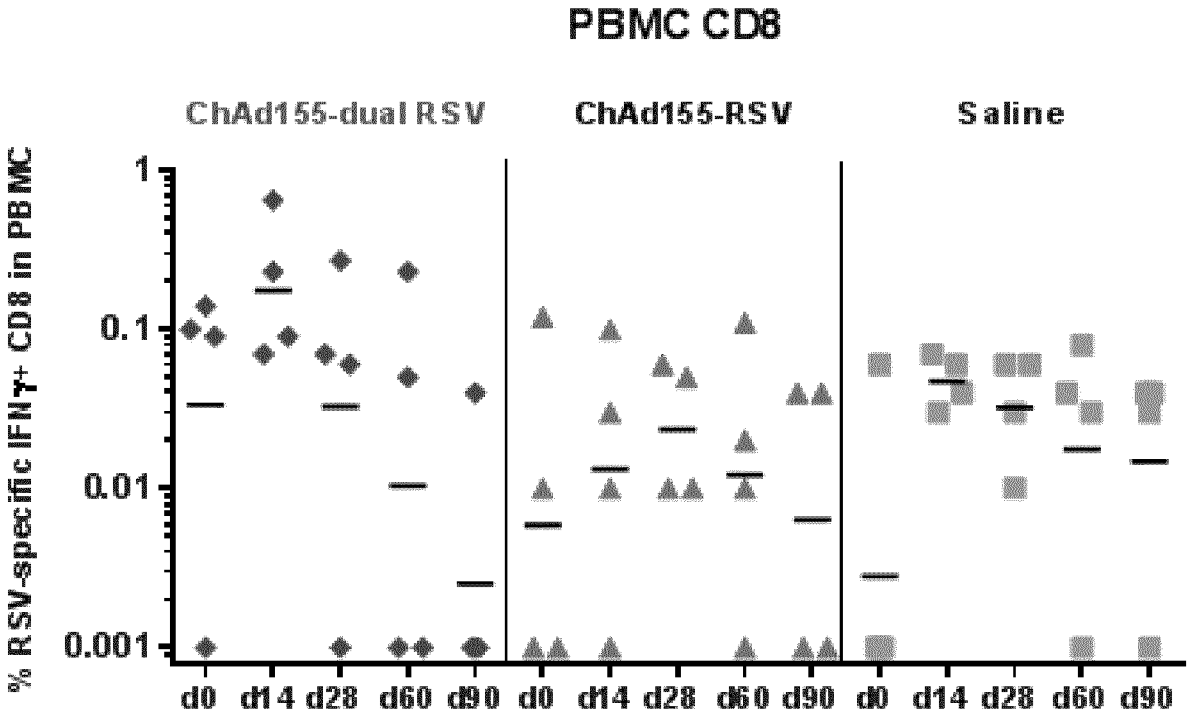

PBMC CD8
ChAd155-dual RSV
ChAd155-RSV
Saline
% RSV-specific IFNγ+ CD8 in PBMC
1
0.1
0.01
0.001
d0
d14
d28
d60
d90

