

ADENOVIRUS AND USES THEREOF

FIELD OF THE INVENTION

[0001] This invention relates to biotechnology. More particularly, to the field and
5 use of adenoviral vectors, such as replication defective adenoviral vectors to deliver
antigens and elicit an immune response in hosts.

BACKGROUND OF THE INVENTION

[0002] Recombinant adenoviral vectors are widely applied for gene therapy
10 applications and vaccines. AdV-5 vector-based vaccines have been shown to elicit
potent and protective immune responses in a variety of animal models (see, e.g.,
WO2001/02607; WO2002/22080; Shiver et al., Nature 415:331 (2002); Letvin et al.,
Ann. Rev. Immunol. 20:73 (2002); Shiver and Emini, Ann. Rev. Med. 55:355 (2004)).
However, the utility of recombinant AdV-5 vector-based vaccines will likely be
15 limited by the high seroprevalence of AdV-5-specific neutralizing antibodies (NAbs)
in human populations. The existence of anti-AdV-5 immunity has been shown to
substantially suppress the immunogenicity of AdV-5-based vaccines in studies in mice,
rhesus monkeys, and humans.

[0003] One promising strategy to circumvent the existence of pre-existing immunity
20 in individuals previously infected or treated with the most common human adenovirus,
e.g., AdV-5, involves the development of recombinant vectors from adenovirus
serotypes that do not encounter such pre-existing immunities. One such strategy is
based on the use of non-human simian adenoviruses since these do not typically infect
humans and exhibit low seroprevalence in human samples. Non-human simian
25 adenoviruses are applicable for human use since it was shown that these viruses could
infect human cells *in vitro* (WO2003/000283; WO2004/037189).

[0004] Thus, there is a need in the field for alternative adenoviral vectors that are
producible in large quantities, that do not encounter pre-existing immunities in the
host, but that are still immunogenic and capable of inducing a strong immune response
30 against the antigens encoded by the heterologous nucleic acids inserted in the vector.

BRIEF SUMMARY OF THE INVENTION

[0005] Provided are isolated nucleic acid sequences encoding hexon polypeptides. In certain embodiments, the hexon polypeptide or a functional derivative thereof comprises a hexon hypervariable regions-encompassing polypeptide having the amino acid sequence of SEQ ID NO:1 or an amino acid sequence which is at least 95% identical over its entire length to the amino acid sequence of SEQ ID NO:1.

[0006] In certain embodiments, the hexon polypeptide comprises a hexon hypervariable regions-encompassing polypeptide having the amino acid sequence of SEQ ID NO:1. In certain embodiments, the hexon polypeptide or the functional derivative thereof comprises the amino acid sequence of a BLY6 hexon polypeptide (SEQ ID NO:2) or an amino acid sequence which is at least 95% identical over its entire length to the amino acid sequence of SEQ ID NO:2.

[0007] Also provided are isolated nucleic acid sequences encoding a fiber polypeptide or a functional derivative thereof. In certain embodiments, the fiber polypeptide comprises at least one of a fiber knob polypeptide sequence comprising the amino acid sequence of SEQ ID NO:10; a fiber shaft polypeptide sequence comprising the amino acid sequence of SEQ ID NO:11; and a fiber tail polypeptide sequence comprising the amino acid sequence of SEQ ID NO:12. In certain embodiments, the fiber polypeptide or a functional derivative thereof comprises the amino acid sequence of a BLY6 fiber polypeptide (SEQ ID NO:3) or an amino acid sequence which is at least 95% identical over its entire length to the amino acid sequence of SEQ ID NO:3.

[0008] Embodiments of the invention also include isolated fiber and hexon polypeptides encoded by the fiber and hexon nucleic acid sequences of the invention.

[0009] Further provided herein are isolated nucleic acids comprising a hexon nucleic acid sequence encoding at least one of the hexon polypeptides disclosed herein, and a fiber nucleic acid sequence encoding at least one of the fiber polypeptides disclosed herein. In certain embodiments, provided herein are vectors comprising the isolated nucleic acids described herein. In one embodiment, the vector is a viral vector. In another embodiment, the vector is an expression vector. In one preferred embodiment, the vector is an adenoviral vector. More preferably, the vector further comprises a transgene.

[0010] Also provided are recombinant cells comprising the vectors described herein. Such cells can be used for recombinant protein production, recombinant protein

expression, or the production of vectors or viral particles. Also provided are methods of producing a vector. The methods comprise (a) growing the recombinant cell disclosed herein under conditions for production of the vector; and (b) isolating the vector from the recombinant cell.

- 5 [0011] In certain embodiments, provided are immunogenic compositions comprising the vectors disclosed herein. Also provided are methods of inducing an immune response in a subject in need thereof, comprising administering to the subject the immunogenic compositions disclosed herein.

[0012] In certain embodiments, provided are adenoviral vectors comprising (a) at
10 least one transgene; and (b) a nucleic acid sequence encoding a hexon polypeptide according to embodiments of the invention. The hexon polypeptide can, for example, comprise a hexon hypervariable regions-encompassing polypeptide having the amino acid sequence of SEQ ID NO:1 or an amino acid sequence which is at least 95% identical over its entire length to the amino acid sequence of SEQ ID NO:1. The
15 hexon polypeptide can, for example, comprise an amino acid sequence having the amino acid sequence of SEQ ID NO:1. In certain embodiments, the hexon polypeptide comprises the amino acid sequence of a BLY6 hexon polypeptide (SEQ ID NO:2) or an amino acid sequence which is at least 95% identical over its entire length to the amino acid sequence of SEQ ID NO:2.

- 20 [0013] In certain embodiments, provided are adenoviral vectors comprising (a) at least one transgene; and (b) a nucleic acid sequence encoding a fiber polypeptide according to embodiments of the invention. In certain embodiments, the fiber polypeptide can comprise at least one of a fiber knob polypeptide sequence comprising the amino acid sequence of SEQ ID NO:10; a fiber shaft polypeptide
25 sequence comprising the amino acid sequence of SEQ ID NO:11; and a fiber tail polypeptide sequence comprising the amino acid sequence of SEQ ID NO:12. In certain embodiments, the fiber polypeptide or a functional derivative thereof comprises the amino acid sequence of a BLY6 fiber polypeptide (SEQ ID NO:3) or an amino acid sequence which is at least 95% identical over its entire length to the amino
30 acid sequence of SEQ ID NO:3. Embodiments of the invention also include adenoviral vectors comprising (a) at least one transgene; (b) a nucleic acid sequence encoding a hexon polypeptide according to embodiments of the invention; and (c) a nucleic acid sequence encoding a fiber polypeptide according to embodiments of the invention.

[0014] In certain embodiments, the adenoviral vectors provided herein are replication-defective adenovirus vectors (rAd). In one embodiment, the adenoviral vectors can comprise an E1 deletion. In certain embodiments, the adenoviral vectors provided herein can further comprise an E3 deletion. The adenoviral vectors can be simian adenoviral vectors comprising adenoviral nucleic acid sequences from one or more simian adenoviruses (SAdV), such as chimpanzee adenoviruses (e.g., ChAd3); gorilla adenoviruses; or rhesus adenoviruses (e.g., rhAd51, rhAd52 or rhAd53). The adenoviral vectors can be human adenoviral vectors comprising adenoviral sequences from one or more human adenoviruses (e.g., hAdV-4, hAdV-5, hAdV-26, hAdV-35). Preferably, the adenoviral vector is a chimeric adenoviral vector comprising one or more human adenoviral nucleic acid sequences. The human adenoviral nucleic acid sequences can, for example, be from human adenovirus-4 (hAdV-4), human adenovirus-5 (hAdV-5), human adenovirus-26 (hAdV-26), or human adenovirus-35 (hAdV-35). The adenoviral vectors can, for example, comprise a human adenovirus-5 (hAdV-5) E4 orf6 and orf 6/7.

[0015] In certain embodiments, the transgene is located adjacent to an inverted terminal repeat (ITR). In certain embodiments, a transgene is located at or adjacent to the E1 deletion, at or adjacent to the E3 deletion, and/or at or adjacent to the ITR, e.g., between the E4 region and the right ITR (RITR).

[0016] In certain embodiments, the adenoviral vectors provided herein comprises a nucleic acid sequence of SEQ ID NO:13 or SEQ ID NO:14.

[0017] Also provided are immunogenic compositions or vaccines comprising the adenoviral vectors described herein and a pharmaceutically acceptable carrier. Further provided are methods for inducing an immune response in a subject in need thereof. The methods comprise administering to the subject the vaccines disclosed herein. Further provided are methods of producing a vaccine. The methods comprise combining an adenoviral vector disclosed herein with a pharmaceutically acceptable carrier.

BRIEF DESCRIPTION OF THE DRAWINGS

[0018] The foregoing summary, as well as the following detailed description of preferred embodiments of the present application, will be better understood when read in conjunction with the appended drawings. It should be understood, however, that the application is not limited to the precise embodiments shown in the drawings.

