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Modified Vaccinia Ankara Virus Variant

The present invention provides an attenuated virus, which is derived from Modified Vaccinia Ankara virus and which is characterized by the loss of its capability to reproductively replicate in human cell lines. It further describes recombinant viruses derived from this virus and the use of the virus or its recombinants as medicament or vaccine. Additionally, a method is provided for inducing an immune response even in immuno-compromised patients, patients with pre-existing immunity to the vaccine virus or patients undergoing antiviral therapy.

Background of the invention

Modified Vaccinia Ankara (MVA) virus is related to Vaccinia virus, a member of the genera Orthopoxvirus in the family of Poxviridae. MVA has been generated by 516 serial passages on chicken embryo fibroblasts of the Ankara strain of vaccinia virus (CVA) (for review see Mayr, A., et al. Infection 3, 6-14 [1975]). As a consequence of these long-term passages the resulting MVA virus deleted about 31 kilobases of its genomic sequence and, therefore, was described as highly host cell restricted to avian cells (Meyer, H. et al., J. Gen. Virol. 72, 1031-1038 [1991]). It was shown, in a variety of animal models that the resulting MVA was significantly avirulent (Mayr, A. & Danner, K. [1978] Dev. Biol. Stand. 41: 225-34). Additionally, this MVA strain has been tested in clinical trials as vaccine to immunize

against the human smallpox disease (Mayr *et al.*, Zbl. Bakt. Hyg. I, Abt. Org. B 167, 375-390 [1987], Stickl *et al.*, Dtsch. med. Wschr. 99, 2386-2392 [1974]). These studies involved over 120,000 humans, including high risk patients, and proved that, compared to Vaccinia based vaccines, MVA had diminished virulence or infectiousness while it maintained good immunogenicity.

In the following decades MVA has been engineered to use it as viral vector for recombinant gene expression or as recombinant vaccine (Sutter, G. *et al.* [1994], Vaccine 12: 1032-40).

In this respect it is most astonishing that even though Mayr *et al.* demonstrated during the 1970s that MVA is highly attenuated and avirulent in humans and mammals, some recently reported observations (Blanchard *et al.*, 1998, J Gen Virol 79, 1159-1167; Carroll & Moss, 1997, Virology 238, 198-211; Altenberger, US Patent 5,185,146; Ambrosini *et al.*, 1999, J Neurosci Res 55(5), 569) have shown that MVA is not fully attenuated in mammalian and human cell lines since residual replication might occur in these cells. It is assumed that the results reported in these publications have been obtained with various strains of MVA, since the used viruses essentially differ in their properties, particularly in their growth behavior in various cell lines.

Growth behavior is recognized as an indicator for virus attenuation. Generally, a virus strain is regarded as attenuated if it has lost its capacity or only has reduced capacity to reproductively replicate in

host cells. The above-mentioned observation, that MVA is not completely replication incompetent in human and mammalian cells, brings into question the absolute safety of MVA as a human vaccine or a vector for recombinant vaccines.

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Particularly, for a vaccine as well as for a recombinant vaccine the balance between the efficacy and the safety of the vaccine vector virus is extremely important.

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Object of the invention

Thus, it is an object of the invention to provide novel virus strains having enhanced safety for the development of safer products such as vaccines or pharmaceuticals. Moreover, a further object is to provide means for improving an existing vaccination regimen.

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Detailed description of the invention

To achieve the foregoing objects, according to a preferred embodiment of the present invention new vaccinia viruses are provided, which are capable of reproductive replication in non-human cells and cell lines, especially in chicken embryo fibroblasts (CEF) and in the Baby hamster kidney cell line BHK (ECACC 85011433), but not capable of reproductive replication in human cell lines.

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The known vaccinia strains reproductively replicate in at least some human cell lines, in particular in the the human keratinocyte cell line HaCat_(Boukamp *et al.* 1988, J Cell Biol 106(3): 761-71). The replication in the cell line HaCat is predictive for replication in vivo, in particular for in vivo replication in humans. Indeed, it is shown in the example section that all known vaccinia strains tested that show a residual productive replication in HaCat also replicate in vivo. Thus, the invention preferably relates to vaccinia viruses that do not reproductively replicate in the human cell line HaCat. Most preferably the invention concerns vaccinia virus strains that are not capable of reproductive replication in any of the following human cell lines: the human cervix adenocarcinoma cell line HeLa (ATCC No. CCL-2), the human embryo kidney cell line 293 (ECACC No. 85120602), the human bone osteosarcoma cell line 143B (ECACC No. 91112502) and the cell line HaCat.