FIG. 14A

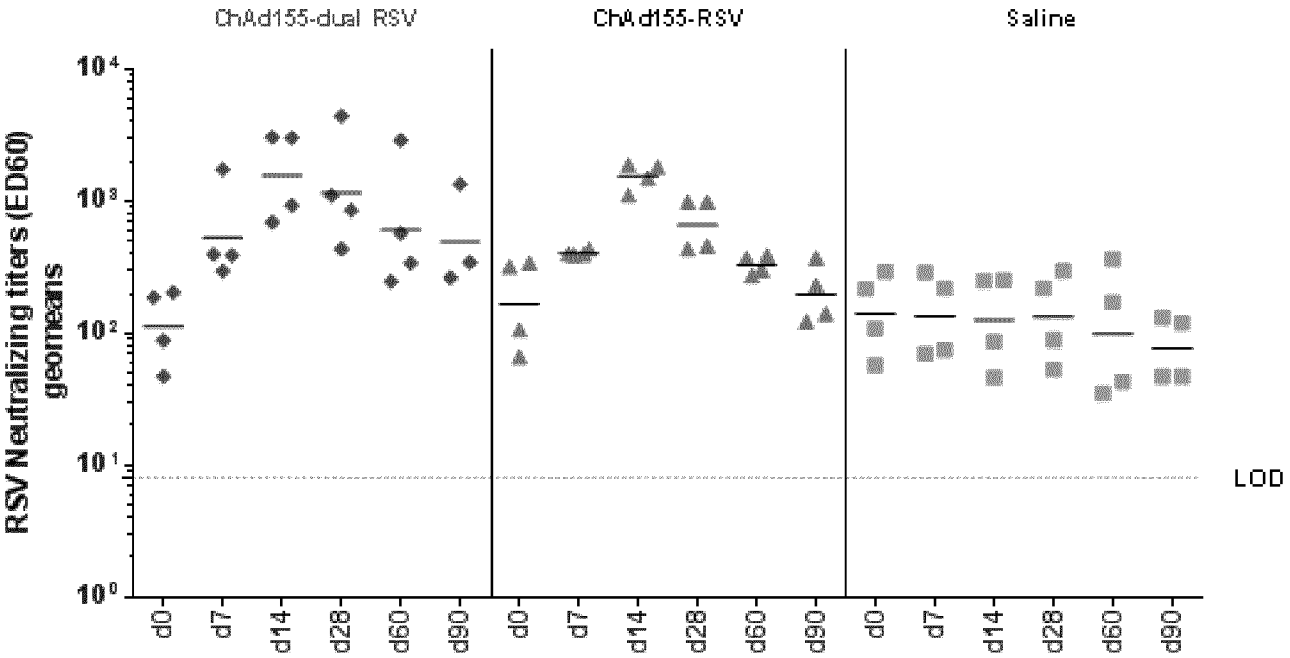

ChAd155-dual RSV
ChAd155-RSV
Saline
RSV Neutralizing titers (ED60) geomeans
$10^4$
$10^3$
$10^2$
$10^1$
$10^0$
LOD
d0
d7
d14
d28
d60
d90

FIG. 14B

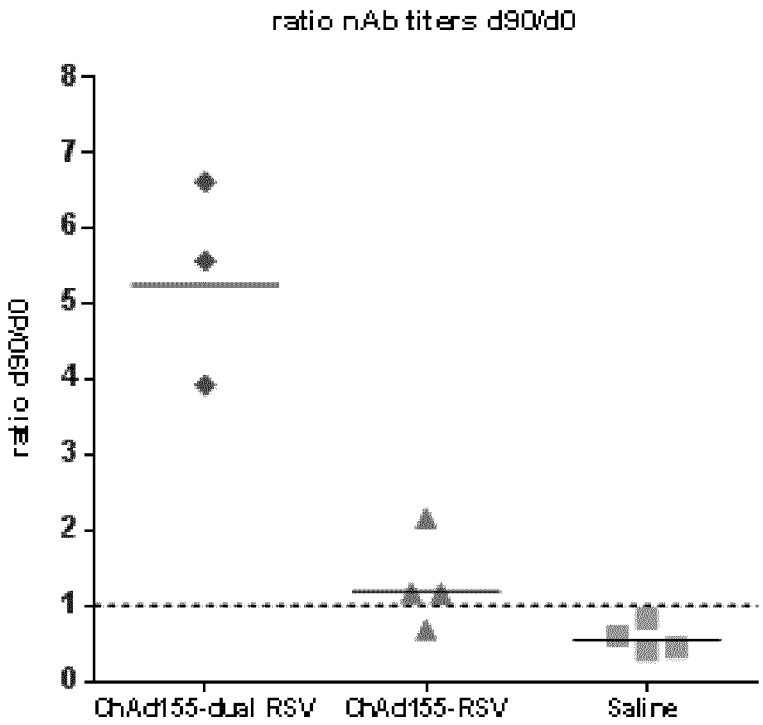

ratio nAb titers d90/d0
ratio d90/d0
8
7
6
5
4
3
2
1
0
ChAd155-dual RSV
ChAd155-RSV
Saline