[0019] Figure 1 shows the cellular and humoral immune responses induced by BLY6.FLuc and Ad49.FLuc. Figure 1A shows the experimental set-up. Figure 1B shows the cellular immune response induced by Ad26.FLuc, BLY6.FLuc and Ad49.FLuc against the vector-encoded antigen (i.e. Fluc, firefly luciferase) as determined by Interferon gamma (IFN- γ) ELISPOT analysis. The y-axis shows the number of Spot Forming Units (SFU) per 10^6 splenocytes and the dotted line indicates 95% percentile of the medium stimuli.

[0020] Figure 2 shows cellular and humoral immune responses induced by BLY6.RSVF-2A-GLuc. Figure 2A shows the experimental set-up. Figure 2B shows a graph of the results of a virus neutralization assay (VNA) performed at eight weeks after immunization with Ad26.RSVF-2A-GLuc or with BLY6.RSVF-2A-GLuc at three different concentrations (10^8 , 10^9 and 10^{10} vp), or with Ad26.FLuc or BLY6.FLuc at 10^{10} vp. Figure 2C shows the cellular immune responses induced by Ad26.RSVF-2A-GLuc and BLY6.RSVF-2A-GLuc after immunization as determined by IFN- γ ELISPOT analysis. Figure 2D shows a graph of RSVF-specific IgG binding antibodies induced by Ad26.RSVF-2A-GLuc or BLY6.RSVF-2A-GLuc in serum of immunized mice at 8 weeks post-immunization.

[0021] Figure 3 shows homologous and heterologous adenovirus neutralization titers induced in mice immunized with adenoviral vectors Ad35, Ad26, Ad49, Ad5, Ad4, and BLY6.

[0022] Figure 4 shows the seroprevalence of Ad35, Ad26, Ad5 and BLY6 in 200 human cohort serum samples from adults, age 18 to 55 years, living in the United States (US) and European Union (EU). Neutralization titers measured in these sera against each vector were divided into four categories (<16 (negative), 16 to 300, 300 to 1,000, 1000 to 4000 and >4000), represented in the charts as indicated.

[0023] Figure 5 shows a schematic of the plasmid pBLY6.dE1.dE3 (SEQ ID NO:8).

[0024] Figure 6 shows a schematic of the plasmid pBLY6.dE1.dE3.5IXp (SEQ ID NO:9).

[0025] Figure 7 shows an alignment of BLY6 hexon polypeptide (SEQ ID NO:2) and SAdV-30-1 hexon polypeptide (SEQ ID NO:4) sequences.

[0026] Figure 8 shows productivity of novel vector BLY6.FLuc in production cell line sPER.C6.

DETAILED DESCRIPTION OF THE INVENTION

[0027] This disclosure is based upon, at least in part, the isolation and identification of a new gorilla adenovirus isolate, allocated into adenovirus species E, as well as construction and evaluation of vaccine vectors comprising nucleic acids encoding
5 variable regions of the hexon and fiber polypeptides of said gorilla adenovirus. The adenoviral vectors are capable of eliciting an immune response and, furthermore, have low seroprevalence in humans. The adenoviral vectors can be formulated for vaccines and used to induce protective immunity against specific antigens of interest.

[0028] Various publications, articles and patents are cited or described in the
10 background and throughout the specification; each of these references is herein incorporated by reference in its entirety. Discussion of documents, acts, materials, devices, articles or the like which has been included in the present specification is for the purpose of providing context for the invention. Such discussion is not an admission that any or all of these matters form part of the prior art with respect to any
15 inventions disclosed or claimed.

[0029] Unless defined otherwise, all technical and scientific terms used herein have the same meaning as commonly understood to one of ordinary skill in the art to which this invention pertains. Otherwise, certain terms used herein have the meanings as set forth in the specification.

[0030] It must be noted that as used herein and in the appended claims, the singular forms “a,” “an,” and “the” include plural reference unless the context clearly dictates otherwise.

[0031] Unless otherwise stated, any numerical values, such as a concentration or a concentration range described herein, are to be understood as being modified in all
25 instances by the term “about.” Thus, a numerical value typically includes $\pm 10\%$ of the recited value. For example, a concentration of 1 mg/mL includes 0.9 mg/mL to 1.1 mg/mL. Likewise, a concentration range of 1% to 10% (w/v) includes 0.9% (w/v) to 11% (w/v). As used herein, the use of a numerical range expressly includes all possible subranges, all individual numerical values within that range, including
30 integers within such ranges and fractions of the values unless the context clearly indicates otherwise.

[0032] Unless otherwise indicated, the term “at least” preceding a series of elements is to be understood to refer to every element in the series. Those skilled in the art will recognize or be able to ascertain using no more than routine

experimentation, many equivalents to the specific embodiments of the invention described herein. Such equivalents are intended to be encompassed by the invention.

[0033] As used herein, the terms "comprises," "comprising," "includes,"

"including," "has," "having," "contains" or "containing," or any other variation

5 thereof, will be understood to imply the inclusion of a stated integer or group of integers but not the exclusion of any other integer or group of integers and are intended to be non-exclusive or open-ended. For example, a composition, a mixture, a process, a method, an article, or an apparatus that comprises a list of elements is not necessarily limited to only those elements but can include other elements not
10 expressly listed or inherent to such composition, mixture, process, method, article, or apparatus. Further, unless expressly stated to the contrary, "or" refers to an inclusive or and not to an exclusive or. For example, a condition A or B is satisfied by any one of the following: A is true (or present) and B is false (or not present), A is false (or not present) and B is true (or present), and both A and B are true (or present).

15 [0034] As used herein, the conjunctive term "and/or" between multiple recited elements is understood as encompassing both individual and combined options. For instance, where two elements are conjoined by "and/or", a first option refers to the applicability of the first element without the second. A second option refers to the applicability of the second element without the first. A third option refers to the
20 applicability of the first and second elements together. Any one of these options is understood to fall within the meaning, and therefore satisfy the requirement of the term "and/or" as used herein. Concurrent applicability of more than one of the options is also understood to fall within the meaning, and therefore satisfy the requirement of the term "and/or."

25 [0035] As used herein, the term "consists of," or variations such as "consist of" or "consisting of," as used throughout the specification and claims, indicate the inclusion of any recited integer or group of integers, but that no additional integer or group of integers can be added to the specified method, structure, or composition.

[0036] As used herein, the term "consists essentially of," or variations such as
30 "consist essentially of" or "consisting essentially of," as used throughout the specification and claims, indicate the inclusion of any recited integer or group of integers, and the optional inclusion of any recited integer or group of integers that do not materially change the basic or novel properties of the specified method, structure or composition. See M.P.E.P. § 2111.03.

[0037] As used herein, "subject" means any animal, preferably a mammal, most preferably a human, to whom will be or has been vaccinated by a method according to an embodiment of the invention. The term "mammal" as used herein, encompasses any mammal. Examples of mammals include, but are not limited to, cows, horses, sheep, pigs, cats, dogs, mice, rats, rabbits, guinea pigs, monkeys, humans, etc., more preferably a human.

[0038] The words "right", "left", "lower" and "upper" designate directions in the drawings to which reference is made.

[0039] It should also be understood that the terms "about," "approximately," "generally," "substantially" and like terms, used herein when referring to a dimension or characteristic of a component of the preferred invention, indicate that the described dimension/characteristic is not a strict boundary or parameter and does not exclude minor variations therefrom that are functionally the same or similar, as would be understood by one having ordinary skill in the art. At a minimum, such references that include a numerical parameter would include variations that, using mathematical and industrial principles accepted in the art (e.g., rounding, measurement or other systematic errors, manufacturing tolerances, etc.), would not vary the least significant digit.

[0040] The terms "identical" or percent "identity," in the context of two or more nucleic acids or polypeptide sequences (e.g., hexon and fiber polypeptides and polynucleotides that encode them), refer to two or more sequences or subsequences that are the same or have a specified percentage of amino acid residues or nucleotides that are the same, when compared and aligned for maximum correspondence, as measured using one of the following sequence comparison algorithms or by visual inspection.

[0041] For sequence comparison, typically one sequence acts as a reference sequence, to which test sequences are compared. When using a sequence comparison algorithm, test and reference sequences are input into a computer, subsequence coordinates are designated, if necessary, and sequence algorithm program parameters are designated. The sequence comparison algorithm then calculates the percent sequence identity for the test sequence(s) relative to the reference sequence, based on the designated program parameters.

[0042] Optimal alignment of sequences for comparison can be conducted, e.g., by the local homology algorithm of Smith & Waterman, *Adv. Appl. Math.* 2:482 (1981),

by the homology alignment algorithm of Needleman & Wunsch, *J. Mol. Biol.* 48:443 (1970), by the search for similarity method of Pearson & Lipman, *Proc. Nat'l. Acad. Sci. USA* 85:2444 (1988), by computerized implementations of these algorithms (GAP, BESTFIT, FASTA, and TFASTA in the Wisconsin Genetics Software Package, Genetics Computer Group, 575 Science Dr., Madison, WI), or by visual inspection (see generally, *Current Protocols in Molecular Biology*, F.M. Ausubel *et al.*, eds., Current Protocols, a joint venture between Greene Publishing Associates, Inc. and John Wiley & Sons, Inc., (1995 Supplement) (Ausubel)).