The growth behavior or amplification/replication of a virus is normally expressed by the ratio of virus produced from an infected cell (Output) to the amount originally used to infect the cells in the first place (Input) ("amplification ratio"). A ratio of "1" between Output and Input defines an amplification status wherein the amount of virus produced from the infected cells is the same as the amount initially used to infect the cells. This status hints to the fact, that the infected cells are permissive for virus infection and virus reproduction.

An amplification ratio of less than 1, i.e. a decrease of the amplification below input level is an indicator for a lack of reproductive replication and, thus, an indicator for attenuation of the virus. Therefore, it was of particular interest for the inventors to identify and finally to isolate a strain, which shows an amplification ratio of less than 1 in several human cell lines, in particular in all of the human cell lines 143B, HeLa, 293 and HaCat.

Thus, the term "not capable of reproductive replication" means that the virus according to the invention shows an amplification ratio of less than 1 in human cell lines, such as the cell lines 293 (ECACC No. 85120602), 143B (ECACC No. 91112502), HeLa (ATCC No. CCL-2) and HaCat (Boukamp *et al.* 1988, J Cell Biol 106(3): 761-71), under the conditions as outlined in example 1 of the present specification for some specific MVA strains. Preferably, the amplification rate of the virus according to the invention is 0.8 or less in each of the above human cell lines HeLa, HaCat and 143B.

It is shown in detail in Example 1 and in table 1 that the viruses according to the present invention do not reproductively replicate in anyone of the cell lines 143B, HeLa and HaCat. The particular strain according to the present invention that has been used in the examples has been deposited at the European Collection of Cell Cultures under number V00083008. This strain is referred to as "MVA-BN" throughout the specification.

The known MVA strains show residual replication in at least one of the human cell lines tested (figure 1, example 1). All known Vaccinia strains show at least some replication in the cell line HaCat, whereas the MVA strains according to the present invention, in particular MVA-BN, do not productively replicate in HaCat cells. In more detail MVA-BN shows an amplification ratio of 0.05 to 0.2 in the Human embryo kidney cell line 293 (ECACC No. 85120602). In the Human bone osteosarcoma cell line 143B (ECACC No. 91112502) the ratio is in the range of 0.0 to 0.6. For the Human cervix adeocarcinoma cell line HeLa (ATCC No. CCL-2) and the human keratinocyte cell line HaCat (Boukamp *et al.* 1988, J Cell Biol 106(3): 761-71) the amplification ratio is in the range of 0.04 to 0.8 and of 0.02 to 0.8, respectively. MVA-BN has an amplification ratio of 0.01 to 0.06 in African green monkey kidney cells (CV1: ATCC No. CCL-70). Thus, MVA-BN which is a prototype strain according to the present invention does not productively replicate in anyone of the tested human cell lines.

The amplification ratio of MVA-BN is clearly above 1 in chicken embryo fibroblasts (CEF: primary cultures) or the baby hamster kidney cell line BHK (ATCC No. CRL-1632). As outlined above, a ratio of more than "1" indicates reproductive replication, since the amount of virus produced from the infected cells is increased compared to the amount of virus, which was used to infect the cells. Therefore, the virus can be easily propagated and amplified in CEF primary cultures with a ratio of above 500 or in BHK cells with a ratio of above 50.

In a particular embodiment of the present invention the invention concerns derivatives of the virus as deposited under ECACC V0083008. "Derivatives" of the viruses as deposited under ECACC V0083008 refer to viruses showing essentially the same replication characteristics as the deposited strain but showing differences in one or more parts of its genome. Viruses having the same "replication characteristics" than the deposited virus are viruses that replicate with similar amplification ratios than the deposited strain in CEF cells and the cell lines BHK, HeLa, HaCat and 143B and that show a similar replication in vivo as determined in the AGR129 transgenic mouse model (see below).