FIG. 15A

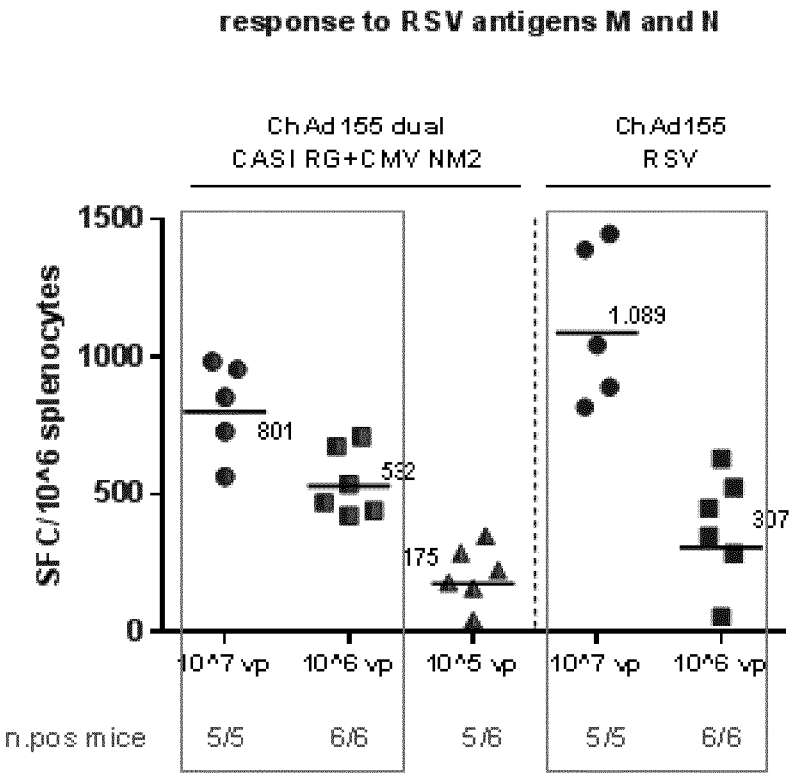

response to RSV antigens M and N
ChAd155 dual
CASI RG+CMV NM2
ChAd155
RSV
SFC/10^6 splenocytes
1500
1000
500
0
801
532
175
1.089
307
10^7 vp
10^6 vp
10^5 vp
10^7 vp
10^6 vp
n.pos mice
5/5
6/6
5/6
5/5
6/6

FIG. 15B

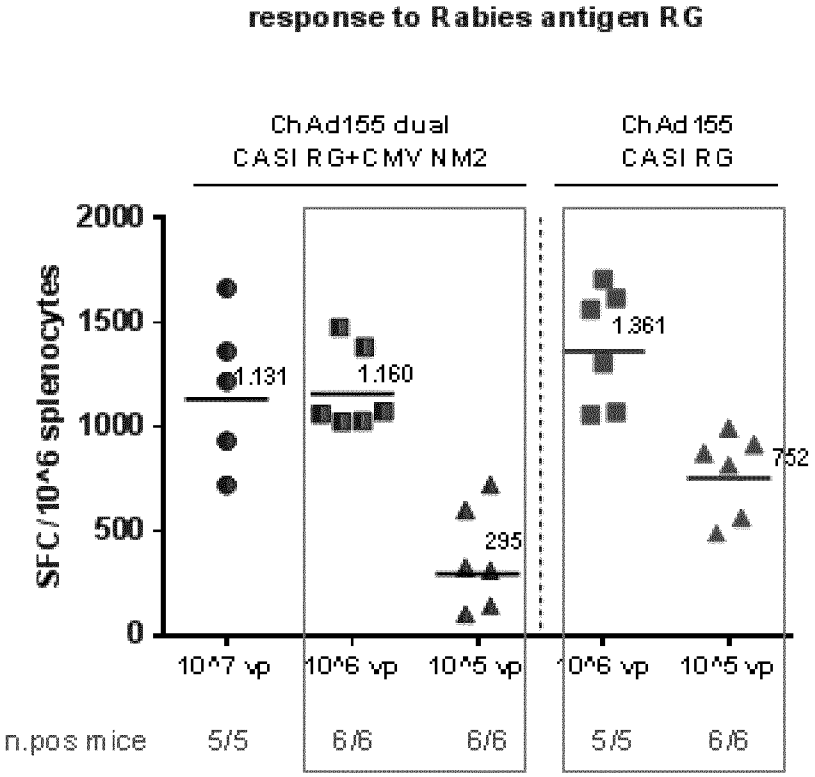

response to Rabies antigen RG
ChAd155 dual
CASI RG+CMV NM2
ChAd155
CASI RG
SFC/10^6 splenocytes
2000
1500
1000
500
0
1.131
1.160
295
1.361
752
10^7 vp
10^6 vp
10^5 vp
10^6 vp
10^5 vp
n.pos mice
5/5
6/6
6/6
5/5
6/6

