ADENOVIRAL VECTOR

The present invention relates to novel adenoviral vectors, immunogenic compositions thereof and their use in medicine.

All publications, patents and patent applications cited herein are incorporated in full by reference.

Background

Traditionally, vaccines have been based on whole inactivated or attenuated pathogens. However, for many infectious diseases such as malaria, this approach is impractical and the focus of research has changed to the development of 'subunit vaccines' expressing only those pathogen-derived antigens that induce immune correlates of protection.

Subunit vaccines present an antigen to the immune system without introducing a whole infectious organism. One such method involves the administration of a specific, isolated protein from an infectious organism. However, this technique often induces only a weak immune response and the isolated proteins may have a different three-dimensional structure than the protein in its normal context, resulting in the production of antibodies that may not recognize the infectious organism.

An alternative method has therefore been developed which utilizes viral vectors for the delivery of antigens. Viruses are obligate intracellular parasites which replicate by transfecting their DNA into a host cell, and inducing the host cell to express the viral genome. This reproductive strategy has been harnessed to create vectored vaccines by creating recombinant, non-replicating viral vectors which carry one or more heterologous transgenes. Transfection or transduction of the recombinant viral genome into the host cell results in the expression of the heterologous transgene in the host cell. When the heterologous transgene encodes an antigen, for example, expression of the antigen within the host cell can elicit a protective or therapeutic immune response by the host immune system. As such, the viral vectors may function as effective vaccines. Alternatively, the heterologous transgene may encode a functional allele of a gene, expression of which can be used to counteract the

effects of a deleterious mutant allele of the gene, in a process known as gene therapy.

Particularly suitable for use as viral vectors are adenoviruses. Adenoviruses are non-enveloped viruses, approximately 90-100nm in diameter, comprising a nucleocapsid and a linear double stranded DNA genome. The viral nucleocapsid comprises penton and hexon capsomers. A unique fibre is associated with each penton base and aids in the attachment of the virus to the host cell via the Coxsackie-adenovirus receptor on the surface of the host cell. Over 50 serotype strains of adenoviruses have been identified, most of which cause respiratory tract infections, conjunctivitis and gastroentiritus in humans. Rather than integrating into the host genome, adenoviruses normally replicate as episomal elements in the nucleus of the host cell. The genome of adenoviruses comprises 4 early transcriptional units (E1, E2, E3 and E4), which have mainly regulatory functions and prepare the host cell for viral replication. The genome also comprises 5 late transcriptional units (L1, L2, L3, L4 and L5), which encode structural proteins including the penton (L2), the hexon (L3), the scaffolding protein (L4) and the fiber protein (L5), which are under the control of a single promoter. Each extremity of the genome comprises an Inverted Terminal Repeat (ITR) which is necessary for viral replication.

Recombinant adenoviruses were originally developed for gene therapy, but the strong and sustained transgene-specific immune responses elicited by these gene delivery agents prompted their use as vaccine carriers. In addition to being highly immunogenic, adenoviruses offer many other advantages for clinical vaccine development. The adenoviral genome is relatively small (between 26 and 45 kbp), well characterised and easy to manipulate. The deletion of a single transcriptional unit, E1, renders the virus replication-incompetent which increases its predictability and reduces side effects in clinical applications. Recombinant adenoviruses can accommodate relatively large transgenes, in some cases up to 8kb, allowing flexibility in subunit design, and have a relatively broad tropism facilitating transgene delivery to a wide variety of cells and tissues. Importantly for clinical applications, methods for scaled-up production and purification of recombinant adenoviruses to high titre are well established. Thus far, subgroup C serotypes AdHu2 or AdHu5 have predominantly been used as vectors.

However, the first generation of vaccine vectors based on the archetypal human adenovirus AdHu5 showed poor efficacy in clinical trials, despite encouraging pre-clinical data[1]. It was subsequently discovered that a large proportion of human adults harbour significant titres of neutralising antibodies to common human serotypes such as AdHu2 and AdHu5, as a result of natural infection. Neutralising antibodies could reduce the potency of viral vector vaccines by blocking viral entry into host cells and hence delivery of the target transgene.

The occurrence of pre-existing anti-vector immunity is being addressed through the development of new adenoviral vectors based on serotypes to which the human population is less likely to have been exposed, including those of chimpanzee origin[2,3]. However, some such chimpanzee adenoviral vectors have limited efficacy on the grounds of unexplained immunity in human populations, varying levels of cross-reactivity with human adenoviruses, and sub-optimal growth in transformed cell lines. In addition, it is advantageous to have a range of different adenoviral vectors available for use in immunising against different diseases, on the grounds that induction of neutralising antibodies against a vector may prevent its re-administration for another indication.

WO2012/172277 describes an adenovirus vector derived from chimpanzee adenovirus AdY25, which addresses some of the above-described problems in the art. This vector is termed ChAdOx1.

However, there continues to be a need in the art for highly immunogenic, non-human adenoviral vectors which effectively deliver the target transgene, minimize the effect of pre-existing immunity to adenovirus serotypes and replicate efficiently in transformed cell lines.

Summary of Invention

In a first aspect, the present invention provides an adenoviral vector comprising the genome of an adenovirus other than AdHu5 and AdY25, wherein the genome of the adenovirus has been modified such that the vector lacks the native E4 locus of the adenovirus and comprises heterologous E4Orf1, E4Orf2 and E4Orf3 coding regions from AdY25.

In a preferred embodiment, the adenoviral vector further comprises heterologous E4Orf4, E4Orf6 and E4Orf6/7 coding regions from AdHu5 in the E4 locus of the adenovirus.

In a preferred embodiment, said adenovirus is C68.

In a preferred embodiment, said adenoviral vector lacks a functional E1 locus and/or lacks an E3 locus.

In a second aspect, the present invention provides an immunogenic composition comprising the adenovirus vector according to the first aspect of the invention and, optionally, one or more additional active ingredients, a pharmaceutically acceptable carrier, diluent, excipient or adjuvant.

Preferably the adjuvant is an oil-in-water adjuvant. For example the adjuvant may comprise squalene. Preferably the adjuvant is selected from MF59®, AS03, AF03 or Addavax.

A third aspect provides the use of the adenoviral vector according to the first aspect or the immunogenic composition according to the second aspect in medicine. In particular, the adenoviral vector and immunogenic compositions are provided for delivery of a transgene into a host cell, elicitation of an immune response in an animal, boosting an immune response in an animal, treating or preventing at least one disease, inducing an immune response in an animal that will break tolerance to a self-antigen and gene therapy.

A fourth aspect provides a polynucleotide sequence encoding the adenoviral vector according to the first aspect of the present invention.

A fifth aspect of the present invention provides a host cell transduced with the viral vector according to the first aspect of the present invention.

A sixth aspect of the present invention provides a method of producing the viral vector according to the first aspect of the present invention by incorporating the

polynucleotide sequence according to the fourth aspect into a Bacterial Artificial Chromosome (BAC).

A seventh aspect of the present invention provides a Bacterial Artificial Chromosome (BAC) clone comprising the polynucleotide sequence according to the fourth aspect of the present invention.

An eighth aspect of the present invention provides a packaging cell line producing the viral vector according to the first aspect of the present invention.

Figures

The present invention is described with reference to the following figures:

Figure 1. Generation of a molecular clone of chimpanzee adenovirus 68 (ChAd68). a) Insertion of ChAd68 genomic DNA into the pBAC 'rescue vector' by gap repair. The E1 left flanking regions 1 (LF1) and 2 (LF2) and terminal right hand side region (RF) are amplified from Chad68 genomic DNA and cloned into pBACe3.6 to produce a BAC adenovirus rescue clone. Recombination occurs between LF1 and LF2 of the isolated ChAd68 genome and the BAC rescue clone and the RF of ChAd68 genome and the BAC rescue clone. The resulting product is a BAC containing an E1 deleted ChAd68 genome. b) Excision of the E3 region of ChAd68 by recombineering. Firstly, the galactokinase gene (GalK) is amplified from pGalK using primers containing sequences homologous to the flanking region of E3 (E3LF and E3RF). The E3 region is replaced by the GalK gene using λ red recombination. The GalK gene is subsequently replaced by a PCR product consisting of E3LF and E3RF, again using λ red recombination. The resulting product is a BAC containing an E1E3 deleted ChAd68 genome. c) Insertion of an antigen cassette at the E1 locus. Firstly, the galactokinase gene (GalK) is amplified from pGalK using primers containing sequences homologous to the flanking region of E1 (LF1 and LF2). The E1 region is replaced by the GalK gene using λ red recombination. The GalK gene is subsequently replaced by a PCR product consisting of LF1-antigen expression cassette-LF2 using λ red recombination. The resulting product is a BAC containing an E1E3 deleted ChAd68 genome with an antigen expression cassette at the E1 locus.

Figure 2. Insertion of an antigen expression cassette into adenovirus vector using *att* recombination sites. A universal cassette expressing a bacteria antibiotic resistance gene and ccdB suicide gene flanked by the specific recombination sequences, *att*R1 and *att*R2 is located at the E1 locus and/or the E3 locus of the BAC- adenovirus genome clone. Shuttle plasmids containing an antigen expression cassette flanked by specific recombination sites paired with those present in the genome (*att*L1/L2) allow site specific recombination in the presence of an enzyme mixture containing bacteriophage λ integrase, integration host factor and excisionase.

Figure 3. Growth of ChAdOx2 compared to ChAd68. E1 complementing Human embryonic kidney 293 cells were infected with a multiplicity of infection (MOI) of 1 virus vector per cell. Samples were taken at 48 and 96 hours post infection. Virus yield was determined by titration in triplicate on HEK293 cells and GFP positive cells counted 48 hours post infection. Results are expressed as the mean Log_{10} fluorescent units (FU) per ml from two separate experiments with standard deviation depicted.

Figure 4. Immunogenicity of ChAdOx1-eGFP compared to ChAdOx2-eGFP. Female BALB/c mice (4 per group) were injected intramuscularly with 10^8 infectious units of vector and spleens harvested 2 weeks later to measure the response to GFP by interferon-gamma enyzyme-linked immunosorbent spot (IFN-γ ELISPOT). Results are expressed as spot-forming units (SFUs) per million splenocytes. Mann-Whitney test was used to statistically analyse the results and the Mean with SEM is depicted.

Figure 5. The study groups (table 1) and current progress of enrollment (table 2) of a phase I clinical trial to determine the safety and immunogenicity of the candidate *Mycobacterium avium* subspecies paratuberculosis (MAP) vaccine ChAdOx2 HAV in healthy adult volunteers.

Figures 6 to 11. The proportions of volunteers presenting adverse events (AEs) at different dose groups in the phase I clinical trial investigating the candidate *Mycobacterium avium* subspecies paratuberculosis (MAP) vaccine ChAdOx2 HAV in

healthy adult volunteers. Dose of 5 x 10^9 vp for Figures 6 and 7 and a dose of 2.5 x 10^{10} vp for Figures 8, 9, 10 and 11.

Figure 12. Median summed response to all pools of antigens in the HAV vaccine stratified by dose. * p=0.01 Kruskall-Wallis test, with Dunn's multiple comparison test for the 2.5x10^{10} dose group. Lines represent medians.

Figure 13 shows the tabulated responses for each individual at day 0, day 28 and day 56 in participants immunised with different dosages of the HAV vaccine.

Figure 14 shows structure of the destination vector for the ChAdOx2 RabGP vaccine.

Figure 15 shows the two-way ANOVA across the ChAdOx2 RabGP vaccine groups immunised with different doses with and without Addavax.

Figure 16 shows the high immunogenicity of the ChAdOx2 RabGP vaccine construct. p=0.005 comparing ELISA responses (measured in arbitrary antibody units [AU]) by Mann-Whitney test. Immunogenicity of ChAdOx2-RabGP compares favourably to that of AdC68. CD-1 outbred mice were vaccinated intramuscularly with 107 infectious units of either ChAdOx2 or AdC68 expressing rabies glycoprotein. Serum was collected 4 weeks after vaccination. Antibody responses were assessed by ELISA against recombinant rabies glycoprotein, and the result shown in graph A and table B.