[0043] Examples of algorithms that are suitable for determining percent sequence identity and sequence similarity are the BLAST and BLAST 2.0 algorithms, which are described in Altschul *et al.* (1990) *J. Mol. Biol.* 215: 403-410 and Altschul *et al.* (1997) *Nucleic Acids Res.* 25: 3389-3402, respectively. Software for performing BLAST analyses is publicly available through the National Center for Biotechnology Information. This algorithm involves first identifying high scoring sequence pairs (HSPs) by identifying short words of length W in the query sequence, which either match or satisfy some positive-valued threshold score T when aligned with a word of the same length in a database sequence. T is referred to as the neighborhood word score threshold (Altschul *et al., supra*). These initial neighborhood word hits act as seeds for initiating searches to find longer HSPs containing them. The word hits are then extended in both directions along each sequence for as far as the cumulative alignment score can be increased.

[0044] Cumulative scores are calculated using, for nucleotide sequences, the parameters M (reward score for a pair of matching residues; always > 0) and N (penalty score for mismatching residues; always < 0). For amino acid sequences, a scoring matrix is used to calculate the cumulative score. Extension of the word hits in each direction are halted when: the cumulative alignment score falls off by the quantity X from its maximum achieved value; the cumulative score goes to zero or below, due to the accumulation of one or more negative-scoring residue alignments; or the end of either sequence is reached. The BLAST algorithm parameters W, T, and X determine the sensitivity and speed of the alignment. The BLASTN program (for nucleotide sequences) uses as defaults a word length (W) of 11, an expectation (E) of 10, M=5, N=-4, and a comparison of both strands. For amino acid sequences, the BLASTP program uses as defaults a word length (W) of 3, an expectation (E) of

10, and the BLOSUM62 scoring matrix (*see* Henikoff & Henikoff, *Proc. Natl. Acad. Sci. USA* 89:10915 (1989)).

[0045] In addition to calculating percent sequence identity, the BLAST algorithm also performs a statistical analysis of the similarity between two sequences (*see, e.g.,* 5 Karlin & Altschul, *Proc. Nat'l. Acad. Sci. USA* 90:5873-5787 (1993)). One measure of similarity provided by the BLAST algorithm is the smallest sum probability (P(N)), which provides an indication of the probability by which a match between two nucleotide or amino acid sequences would occur by chance. For example, a nucleic acid is considered similar to a reference sequence if the smallest sum 10 probability in a comparison of the test nucleic acid to the reference nucleic acid is less than about 0.1, more preferably less than about 0.01, and most preferably less than about 0.001.

[0046] A further indication that two nucleic acid sequences or polypeptides are substantially identical is that the polypeptide encoded by the first nucleic acid is 15 immunologically cross reactive with the polypeptide encoded by the second nucleic acid, as described below. Thus, a polypeptide is typically substantially identical to a second polypeptide, for example, where the two peptides differ only by conservative substitutions. Another indication that two nucleic acid sequences are substantially identical is that the two molecules hybridize to each other under stringent 20 conditions, as described below.

[0047] As used herein, the term "protective immunity" or "protective immune response" means that the vaccinated subject is able to control an infection with the pathogenic agent against which the vaccination was done. The pathogenic agent can, for example, be an antigenic gene product or antigenic protein, or a fragment thereof. 25 Usually, the subject having developed a "protective immune response" develops only mild to moderate clinical symptoms or no symptoms at all. Usually, a subject having a "protective immune response" or "protective immunity" against a certain agent will not die as a result of the infection with said agent.

[0048] The term "adjuvant" is defined as one or more substances that cause 30 stimulation of the immune system. In this context, an adjuvant is used to enhance an immune response to the adenovirus vectors of the invention.

[0049] As used herein, the term "antigenic gene product or fragment thereof" or "antigenic protein" can include a bacterial, viral, parasitic, or fungal protein, or a fragment thereof. Preferably, an antigenic protein or antigenic gene product is

capable of raising in a host a protective immune response, e.g., inducing an immune response against a disease or infection (e.g., a bacterial, viral, parasitic, or fungal disease or infection), and/or producing an immunity in (i.e., vaccinating) a subject against a disease or infection, that protects the subject against the disease or infection.

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Adenoviral Vectors

[0050] Exposure to certain adenoviruses has resulted in immune responses against certain adenoviral serotypes, which can affect efficacy of adenoviral vectors. Because infections with human adenoviruses are common in humans, the prevalence of neutralizing antibodies against human adenoviruses in human populations is high. The presence of such neutralizing antibodies in individuals may be expected to reduce the efficacy of a gene transfer vector based on a human adenoviral backbone. One way to circumvent the reduction of efficacy is to replace the epitopes on the adenoviral capsid proteins that are the targets of neutralizing antibodies. The target sequences on the capsid proteins can be replaced with protein sequences from other adenoviruses which are of low prevalence, and therefore against which neutralizing antibodies are rare in human populations.

[0051] A “capsid protein” refers to a protein on the capsid of an adenovirus (e.g., BLY6, HAdV-4) or a functional fragment or derivative thereof that is involved in determining the serotype and/or tropism of a particular adenovirus. Capsid proteins typically include the fiber, penton and/or hexon proteins. In certain embodiments, the capsid protein is an entire or full length capsid protein of the adenovirus. In other embodiments, the capsid protein is a fragment or a derivative of a full length capsid protein of the adenovirus. In certain embodiments, the hexon, penton and fiber encoded by an adenoviral vector of the invention are of the same or different adenoviral background (i.e., a BLY6 hexon and BLY6 fiber, a BLY6 hexon and a human adenovirus fiber, a human adenovirus hexon and a BLY6 fiber, etc).

[0052] A “hexon polypeptide” refers to adenovirus hexon coat proteins, functional fragments, and derivatives thereof.

[0053] A “fiber polypeptide” refers to adenovirus fiber proteins, functional fragments, and derivatives thereof.

[0054] One target of neutralizing antibodies against adenoviruses is the major coat protein, the hexon protein. Replacing the hexon protein or the variable sequences within the hexon protein, which define serotype and bind to neutralizing antibodies,

with the hexon protein or variable sequences within the hexon protein from adenoviruses that are rare in the human population, such as those gorilla sequences described herein, can allow for the construction of adenovirus vectors that would be less susceptible to neutralization by antibodies commonly found in humans.

- 5 [0055] A second target of neutralizing antibodies against adenoviruses is the fiber protein. Replacing the fiber protein or variable sequences within the fiber protein with the fiber protein or variable sequences within the fiber protein from adenoviruses that are rare in the human population, such as those gorilla sequences described herein, can also allow for the construction of adenovirus vectors that would be less
- 10 susceptible to neutralization by antibodies commonly found in humans. A combination of the fiber replacement with hexon replacements described above can confer additional resistance to neutralization by antibodies commonly present in human populations.

- [0056] This disclosure provides isolated nucleic acid sequences encoding hexon polypeptides and/or fiber polypeptides derived from an isolated simian adenovirus serotype and adenoviral vectors comprising at least one of the isolated nucleic acid sequences.
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- [0057] A "functional derivative" of a polypeptide suitably refers to a modified version of a polypeptide, e.g. wherein one or more amino acids of the polypeptide may be deleted, inserted, modified and/or substituted. A derivative of an unmodified adenoviral capsid protein is considered functional if, for example:
- 20

- (a) an adenovirus comprising the derivative capsid protein within its capsid retains substantially the same or a lower seroprevalence compared to an adenovirus comprising the unmodified capsid protein; and/or
- 25 (b) an adenovirus comprising the derivative capsid protein within its capsid retains substantially the same or a higher host cell infectivity compared to an adenovirus comprising the unmodified capsid protein; and/or
- (c) an adenovirus comprising the derivative capsid protein within its capsid retains substantially the same or a higher immunogenicity compared to an adenovirus
- 30 comprising the unmodified capsid protein; and or
- (d) an adenovirus comprising the derivative capsid protein within its capsid retains substantially the same or a higher level of transgene productivity compared to an adenovirus comprising the unmodified capsid protein.

[0058] An “adenoviral vector” refers to a recombinant vector derived from or containing at least a portion of an adenoviral genome.

[0059] In preferred embodiments, the isolated nucleic acid sequences encode hexon polypeptides or a functional derivative thereof comprising a hexon hypervariable regions-encompassing polypeptide having the amino acid sequence of SEQ ID NO:1 or an amino acid sequence which is at least 95% identical over its entire length to the amino acid sequence of SEQ ID NO:1. In certain embodiments, the hexon polypeptides comprise a hexon hypervariable regions-encompassing polypeptide having the amino acid sequence of SEQ ID NO:1. In preferred embodiments, the hexon polypeptide or the functional derivative thereof comprises the amino acid sequence of a BLY6 hexon polypeptide (SEQ ID NO:2) or an amino acid sequence which is at least 95% identical over its entire length to the amino acid sequence of SEQ ID NO:2. In certain embodiments, the hexon polypeptide or functional derivative thereof comprises an amino acid sequence which is at least 95%, at least 96%, at least 97%, at least 98%, or at least 99% identical over its entire length to the amino acid sequence of SEQ ID NO:2.