FIG. 15C

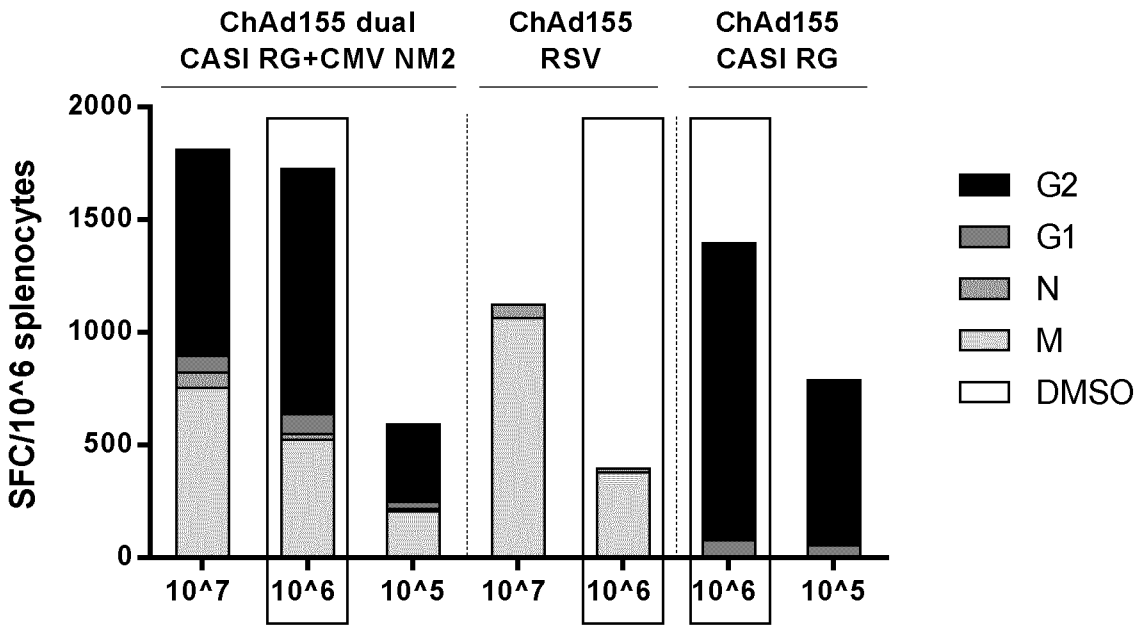

ChAd155 dual
CASI RG+CMV NM2
ChAd155
RSV
ChAd155
CASI RG
SFC/10^6 splenocytes
2000
1500
1000
500
0
10^7
10^6
10^5
10^7
10^6
10^6
10^5
G2
G1
N
M
DMSO