Detailed Description

The present invention relates to novel adenoviral vectors derived from an adenovirus other than AdHu5 and AdY25, immunogenic compositions thereof and their use in medicine.

The invention provides an adenoviral vector comprising the genome of an adenovirus other than AdHu5 and AdY25, wherein the genome of the adenovirus has been modified such that the vector lacks the native E4 locus of the adenovirus and comprises heterologous E4Orf1, E4Orf2, and E4Orf3 coding regions from AdY25.

The adenovirus E4 region comprises at least six Open Reading Frames (ORFs or Orfs). Preferably, the native E4 locus of the adenovirus is deleted.

In a preferred embodiment, the adenovirus is a chimpanzee adenovirus, C68 (also known as C9, Pan6 and sAd25). The nucleotide sequence of C68 is provided as SEQ ID NO. 1. The complete genome of simian adenovirus 25 (i.e. C68) has been deposited and assigned GenBank accession number AC_000011.

According to the invention, the genome of the adenovirus has been modified such that the vector lacks the native E4 locus of the adenovirus. The E4 region of C68 is provided herein as SEQ ID NO. 2.

Furthermore, according to the invention, the genome of the adenovirus is modified such that the vector and comprises heterologous E4Orf1, E4Orf2, and E4Orf3 coding regions from AdY25. AdY25 is a chimpanzee adenovirus described in detail in WO2012/172277.

The complete nucleotide sequence of AdY25 is provided in SEQ ID NO. 6.

The amino acid sequence of E4Orf1 from AdY25 is provided herein as SEQ ID NO. 3. The corresponding nucleotide sequence is nucleotides 35930 to 36304 of SEQ ID NO. 6.

The amino acid sequence of E4Orf2 from AdY25 is provided herein as SEQ ID NO. 4. The corresponding nucleotide sequence is nucleotides 35491 to 35880 of SEQ ID NO. 6.

The amino acid sequence of E4Orf3 from AdY25 is provided herein as SEQ ID NO. 5. The corresponding nucleotide sequence is nucleotides 35141 to 35494 of SEQ ID NO. 6.

In a preferred embodiment, the adenoviral vector further comprises heterologous E4Orf4, E4Orf6, and E4Orf6/7 coding regions from AdHu5.

AdHu5 is human serotype 5 adenovirus. The amino acid sequence of E4Orf4 from AdHu5 is provided herein as SEQ ID NO. 7. The amino acid sequence of E4Orf6 from AdHu5 is provided herein as SEQ ID NO. 8. The amino acid sequence of E4Orf6/7 from AdHu5 is provided herein as SEQ ID NO. 9.

As the skilled person will be aware, adenoviral vectors based on the adenovirus C68 are referred to in the art by various names, including AdCh68, AdC68, ChAd68 and sAdV25 (see, for example, Abbink *et al.*, J Virol. 2015 Feb;89(3):1512-22 (PubMed ID: 25410856) and Jeyanathan *et al.*, Mucosal Immunol. 2015 Nov;8(6):1373-87 (PubMed ID: 25872483). These names are also used interchangeably herein.

The vector of the present invention preferably comprises a capsid derived from chimpanzee adenovirus C68. Preferably, the capsid comprises the native or wild-type C68 capsid proteins, including penton proteins, hexon proteins, fibre proteins and/or scaffolding proteins. However, one of skill in the art will readily appreciate that small modifications can be made to the capsid proteins without adversely altering vector tropism.

In a particularly preferred embodiment, the vector capsid comprises one or more capsid proteins selected from the group consisting of:

(a) a hexon protein encoded by the coding sequence corresponding to nucleotides 18315 to 21116 of SEQ ID NO. 1 or a sequence substantially identical thereto;

(b) a penton protein encoded by the coding sequence corresponding to nucleotides 13884 to 15488 of SEQ ID NO. 1, or a sequence substantially identical thereto; and

(c) a fibre protein encoded by the coding sequence corresponding to nucleotides 32134 to 33411 of SEQ ID NO. 1, or a sequence substantially identical thereto.

Preferably, the hexon protein comprises the amino acid sequence of SEQ ID NO. 18, or an amino acid sequence substantially identical to SEQ ID NO. 18.

Preferably, the penton protein comprises the amino acid sequence of SEQ ID NO. 19, or an amino acid sequence substantially identical to SEQ ID NO. 19.

Preferably, the fiber protein comprises the amino acid sequence of SEQ ID NO. 20, or an amino acid sequence substantially identical to SEQ ID NO. 20.

The adenoviral vector of the present invention may comprise one of the hexon, penton and fibre proteins as described above, any combination of two of said proteins, or all three of said proteins.

The adenoviral vector of the invention is referred to herein as ChAdOx2. The nucleotide sequence of the ChAdOx2 vector (with a Gateway™ cassette in the E1 locus) is shown in SEQ ID NO. 10.

The person skilled in the art will appreciate that there are homologues, equivalents and derivatives of all of the nucleic acid sequences described herein. Thus, the invention also encompasses nucleic acid molecules having a sequence substantially identical to the nucleic acid sequences described herein over their entire length.

One of skill in the art will appreciate that the present invention can also include variants of those particular nucleic acid molecules which are exemplified herein. These may occur in nature, for example because of strain variation. For example, additions, substitutions and/or deletions are included. One of skill in the art will also appreciate that variation from the particular nucleic acid molecules exemplified herein will be possible in view of the degeneracy of the genetic code. Preferably, the variants have substantial identity to the nucleic acid sequences described herein over their entire length.

As used herein, nucleic acid sequences which have “substantial identity” preferably have at least 80%, 90%, 91%, 92%, 93%, 94%, 95% 96%, 97%, 98%, 98.1%, 98.2%, 98.3%, 98.4%, 98.5%, 98.6%, 98.7%, 98.8%, 98.9%, 99%, 99.1%, 99.2%, 99.3%, 99.4% 99.5%, 99.6%, 99.7%, 99.8% or 99.9% identity with said sequences.

Desirably, the term "substantial identity" indicates that said sequence has a greater degree of identity with any of the sequences described herein than with prior art nucleic acid sequences.

When comparing nucleic acid sequences for the purposes of determining the degree of homology or identity one can use programs such as BESTFIT and GAP (both from the Wisconsin Genetics Computer Group (GCG) software package). BESTFIT, for example, compares two sequences and produces an optimal alignment of the most similar segments. GAP enables sequences to be aligned along their whole length and finds the optimal alignment by inserting spaces in either sequence as appropriate. Suitably, in the context of the present invention, when discussing identity of nucleic acid sequences, the comparison is made by alignment of the sequences along their whole length. The above applied *mutatis mutandis* to all nucleic acid sequences disclosed in the present application.

References herein to “nucleic acid” can be DNA, including cDNA, RNA including mRNA or PNA (peptide nucleic acid) or a mixture thereof.

Merely for the convenience of those of skill in the art, a sample of *E. coli* strain Stellar containing bacterial artificial chromosomes (BACs) containing the ChAdOx2-GFP was deposited by Isis Innovation Limited on 13 June 2016 with the European Collection of Cell Cultures (ECACC) at the Health Protection Agency Culture Collections, Health Protection Agency, Porton Down, Salisbury SP4 0JG, United Kingdom under the Budapest Treaty and designated by provisional accession no. 16061301.

The *E. coli* containing the BAC is a class I genetically modified organism. The genotype of *E. coli* strain Stellar is:
F–, endA1, supE44, thi-1, recA1, relA1, gyrA96, phoA, Φ80d lacZΔ M15, Δ (lacZYA - argF) U169, Δ (mrr - hsdRMS - mcrBC), ΔmcrA, λ–. Chimpanzee adenovirus ChAd68 is provisionally classified within the species *Human adenovirus E* based on the nucleotide sequence of the viral DNA polymerase.

The BAC propagates within the bacteria during replication and can be maintained by selection with chloramphenicol. The *E. coli* strain Stellar containing the BAC into

which the genome is cloned can be propagated in Luria-Bertani broth or agar containing 12.5µg/mL chloramphenicol at 37°C.

Converting the BAC clones of the viral genomes into viruses ("rescue") can be carried out by the following steps. The *E. coli* host is propagated and the BAC DNA is purified from the bacteria according to standard methods. The DNA is linearised with the restriction endonuclease *Pac*I and transfected into HEK293 cells (or a similar E1 complementing cell line). The resulting adenovirus can then be propagated and purified for use as a vaccine for example. All of these reagents and cells are publicly available. If the deposition were rescued, the resulting virus would be a class I genetically modified organism.

As used herein, the phrase "viral vector" refers to a recombinant virus or a derivative thereof which is capable of introducing genetic material, including recombinant DNA, into a host cell or host organism by means of transduction or non-productive infection. For example, the vector of the present invention may be a gene delivery vector, a vaccine vector, an antisense delivery vector or a gene therapy vector.

As used herein, "C68" refers to the chimpanzee adenovirus 68 or subunits derived therefrom, and the term "ChAd68" refers to vectors derived therefrom or based thereon.

Shorthand terms are used to indicate modifications made to the wildtype virus. For example, "ΔE1" or "delE1" indicates deletion or functional deletion of the E1 locus. The phrase "Ad5E4Orf6" indicates that the viral vector comprises heterologous E4 open reading frame 6 from the Ad5 virus.

One of skill in the art will appreciate that the present invention can include variants of those particular amino acid sequences which are exemplified herein. Particularly preferred are variants having an amino acid sequence similar to that of the parent protein, in which one or more amino acid residues are substituted, deleted or added in any combination. Especially preferred are silent substitutions, additions and deletions, which do not alter the properties and activities of the protein of the present invention. Various amino acids have similar properties, and one or more such amino acids of a substance can often be substituted by one or more other such amino acids

without eliminating a desired activity of that substance. Thus, the amino acids glycine, alanine, valine, leucine and isoleucine can often be substituted for one another (amino acids having aliphatic side chains). Of these possible substitutions it is preferred that glycine and alanine are used to substitute for one another (since they have relatively short side chains) and that valine, leucine and isoleucine are used to substitute for one another (since they have larger aliphatic side chains which are hydrophobic). Other amino acids which can often be substituted for one another include: phenylalanine, tyrosine and tryptophan (amino acids having aromatic side chains); lysine, arginine and histidine (amino acids having basic side chains); aspartate and glutamate (amino acids having acidic side chains); asparagine and glutamine (amino acids having amide side chains); and cysteine and methionine (amino acids having sulphur containing side chains).Variants include naturally occurring and artificial variants. Artificial variants may be generated using mutagenesis techniques, including those applied to nucleic acid molecules, cells or organisms. Preferably, the variants have substantial identity to the amino acid sequences exemplified herein.

As used herein, amino acid sequences which have “substantial identity” preferably have at least 80%, 90%, 91%, 92%, 93%, 94%, 95% 96%, 97%, 98%, 98.1%, 98.2%, 98.3%, 98.4%, 98.5%, 98.6%, 98.7%, 98.8%, 98.9%, 99%, 99.1%, 99.2%, 99.3%, 99.4%,99.5%, 99.6%, 99.7%, 99.8% or 99.9% identity with said sequences. Desirably, the term "substantial identity" indicates that said sequence has a greater degree of identity with any of the sequences described herein than with prior art amino acid sequences.

One can use a program such as the CLUSTAL program to compare amino acid sequences. This program compares amino acid sequences and finds the optimal alignment by inserting spaces in either sequence as appropriate. It is possible to calculate amino acid identity or similarity (identity plus conservation of amino acid type) for an optimal alignment. A program like BLASTx will align the longest stretch of similar sequences and assign a value to the fit. It is thus possible to obtain a comparison where several regions of similarity are found, each having a different score. The above applied *mutatis mutandis* to all amino acid sequences disclosed in the present application.

The vector of the present invention also preferably comprises an exogenous nucleotide sequence. Preferably, the exogeneous nucleotide sequence is operably linked to expression control sequences which direct the translation, transcription and/or expression thereof in an animal cell and an adenoviral packaging signal sequence.