[0060] In preferred embodiments, the isolated nucleic acid sequences encode fiber polypeptides or a functional derivative thereof. The fiber polypeptide can, for example, comprise at least one of a fiber knob polypeptide comprising the amino acid sequence of SEQ ID NO:10; a fiber shaft polypeptide comprising the amino acid sequence of SEQ ID NO:11; and a fiber tail polypeptide comprising the amino acid sequence of SEQ ID NO:12. In preferred embodiments, the fiber polypeptide or a functional derivative thereof comprise the amino acid sequence of a BLY6 fiber polypeptide (SEQ ID NO:3) or an amino acid sequence which is at least 95% identical over its entire length to the amino acid sequence of SEQ ID NO:3.

[0061] In preferred embodiments, provided is an isolated nucleic acid comprising a hexon nucleic acid sequence encoding at least one of the hexon polypeptides disclosed herein and a nucleic acid sequence encoding at least one of the fiber polypeptides disclosed herein.

[0062] In preferred embodiments, provided are vectors, preferably adenoviral vectors, comprising at least one of an isolated hexon nucleic acid sequence and/or an isolated fiber nucleic acid sequence according to embodiments of the invention. The adenoviral vectors can, for example, comprise at least one transgene; and a nucleic acid sequence encoding a hexon polypeptide and/or a fiber polypeptide, wherein the

hexon polypeptide comprises a polypeptide comprising a hexon hypervariable regions-encompassing polypeptide disclosed herein and the fiber polypeptide comprises a fiber polypeptide described herein.

5 [0063] Typically, an adenoviral vector of the invention comprises the entire recombinant adenoviral genome on, e.g., a plasmid, cosmid, or baculovirus vector. The nucleic acid molecules of the invention can be in the form of RNA or in the form of DNA obtained by cloning or produced synthetically. The DNA can be double-stranded or single-stranded.

10 [0064] One of ordinary skill will recognize that elements derived from multiple serotypes can be combined in a single adenoviral vector, for example human or simian adenovirus. Thus, a chimeric adenovirus vector that combines desirable properties from different serotypes can be produced. Thus, in some embodiments, a chimeric adenovirus vector of the invention could combine the absence of pre-existing immunity of the simian hexon and/or fiber polypeptide sequences with the
15 high level antigen delivery and presentation capacity of an existing adenoviral vectors, such as rAd4, rAd5, rAd26 or rAd35.

[0065] Advantages of adenoviral vectors for use as vaccines include ease of manipulation, good manufacturability at large scale, and an excellent safety record based on many years of experience in research, development, manufacturing and
20 clinical trials with numerous adenoviral vectors that have been reported. Adenoviral vectors that are used as vaccines generally provide a good immune response to the transgene-encoded protein, including a cellular immune response. An adenoviral vector according to the invention can be based on any type of adenovirus, and in certain embodiments is a human adenovirus, which can be of any group or serotype.
25 In preferred embodiments, the recombinant adenovirus is based upon a human adenovirus from group A, B, C, D, E, F or G. In other preferred embodiments, the recombinant adenovirus is based upon a human adenovirus serotype 5, 11, 26, 34, 35, 48, 49, or 50. In other embodiments, it is a simian adenovirus, such as chimpanzee or gorilla adenovirus, which can be of any serotype. In certain embodiments, the
30 recombinant adenovirus is based upon chimpanzee adenovirus type 1, 3, 7, 8, 21, 22, 23, 24, 25, 26, 27.1, 28.1, 29, 30, 31.1, 32, 33, 34, 35.1, 36, 37.2, 39, 40.1, 41.1, 42.1, 43, 44, 45, 46, 48, 49, 50, 67, or SA7P.

[0066] In a more preferred embodiment, the chimpanzee adenovirus vector of the second composition is ChAdV3. Recombinant chimpanzee adenovirus serotype 3

(ChAd3 or cAd3) is a subgroup C adenovirus with properties similar to those of human adenovirus serotype 5 (Ad5). ChAd3 has been shown to be safe and immunogenic in human studies evaluating candidate vaccines for hepatitis C virus (HCV) (Barnes E, et al. 2012 Science translational medicine 4: 115ra1). It was reported that ChAd3-based vaccines were capable of inducing an immune response comparable to a human Ad5 vectored vaccine. See, e.g., Peruzzi D, et al. 2009 Vaccine 27: 1293-300 and Quinn KM, et al. 2013 J Immunol 190: 2720-35; WO 2005/071093; WO2011/0130627, etc.

[0067] Adenoviral vectors, methods for construction thereof and methods for propagating thereof, are well known in the art and are described in, for example, U.S. Pat. Nos. 5,559,099, 5,837,511, 5,846,782, 5,851,806, 5,994,106, 5,994,128, 5,965,541, 5,981,225, 6,040,174, 6,020,191, and 6,113,913, and Thomas Shenk, "Adenoviridae and their Replication", M. S. Horwitz, "Adenoviruses", Chapters 67 and 68, respectively, in *Virology*, B. N. Fields *et al.*, eds., 3d ed., Raven Press, Ltd., New York (1996), and other references mentioned herein. Typically, construction of adenoviral vectors involves the use of standard molecular biological techniques, such as those described in, for example, Sambrook *et al.*, *Molecular Cloning, a Laboratory Manual*, 2d ed., Cold Spring Harbor Press, Cold Spring Harbor, N.Y. (1989), Watson *et al.*, *Recombinant DNA*, 2d ed., Scientific American Books (1992), and Ausubel *et al.*, *Current Protocols in Molecular Biology*, Wiley Interscience Publishers, NY (1995), and other references mentioned herein.

[0068] In certain embodiments, the adenoviral vector comprises an E1 deletion and/or an E3 deletion. An E1 or E3 deletion can, for example, include a complete deletion of the gene or a partial deletion, which renders the E1 or E3 gene product functionally defective. Thus, in certain embodiments, the adenovirus is replication deficient, e.g. because it contains a deletion in the E1 region of the genome. As known to the skilled person, in case of deletions of essential regions from the adenovirus genome, the functions encoded by these regions have to be provided in trans, preferably by the producer cell, i.e. when parts or whole of E1, E2 and/or E4 regions are deleted from the adenovirus, these have to be present in the producer cell, for instance integrated in the genome thereof, or in the form of so-called helper adenovirus or helper plasmids. The adenovirus may also have a deletion in the E3 region, which is dispensable for replication, and hence such a deletion does not have to be complemented. One or more of the E1, E2, E3 and E4 regions can also be

inactivated by other means, such as by inserting a transgene of interest (usually linked to a promoter) into the regions to be inactivated.

[0069] A producer cell (sometimes also referred to in the art and herein as ‘packaging cell’ or ‘complementing cell’) that can be used can be any producer cell wherein a desired adenovirus can be propagated. For example, the propagation of recombinant adenovirus vectors is done in producer cells that complement deficiencies in the adenovirus. Such producer cells preferably have in their genome at least an adenovirus E1 sequence, and thereby are capable of complementing recombinant adenoviruses with a deletion in the E1 region. Any E1-complementing producer cell can be used, such as human retina cells immortalized by E1, e.g. 911 or PER.C6 cells (see US patent 5,994,128), E1-transformed amniocytes (See EP patent 1230354), E1-transformed A549 cells (see e.g. WO 98/39411, US patent 5,891,690), GH329:HeLa (Gao *et al.*, 2000, *Hum Gene Ther* 11: 213-19), 293, and the like. In certain embodiments, the producer cells are for instance HEK293 cells, or PER.C6 cells, or 911 cells, or IT293SF cells, and the like. Production of adenoviral vectors in producer cells is reviewed in (Kovesdi *et al.*, 2010, *Viruses* 2: 1681-703).

[0070] In certain embodiments, the adenoviral vector is a chimeric adenoviral vector comprising one or more human adenoviral nucleic acid sequences. The human adenoviral nucleic acids can, for example, be selected from human adenovirus-4 (Ad-4), human adenovirus-5 (Ad-5), human adenovirus-26 (Ad-26), or human adenovirus-35 (Ad-35). In certain embodiments, an E1-deficient adenoviral vector comprises the E4-orf6 coding sequence of an adenovirus of human Ad5. This allows propagation of such adenoviruses in well-known complementing cell lines that express the E1 genes of Ad5, such as for example 293 cells or PER.C6 cells (see, e.g. Fallaux *et al.*, 1998, *Hum Gene Ther* 9: 1909-17, Havenga *et al.*, 2006, *J Gen Virol* 87: 2135-43; WO 03/104467, incorporated in their entirety by reference herein).