In a preferred embodiment the vaccinia virus strains according to the present invention, in particular MVA-BN and its derivatives, are characterized by a failure to replicate in vivo. In the context of the present invention "failure to replicate in vivo" refers to viruses that do not replicate in humans and in the mice model explained below. The "failure to replicate in vivo" can preferably determined in mice that are incapable of producing mature B and T cells. An example for such mice is the transgenic mouse model AGR129 (obtained from Mark Sutter, Institute of Virology, University of Zurich, Zurich, Switzerland). This mouse strain has gene targeted disruptions in the IFN receptor type I (IFN- α/β) and type II (IFN- γ) genes and in RAG. Due to these disruptions the mice have no IFN system and are incapable of producing mature B and T cells and as such are severely immune

compromised and highly susceptible to a replicating virus. Instead of the AGR129 mice any other mouse strain can be used that is incapable of producing mature B and T cells and as such is severely immune compromised and highly susceptible to a replicating virus. In particular the viruses according to the present invention do not kill AGR129 mice within a time period of at least 45 days, more preferably within at least 60 days, most preferably within 90 days after the infection of the mice with 10^7 pfu virus administered intra peritoneally. Preferably, the viruses that show "failure to replicate in vivo" are further characterized in that no virus can be recovered from organs or tissues of the AGR129 mice 45 days, preferably 60 days and most preferably 90 days after the infection of the mice with 10^7 pfu virus administered intra peritoneally. Detailed information regarding the infection assays with AGR129 mice and the assays that are used to determine whether virus can be recovered from organs and tissues of infected mice can be found in the example section.

In a preferred embodiment the vaccinia virus strains according to the present invention, in particular MVA-BN and its derivatives, is characterized by a higher immunogenicity compared to the known strain MVA 575 as determined in a lethal challenge mouse model. The details of this experiment are outlined in example 2, shown below. Briefly, in such a model unvaccinated mice die after the infection with replication competent vaccinia strains such as the Western Reserve strain L929 TK+ or IHD-J. The infection with replication competent vaccinia viruses is referred to as "challenge" in

the context of description of the lethal challenge model. Four days after the challenge the mice are usually killed and the viral titer in the ovaries is determined by standard plaque assays using VERO cells (for more details see example section). The viral titer is determined for unvaccinated mice and for mice vaccinated with vaccinia viruses according to the present invention. More specifically the viruses according to the present invention are characterized in that in this test after the vaccination with 10^2 TCID₅₀/ml virus according to the present invention the ovary virus titers are reduced by at least 70%, preferably by at least 80%, more preferably by at least 90% compared to unvaccinated mice.

In a preferred embodiment the vaccinia viruses according to the present invention, in particular MVA-BN and its derivatives, are useful for immunization with prime/boost administration of the vaccine. There have been numerous reports suggesting that prime/boost regimes using MVA as a delivery vector induce poor immune responses and are inferior to DNA-prime MVA-boost regimes (Schneider *et al.*, 1998, Nat. Med. 4; 397-402). In all these studies MVA strains have been used that are different from the vaccinia viruses according to the present invention. To explain the poor immune response if MVA was used for prime and boost administration it has been hypothesized that antibodies generated to MVA during the prime-administration neutralize the MVA given in the second immunization, preventing an effective boost of the immune response. In contrast, DNA-prime/MVA-boost regimes are reported

to be superior at generating high avidity responses, because this regime combines the ability of DNA to effectively prime the immune response with the properties of MVA to boost this response in the absence of a pre-existing immunity to MVA. Clearly, if a pre-existing immunity to MVA and/or vaccinia prevents boosting of the immune response then the use of MVA as a vaccine or therapeutic would have limited efficacy, particularly in the individuals that have been vaccinated against smallpox. However, according to a further embodiment the vaccinia virus according the present invention, in particular MVA-BN and its derivatives as well as corresponding recombinant viruses harbouring heterologous sequences, can be used to efficiently first prime and then boost immune responses in native animals as well as in animals with a pre-existing immunity to poxviruses. Thus the vaccinia virus according to the present invention induces at least substantially the same level of immunity in vaccinia virus prime/ vaccinia virus boost regimes compared to DNA-prime/ vaccinia virus boost regimes.