Preferably, the exogeneous nucleotide sequence encodes a molecule of interest. The molecule of interest may be a protein, polypeptide or nucleic acid molecule of interest. The exogeneous nucleotide sequence may encode one or more, two or more or three or more molecules of interest.

Proteins and polypeptides of interest include antigens, molecular adjuvants, immunostimulatory proteins and recombinases.

Preferably the antigen is a pathogen-derived antigen. Preferably the pathogen is selected from the group consisting of *M. tuberculosis*, *Plasmodium sp*, influenza virus, HIV, *Hepatitis C virus*, *Cytomegalovirus*, *Human papilloma virus*, rabies virus, measles virus, mumps, rubella, zika virus, leishmania parasites or any mycobacterial species. Preferably the antigen is selected from TRAP, MSP-1, AMA-1 and CSP from *Plasmodium*, influenza virus antigens, or ESAT6, TB10.4 85A and 85B antigens from *Mycobacterium tuberculosis.* More preferably, the antigen may be Ag85A from *Mycobacterium tuberculosis.* The antigen may be nucleoprotein (NP) and/or matrix protein 1 (M1) from influenza A virus.

More preferably the antigen is from Mycobacterium avium subspecies paratuberculosis (MAP) or the antigen is rabies virus glycoprotein.

Preferably, the protein or polypeptide of interest is an antigen. In one embodiment, the antigen is a pathogen-derived antigen. Preferably, the pathogen is selected from the group consisting of bacteria, viruses, prions, fungi, protists and helminths. Preferably, the antigen is derived from the group consisting of *M. tuberculosis*, *Plasmodium sp*, influenza virus, HIV, *Hepatitis C virus*, *Cytomegalovirus*, *Human papilloma virus*, rabies virus, measles virus, mumps, rubella, zika virus, malaria parasites, leishmania parasites or any mycobacterial species. Preferred antigens include TRAP, MSP-1, AMA-1 and CSP from *Plasmodium*, influenza virus antigens and ESAT6, TB10.4 85A and 85B antigens from *Mycobacterium tuberculosis*.

Particularly preferred antigens include Ag85A from *Mycobacterium tuberculosis* and nucleoprotein (NP) and matrix protein 1 (M1) from influenza A virus, preferably *Influenza A virus*.

The nucleic acid sequence of *Mycobacterium tuberculosis* protein Ag85A is shown in SEQ ID NO. 11 and the amino acid sequence is shown in SEQ ID NO. 12. The nucleic acid sequence of nucleoprotein (NP) and matrix protein 1 (M1) from influenza A virus is shown in SEQ ID NO. 13 and the amino acid sequence is shown in SEQ ID NO. 14.

In a preferred embodiment, the vaccine contains antigens from *Mycobacterium avium* subspecies paratuberculosis (MAP) which is the causative agent for Johne's disease in cattle and has been linked to Crohn's disease in humans.

In another preferred embodiment, the exogenous nucleotide sequence encodes the rabies virus glycoprotein, preferably the ERA strain.

In an alternative embodiment, the antigen is a self-antigen. Suitable self-antigens include antigens expressed by tumour cells which allow the immune system to differentiate between tumour cells and other cell types. Suitable self-antigens include antigens that are either inappropriate for the cell type and/or its environment, or are only normally present during the organisms' development (e.g. foetal antigens). For example, GD2 is normally only expressed at a significant level on the outer surface membranes of neuronal cells, where its exposure to the immune system is limited by the blood-brain barrier. However, GD2 is expressed on the surfaces of a wide range of tumour cells including small-cell lung cancer, neuroblastoma, melanomas and osteosarcomas. Other suitable self-antigens include cell-surface receptors that are found on tumour cells but are rare or absent on the surface of healthy cells. Such receptors may be responsible for activating cellular signalling pathways that result in the unregulated growth and division of the tumour cell. For example, ErbB2 is produced at abnormally high levels on the surface of breast cancer tumour cells. Preferably, the self antigen comprises a tumour-associated antigen (TAA).

As used herein, the term 'antigen' encompasses one or more epitopes from an antigen and includes the parent antigen, and fragments and variants thereof. These

fragments and variants retain essentially the same biological activity or function as the parent antigen. Preferably, they retain or improve upon the antigenicity and/or immunogenicity of the parent antigen. Generally, "antigenic" is taken to mean that the protein or polypeptide is capable of being used to raise antibodies or T cells or indeed is capable of inducing an antibody or T cell response in a subject. "Immunogenic" is taken to mean that the protein or polypeptide is capable of eliciting a potent and preferably a protective immune response in a subject. Thus, in the latter case, the protein or polypeptide may be capable of generating an antibody response and a non-antibody based immune response.

Preferably, fragments of the antigens comprise at least *n* consecutive amino acids from the sequence of the parent antigen, wherein *n* is preferably at least, or more than, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 57, 58, 59, 60, 70, 80, 90 or 100. The fragments preferably include one or more epitopic regions from the parent antigen. Indeed, the fragment may comprise or consist of an epitope from the parent antigen. Alternatively, the fragment may be sufficiently similar to such regions to retain their antigenic/immunogenic properties.

The antigens of the present invention include variants such as derivatives, analogues, homologues or functional equivalents of the parent antigen. Particularly preferred are derivatives, analogues, homologues or functional equivalents having an amino acid sequence similar to that of the parent antigen, in which one or more amino acid residues are substituted, deleted or added in any combination. Preferably, these variants retain an antigenic determinant or epitope in common with the parent antigen.

Preferably, the derivatives, analogues, homologues, and functional equivalents have an amino acid sequence substantially identical to amino acid sequence of the parent antigen.

The exogeneous nucleotide sequence may encode more than one antigen. The viral vector may be designed to express the one or more antigen genes as an epitope string. Preferably, the epitopes in a string of multiple epitopes are linked together

without intervening sequences such that unnecessary nucleic acid and/or amino acid material is avoided. The creation of the epitope string is preferably achieved using a recombinant DNA construct that encodes the amino acid sequence of the epitope string, with the DNA encoding the one or more epitopes in the same reading frame. An exemplary antigen, TIPeGFP, comprises an epitope string which includes the following epitopes: E6FP, SIV-gag, PyCD4 and Py3. Alternatively, the antigens may be expressed as separate polypeptides.

One or more of the antigens or antigen genes may be truncated at the C-terminus and/or the N-terminus. This may facilitate cloning and construction of the vectored vaccine and/or enhance the immunogenicity or antigenicity of the antigen. Methods for truncation will be known to those of skill in the art. For example, various well-known techniques of genetic engineering can be used to selectively delete the encoding nucleic acid sequence at either end of the antigen gene, and then insert the desired coding sequence into the viral vector. For example, truncations of the candidate protein are created using 3' and/or 5' exonuclease strategies selectively to erode the 3' and/or 5' ends of the encoding nucleic acid, respectively. Preferably, the wild type gene sequence is truncated such that the expressed antigen is truncated by 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20 or more amino acids relative to the parent antigen. Preferably, the antigen gene is truncated by 10 – 20 amino acids at the C- terminus relative to the wild type antigen. More preferably, the antigen gene is truncated by 13 – 18 amino acids, most preferably by 15 amino acids at the C- terminus relative to the wild type antigen. Preferably, the Ag85A antigen is C-terminally truncated in this manner.

One or more of the antigen genes may also comprise a leader sequence. The leader sequence may affect processing of the primary transcript to mRNA, translation efficiency, mRNA stability, and may enhance expression and/or immunogenicity of the antigen. Preferably, the leader sequence is tissue plasminogen activator (tPA). Preferably, the tPA leader sequence is positioned N-terminal to the one or more antigens.

The leader sequence such as the tPA leaders sequence may be linked to the sequence of the antigen via a peptide linker. Peptide linkers are generally from 2 to about 50 amino acids in length, and can have any sequence, provided that it does

not form a secondary structure that would interfere with domain folding of the fusion protein.

One or more of the antigen genes may comprise a marker such as the Green Fluorescent Protein (GFP) marker to facilitate detection of the expressed product of the inserted gene sequence.

One or more of the antigen genes may comprise a nucleic acid sequence encoding a tag polypeptide that is covalently linked to the antigen upon translation. Preferably the tag polypeptide is selected from the group consisting of a PK tag, a FLAG tag, a MYC tag, a polyhistidine tag or any tag that can be detected by a monoclonal antibody. The nucleic acid sequence encoding the tag polypeptide may be positioned such that, following translation, the tag is located at the C-terminus or the N-terminus of the expressed antigen or may be internal to the expressed antigen. Preferably, the tag is located at the C-terminus of the expressed antigen. In a preferred embodiment, one or more of the antigen genes encode a PK tag. A tag of this type may facilitate detection of antigen expression and clones expressing the antigen, and/or enhance the immunogenicity or antigenicity of the antigen.

If a tag polypeptide is used, nucleotides encoding a linker sequence are preferably inserted between the nucleic acid encoding the tag polypeptide and the nucleic acid encoding the expressed antigen. An exemplary linker is IPNPLLGLD (SEQ ID NO.15).

In an alternative embodiment, the exogeneous sequence of interest may be non-protein encoding. For example, the exogeneous nucleotide sequence may be an miRNA or immunostimulatory RNA sequence.

The adenoviral vector may comprise one or more exogeneous nucleotide sequences, for example 1, 2 or 3 or more exogeneous nucleotide sequences. Preferably, each exogeneous nucleotide sequence embodies a transgene. The exogeneous nucleotide sequence embodying the transgene can be a gene or a functional part of the gene. The adenoviral vector may comprise one nucleotide sequence encoding a single molecule of interest. Alternatively, the adenoviral vector may comprise one

nucleotide sequence or more than one nucleotide sequence encoding more than one molecule of interest.

Preferably, the exogeneous nucleotide sequence is located within the genome of the adenovirus, i.e. in a nucleic acid molecule that contains other adenoviral sequences. The exogeneous nucleotide sequence may be inserted into the site of a partially or fully deleted gene, for example into the site of an E1 deletion or an E3 deletion within the adenovirus genome.

The exogeneous nucleotide sequence may be inserted into an existing C68 gene region to disrupt the function of that region. Alternatively, the exogeneous nucleotide sequence may be inserted into a region of the genome with no alteration to the function or sequence of the surrounding genes.

The exogeneous nucleotide sequence or transgene is preferably operably linked to regulatory sequences necessary to drive translation, transcription and/or expression of the exogeneous nucleotide sequence/transgene in a host cell, for example a mammalian cell. As used herein, the phrase "operably linked" means that the regulatory sequences are contiguous with the nucleic acid sequences they regulate or that said regulatory sequences act in *trans*, or at a distance, to control the regulated nucleic acid sequence. Such regulatory sequences include appropriate expression control sequences such as transcription initiation, termination, enhancer and promoter sequences, efficient RNA processing signals, such as splicing and polyadenylation signals, sequences that enhance translation efficiency and protein stability and sequences promote protein secretion. Additionally they may contain sequences for repression of transgene expression, for example during production in cell lines expression a trans-activating receptor. Promoters and other regulatory sequences which control expression of a nucleic acid have been identified and are known in the art. Preferably, the promoter is selected from the group consisting of human CMV promoters, simian CMV promoters, murine CMV promoters, ubiquitin, the EF1 promoter, frog EF1 promoter, actin and other mammalian promoters. Most preferred are human CMV promoters and in particular the human CMV major immediate early promoter.

The exogeneous nucleotide sequence(s) of interest may be introduced into the viral vector as part of a cassette. As used herein, the term "cassette" refers to a nucleic acid molecule comprising at least one nucleotide sequence to be expressed, along with its transcriptional and translational control sequences to allow the expression of the nucleotide sequence(s) in a host cell, and optionally restriction sites at the 5' and 3' ends of the cassette. Because of the restriction endonuclease sites, the cassettes can easily be inserted, removed or replaced with another cassette. Changing the cassette will result in the expression of different sequence(s) by the vector into which the cassette is incorporated. Alternatively, any method known to one of skill in the art could be used to construct, modify or derive said cassette, for example PCR mutagenesis, In-Fusion®, recombineering, Gateway® cloning, site-specific recombination or topoisomerase cloning.