[0071] In certain embodiments, the adenoviral vector comprises a transgene. A “transgene” refers to a heterologous nucleic acid, which is a nucleic acid that is not naturally present in the vector, and according to the present invention the transgene can encode an antigenic gene product or antigenic protein that elicits an immune response in the subject. The transgene can, for example, be introduced into the vector by standard molecular biology techniques. The transgene can, for example, be cloned into a deleted E1 or E3 region of an adenoviral vector, or in the region between the E4 region and the rITR. A transgene is generally operably linked to expression control

sequences. In preferred embodiments, the transgene is inserted at a transgene insertion site.

[0072] If required, the nucleic acid sequences encoding hexon and/or fiber polypeptides according to embodiments of the invention, and/or the transgene can be codon- optimized to ensure proper expression in the treated host (e.g., human). Codon-optimization is a technology widely applied in the art.

[0073] The transgene can be under the control of (i.e., operably linked to) an adenovirus-derived promoter (e.g., the Major Late Promoter) or can be under the control of a heterologous promoter. Examples of suitable heterologous promoters include the CMV promoter and the RSV promoter. Preferably, the promoter is located upstream of the heterologous gene of interest within an expression cassette.

[0074] In preferred embodiments, the adenoviral vector comprises a nucleic acid sequence of SEQ ID NO:13 or SEQ ID NO:14.

15 Immunogenic compositions

[0075] Immunogenic compositions are compositions comprising an immunologically effective amount of purified or partially purified human or simian (e.g., gorilla) adenoviral vectors for use in the invention. Said compositions can be formulated as a vaccine (also referred to as an “immunogenic composition”) according to methods well known in the art. Such compositions can include adjuvants to enhance immune responses. The optimal ratios of each component in the formulation can be determined by techniques well known to those skilled in the art in view of the present disclosure.

[0076] The immunogenic compositions according to embodiments of the present invention can be made using methods known to those of skill in the art in view of the present disclosure. Liquid pharmaceutical compositions generally include a liquid carrier such as water, petroleum, animal or vegetable oils, mineral oil or synthetic oil. Physiological saline solution, dextrose or other saccharide solution or glycols such as ethylene glycol, propylene glycol or polyethylene glycol can be included.

[0077] The immunogenic compositions useful in the invention can comprise adjuvants. Adjuvants suitable for co-administration in accordance with the invention should be ones that are potentially safe, well tolerated and effective in people including QS-21, Detox-PC, MPL-SE, MoGM-CSF, TiterMax-G, CRL- 1005,

GERBU, TERamide, PSC97B, Adjumer, PG-026, GSK-I, AS01, AS03, AS04, AS15, GcMAF, B-aletine, MPC-026, Adjuvax, CpG ODN, Betafectin, Alum, and MF59.

- [0078] Other adjuvants that can be administered include lectins, growth factors, cytokines and lymphokines such as alpha-interferon, gamma interferon, platelet derived growth factor (PDGF), granulocyte-colony stimulating factor (gCSF), granulocyte macrophage colony stimulating factor (gMCSF), tumor necrosis factor (TNF), epidermal growth factor (EGF), IL-1, IL-2, IL-4, IL-6, IL-8, IL-10, and IL-12 or encoding nucleic acids therefore.
- [0079] The compositions of the invention can comprise a pharmaceutically acceptable excipient, carrier, buffer, stabilizer or other materials well known to those skilled in the art. Such materials should be non-toxic and should not interfere with the efficacy of the active ingredient. The precise nature of the carrier or other material can depend on the route of administration, e.g., intramuscular, subcutaneous, oral, intravenous, cutaneous, intramucosal (e.g., gut), intranasal or intraperitoneal routes.

Method for Inducing Protective Immunity

- [0080] Another general aspect of the invention relates to a method of inducing an immune response in a subject in need thereof. The methods can, for example, comprise administering to the subject a vaccine comprising an adenoviral vector described herein and a pharmaceutically acceptable carrier. Also provided herein are methods of producing a vaccine. The methods comprise combining an adenoviral vector described herein with a pharmaceutically acceptable carrier.
- [0081] Any of the immunogenic compositions according to embodiments of the invention, including but not limited to those described herein, can be used in methods of the invention as a vaccine.
- [0082] Administration of the immunogenic compositions/vaccines comprising the vectors is typically intramuscular or subcutaneous. However other modes of administration such as intravenous, cutaneous, intradermal or nasal can be envisaged as well. Intramuscular administration of the immunogenic compositions can be achieved by using a needle to inject a suspension of the adenovirus vector. An alternative is the use of a needleless injection device to administer the composition (using, e.g., BiojectorTM) or a freeze-dried powder containing the vaccine.

[0083] For intravenous, cutaneous or subcutaneous injection, or injection at the site of affliction, the vector will be in the form of a parenterally acceptable aqueous solution which is pyrogen-free and has suitable pH, isotonicity and stability. Those of skill in the art are well able to prepare suitable solutions using, for example, isotonic vehicles such as Sodium Chloride Injection, Ringer's Injection, Lactated Ringer's Injection. Preservatives, stabilizers, buffers, antioxidants and/or other additives can be included, as required. A slow-release formulation can also be employed.

[0084] Typically, administration will have a prophylactic aim to generate an immune response against an antigen of interest (e.g., a bacterial, viral, parasitic, and/or fungal pathogen) before infection or development of symptoms. Diseases and disorders that can be treated or prevented in accordance with the invention include those in which an immune response can play a protective or therapeutic role. In other embodiments, the adenovirus vectors can be administered for post-exposure prophylactics.

[0085] The immunogenic compositions containing the human or simian (e.g., gorilla) adenovirus vectors are administered to a subject, giving rise to an immune response to the antigen of interest in the subject. An amount of a composition sufficient to induce a detectable immune response is defined to be an "immunologically effective dose" or an "effective amount" of the composition. The immunogenic compositions of the invention can induce a humoral as well as a cell-mediated immune response. In a typical embodiment the immune response is a protective immune response.

[0086] The actual amount administered, and rate and time-course of administration, will depend on the nature and severity of what is being treated. Prescription of treatment, e.g., decisions on dosage etc., is within the responsibility of general practitioners and other medical doctors, or in a veterinary context a veterinarian, and typically takes account of the disorder to be treated, the condition of the individual patient, the site of delivery, the method of administration and other factors known to practitioners. Examples of the techniques and protocols mentioned above can be found in Remington's Pharmaceutical Sciences, 16th edition, Osol, A. ed., 1980.

[0087] Following production of adenovirus vectors and optional formulation of such particles into compositions, the vectors can be administered to an individual, particularly human or other primate. Administration can be to humans, or another

mammal, e.g., mouse, rat, hamster, guinea pig, rabbit, sheep, goat, pig, horse, cow, donkey, monkey, dog or cat. Delivery to a non-human mammal need not be for a therapeutic purpose, but can be for use in an experimental context, for instance in investigation of mechanisms of immune responses to the adenovirus vectors.

- 5 [0088] In one exemplary regimen, the adenoviral vector is administered (e.g., intramuscularly) in a volume ranging between about 100 μ l to about 10 ml containing concentrations of about 10^4 to 10^{12} virus particles/ml. Preferably, the adenoviral vector is administered in a volume ranging between 0.1 and 2.0 ml. For example, the adenoviral vector can be administered with 100 μ l, 500 μ l, 1 ml, 2 ml. More
- 10 preferably the adenoviral vector is administered in a volume of 0.5 ml. Optionally, the adenoviral vector can be administered in a concentration of about 10^7 vp/ml, 10^8 vp/ml, 10^9 vp/ml, 10^{10} vp/ml, 5×10^{10} vp/ml, 10^{11} vp/ml, or 10^{12} vp/ml. Typically, the adenoviral vector is administered in an amount of about 10^9 to about 10^{12} viral particles (vp) to a human subject during one administration, more typically in an
- 15 amount of about 10^{10} to about 10^{12} vp.

[0089] The initial vaccination can be followed by a boost or a kick from a vaccine/composition comprising the same adenoviral vector encoding an antigen of interest or a vaccine/composition comprising a different adenoviral vector encoding the same antigen of interest.

- 20 [0090] The composition can, if desired, be presented in a kit, pack or dispenser, which can contain one or more unit dosage forms containing the active ingredient. The kit, for example, can comprise metal or plastic foil, such as a blister pack. The kit, pack, or dispenser can be accompanied by instructions for administration.

- [0091] The compositions of the invention can be administered alone or in
- 25 combination with other treatments, either simultaneously or sequentially dependent upon the condition to be treated.

EMBODIMENTS

[0092] The invention provides also the following non-limiting embodiments.

- 30 [0093] Embodiment 1 is an isolated nucleic acid sequence encoding a hexon polypeptide or a functional derivative thereof comprising a hexon hypervariable regions-encompassing polypeptide having the amino acid sequence of SEQ ID NO:1 or an amino acid sequence which is at least 95% identical over its entire length to the amino acid sequence of SEQ ID NO:1.