FIG. 16A

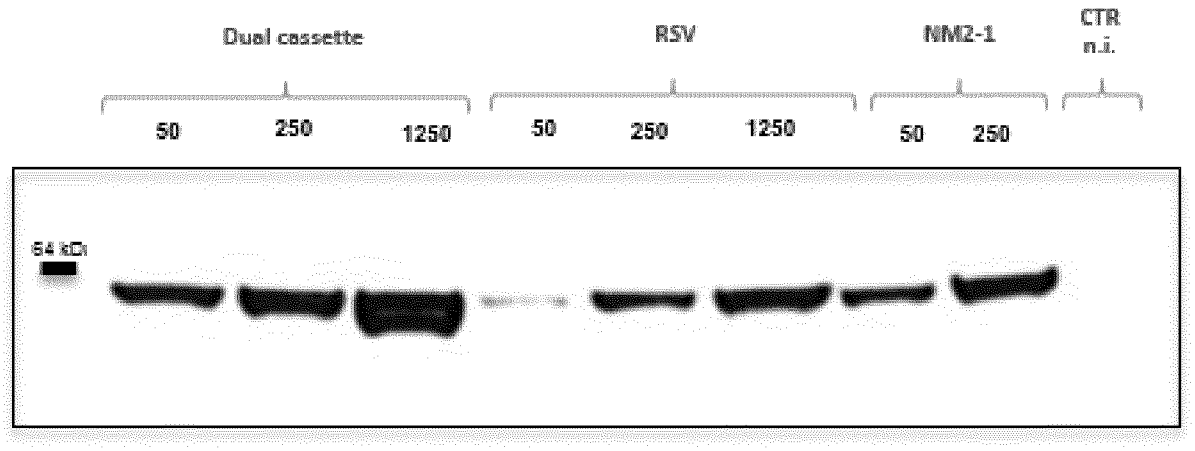

Dual cassette
RSV
NM2-1
CTR
n.i.
50
250
1250
50
250
1250
50
250
64 kDa

FIG. 16B

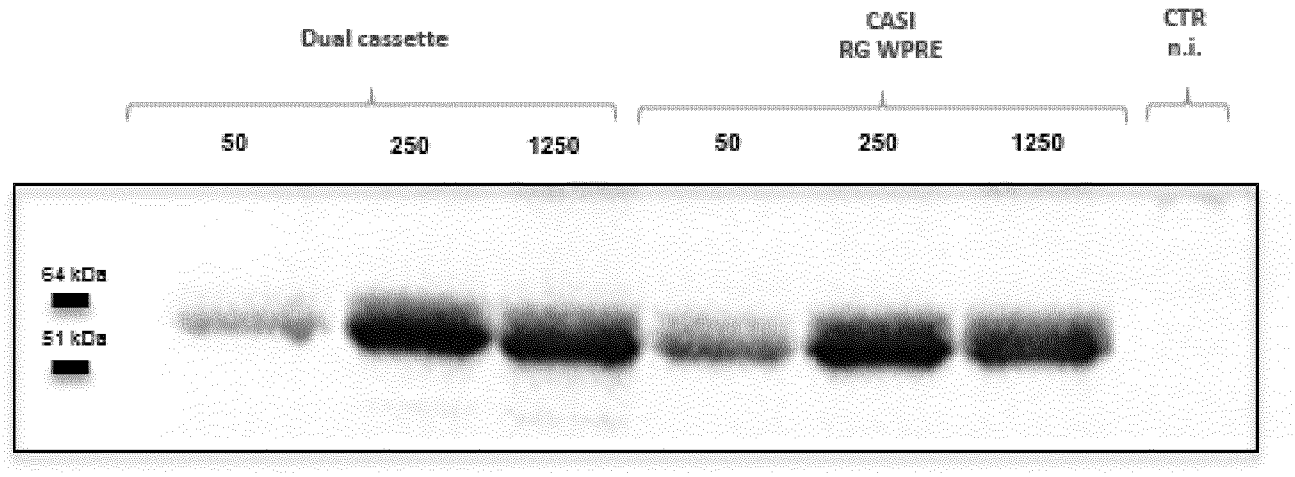

Dual cassette
CASI
RG WPRE
CTR
n.i.
50
250
1250
50
250
1250
64 kDa
51 kDa

FIG. 17

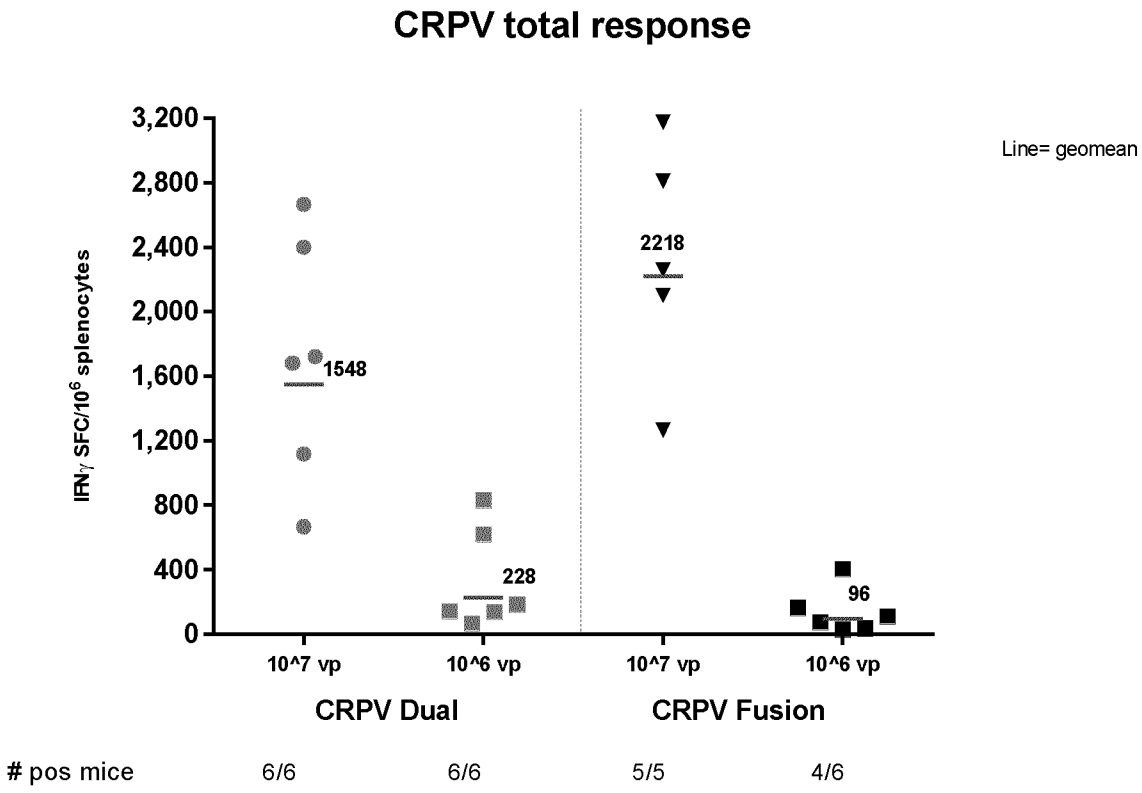
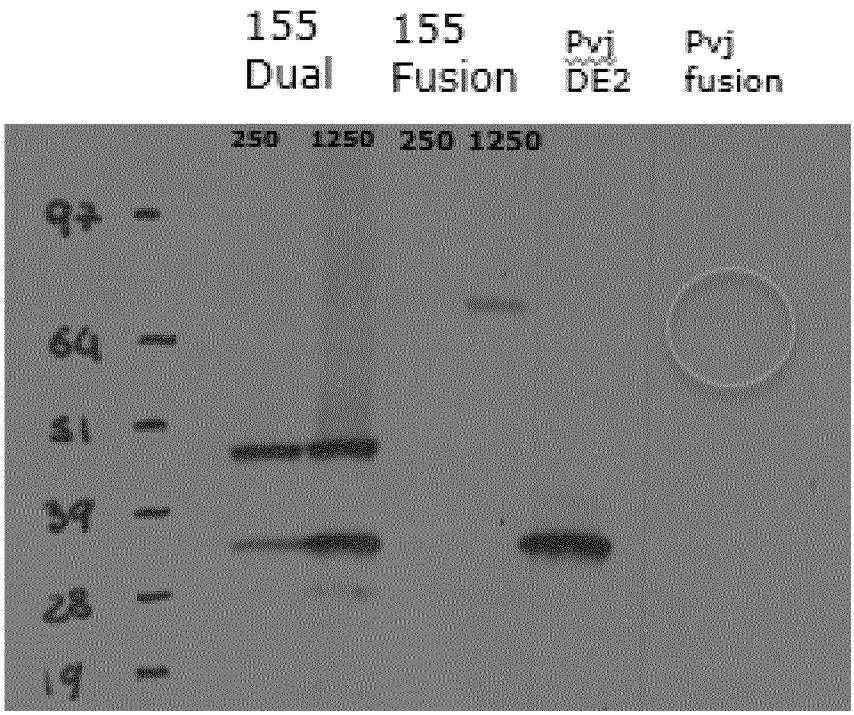

CRPV total response
IRNγ SFC/10^6 splenocytes
3,200
2,800
2,400
2,000
1,600
1,200
800
400
0
1548
228
2218
96
Line= geomean
10^7 vp
10^6 vp
10^7 vp
10^6 vp
CRPV Dual
CRPV Fusion
# pos mice
6/6
6/6
5/5
4/6

FIG.18


155 Dual
155 Fusion
Pvj DE2
Pvj fusion
250 1250 250 1250
97
64
51
39
28
19

# INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2018/078210

A. CLASSIFICATION OF SUBJECT MATTER
INV. C12N15/861 A61K39/235
ADD.

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
C12N A61K

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal, BIOSIS, Sequence Search, EMBASE, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
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| Y | figure 2 | 16,17 |
| X | WO 2017/017049 A1 (GLAXOSMITHKLINE BIOLOGICALS SA [BE]) 2 February 2017 (2017-02-02) | 1,6-11, 14,15, 18-22 |
| Y | figures 5,6; examples 3.1, 3.2, 5 | 16,17 |

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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

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

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

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

"&" document member of the same patent family

| Date of the actual completion of the international search | Date of mailing of the international search report |
|---|---|
| 16 November 2018 | 28/11/2018 |

| Name and mailing address of the ISA/ | Authorized officer |
|---|---|
| European Patent Office, P.B. 5818 Patentlaan 2<br>NL - 2280 HV Rijswijk<br>Tel. (+31-70) 340-2040,<br>Fax: (+31-70) 340-3016 | Brenz Verca, Stefano |

1

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C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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| Y | Section "Induction of antibody responses"; page 328, right-hand column, lines 6-9; figures 1,6,7 | 16,17 |
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International application No
PCT/EP2018/078210

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