The expression control sequences preferably include the adenovirus elements necessary for replication and virion encapsidation. Preferably, the elements flank the exogeneous nucleotide sequence. Preferably, the ChAd68 vector comprises the 5' inverted terminal repeat (ITR) sequences of C68, which function as origins of replication, and 3' ITR sequences.

The packaging signal sequence functions to direct the assembly of the viral vector, and are well characterised and understood in the art.

As one of skill in the art will appreciate, there are minimum and maximum constraints upon the length of the nucleic acid molecule that can be encapsidated in the viral vector. Therefore, if required, the nucleic acid molecule may also comprise "stuffing", i.e. extra nucleotide sequence to bring the final vector genome up to the required size. Preferably, the nucleic acid molecule comprises sufficient "stuffing" to ensure that the nucleic acid molecule is about 80% to about 108% of the length of the wild-type nucleic acid molecule.

The nucleic acid molecule may also comprise one or more genes or loci from the C68 genome. The wild-type C68 genome comprises 4 early transcriptional units (E1, E2, E3 and E4), which have mainly regulatory functions and prepare the host cell for viral replication. The genome also comprises 5 late transcriptional units (L1, L2, L3, L4 and L5), which encode structural proteins including the penton (L2), the hexon

(L3), the scaffolding protein (L4) and the fiber protein (L5), which are under the control of a single promoter. Each extremity of the genome comprises an Inverted Terminal Repeat (ITR) which is necessary for viral replication.

The viral vector of the present invention may be based on the complete native C68 genome, from which the native E4 region has been deleted and into which the heterologous E4Orf1, E4Orf2 and E4Orf3 coding regions from AdY25 have been inserted.

The native E4 region of C68 is provided herein as SEQ ID NO. 2.

An exogeneous nucleotide sequence of interest may also be inserted into the C68 genome. One of skill in the art will appreciate that various additional modifications to the native C68 genome are possible, and indeed desirable, when creating a viral vector.

One or more native C68 genes may be deleted, functionally deleted or modified to optimise the viral vector.

As used herein, the phrase "deleted" refers to total deletion of a gene, whilst "functional deletion" refers to a partial deletion of a gene/locus, or some other modification such as a frame shift mutation, which destroys the ability of the adenovirus to express the gene/locus or renders the gene product non-functional.

The C68 genome may be modified to increase the insert capacity or hinder replication in host cells and/or increase growth and yield of the viral vector in transformed packaging cell lines. One of skill in the art will appreciate that any number of early or late genes can be functionally deleted. Replication of such modified viral vectors will still be possible in transformed cell lines which comprise a complement of the deleted genes. For example, the viral proteins necessary for replication and assembly can be provided in *trans* by engineered packaging cell lines or by a helper virus.

Therefore, in addition to the exogeneous nucleotide sequence, the vector of the present invention may comprise the minimal adenoviral sequences, the adenoviral

genome with one or more deletions or functional deletions of particular genes, or the complete native adenoviral genome, into which has been inserted the exogeneous nucleotide sequence.

Preferably, one or more of the early transcriptional units are modified, deleted or functionally deleted.

In one embodiment, the viral vector is non-replicating or replication-impaired. As used herein, the term "non-replicating" or "replication-impaired" means not capable of replicating to any significant extent in the majority of normal mammalian cells, preferably normal human cells. It is preferred that the viral vector is incapable of causing a productive infection or disease in the human patient. However, the viral vector is preferably capable of stimulating an immune response. Viruses which are non-replicating or replication-impaired may have become so naturally, i.e. they may be isolated as such from nature. Alternatively, the viruses may be rendered non-replicating or replication-impaired artificially, e.g. by breeding *in vitro* or by genetic manipulation. For example, a gene which is critical for replication may be functionally deleted.

Preferably, the adenoviral vector replication is rendered incompetent by functional deletion of a single transcriptional unit which is essential for viral replication. Preferably, the E1 gene/locus is deleted or functionally deleted. The E1 gene/locus may be replaced with a heterologous transgene, for example a nucleotide sequence or expression cassette encoding a protein or polypeptide of interest.

The native E1 region of C68 is provided herein as SEQ ID NO. 16.

As discussed herein, the recombinant adenovirus may be created by generating a molecular clone of C68 in a Bacterial Artificial Chromosome (BAC), and the E1 locus is preferably deleted by including an extra homology flank downstream of the adenovirus E1 region to enable simultaneous deletion of E1 during homologous recombination between the C68 viral DNA and a linearised BAC “rescue vector”.

Preferably, the viral vector according to the present invention comprises one or more recombination sites to enable the insertion of one or more transgenes or cassettes

comprising the exogeneous nucleotide sequence. Preferably, the recombination sites comprise phage lambda site specific recombination sites. These recombination sites may be introduced at any suitable locus, but are preferably introduced at the adenovirusE1 locus. Thus, the non-replicating or replication-impaired vector may be prepared by replacing the E1 gene with a nucleotide sequence encoding the protein or polypeptide of interest. Preferably, the recombination sites *attR1* and *attR2* are introduced at the adenovirusE1 locus as part of an Invitrogen Gateway® destination cassette.

Preferably, the vector lacks an adenovirus E3 gene/locus. Deletion of the adenovirus E3 region increases the insert capacity of the new vector by approximately 5kb. Deletion of E3 has little consequence to viral vector yield since this region is not required for virus replication and therefore does not need to be provided *in trans* in the packaging cell line. The E3 locus may be deleted using GalK recombineering.

The native E3 region of C68 is provided herein as SEQ ID NO. 17.

In a particularly preferred embodiment of the present invention, both the E1 and E3 loci are deleted from the C68 genome.

The viral vectors of the present invention may be produced in engineered cell lines containing a complement of any deleted genes required for viral replication. However, replication of viral vectors according to the present invention may be sub-optimal in cells designed to facilitate replication of other serotypes. Therefore, the adenoviral vectors according to the present invention preferably further comprise one or more modifications designed to optimise vector growth and yield in transformed cell lines, such as HEK293, expressing the genes functionally deleted in the adenoviral vector according to the present invention.

Of particular importance for viral replication in HEK293 cells is the gene product of E4Orf6, a multifunctional protein implicated in late viral mRNA splicing and selective export of viral mRNA, viral DNA synthesis and inhibition of apoptosis. Suboptimal interaction between E4Orf6 and the cell-expressed E1B-55K is believed to reduce the yield of ChAdOx2 vectors in HEK293 cells. Therefore, the native E4Orf6 region may be replaced with a heterologous E4Orf6 region.

In a preferred embodiment, the native E4Orf4, E4Orf6 and E4Orf6/7 coding regions are replaced with the E4Orf4, E4Orf6 and E4Orf6/7 coding regions from AdHu5. In a particularly preferred embodiment, the recombinant E4 region comprises the E4Orf1, E4Orf2 and E4Orf3 coding regions from AdY25 and the E4Orf4, E4Orf6 and E4Orf6/7 coding regions from AdHu5.

The amino acid sequence of E4Orf4 from AdHu5 is found in SEQ ID NO. 7. A corresponding nucleotide sequence is found at nucleotides 29262 to 28918 of the ChAdOx2 vector sequence (SEQ ID NO. 10). The amino acid sequence of the E4Orf6 from AdHu5 is found in SEQ ID NO. 8. A corresponding nucleotide sequence is found at nucleotides 28997 to 28113 of SEQ ID NO. 10. The amino acid sequence of the E4Orf6/7 from AdHu5 is found in SEQ ID NO. 9. A corresponding nucleotide sequence is found at nucleotides 28997 to 27834 of SEQ ID NO. 10.

In one preferred embodiment, the vector of the present invention comprises the nucleotide sequences of AdHu5 E4Orf4, E4Orf6 and E4Orf6/7 or sequences substantially identical thereto.

The amino acid sequence of E4Orf1 from AdY25 is provided herein as SEQ ID NO. 3. A corresponding nucleotide sequence is found at nucleotides 30434 to 30060 of the ChAdOx2 vector sequence (SEQ ID NO. 10).

The amino acid sequence of E4Orf2 from AdY25 is provided herein as SEQ ID NO. 4. A corresponding nucleotide sequence is found at nucleotides 30010 to 29621 of SEQ ID NO. 10.

The amino acid sequence of E4Orf3 from AdY25 is provided herein as SEQ ID NO. 5. A corresponding nucleotide sequence is found at nucleotides 29624 to 29271 of SEQ ID NO. 10.

In a particularly preferred embodiment of the present invention, the viral vector comprises a modified form of the native C68 genome, wherein the native C68 nucleotide sequence lacks the nucleotide sequences which encode the adenovirus E1 and E3 regions, and has the native E4 locus replaced with E4Orf4, E4Orf6 and

E4Orf6/7 coding regions from AdHu5, and the E4Orf1, E4Orf2 and E4Orf3 coding regions from AdY25. This particularly preferred viral vector according to the invention is referred to herein as "ChAdOx2".

An exemplary nucleotide sequence encoding ChAdOx2, with a Gateway® Destination Cassette in the E1 locus) is set out in SEQ ID NO. 10.

Preferably, the genome of the viral vector according to the present invention comprises the nucleotide sequence of SEQ ID NO.10 or a sequence substantially identical thereto, into which is inserted the exogeneous nucleotide sequence encoding the protein of interest.

A second aspect of the present invention provides a pharmaceutical or immunogenic composition comprising the viral vector according to the second aspect of the present invention optionally in combination with one or more additional active ingredients, a pharmaceutically acceptable carrier, diluent, excipient or adjuvant.

Preferably, the composition is an immunogenic and/or antigenic composition. The immunogenic and/or antigenic compositions according to the present invention may be prophylactic (to prevent infection), post-exposure (to treat after infection but before disease) or therapeutic (to treat disease). Preferably, the composition is prophylactic or post-exposure. Preferably, the composition is a vaccine.

Where the immunogenic composition is for prophylactic use, the subject is preferably an infant, young child, older child or teenager. Where the immunogenic composition is for therapeutic use, the subject is preferably an adult.

The composition may comprise one or more additional active agents, such as an anti-inflammatory agent (for example a p38 inhibitor, glutamate receptor antagonist, or a calcium channel antagonist), AMPA receptor antagonist, a chemotherapeutic agent and/or an antiproliferative agent. The composition may also comprise one or more antimicrobial compounds. Examples of suitable antimicrobial compounds include antituberculous chemotherapeutics such as rifampicin, isoniazid, ethambutol and pyrizinamide.

Suitable carriers and/or diluents are well known in the art and include pharmaceutical grade starch, mannitol, lactose, magnesium stearate, sodium saccharin, talcum, cellulose, glucose, sucrose, (or other sugar), magnesium carbonate, gelatin, oil, alcohol, detergents, emulsifiers or water (preferably sterile). The composition may be a mixed preparation of a composition or may be a combined preparation for simultaneous, separate or sequential use (including administration).

Suitable adjuvants are well known in the art and include incomplete Freund's adjuvant, complete Freund's adjuvant, Freund's adjuvant with MDP (muramyldipeptide), alum (aluminium hydroxide), alum plus *Bordatella pertussis* and immune stimulatory complexes (ISCOMs, typically a matrix of Quil A containing viral proteins).

The composition according to the invention for use in the aforementioned indications may be administered by any convenient method, for example by oral (including by inhalation), parenteral, mucosal (e.g. buccal, sublingual, nasal), rectal or transdermal administration and the compositions adapted accordingly.

For oral administration, the composition can be formulated as liquids or solids, for example solutions, syrups, suspensions or emulsions, tablets, capsules and lozenges.

A liquid formulation will generally consist of a suspension or solution of the compound or physiologically acceptable salt in a suitable aqueous or non-aqueous liquid carrier(s) for example water, ethanol, glycerine, polyethylene glycol or oil. The formulation may also contain a suspending agent, preservative, flavouring or colouring agent.