[0094] Embodiment 2 is an isolated nucleic acid sequence encoding a hexon polypeptide comprising a hexon hypervariable regions-encompassing polypeptide having the amino acid sequence of SEQ ID NO:1.

5 [0095] Embodiment 3 is the isolated nucleic acid sequence of any one of embodiments 1-2, wherein the hexon polypeptide or the functional derivative thereof comprises the amino acid sequence of a BLY6 hexon polypeptide (SEQ ID NO:2) or an amino acid sequence which is at least 95% identical over its entire length to the amino acid sequence of SEQ ID NO:2.

10 [0096] Embodiment 4 is an isolated nucleic acid sequence comprising any one of the nucleic acid sequences of embodiments 1-3, and further comprising an isolated nucleic acid sequence encoding a fiber polypeptide or a functional derivative thereof.

[0097] Embodiment 5 is the isolated nucleic acid sequence of embodiment 4, wherein the fiber polypeptide comprises a fiber knob polypeptide sequence comprising the amino acid sequence of SEQ ID NO:10.

15 [0098] Embodiment 6 is the isolated nucleic acid sequence of embodiment 4, wherein the fiber polypeptide comprises a fiber shaft polypeptide sequence comprising the amino acid sequence of SEQ ID NO:11.

20 [0099] Embodiment 7 is the isolated nucleic acid sequence of embodiment 4, wherein the fiber polypeptide comprises a fiber tail polypeptide sequence comprising the amino acid sequence of SEQ ID NO:12.

[00100] Embodiment 8 is the isolated nucleic acid sequence of any one of embodiments 4-7, wherein the fiber polypeptide or a functional derivative thereof comprises the amino acid sequence of a BLY6 fiber polypeptide (SEQ ID NO:3) or an amino acid sequence which is at least 95% identical over its entire length to the amino acid sequence of SEQ ID NO:3.

[00101] Embodiment 9 is an isolated nucleic acid sequence encoding a fiber polypeptide comprising a fiber knob polypeptide sequence, wherein the fiber knob polypeptide sequence comprises the amino acid sequence of SEQ ID NO:10.

30 [00102] Embodiment 10 is an isolated nucleic acid sequence encoding a fiber polypeptide comprising a fiber shaft polypeptide sequence, wherein the fiber shaft polypeptide sequence comprises the amino acid sequence of SEQ ID NO:11.

[00103] Embodiment 11 is an isolated nucleic acid sequence encoding a fiber polypeptide comprising a fiber tail polypeptide sequence, wherein the fiber tail polypeptide sequence comprises the amino acid sequence of SEQ ID NO:12.

[00104] Embodiment 12 is the isolated nucleic acid sequence of any one of embodiments 9-11, wherein the fiber polypeptide comprises the amino acid sequence of a BLY6 fiber polypeptide (SEQ ID NO:3).

5 [00105] Embodiment 13 is a vector comprising the nucleic acid of any of embodiments 1-12.

[00106] Embodiment 14 is the vector of embodiment 13, being an adenoviral vector, and further comprising a transgene.

[00107] Embodiment 15 is a recombinant cell comprising the vector of embodiment 13 or 14.

10 [00108] Embodiment 16 is a method of producing a vector, comprising; (a) growing the recombinant cell of embodiment 15 under conditions for production of the vector; and (b) isolating the vector from the recombinant cell.

[00109] Embodiment 17 is an immunogenic composition comprising the vector of embodiment 14.

15 [00110] Embodiment 18 is a method of inducing an immune response in a subject in need thereof, comprising administering to the subject the immunogenic composition of embodiment 17.

[00111] Embodiment 19 is an adenoviral vector comprising (a) at least one transgene; and (b) a nucleic acid sequence encoding a hexon polypeptide comprising a
20 hexon hypervariable regions-encompassing polypeptide having the amino acid sequence of SEQ ID NO:1.

[00112] Embodiment 20 is an adenoviral vector comprising (a) at least one transgene; and (b) a nucleic acid sequence encoding a hexon polypeptide comprising the amino acid sequence of a BLY6 hexon polypeptide (SEQ ID NO:2).

25 [00113] Embodiment 21 is an adenoviral vector comprising (a) at least one transgene; a nucleic acid sequence encoding a hexon polypeptide comprising the amino acid sequence of a BLY6 hexon polypeptide (SEQ ID NO:2); and (c) a nucleic acid sequence encoding a fiber polypeptide comprising the amino acid sequence of a BLY6 fiber polypeptide (SEQ ID NO:3).

30

EXAMPLES

Example 1: Generation of E1- and E3-deleted vectors based on novel adenovirus isolate BLY6

5 [00114] A novel gorilla adenovirus isolate, BLY6 (also designated JAd1-WT), was identified and sequenced. This gorilla adenovirus isolate was found to phylogenetically belong to the human adenovirus species E (HAdV-E). The full genome nucleotide sequence of BLY6 was determined to be SEQ ID NO:5.

10 Description of the single plasmid system used for the generation of BLY6-based Ad vectors

[00115] pBLY6.dE1.dE3 (SEQ ID NO:8; Figure 5) and pBLY6.dE1.dE3.5IXP (SEQ ID NO:9; Figure 6) are plasmids carrying full-length, E1- and E3-deleted adenoviral vector genomes based on isolate BLY6. The Ad vector genome sequences contained within these plasmids are set forth in SEQ ID NO:13 and SEQ ID NO:14, 15 respectively. Within each of these plasmids, the adenoviral vector genome is flanked by two SmaI restriction enzyme sites (i.e. one SmaI site is located at either end of the vector genome). These SmaI sites are meant to facilitate excision of the Ad vector genome from the plasmid backbone prior to viral rescue by transfection of suitable E1-complementing cells (such as HEK293, 911, and PER.C6 cells). The Ad vector 20 genomes comprised by these plasmids further carry certain restriction enzyme sites introduced in the location of the E1 deletion, in the E3 deletion, and adjacent to the right inverted terminal repeat (RITR). These restriction enzyme sites were selected to be unique in the context of the complete Ad genome plasmids. They represent “transgene insertion sites” that allow for the facile construction, by standard 25 molecular cloning techniques, of Ad vectors carrying one or more transgene expression cassettes inserted at any of said respective locations or any combinations thereof. Ad vector designs and plasmid constructions are described in more detail in the sections below.

30 BLY6-based Ad vector genome design

[00116] BLY6-based Ad vector genomes were each designed to comprise an E1 deletion, an E3 deletion, different transgene insertion sites, and a replacement of the native E4 open reading frame (orf) 6 and orf6/7 with that of human adenovirus-5 (HAdV-5). The E1 region of each adenovirus was deleted and replaced with a

transgene insertion site comprising an AsiSI restriction enzyme site sequence. The E3 region of each adenovirus was deleted and replaced with a transgene insertion site comprising an FseI restriction enzyme site sequence. Another transgene insertion site was created by insertion of a PacI restriction enzyme site sequence adjacent to the right inverted terminal repeat (ITR) of each adenovirus. The BLY6 sequences comprising E4 orf6 and orf6/7 coding sequences were replaced by SEQ ID NO:6. This replacing sequence comprises the E4 orf6 and orf6/7 coding sequences of human adenovirus-5 (HAdV-5) (base pairs 32914-34077 of GenBank sequence AC_000008).

[00117] Two types of E1 region deletions were designed and constructed. The BLY6-based Ad vector genome comprised by pBLY6.dE1.dE3 carries an E1 region deletion corresponding to removal of nucleotides 453 to 3016 of SEQ ID NO:5. By contrast, the BLY6-based Ad vector genome comprised by pBLY6.dE1.dE3.5IXP carries a larger E1 region-comprising sequence deletion that removes all the E1 coding sequences of BLY6 (i.e. nucleotides 453 to 3366 of SEQ ID NO:5).

Furthermore, this latter Ad vector genome was additionally designed to carry a replacement of the non-coding sequence stretch between E1B 55K and pIX coding sequences by that of HAdV-5 (i.e. sequences corresponding to nucleotides 3367 to 3454 of SEQ ID NO:5 were replaced by nucleotides 3510-3608 of GenBank AC_000008 (i.e. by SEQ ID NO:7)).

Construction of single plasmids comprising BLY6-based Ad vector genomes

[00118] pBLY6.dE1.dE3 (SEQ ID NO:8) was constructed by several steps of gene synthesis (performed by GenScript) and standard molecular cloning procedures. First, a 3586 bp DNA fragment (SEQ ID NO:15) containing the left end of the desired Ad vector genome (i.e. harboring the aforementioned E1 deletion) was synthesized and ligated, as an MfeI-NdeI restriction fragment, into EcoRI- and NdeI-digested pBR322 (GenBank accession number - J01749.1), leading to BLY6 intermediate plasmid 1. Second, A 4138 bp fragment (SEQ ID NO:16) containing the right end of the desired Ad vector genome (i.e. harboring the aforementioned E3 deletion, partial E4 sequence replacement, and transgene insertion site adjacent to the rITR) was synthesized and ligated, as a BamHI-NdeI restriction fragment, into BamHI- and NdeI-digested BLY6 intermediate plasmid 1, leading to BLY6 intermediate plasmid 2. Third, a 4563 bp fragment (SEQ ID NO:17) containing a middle Ad vector genome fragment was synthesized and ligated as a BamHI-MfeI restriction fragment into BamHI- and MfeI-

digested BLY6 intermediate plasmid 2, leading to BLY6 intermediate plasmid 3 (SEQ ID NO:18). Fourth, the 18987 bp BsrGI-BsrGI restriction fragment of the BLY6 viral genome (SEQ ID NO:5) was ligated into BsrGI-digested BLY6 intermediate plasmid 3, leading to the final plasmid pBLY6.dE1.dE3 (SEQ ID NO:8).