A composition in the form of a tablet can be prepared using any suitable pharmaceutical carrier(s) routinely used for preparing solid formulations. Examples of such carriers include magnesium stearate, starch, lactose, sucrose and microcrystalline cellulose.

A composition in the form of a capsule can be prepared using routine encapsulation procedures. For example, powders, granules or pellets containing the active

ingredient can be prepared using standard carriers and then filled into a hard gelatine capsule; alternatively, a dispersion or suspension can be prepared using any suitable pharmaceutical carrier(s), for example aqueous gums, celluloses, silicates or oils and the dispersion or suspension then filled into a soft gelatine capsule.

Compositions for oral administration may be designed to protect the active ingredient against degradation as it passes through the alimentary tract, for example by an outer coating of the formulation on a tablet or capsule.

Typical parenteral compositions consist of a solution or suspension of the compound or physiologically acceptable salt in a sterile aqueous or non-aqueous carrier or parenterally acceptable oil, for example polyethylene glycol, polyvinyl pyrrolidone, lecithin, arachis oil or sesame oil. Alternatively, the solution can be lyophilised and then reconstituted with a suitable solvent just prior to administration.

Compositions for nasal or oral administration may conveniently be formulated as aerosols, drops, gels and powders. Aerosol formulations typically comprise a solution or fine suspension of the active substance in a physiologically acceptable aqueous or non-aqueous solvent and are usually presented in single or multidose quantities in sterile form in a sealed container, which can take the form of a cartridge or refill for use with an atomising device. Alternatively the sealed container may be a unitary dispensing device such as a single dose nasal inhaler or an aerosol dispenser fitted with a metering valve, which is intended for disposal once the contents of the container have been exhausted. Where the dosage form comprises an aerosol dispenser, it will contain a pharmaceutically acceptable propellant. The aerosol dosage forms can also take the form of a pump-atomiser.

Compositions suitable for buccal or sublingual administration include tablets, lozenges and pastilles, wherein the active ingredient is formulated with a carrier such as sugar and acacia, tragacanth, or gelatin and glycerin.

Compositions for rectal or vaginal administration are conveniently in the form of suppositories (containing a conventional suppository base such as cocoa butter), pessaries, vaginal tabs, foams or enemas.

Compositions suitable for transdermal administration include ointments, gels, patches and injections including powder injections.

Conveniently the composition is in unit dose form such as a tablet, capsule or ampoule.

The pharmaceutical composition is preferably sterile. It is preferably pyrogen-free. It is preferably buffered e.g. at between pH 6 and pH 8, generally around pH 7. Preferably, the composition is substantially isotonic with humans.

Preferably, the pharmaceutical compositions of the present invention deliver an immunogenically or pharmaceutically effective amount of the viral vector to a patient. As used herein 'immunogenically or pharmaceutically effective amount' means that the administration of that amount to an individual, either as a single dose or as a series of doses, is effective for prevention or treatment of a disease or condition. In particular, this phrase means that a sufficient amount of the viral vector is delivered to the patient over a suitable timeframe such that a sufficient amount of the antigen is produced by the patient's cells to stimulate an immune response which is effective for prevention or treatment of a disease or condition. This amount varies depending on the health and physical condition of the individual to be treated, age, the capacity of the individual's immune system, the degree of protection desired, the formulation of the vaccine, the doctor's assessment of the medical situation and other relevant factors.

In general, a pharmaceutically effective dose comprises 1×10^7 to 1×10^{12} viral particles (vp), preferably 1×10^{10} to 1×10^{11} particles. More preferably, a pharmaceutically effective dose comprises 2.5×10^{10} v.p. to 5×10^{10} vp. Most preferably, a pharmaceutically effective dose comprises 2.5×10^{10} v.p.

In a preferred embodiment, there is provided a vaccine based on ChAdOx2, wherein the vaccine contains antigens from Mycobacterium avium subspecies paratuberculosis (MAP). Preferably, this vaccine is administered at a dose of between 5×10^9 and 5×10^{10} vp. More preferably, this vaccine is administered at a dose of between 2.5×10^{10} v.p. and 5×10^{10} vp. Most preferably, the vaccine is administered at a dose of 2.5×10^{10} v.p.

In a preferred embodiment, there is provided a vaccine based on ChAdOx2, wherein the ChAdOx2 vector encodes the rabies virus glycoprotein. In a preferred embodiment, this vaccine is administered to animals at a dose of between 1 $x10^6$ and 1 $x10^8$ infectivity units. In another preferred embodiment, this vaccine is administered to humans at a dose of between 5 x 10^9 and 5 x 10^{10} vp. More preferably, this vaccine is administered in humans at a dose of between $2.5x10^{10}$ v.p. and 5 x 10^{10} vp. Most preferably, the vaccine is administered in humans at a dose of $2.5x10^{10}$ v.p.

The immunogenic composition of the present invention may also comprise one or more other viral vectors, preferably other adenoviral vectors.

A third aspect of the present invention provides the use of the viral vector according to the first aspect of the present invention or the immunogenic composition according to the second aspect of the present invention. In particular, the third aspect provides the use of the viral vector or the immunogenic composition of the present invention in medicine.

This aspect also provides: i) the viral vector or the immunogenic composition according to the present invention for use in medicine and ii) the use of the viral vector or the immunogenic composition according to the present invention in the manufacture of a medicament for use in medicine. Some exemplary medical uses are described in further detail below.

In one embodiment, the viral vector according to the first aspect of the present invention or the immunogenic composition according to the second aspect of the present invention may be used to deliver a transgene into a host cell.

This method preferably comprises the step of administering to said host cell a viral vector according to the second aspect of the present invention or the immunogenic composition according to the third aspect of the present invention.

Preferably, the host cell is an animal cell, more preferably a mammalian cell. Preferred mammals include chickens, other poultry, cows, sheep, goats, pigs, wild boar, buffalo, bison, horses, camelids, deer, elephants, badgers, possums, cats,

lions, monkeys and humans. Preferably, the host cell is a somatic cell. The host cell may be selected from the group consisting of an antigen-presenting dendritic cell, langerhans cell, macrophage, B cell, lymphocyte, leukocyte, myocyte and fibroblast.

This method may be carried out *in vitro* or *in vivo*. Where the method is carried out *in vitro*, the viral vector or immunogenic composition is brought into contact with the host cell under suitable conditions such that transduction or non-productive infection of the host cell with the viral vector is facilitated. In this embodiment, the host cell may comprise an isolated host cell or a sample from an animal subject. Where the method is carried out *in vivo*, the viral vector or immunogenic composition is preferably administered to the animal subject such that transduction of one or more cells of the subject with the viral vector is facilitated. Preferably, the viral vector or immunogenic composition is administered to the subject by oral (including by inhalation), parenteral (e.g. intramuscular, subcutaneous, intravenous or intraperitoneal), mucosal (e.g. buccal, sublingual, nasal), rectal or transdermal administration.

Preferably, the transduction of the host cell with the viral vector of the present invention results in the stable delivery of the exogeneous nucleotide sequence of interest into the host cell.

Therefore, in another embodiment, the viral vector according to the first aspect of the present invention or the immunogenic composition according to the second aspect of the present invention may be used to elicit an immune response in an animal. This method preferably comprises the step of administering to said animal a viral vector according to the first aspect of the present invention or the immunogenic composition according to the second aspect of the present invention.

Where the protein or polypeptide of interest is an antigen, expression of the protein or polypeptide in an animal will result in the elicitation of a primary immune response to that antigen, leading to the development of an immunological memory which will provide an enhanced response in the event of a secondary encounter, for example upon infection by the pathogen from which the antigen was derived.

Preferably, the animal is a naïve animal, i.e. an animal that has not previously been exposed to the pathogen or antigens in question.

As well as eliciting an immune response in an animal, the viral vector of the present invention or the immunogenic composition thereof can be used to boost the immune response of an animal previously exposed to the antigen.

Therefore, in a further embodiment, the viral vector according to the first aspect of the present invention or the immunogenic composition according to the second aspect of the present invention may be used to boost an immune response in an animal. This method preferably comprises the step of administering to said animal a viral vector according to the second aspect of the present invention or the immunogenic composition according to the third aspect of the present invention.

Preferably, the animal subject has been previously exposed to the antigen in question, or "primed". For example, the subject may have previously been inoculated or vaccinated with a composition comprising the antigen, or may have previously been infected with the pathogen from which the antigen was derived. The subject may be latently infected with the pathogen from which the antigen was derived.

In another embodiment, the vector according to the first aspect of the present invention or the immunogenic composition according to the second aspect of the present invention may be used to treat or prevent at least one disease in a patient. A method of treating or preventing a disease in a patient according to the invention preferably comprises the step of administering to said patient a viral vector according to the first aspect of the present invention or the immunogenic composition according to the second aspect of the present invention.

Preferably, the disease is selected from the group consisting of Tuberculosis and other mycobacterial infections including Johne's disease, Crohn's disease, malaria, influenza, HIV/AIDS, Hepatitis C, Cytomegalovirus infection, Human papilloma virus infection, adenoviral infection, leishmaniasis, *streptococcus spp.*, *staphylococcus spp.*, *meningococcus spp.*, infection, foot and mouth disease, chikungunya virus infection, Zika virus, rabies, Crimean Congo haemorrhagic fever, Ebola virus

disease, Marburg, Lassa fever, MERS and SARS coronavirus diseases, Nipah and Rift Valley fever, Zika, Chikungunya.

Most preferably, the disease is selected from the group consisting of Tuberculosis and other mycobacterial infections, and rabies.

As well as inducing an immune response against the pathogenic organism from which the heterologous antigen is derived, the adenoviral vector of the present invention may also induce an immune response against the adenovirus from which the viral vector is derived. As such, an immune response against C68 may be elicited. The immune response induced against C68 may also be cross-reactive with other adenoviral serotypes, and as such an immune response against more than one adenovirus may be elicited. The viral vector according to the second aspect of the present invention or the immunogenic composition according to the third aspect of the present invention can therefore also be used for treating or preventing an adenoviral disease.

This embodiment of the present invention therefore also provides the treatment or prevention of at least one adenoviral disease and at least one non-adenoviral disease in a patient.

In a further embodiment, the viral vector according to the first aspect of the present invention or the immunogenic composition according to the second aspect of the present invention may be used to induce an immune response in an animal that will break tolerance to a self antigen. This method preferably comprises the step of administering to said animal a viral vector according to the first aspect of the present invention or the immunogenic composition according to the second aspect of the present invention.

Many tumour cells are tolerated by the patient's immune system, on the grounds that tumour cells are essentially the patient's own cells that are growing, dividing and spreading without proper regulatory control. Thus, cancerous tumours are able to grow unchecked within the patient's body. However, the viral vector of the present invention can be used to stimulate a patient's immune system to attack the tumour cells in a process known as "cancer immunotherapy". Specifically, the vector of the

present invention can be used to 'train' the patient's immune system to recognise tumour cells as targets to be destroyed. This can be achieved by including within the viral vector an exogeneous nucleotide sequence encoding a suitable self-antigen. As described previously, suitable self-antigens include antigens expressed by tumour cells which allow the immune system to differentiate between tumour cells and other cell types. Suitable self-antigens include antigens that are either inappropriate for the cell type and/or its environment, or are only normally present during the organisms' development (e.g. foetal antigens). For example, GD2 is normally only expressed at a significant level on the outer surface membranes of neuronal cells, where its exposure to the immune system is limited by the blood-brain barrier. However, GD2 is expressed on the surfaces of a wide range of tumour cells including small-cell lung cancer, neuroblastoma, melanomas and osteosarcomas. Other suitable self-antigens include cell-surface receptors that are found on tumour cells but are rare or absent on the surface of healthy cells. Such receptors may be responsible for activating cellular signalling pathways that result in the unregulated growth and division of the tumour cell. For example, ErbB2 is produced at abnormally high levels on the surface of breast cancer tumour cells. Thus, the adenoviral vector of the present invention may be used to induce an immune response against a tumour cell, and can therefore be used in the treatment of cancer.

The adenoviral vector of the invention can be used to treat, prevent or limit development of a tumour or cancer, including, but not limited to, cancer of the spleen, pancreas, prostate, liver, lung, breast, bowel, brain and colon.

A method of treating or preventing cancer in a patient comprises administering a therapeutically-effective dose of the adenoviral vector of the invention to a patient.

The adenoviral vector of the invention can also be used to treat autoimmune conditions, or conditions caused by hypersensitivity to own antigens.

A method of treating an autoimmune condition in a patient comprises administering a therapeutically-effective dose of the adenoviral vector of the invention to a patient.

The following details apply *mutatis mutandis* to all of the above uses of the vector and immunogenic composition of the present invention.

The treatment and prevention of many diseases, including liver stage malaria, tuberculosis and influenza, are associated with the maintenance of a strong cell-mediated response to infection involving both CD4+ and CD8+ T cells and the ability to respond with Th1-type cytokines, particularly IFN-γ, TNF-α, IL-2 and IL-17. Although many subunit vaccine platforms effectively generate human immunity, the generation of robust cell-mediated immune responses, particularly CD4+ and CD8+ T cell immune responses, has been much more challenging. The viral vector of the present invention preferably stimulates both cellular and humoral immune responses against the encoded antigen.

It is also desirable to induce a memory immune response. Memory immune responses are classically attributed to the reactivation of long-lived, antigen-specific T lymphocytes that arise directly from differentiated effector T cells and persist in a uniformly quiescent state. Memory T cells have been shown to be heterogeneous and to comprise at least two subsets, endowed with different migratory capacity and effector function; effector memory T cells (TEM) and central memory T cells (CTM). TEM resemble the effector cells generated in the primary response in that they lack the lymph node-homing receptors L-selectin and CCR7 and express receptors for migration into inflamed tissues. Upon re-encounter with antigen, these TEM can rapidly produce IFN-γ or IL-4 or release pre- stored perform. TCM express L-selectin and CCR7 and lack immediate effector function. These cells have a low activation threshold and, upon re-stimulation in secondary lymphoid organs, proliferate and differentiate to effectors.

Preferably, the viral vector according to the first aspect of the present invention or the immunogenic composition according to the second aspect of the present invention is capable of eliciting, inducing or boosting an antigen-specific immune response. Preferably, the immune response is a strong T cell immune response, for example a strong CD8+ and CD4+ T cell response. Preferably, the T cell immune response is a protective T cell immune response. Preferably, the T cell immune response is long lasting and persists for at least 1, 2, 5, 10, 15, 20, 25 or more years. Preferably, the immune response induced is a memory T cell immune response.

The viral vector of the first aspect of the present invention or immunogenic composition according to the second aspect of the present invention may be administered to the host cell or subject either as a single immunisation or multiple immunisations. Preferably, the viral vector or immunogenic composition thereof are administered as part of a single, double or triple vaccination strategy. They may also be administered as part of a homologous or heterologous prime-boost immunisation regime.

The vaccination strategy or immunisation regime may include second or subsequent administrations of the viral vector or immunogenic composition of the present invention. The second administration can be administered over a short time period or over a long time period. The doses may be administered over a period of hours, days, weeks, months or years, for example up to or at least 1, 2, 3, 4, 5, 6, 7, 8, 9, or 10 or more weeks or 0.25, 0.5, 0.75, 1, 5, 10, 15, 20, 25, 30, 35 or 40 or more years after the first administration. Preferably, the second administration occurs at least 2 months after the first administration. Preferably, the second administration occurs up to 10 years after the first administration. These time intervals preferably apply *mutatis mutandis* to the period between any subsequent doses.

The viral vector and/or immunogenic composition may be administered alone or in combination with other viral or non-viral DNA/protein vaccines. Preferred examples include modified vaccinia Ankara (MVA), Fowlpox 9 (FP9) and other adenoviral vector vaccines.

The viral vector and/or immunogenic composition may be administered to the subject by oral (including by inhalation), parenteral, mucosal (e.g. buccal, sublingual, nasal), rectal or transdermal administration. Alternatively, the viral vector and/or immunogenic composition may be administered to an isolated host cell or sample from a subject by contacting the cell(s) with the viral vector or immunogenic composition *in vitro* under conditions that facilitate the transduction of the host cell with the viral vector.

The viral vector and immunogenic composition of the present invention are not limited to the delivery of nucleic acid sequences encoding antigens. Many diseases, including cancer, are associated with one or more deleterious mutant alleles in a

patient's genome. Gene therapy is a process involving the insertion of genes into the patient's cells or tissues to replace the deleterious mutant or non-functional allele(s) with 'normal' or functional allele(s). Commonly, a functional allele is inserted into a non-specific location within the genome to replace the non-functional allele. Alternatively, the non-functional allele may be swapped for the functional allele through homologous recombination. Subsequent expression of the functional allele within the target cell restores the target cell to a normal state and thus provides a treatment for the disease. The 'normal' or functional allele(s) may be inserted into a patient's genome using a viral vector. The present invention therefore also provides the use of the viral vector according to the first aspect of the present invention or the immunogenic composition according to the second aspect of the present invention in gene therapy.

This method preferably comprises the step of administering to said animal a viral vector according to the second aspect of the present invention or the immunogenic composition according to the third aspect of the present invention.

The vector of the present invention may comprise an exogeneous nucleotide sequence encoding the functional or 'normal' protein, the non-functional or 'mutant' version of which is associated with a disease or condition.

Preferably, the target cell is a somatic cell. The subject to be treated is preferably mammalian. Preferred mammals include chickens, other poultry, cows, sheep, goats, pigs, wild boar, buffalo, bison, horses, camelids, deer, elephants, badgers, possums, cats, lions, monkeys and humans.

A fourth aspect of the present invention provides a polynucleotide sequence encoding the viral vector according to the first aspect of the present invention.

Preferably, the polynucleotide sequence comprises the sequence of SEQ ID NO. 10, or a sequence substantially identical thereto. The polynucleotide may additionally comprise the exogeneous nucleotide sequence of interest.

A fifth aspect of the present invention provides a host cell transduced or infected with the viral vector according to the first aspect of the present invention. Following

transduction or infection, the host cell will express the exogeneous nucleotide sequence in the nucleic acid molecule to produce the molecule of interest, in addition to any other adenoviral proteins encoded by the nucleic acid molecule. Preferably, the host cell is stably transduced and suitable for viral propagation.

The host cell may be an isolated host cell, part of a tissue sample from an organism, or part of a multicellular organism or organ or tissue thereof.

Preferably, the host cell is a somatic cell. Preferably, the host cell is not a stem cell, more particularly an embryonic stem cell, more particularly a human embryonic stem cell.

The host cell may be selected from the group consisting of an antigen-presenting dendritic cell, langerhans cell, macrophage, B cell, lymphocyte, leukocyte, myocyte and fibroblast.

Preferably, the host cell is an animal cell, more preferably a mammalian cell. Preferred mammals include chickens, other poultry, cows, sheep, goats, pigs, wild boar, buffalo, bison, horses, camelids, deer, elephants, badgers, possums, cats, lions, monkeys and humans.

The fifth aspect of the present invention also encompasses an animal transduced or infected with the viral vector according to the first aspect of the present invention. Preferably, the animal comprises one or more cells transformed or transfected with the viral vector according to the first aspect of the present invention. Preferably, the animal is a mammal. Preferred mammals include chickens, other poultry, cows, sheep, goats, pigs, wild boar, buffalo, bison, horses, camelids, deer, elephants, badgers, possums, cats, lions, monkeys and humans.

In a sixth aspect, the present invention provides a method of producing the viral vector according to the first aspect of the present invention. Preferably, the method comprises the step of incorporating the polynucleotide sequence according to the fourth aspect of the invention into a Bacterial Artificial Chromosome (BAC) to produce an Ad-BAC vector.

Unlike plasmid vectors, BACs are present within *E. coli* in single copy conferring increased genetic stability. In addition, the single copy BAC vectors permit very precise modifications to be made to the viral genome by recombineering (recombination mediated genetic engineering).

Preferably, incorporation of the polynucleotide sequence of the invention (preferably derived from C68) into a Bacterial Artificial Chromosome (BAC) comprises the steps of:

i) constructing a BAC rescue vector comprising regions of homology to the left and right flanks of the viral nucleotide sequence;
ii) linearising the BAC rescue vector; and
iii) performing homologous recombination in a host cell between the viral nucleotide sequence and the linearised BAC rescue vector to incorporate the viral nucleotide sequence into the BAC rescue vector.

Preferably, the polynucleotide sequence incorporated into the BAC rescue vector comprises the sequence of SEQ ID NO. 10 or a sequence substantially identical thereto.

Preferably, the method additionally comprises the step of further modifying the Ad-BAC vector genome. These further modifications may be carried out by *GalK* recombineering. This technique, pioneered by Søren Warming and colleagues, utilises the *GalK* gene for both positive and negative selection of recombinant clones[6]. SW102 *E. coli* cells, in which recombination may be performed, have been specifically engineered to lack the *GalK* gene which is required for the utilisation of galactose as the sole carbon source. Gene deletion is performed by recombination between the vector genome and a PCR amplified *GalK* cassette, flanked by 50bp regions of homology either side of the gene targeted for deletion. Selection on minimal media containing only galactose should ensure that only recombinants containing the *GalK* gene (in place of the target gene) should grow. Replacement of *GalK* with a different gene sequence can be performed in a similar fashion, this time using *GalK* for negative selection. The addition of 2-deoxygalactose (DOG) to selection media will select clones in which *GalK* has been replaced since the product of *GalK*, galactokinase, metabolises DOG into a product that is highly toxic to *E. coli*.

Preferably, the host cell is BJ5183 *E. coli* for steps i) to iii) above and SW102 for further modifications.

Preferably, an extra homology flank is included downstream of the adenovirus E1 region to enable simultaneous deletion of E1.

Preferably, the method further includes deletion of the E3 region of the Ad-BAC vector genome. Deletion of the E3 region may be carried out by GalK recombineering.

Preferably, the method further includes introducing phage lambda site specific recombination sites *attR1* and *attR2* at the Ad E1 locus as part of an Invitrogen Gateway® destination cassette. Such a modification enables the efficient directional insertion of vaccine transgenes. Transgenes could also be inserted by recombineering, In-Fusion®, conventional ligation or gap repair.

A seventh aspect of the present invention provides a Bacterial Artificial Chromosome (BAC) clone comprising a polynucleotide sequence encoding the viral vector according to the first aspect of the present invention.

Preferably, the BAC clone comprises:

(a) a BAC backbone;

(b) the polynucleotide sequence according to the fourth aspect of the present invention.

As described above, the viral vector according to the first aspect of the present invention may be replicated in a transformed cell line or helper virus (gutless vector system) which, if necessary, comprises the complement of any genes deleted from the virus. Such genes may be deleted from the virus in order to hinder replication in host cells, but are of course required in order to replicate the viral vector to produce immunogenic compositions according to the second aspect of the present invention. One can make use of any cell line permissive of wild type adenovirus replication that has been modified to express the functionally deleted genes, or a cell line which is not permissive of wild-type virus replication which has additionally or alternatively

been modified to express CAR or integrins in addition to the functionally deleted genes.

The present invention provides host cells comprising a Bacterial Artificial Chromosome (BAC) in accordance with the seventh aspect of the present invention, and suitable for propagation thereof. Preferably such host cells are bacteria, most preferably *E.coli*. Suitable examples include *E.coli* strains DH10B and SW102[9].

An eighth aspect of the present invention therefore provides a packaging cell or cell line producing or capable of producing the viral vector according to the first aspect of the present invention.

The packaging cell or cell line comprises one or more nucleotide sequences which encode the viral vector of the first aspect of the present invention. Expression of these sequences results in the production of the viral vector. Some of the required genes may be provided by infection of the cell or cell line with a viral vector according to the first aspect. Preferably, the cell comprises the complement of any genes deleted or functionally deleted from the viral vector. Preferably, the cell is an HEK293 cell or a PER.C6® cell.