- 5 [00119] pBLY6.dE1.dE3.5IXP (SEQ ID NO:9) was constructed in the same way as pBLY6.dE1.dE3 except that abovementioned BLY6 intermediate plasmid 3 (SEQ ID NO:18) was first modified to contain the desired E1 deletion and Ad5 pIX promoter insertion. This was done by synthesis of a 638 bp fragment (SEQ ID NO:19) that was subsequently ligated as an AsiSI-AgeI restriction fragment into AsiSI- and AgeI-
- 10 digested BLY6 intermediate plasmid 3.
- [00120] pBLY6.FLuc (SEQ ID NO:20) and pBLY6.RSVF-2A-GLuc (SEQ ID NO:21) are pBLY6.dE1.dE3-derived plasmids that each harbor a BLY6-based Ad vector genome equipped with a transgene expression cassette inserted at the location of the E1 deletion. The Ad vector genome sequences carried within these plasmids are set forth in SEQ ID NO:22 and SEQ ID NO:23, respectively. pBLY6.FLuc carries a transgene expression cassette for firefly luciferase (FLuc). This cassette is driven by the cytomegalovirus major immediate early promoter (i.e. the “CMV promoter”) and contains an SV40-derived polyadenylation signal. pBLY6.RSVF-2A-GLuc carries a transgene expression cassette for “RSV-FA₂-2A-GLuc” (RSVF-2A-GLuc), which is a
- 15 20 chimeric protein composed of the respiratory syncytial virus strain A2 fusion glycoprotein, a foot-and-mouth-disease virus 2A peptide, and Gaussia luciferase (GLuc). Like the Fluc cassette, this cassette is driven a CMV promoter and carries an SV40 polyadenylation signal. In addition, this cassette contains within its 5’untranslated region a sequence comprising intron 2 of the human Apolipoprotein A1 gene. The Fluc and RSVF-2A-GLuc expression cassettes were each constructed by several standard gene synthesis and molecular cloning steps after which they were ligated into the unique AsiSI restriction enzyme site of pBLY6.dE1.dE3, generating pBLY6.FLuc and pBLY6.RSVF-2A-GLuc, respectively.

30 Generation and production of BLY6-based adenoviral vectors

[00121] Adenoviral vectors BLY6.FLuc (also designated JAd1NVT003) and BLY6.RSVF-2A-GLuc (also designated JAd1NVT001), which respectively comprise adenoviral vector genome sequences SEQ ID NO:22 and SEQ ID NO:23, were generated by transfection of the corresponding Ad vector genome plasmids (i.e.

pBLY6.Fluc and pBLY6.RSVF-2A-Gluc) into E1-complementing PER.C6 cells. Prior to transfection into PER.C6 cells, which were grown as adherent cultures in Dulbecco's modified Eagle's medium (DMEM) supplemented with 10% fetal bovine serum (FBS) and 10 mM MgCl₂, the Ad vector genome plasmids were digested with
5 SwaI to release the respective adenoviral vector genomes from the plasmid. The transfections were performed according to standard procedures using Lipofectamine transfection reagent (Invitrogen; Carlsbad, CA). After harvesting of the viral rescue transfections, the viruses were further amplified by several successive infection rounds on PER.C6 cell cultures. The viruses were purified from crude viral harvests
10 using a two-step cesium chloride (CsCl) density gradient ultracentrifugation procedure as described before (Havenga et al., "Novel replication-incompetent adenoviral B-group vectors: high vector stability and yield in PER.C6 cells," J. Gen. Virol. 87(8):2135-43 (2006)). Viral particle (VP) titers were measured by a spectrophotometry-based procedure described previously (Maizel et al., "The
15 polypeptides of adenovirus: I. Evidence for multiple protein components in the virion and a comparison of types 2, 7A, and 12," Virology, 36(1):115-25 (1968)).

Cellular and humoral immune responses induced by novel adenoviral vectors

[00122] Examples 2 and 3 describe experiments performed to assess the
20 immunogenicity of the novel BLY6-based adenoviral vectors generated herein. In these experiments, the novel vectors were assessed for their abilities to induce humoral and cellular immune responses against vector-encoded (model) antigens in mice after intramuscular immunization. The vectors were tested using two different antigens: Firefly luciferase (FLuc) and RSV-F_{A2}-2A-GLuc (RSVF-2A-GLuc). RSVF-
25 2A-GLuc is a chimeric protein composed of the respiratory syncytial virus strain A2 fusion glycoprotein, a foot-and-mouth-disease virus 2A peptide, and Gaussia luciferase (GLuc). Each vector was compared side-by-side with a benchmark vector based on human adenovirus type 26 (HAdV-26, also referred to herein as Ad26) or on human adenovirus type 49 (HAdV-49, also referred to herein as Ad49) carrying the
30 same antigen-encoding transgene cassette. Immune responses against the respective antigens were measured using well-known immunological assays, such as enzyme-linked immunospot assay (ELISPOT), enzyme-linked immunosorbent assay (ELISA), and, in case of the RSVF-2A-GLuc antigen, a respiratory syncytial virus neutralization assay (VNA).

Example 2: Cellular immune responses induced by BLY6.FLuc

[00123] To evaluate the cellular immunogenicity of the novel adenoviral vector BLY6, Balb/C mice were immunized by intra-muscular injection with Ad26.FLuc, Ad49.FLuc (positive controls), a BLY6 vector expressing firefly luciferase (BLY6.FLuc), or with an adenovector not encoding a transgene (Ad26 empty). Two vector doses were tested for administration: 10^9 and 10^{10} viral particles (vp) per mouse. Two weeks after immunization, mice were sacrificed and splenocytes were stimulated overnight with a 15mer overlapping FLuc peptide pool (experimental set up Figure 1A). Cellular immune responses were determined by *ex-vivo* ELISPOT assay measuring the relative number of IFN- γ -secreting cells (Figure 1B). The results show that at the higher-dose immunization (10^{10}), the cellular immune responses induced by BLY6 were about as high as the response seen for Ad26.FLuc. By contrast, at the lower-dose immunization (10^9), BLY6.FLuc gave a stronger response than Ad26.FLuc.

[00124] Overall, the cellular immune responses induced by the FLuc-expressing recombinant BLY6 adenoviral vector of the invention clearly indicate potent immunogenicity of this vector in mice.

Example 3: Cellular and humoral immune responses induced by BLY6.RSVF-2A-GLuc

[00125] The immunogenicity of novel adenoviral vector BLY6 was further evaluated using RSV-F_{A2}-2A-GLuc (RSVF-2A-GLuc) as a vector-encoded (model) vaccine antigen. Balb/C mice were immunized intramuscularly with Ad26.RSVF-2A-GLuc (positive control) or BLY6.RSVF-2A-GLuc (both at 10^8 , 10^9 and 10^{10} viral particles per mouse), or with Ad26.FLuc or BLY6.FLuc (both at 10^{10} viral particles per mouse). Mice were sacrificed after eight weeks and blood samples and splenocytes were collected (Figure 2A). Different immune parameters were assessed as described below.

[00126] A virus neutralization assay was performed in order to assess the capacity of BLY6.RSVF-2A-GLuc to elicit respiratory syncytial virus-neutralizing-antibodies. Figure 2B depicts the respiratory syncytial virus strain A2 (RSV A2) VNA titers measured for sera samples collected eight weeks after immunization. Each dot represents one mouse; the bars represent the group mean and the dotted line

corresponds to the lower limit of quantification (LLOQ = 6,88; mean endpoint titer of linearity samples). The results show that the 10^{10} vp-dose immunizations with BLY6.RSVF-2A-GLuc gave rise to higher RSV A2 neutralization titers as those found for the benchmark Ad26 vector encoding the same antigen. Titers against BLY6.RSVF-2A-GLuc were detected mainly at the highest dose used for immunization, 10^{10} vp. As expected, no RSV A2 specific responses were detected against the adenovectors encoding Firefly luciferase.