Merely for the convenience of those of skill in the art, a sample of *E. coli* strain Stellar containing bacterial artificial chromosomes (BACs) containing the ChAdOx2-GFP was deposited by Isis Innovation Limited on 13 June 2016 with the European Collection of Cell Cultures (ECACC) at the Health Protection Agency Culture Collections, Health Protection Agency, Porton Down, Salisbury SP4 0JG, United Kingdom under the Budapest Treaty and designated by provisional accession no. 16061301.

In respect of all designated states to which such action is possible and to the extent that it is legally permissible under the law of the designated state, it is requested that a sample of the deposited material be made available only by the issue thereof to an independent expert, in accordance with the relevant patent legislation, e.g. Rule 32(1) EPC, Rule 13(1) and Schedule 1 of the UK Patent Rules 2007, Regulation 3.25(3) of the Australian Patent Regulations and generally similar provisions *mutatis mutandis* for any other designated state.

As described herein, the vector ChAdOx2 is derived from chimpanzee adenovirus C68, with deletion of E1 region, E3 region, modification of E4 region and insertion of eGFP model antigen into E1 locus. The *E. coli* containing the BAC is a class I genetically modified organism.

The BAC propagates within the bacteria during replication and can be maintained by selection with chloramphenicol. The *E. coli* strain SW102 containing the bacterial artificial chromosomes into which the genomes are cloned can be propagated in Luria-Bertani broth or agar containing 12.5µg/mL chloramphenicol at 32°C. The genome may be modified by genetic engineering in *E. coli* according to standard methods, as described in the specification, e.g. to insert an alternative recombinant antigen in place of eGFP.

Converting the BAC clones of the viral genomes into viruses ("rescue") can be carried out by the following steps. The *E. coli* host is propagated and the BAC DNA is purified from the bacteria according to standard methods. The DNA is linearised with the restriction endonuclease *Pac*I and transfected into HEK293 cells (or a similar E1 complementing cell line). The resulting adenovirus can then be propagated and purified for use as a vaccine, for example. All of these reagents and cells are publicly available. If the deposition were rescued, the resulting virus would be a class I genetically modified organism.

In respect of all designated states to which such action is possible and to the extent that it is legally permissible under the law of the designated state, it is requested that a sample of the deposited material be made available only by the issue thereof to an independent expert, in accordance with the relevant patent legislation, e.g. Rule 32(1) EPC, Rule 13(1) and Schedule 1 of the UK Patent Rules 2007, Regulation 3.25(3) of the Australian Patent Regulations and generally similar provisions *mutatis mutandis* for any other designated state.

A specific embodiment of the fourth aspect of the present invention provides a polynucleotide sequence encoding an adenoviral vector according to the first aspect of the present invention, wherein said polynucleotide sequence comprises or consists of the polynucleotide sequence of the viral vector ChAdOx2 (SEQ ID NO. 10).

ChAdOx2 was deposited in a BAC contained in *E.coli* strain Stellar by Isis Innovation Limited on 13 June 2016 with the European Collection of Cell Cultures (ECACC) at the Health Protection Agency Culture Collections, Health Protection Agency, Porton Down, Salisbury SP4 0JG, United Kingdom under the Budapest Treaty and designated by provisional accession no. 16061301. The deposited BAC additionally comprises a transgene encoding the antigen eGFP. In this aspect of the present invention, the polynucleotide sequence for ChAdOx2 preferably does not include the sequence encoding the eGFP antigen.

A further embodiment of the present invention provides a host cell transduced with the viral vector according to the first aspect of the present invention, wherein said host cell is preferably a bacterium, more preferably *E.coli* strain Stellar containing a bacterial artificial chromosome (BAC) containing the cloned genome of ChAdOx2 deposited by Isis Innovation Limited on 13 June 2016 with the European Collection of Cell Cultures (ECACC) at the Health Protection Agency Culture Collections, Health Protection Agency, Porton Down, Salisbury SP4 0JG, United Kingdom under the Budapest Treaty and designated by provisional accession no. 16061301. The deposited BAC additionally comprises a transgene encoding the antigen eGFP. In this aspect of the present invention, the polynucleotide sequence for ChAdOx2 preferably does not include the sequence encoding the eGFP antigen. Such a host cell may be used for BAC propagation.

A specific embodiment of the seventh aspect of the present invention provides a Bacterial Artificial Chromosome (BAC) clone comprising the polynucleotide sequence according to the fourth aspect of the present invention, wherein said BAC is the BAC containing the cloned genome of ChAdOx2, deposited in *E.coli* strain Stellar by Isis Innovation Limited on 13 June 2016 with the European Collection of Cell Cultures (ECACC) at the Health Protection Agency Culture Collections, Health Protection Agency, Porton Down, Salisbury SP4 0JG, United Kingdom under the Budapest Treaty and designated by provisional accession no. 16061301. The deposited BAC additionally comprises a transgene encoding the antigen eGFP. In this aspect of the present invention, the polynucleotide sequence for ChAdOx2 preferably does not include the sequence encoding the eGFP antigen.

A further aspect of the invention provides a kit, comprising an adenoviral vector according to the first aspect of the invention, or an immunogenic composition according to the second aspect of the invention, together with instructions for use.

The kit may include medical equipment for administering the adenoviral vector or immunogenic composition to a subject, such as a syringe. The kit may comprise instructions for administering the adenoviral vector or immunogenic composition to a subject, and may include specific dosage instructions. The kit may be useful for vaccinating a subject against a disease by inducing or enhancing an immune response, or for otherwise treating or preventing disease in a subject.

For the avoidance of doubt, it is hereby expressly stated that features described herein as 'preferred', 'preferable', "alternative" or the like may be present in the invention in isolation or in any combination with any one or more other features so described (unless the context dictates otherwise) and this constitutes and explicit disclosure of such combinations of features.

All the features of each embodiment described above apply *mutatis mutandis* to all other embodiments of the present invention.

The invention will now be further described with reference to the following non-limiting examples.

Example 1

Simian adenvorius (sAd) vaccine vector design and development

Key considerations in the design of sAd vectors for use as vaccines are similar to those for AdHu5. The vaccine vector must be non-replicating and unlike adenovirus gene therapy vectors have negligible immune modulatory activity. Hence, SAd vectors lack the E1 region encoding viral transactivator proteins which are essential for virus growth and the E3 region encoding immunomodulatory proteins.

The advent of bacterial artificial chromosomes (BACs) coupled to bacteriophage λ Red recombination (recombineering) technology has facilitated the manipulation of

large virus genome. Using this approach linear DNA adenovirus genomes isolated from non-human primates have been cloned for use as viral vectors.

The first stage, following virus isolation and genome sequencing, is either the amplification or artificial synthesis of two products homologous to the left arm of the genome, flanking the E1 region and one, approximately 1000bp, product homologous to the right arm of the genome each incorporating a unique restriction enzyme site for cloning and genome excision for vector production. These fragments are assembled and inserted into a BAC by conventional restriction enzyme cloning. The virus genome is then inserted into the BAC clone by single step gap repair homologous recombination to generate an E1 deleted viral vector molecular clone (Fig 1a).

The bacteriophage λ Red recombination (recombineering) system is then used to allow seamless deletion of the adenovirus E3 immunomodulatory genes. Firstly, the bacterial galactokinase gene (GalK) is amplified from the plasmid, pGalK, such that it contains ~50 bp homology arms flanking the E3 region, this gene is inserted at the E3 locus of the BAC rescued adenovirus genome by λ Red recombination. Clones are screened for growth on galactose as this phenotype is attributed to the GalK gene product. The GalK gene is then removed by λ Red recombination with a PCR product comprised of the E3 left and right flanking region only (Fig 1b).

Positive clones are selected on 2-deoxygalactose media which prevents growth of bacteria expressing the GalK gene. Further manipulation using λ Red recombination firstly to insert the GalK gene and then to exchange it for an antigen expression cassette at the E1 locus completes the engineering of the vaccine vector (Fig 1c).

The linear virus genome is excised from the BAC using unique restriction enzymes, usually PacI or PmeI, and transfected into complementing cells to generate the viral vector. The antigen cassette typically consists of a strong promoter such as the minimal CMV immediate early promoter, to drive antigen expression, the antigen of interest and a polyadenylation signal.

The inventors have generated a molecular toolbox that allows the insertion of any gene easily into a set region within the ChAd genome by inserting universal cassettes expressing a bacteria antibiotic resistance gene flanked by specific

recombination sequences, such as *att*R1 and *att*R2, derived from bacteriophage λ (note this system is based on the Gateway cloning system from Invitrogen), into our ChAd derived vaccine vectors at the E1 locus and/or the E3 locus. Shuttle plasmids containing an antigen expression cassette flanked by specific recombination sites paired with those present in the genome (for example *att*R1/R2 recombination sequence requires *att*L1/L2 recombination sequence) allow site specific recombination in the presence of an enzyme mixture containing bacteriophage λ integrase, integration host factor and excisionase (Fig 2).

Although the deleted E1 region from SAds is complemented by AdHu5 E1 proteins constitutively expressed by human embryonic kidney (HEK) 293 cells or PerC.6 cells, viral yields vary depending on SAd serotype. High yields of Pan5, Pan6 and Pan7, all derived from chimpanzees can be obtained from HEK293 cells, whereas ChAd1 yields are poor. For virus vectors with poor replication, further genome manipulation has been shown to increase yields. In the case of AdHu5, the E4 gene products in particular those from orf3, orf4, orf6 and orf6/7 coordinate their function with the E1 proteins (E1A and E1B 55K) and host cell cofactors to bind, regulate and de-repress several cellular functions during viral multiplication. Manipulation of the E4 region can therefore be a promising means of increasing virus yields.

In patent publication WO2012/172277, the present inventors described the generation of a chimeric vaccine vector, ChAdOx1, derived from ChAd serotype Y25 engineered by λ Red recombination to exchange the native E4 orf4 orf6 and orf6/7 genes for those from AdHu5. This vector showed an increase in hexon protein production from HEK 293 cells compared to the ChAd parent virus. Using this approach, the inventors have now generated a novel adenovirus vector according to the present invention, ChAdOx2, an E1/E3 deleted vaccine vector derived from ChAd68 (also referred to as Pan6 and sAd25) containing E4 orf1, orf2 and orf3 from Y25 and E4 orf4, orf6 and orf6/7 from AdHu5 to increase virus yields in HEK 293 cells (Fig 3).

SAd vector engineering to improve immunogenicity

Adenovirus vaccine vectors, regardless of parental origin, can induce humoral, mucosal and cellular immune responses, depending on the route of administration.

However, although the T- and B-cell responses elicited are good for most vectors, the level of immunological potency can differ depending on adenovirus vector parental strain/serotype[10, 11]. For example, when the two simian vectors ChAdOx1 (derived from Y25 and disclosed in WO2012/172277) and ChAdOx2 (derived from C68, according to the present invention), which both carried a GFP expression cassette in the E1 locus, were compared, the T-cell response elicited to GFP was significantly higher for ChAdOx2 (Fig 4).

Example 2: Results from phase I clinical trial of the candidate Mycobacterium avium subspecies paratuberculosis (MAP) vaccine ChAdOx2 HAV

A phase I clinical trial was initiated to determine the safety and immunogenicity of the candidate *Mycobacterium avium* subspecies paratuberculosis (MAP) vaccine ChAdOx2 HAV in healthy adult volunteers. The vaccine contains antigens from *Mycobacterium avium* subspecies paratuberculosis (MAP) which is the causative agent for Johne's disease in cattle and has been linked to Crohn's disease in humans.