[00127] Induction of cellular immunity against the vector-encoded antigen was evaluated by an RSV- F_{A2} -specific ELISPOT assay. To this end, eight weeks after immunization, splenocytes from immunized mice were isolated and stimulated overnight with 15mer overlapping peptides spanning the RSV- F_{A2} protein and cellular immune responses were determined by *ex-vivo* ELISPOT assay measuring the relative number of IFN- γ -secreting cells. The data show that the antigen-specific cellular immune responses elicited by the novel vector BLY6 encoding RSVF-2A-GLuc were dose-dependent and, per dose, similar in magnitude to those induced by the benchmark vector, Ad26.RSVF-2A-GLuc (Figure 2C). As expected, no RSVF- F_{A2} -specific responses were measured from splenocytes of mice immunized with adenovectors encoding Firefly luciferase.

[00128] The ability of the RSVF-2A-GLuc-expressing vectors to elicit RSV- F_{A2} -specific IgG antibodies was assessed by ELISA. Sera collected 8 weeks post-immunization from the mice immunized with Ad26 (positive control) and BLY6 vectors expressing RSVF-2A-GLuc transgene or Firefly luciferase (control) were tested in an anti-RSV F_{A2} IgG antibody ELISA. Specifically, this ELISA detects IgG antibodies capable of binding to a recombinant stable pre-fusion RSV- F_{A2} protein (pre-RSV-F). The results show that BLY6.RSVF-2A-GLuc dose-dependently elicited higher pre-RSV-F-specific IgG antibody titers than those induced by Ad26.RSVF-2A-GLuc (Figure 2D). As expected, no RSV- F_{A2} -specific antibody titers were detected in sera from mice immunized with vectors encoding Firefly luciferase only.

[00129] Altogether, the data show that the BLY6 vector induced potent cellular and humoral immune responses against the encoded antigens, similar to or higher than those induced by the benchmark vector based on HAdV-26. These immune responses clearly indicate potent immunogenicity of the BLY6 vector in mice.

Example 4: Evaluation of serological cross-neutralization among novel and existing adenoviral vectors

For their potential utility as new adenoviral vaccine vectors, the novel BLY6 adenoviral vectors created herein would preferably be serologically distinct from existing adenoviral vectors currently already in development as vaccine vectors, such as vectors based on human adenovirus serotypes HAdV-5 and HAdV-35. Therefore, cross-neutralization tests were performed among the novel BLY6 adenoviral vectors and several existing vectors based on HAdV-4, HAdV-5, HAdV-26, HAdV-35 and HAdV49. To this end, mice antisera, each raised against one of these adenoviral vectors, were tested against each of the different vectors in an adenovirus neutralization assay. The mice antisera used for this assay were collected from Balb/C mice, two or eight weeks after their immunization with 10^{10} vector particles per mouse. The adenovirus neutralization assay was carried out as described previously (Spangers et al 2003. J.Clin. Microbiol. 41:5046-5052). Briefly, starting from a 1:16 dilution, the sera were 2-fold serially diluted, then pre-mixed with the adenoviral vectors expressing firefly luciferase (FLuc), and subsequently incubated overnight with A549 cells (at multiplicity of infection of 500 virus particles per cell). Luciferase activity levels in infected cell lysates measured 24 hours post-infection represented vector infection efficiencies. Neutralization titers against a given vector were defined as the highest serum dilution capable of giving a 90% reduction of vector infection efficiency. The neutralization titers were arbitrarily divided into the following categories: <16 (no neutralization), 16 to 200, 200 to 2,000, and >2,000. The results show no major cross-neutralization among the vectors tested (Figure 3). There was only some slight, one-way cross-neutralization seen between vectors BLY6 and Ad26, with BLY6 antiserum displaying a neutralization titer against Ad26 of 16.12 (i.e. just above the lower limit of detection of 16) and Ad26 antiserum not showing a neutralization titer against BLY6. Thus, the new adenoviral vector BLY6 displayed no, or only very slight, cross-neutralization with the human adenoviral vectors included in the tested panel, i.e. Ad26, Ad35, Ad49, Ad5, and Ad4. Therefore, this vector could potentially be used in combination with one or more of these or other distinct adenoviral vectors in sequential immunizations, for example in the context of a heterologous prime-boost vaccination regimen or, alternatively or additionally, in the context of a series of two or more consecutive vaccination regimens against different diseases or antigens.

Example 5: Seroprevalence of novel adenoviral vectors in human populations

Important for their potential use as efficacious vaccine vectors is that the novel adenoviral vectors described herein are not hampered by high levels of pre-existing anti-vector humoral immunity in vaccine target populations. Therefore, the BLY6 vector was evaluated for its seroprevalence within 200 human cohort serum samples from adults, ages 18 to 55 years, living in the United States (US) and the European Union (EU). The vector was tested for neutralization by the human serum samples by performing a standard adenovirus neutralization assay as carried out in Example 3 and described previously (Spangers et al 2003. J.Clin. Microbiol. 41:5046-5052). Briefly, starting from a 1:16 dilution, the sera were 2-fold serially diluted, then pre-mixed with the adenoviral vectors expressing firefly luciferase (FLuc), and subsequently incubated overnight with A549 cells (at a multiplicity of infection of 500 virus particles per cell). Luciferase activity levels in infected cell lysates, measured 24 hours post-infection, represented vector infection efficiencies. Neutralization titers against a given vector were defined as the highest serum dilution capable of giving a 90% reduction of vector infection efficiency. The neutralization titers were arbitrarily divided into the following categories: <16 (no neutralization), 16 to 300, 300 to 1,000, 1000 to 4000 and >4000.

The results indicate that the BLY6 adenovirus vector has a considerably lower seroprevalence in the human subjects studied than the control Ad5 vector and benchmark Ad26 and Ad35 vectors (Figure 4). Moreover, the positive neutralization titers that were seen against the novel BLY6 vectors were generally quite low, mostly not higher than 300. By contrast, most of the positive neutralization titers found against Ad26 and Ad5 were higher than 300.

[00130] Altogether, the above data indicate that pre-existing humoral anti-vector immunity against BLY6 vectors can be considered to be low in the evaluated vaccine target populations, suggesting that these vectors have potential as efficacious vaccine vectors in these populations.

Example 6: Adenoviral vector productivity in suspension PER.C6 cells

[00131] Adenovirus vectors to be used in clinical trials and beyond need to be readily producible to high titers in a scalable, serum-free adenovirus production platform. Suspension-adapted PER.C6® cells, also referred to herein as suspension

PER.C6 cells or sPER.C6, represent such a platform as they have been shown to support large-scale manufacturing of adenoviral vectors in bioreactors, achieving large quantities of high-titer, clinical grade vector preparations, e.g. of E1-deleted vectors based on HAdV-26 or HAdV-35 (EP 2536829 B1, EP 2350268 B1).

- 5 [00132] As an initial assessment as to whether the novel vectors described herein would fit sPER.C6 cell-based production processes, small-scale vector productivity experiments were performed on sPER.C6 cells cultured in shaker flasks. These productivity experiments were carried out using the Fluc-encoding version of the novel Ad vector BLY6 described in Example 1. Taken along as a benchmark control
- 10 was the HAdV-26-based vector Ad26.Fluc. Suspension PER.C6 cell cultures, seeded into shaker flasks at a density of 1×10^6 cells/ml in a total volume of 10ml of PERMEXCIS® medium (available from Lonza) supplemented with 4 mM L-Glutamine (Lonza), were infected with the different vectors at different virus particle (VP)-to-cell ratios and then incubated for 4 days. The different VP-to-cell ratios used
- 15 for infection were 70, 150 and 900. Samples of the infected cell cultures were taken every day and VP titers were determined in these samples by a quantitative PCR (qPCR)-based protocol that employs primers and probe that are specific for the CMV promoter (which is present in all the vectors tested). This protocol entails a DNase treatment of the test samples prior to the qPCR to remove any free vector DNA (i.e.
- 20 vector genomes that are not packaged into viral particles).
- The productivity results obtained for the novel vector BLY6.Fluc are shown in Figure 8. BLY6.Fluc displayed higher VP titers than the benchmark control vector Ad26.Fluc at all VP-to-cell infection ratios and harvest time points tested. These results demonstrate good productivity of the novel BLY6 vector on a sPER.C6-based,
- 25 serum-free suspension cell culture model.

- Collectively, the studies of humoral and cellular immune responses induced by the novel recombinant BLY6-based adenoviral vectors of the invention, as presented above, clearly indicate potent immunogenicity of these vectors in mice. In addition, the
- 30 vectors demonstrated to induce no, or only very limited, cross-neutralizing antibody responses against certain existing adenoviral vaccine vector candidates (e.g. Ad26 and Ad35) or vice versa. Furthermore, the new vectors showed low seroprevalence in humans. Finally, the new vectors can be readily produced at high yields. The combination of low seroprevalence, potent immunogenicity and producibility

suggests that the novel adenoviral vectors of the invention can be useful as novel vaccine vector candidates against a variety of pathogens and may additionally have utility in gene therapy and/or diagnostics.

- 5 **[00133]** It will be appreciated by those skilled in the art that changes could be made to the embodiments described above without departing from the broad inventive concept thereof. It is understood, therefore, that this invention is not limited to the particular embodiments disclosed, but it is intended to cover modifications within the spirit and scope of the present invention as defined by the present description.