20 volunteers were screened. 13 of these were deemed eligible to take part in the study. 1 volunteer withdrew consent prior to enrolment. 9 participants received their single dose of ChAdOx2 HAV. Figure 5 shows the study groups (table 1) and the current progress of enrollment (table 2, completed follow-up visits shaded):

Figures 6 to 11 show the proportions of volunteers presenting adverse events (AEs) at different dose groups. As can be seen from these figures, the vaccine is safe and well tolerated. There have been no severe or serious AEs related to ChAdOx2 HAV. Figure 6 shows the proportion of volunteers presenting local AEs after a single dose of ChAdOx2 HAV (5×10^9 vp). Figure 7 shows the proportion of volunteers presenting systemic AEs after a single dose of ChAdOx2 HAV (5×10^9 vp). Figure 8 shows the proportion of volunteers presenting local AEs after a single dose of ChAdOx2 HAV (2.5×10^{10} vp). Figure 9 shows the proportion of volunteers presenting systemic AEs after a single dose of ChAdOx2 HAV (2.5×10^{10} vp). Figure 10 shows the proportion of volunteers presenting local AEs after a single dose of ChAdOx2 HAV (5×10^{10} vp). Figure 11 shows the proportion of volunteers presenting systemic AEs after a single dose of ChAdOx2 HAV (5×10^{10} vp).

Responses to vaccination with ChAdOx2 HAV in humans were assessed using the interferon-gamma ELISPOT assay using freshly-isolated peripheral blood mononuclear cells (PBMC) stimulated with pools of peptides spanning the HAV vaccine construct. Assays were performed prior to vaccination (Day 0) and at one and two months' post vaccination (Day 28 and 56).

Responses to HAV antigens prior to vaccination were low, with a median response of 104 spot-forming cells per million PBMC (SFC), which increased to a median of 331 SFC at day 28 taking an average across all dose groups (figure 12). Responses were higher at day 28 in participants immunised with $2.5x10^{10}$ v.p. than $5x10^{9}$ v.p. ($p<0.05$, Kruskall-Wallis test with Dunn's multiple comparison test). Individual responses are tabulated, see figure 13.

Example 3: Antibody responses in mice vaccinated with ChAdOx2 RabGP

The rabies virus glycoprotein coding sequence (RabGP; ERA strain; Genbank accession number AJ489620.1) was PCR amplified from a plasmid kindly supplied by Hildegund Ertl (Wistar Institute), using primers flanking Acc65I and NotI restriction enzyme sites. After digestion with these enzymes, the fragment was cloned into a similarly digested pENTR4 plasmid providing the human cytomegalovirus major immediate early promoter (IE CMV) that includes intron A and flanked by Gateway® recombination cassettes. Gateway LR recombination cloning (Life Technologies) was used to transfer the transgene cassette into the ChAdOx2 destination vector in the E1-homologous site to produce pBAC ChAdOx2 LPTOS RabGP ERA.

Following enzymatic linearization of the ChAdOx2 RabGP destination plasmid and transfection into HEK293A cells (Invitrogen, Cat. R705-07), the resultant viruses were purified by CsCl gradient ultracentrifugation. The titres were determined on HEK293A cells using anti-hexon immunostaining assay based on the QuickTiter™ Adenovirus Titer Immunoassay kit (Cell Biolabs Inc).

The destination vector structure is shown in Figure 14. The amino acid sequence of the rabies glycoprotein is provided in SEQ ID NO. 21.

Vaccine was diluted in PBS prior to administration, and in some cases were mixed with squalene oil-in-water adjuvant (Addavax, Sigma). 6 week old female CD1 outbred mice were immunised with the following formulations (n=6 mice/group), all given intramuscularly into each gastrocnemius.

A: ChAdOx2-RabGP, 1e8 infectivity units (IU)
B: ChAdOx2-RabGP, 1e7 IU
C: ChAdOx2-RabGP, 1e6 IU
D: ChAdOx2-RabGP, with Addavax, 1e8 IU
E: ChAdOx2-RabGP, with Addavax, 1e7 IU
F: ChAdOx2-RabGP, with Addavax, 1e6 IU

Serum was collected 28 days after immunisation, and antibody titers were assessed by ELISA against a recombinant rabies glycoprotein (SAD B19 strain, lacking the transmembrane domain, with a C-terminal C-tag and purified using C-tag affinity resin [ThermoFisher]). Results were expressed in arbitrary units, relative to a dilution series / standard curve of a positive control sample, and $\log_{10}$ transformed prior to analysis.

The vaccine induced ELISA-detectable antibody to the rabies glycoprotein, with statistically significant enhancements of antibody titer associated with rising vaccine dose and with co-formulation with Addavax. Figure 15 shows antibody responses in mice vaccinated with ChAdOx2 RabGP at a range of doses, with and without adjuvant (groups A-F). p=0.004 for effect of dose and p=0.03 for effect of adjuvant co-formulation the two-way ANOVA across groups A-F.

A comparison of the immunogenicity of the ChAdOx2 vaccine construct with a AdC68 vaccine construct having the same antigen insert was made. The AdC68 was a kind gift of Hildegund Ertl, Wistar Institute, as disclosed in Xiang *et al.*, Novel, Chimpanzee Serotype 68-based Adenoviral Vaccine Carrier for Induction of Antibodies to a Transgene Product, Journal of Virology, 76 (6), pp2667-2675. The ChAdOx2 vaccine construct was surprisingly found to have higher immunogenicity than the AdC68 vaccine, as shown in figure 16.

References

1. Buchbinder *et al*, Lancet, Vol 372, Nov 2008
2. Farina *et al*, J. Virol, Dec 2001, p11603-11613
3. Dudareva *et al*, Vaccine 27, 2009, 3501-3504
4. R. Wigand *et al*, Intervirology, Vol30; 1 1989
5. Roy *et al*, Hum. Gen. Ther., 2004, 15:519-530
6. Warming *et al*. Nuc. Acid. Res, 2005, Vol33;4
7. http://www.invitrogen.com/gateway
8. Havenga *et al*, J.G.V., 2006, 87, 2135-214
9. Warming, S. *et al*. Nucleic Acids Res, 2005, Feb 24; 33(4): e36
10. Colloca, S., et al., Sci Transl Med, 2012. **4**(115): p. 115ra2.
11. Quinn, K.M., et al. J Immunol, 2013. **190**(6): p. 2720-35.

List of Sequences

SEQ ID NO.	Description of sequence
1	Complete DNA sequence of C68
2	E4 region of C68
3	E4Orf1 from AdY25
4	E4Orf2 from AdY25
5	E4Orf3 from AdY25
6	Complete DNA sequence of AdY25
7	E4Orf4 from AdHu5
8	E4Orf6 from AdHu5
9	E4Orf6/7 from AdHu5
10	ChAdOx2 vector (with Gateway cassette in E1 locus)
11	Nucleic acid sequence of *M. tuberculosis* protein Ag85A
12	Amino acid sequence of *M. tuberculosis* protein Ag85A
13	Nucleic acid sequence of nucleoprotein (NP) and matrix protein 1 (M1) from influenza A virus

14	Amino acid sequence of nucleoprotein (NP) and matrix protein 1 (M1) from influenza A virus
15	Linker sequence
16	E1 region of C68
17	E3 region of C68
18	Amino acid sequence of C68 hexon protein
19	Amino acid sequence of C68 penton protein
20	Amino acid sequence of C68 fibre protein
21	Amino acid sequence of the rabies glycoprotein

Claims

1. An adenoviral vector comprising the genome of an adenovirus other than AdHu5 and AdY25, wherein the genome of the adenovirus has been modified such that the vector lacks the native E4 locus of the adenovirus and comprises heterologous E4Orf1, E4Orf2 and E4Orf3 coding regions from AdY25.

2. The adenoviral vector of claim 1, further comprising heterologous E4Orf4, E4Orf6 and E4Orf6/7 coding regions from AdHu5 in the E4 locus of the adenovirus.

3. The adenoviral vector of claims 1 or 2, wherein said adenovirus is C68.

4. The adenoviral vector of any of claims 1 to 3, wherein said adenoviral vector lacks a functional E1 locus.

5. The adenoviral vector of any of claims 1 to 4, wherein said adenoviral vector lacks an E3 locus.

6. The adenoviral vector of any of claims 1 to 5, wherein said adenoviral vector comprises one or more capsid proteins selected from the group consisting of:

(a) a hexon protein encoded by the coding sequence corresponding to nucleotides 18315 to 21116 of SEQ ID NO. 1 or a sequence substantially identical thereto;

(b) a penton protein encoded by the coding sequence corresponding to nucleotides 13884 to 15488 of SEQ ID NO. 1, or a sequence substantially identical thereto; and

(c) a fibre protein encoded by the coding sequence corresponding to nucleotides 32134 to 33411 of SEQ ID NO. 1, or a sequence substantially identical thereto.

7. The adenoviral vector of any of claims 1 to 6, further comprising an exogenous nucleotide sequence of interest that encodes a protein or polypeptide.

8. The adenoviral vector of claim 7, wherein said protein or polypeptide is selected from the group comprising an antigen, a molecular adjuvant, an immunostimulatory protein or a recombinase.

9. The adenoviral vector of claim 8, wherein the antigen is a pathogen-derived antigen.

10. The adenoviral vector of claim 9, wherein the pathogen is selected from the group consisting of *M. tuberculosis*, *Plasmodium sp*, influenza virus, HIV, *Hepatitis C virus*, *Cytomegalovirus*, *Human papilloma virus*, rabies virus, measles virus, mumps, rubella, zika virus, leishmania parasites or *Mycobacterium* sp..

11. The adenoviral vector of claim 10, wherein said antigen is from Mycobacterium avium subspecies paratuberculosis (MAP).

12. The adenoviral vector of claim 10, wherein the antigen is rabies virus glycoprotein.

13. The adenoviral vector of claim 7, wherein said exogenous nucleotide sequence of interest is an miRNA or immunostimulatory RNA sequence.

14. An immunogenic composition comprising the adenovirus vector according to any of claims 1 to 13 and optionally one or more additional active ingredients, a pharmaceutically acceptable carrier, diluent, excipient or adjuvant.

15. The immunogenic composition of claim 14 for use in medicine.

16. The immunogenic composition for use according to claim 15, wherein the composition is for use in treating a disease selected from the group

comprising tuberculosis and other mycobacterial infections including Johne's disease, Crohn's disease, malaria, influenza, HIV/AIDS, Hepatitis C virus infection, Cytomegalovirus infection, Human papilloma virus infection, adenoviral infection, leishmaniasis, *streptococcus spp*. infection, *staphylococcus spp*. infection, *meningococcus spp*. infection, foot and mouth disease, chikungunya virus infection, Zika virus infection, rabies, Crimean Congo haemorrhagic fever, Ebola virus infection, Marburg, Lassa fever, MERS and SARS coronavirus diseases, Nipah and Rift Valley fever, and Chikungunya.

17. The immunogenic composition for use according to claim 15 or 16, wherein the disease is selected from the group consisting of tuberculosis and other mycobacterial infections, and rabies.

18. The immunogenic composition of claims 15 to 17, wherein said use comprises delivering a transgene into a host cell.

19. The immunogenic composition of claim 15 to 17, wherein said use comprises eliciting an immune response in an animal.

20. The immunogenic composition of claim 15 to 17, wherein said use comprises boosting an immune response in an animal.

21. The immunogenic composition of claim 15 to 17, wherein said use comprises treating or preventing at least one disease.

22. The immunogenic composition of claim 15, wherein said use comprises inducing an immune response in an animal that will break tolerance to a self-antigen.

23. The immunogenic composition of claim 15, wherein said use comprises gene therapy.

24. A polynucleotide sequence encoding the adenoviral vector of any of claims 1 to 13.

25. A host cell transduced with the adenoviral vector of any of claims 1 to 13.

26. A method of producing the adenoviral vector of any of claims 1 to13, comprising the step of incorporating the polynucleotide of claim 24 into a Bacterial Artificial Chromosome (BAC) to produce an Ad-BAC vector.

27. A Bacterial Artificial Chromosome (BAC) clone comprising the polynucleotide sequence of claim 24.

28. A packaging cell line producing the viral vector of any of claims 1 to 11.

29. The packaging cell line of claim 28, wherein said cell comprises the complement of any genes functionally deleted in the viral vector of any of claims 1 to 13.

30. A kit comprising: (i) an adenoviral vector according to any of claims 1 to 13 or an immunogenic composition according to claim 14, and (ii) instructions for use.