A vaccinia virus is regarded as inducing at least substantially the same level of immunity in vaccinia virus prime/ vaccinia virus boost regimes when compared to DNA-prime/ vaccinia virus boost regimes if the CTL response as measured in one of the following two assays („assay 1“ and „assay 2“), preferably in both assays, is at least substantially the same in vaccinia virus prime/ vaccinia virus boost regimes when compared to DNA-prime/ vaccinia virus boost regimes. More preferably the CTL response after vaccinia virus

prime/vaccinia virus boost administration is higher in at least one of the assays, when compared to DNA-prime/vaccinia virus boost regimes. Most preferably the CTL response is higher in both of the following assays.

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Assay 1: For vaccinia virus prime/vaccinia virus boost administrations 6-8 week old BALB/c (H-2d) mice are prime-immunized by intravenous administration with 10^7 TCID₅₀ vaccinia virus according to the present invention expressing the murine polytope as described in Thomson et al., 1988, J. Immunol. 160, 1717 and boost-immunized with the same amount of the same virus, administered in the same way three weeks later. To this end it is necessary to construct a recombinant vaccinia virus expressing said polytope. Methods to construct such recombinant viruses are known to the person skilled in the art and are described in more detail below. In DNA prime/vaccinia virus boost regimes the prime vaccination is done by intra muscular injection of the mice with 50 µg DNA expressing the same antigen than the vaccinia virus; the boost administration with the vaccinia virus is done in exactly the same way as for the vaccinia virus prime/vaccinia virus boost administration. The DNA plasmid expressing the polytope is also described in the above referenced publication by Thomson et al. In both regimes the development of a CTL response against the epitopes SYIPSAEKI, RPQASGVYM and/or YPHFMPTNL is determined two weeks after the boost administration. The determination of the CTL response is preferably done by using the ELISPOT analysis as described by

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Schneider et al., 1998, Nat. Med. 4, 397-402 and as outlined in the examples section below for one specific virus according to the present invention. The virus according to the present invention is characterized in this experiment in that the CTL immune response against the epitopes mentioned above which is induced by the vaccinia virus prime/vaccinia virus boost administration is substantially the same, preferably at least the same as induced by DNA prime/vaccinia virus boost administration as assessed by the number of IFN- γ producing cells/ 10^6 spleen cells (see also experimental section).

Assay 2: This assay basically corresponds to assay 1. However, instead of using 10^7 TCID₅₀ vaccinia virus administered i.v. as in assay 1, in this assay 10^8 TCID₅₀ vaccinia virus according to the present invention are administered subcutaneously for prime immunization and for boost immunization. The virus according to the present invention is characterized in this experiment in that the CTL immune response against the epitopes mentioned above which is induced by the vaccinia virus prime/vaccinia virus boost administration is substantially the same, preferably at least the same as induced by DNA prime/vaccinia virus boost administration as assessed by the number of IFN- γ producing cells/ 10^6 spleen cells (see also experimental section).

The strenght of a CTL response as measured in one of the assays shown above corresponds to the level of protection.

Thus, the viruses according to the present invention are particularly suitable for vaccination purposes.

In summary the vaccinia virus according to the present invention is characterized by having at least one of the following properties:

- (i) capability of reproductive replication in chicken embryo fibroblasts (CEF) and in the cell line BHK, but no capability of reproductive replication in the human cell line HaCat,
- (ii) failure to replicate in vivo,
- (iii) induction of a higher immunogenicity compared to the known strain MVA 575 (ECACC V00120707) in a lethal challenge model and/or
- (iv) induction of at least substantially the same level of immunity in vaccinia virus prime/ vaccinia virus boost regimes when compared to DNA-prime/ vaccinia virus boost regimes.

Preferably the vaccinia virus according to the present invention has at least two of the above properties, more preferably at least three of the above properties. Most preferred are vaccinia viruses having all of the above properties.

In a further embodiment the invention concerns a kit for vaccination comprising a virus according to the present invention for

the first vaccination („priming“) in a first vial/container and for a second vaccination („boosting“) in a second vial/container. The virus may be a non-recombinant vaccinia virus, i.e. a vaccinia virus that does not contain heterologous nucleotide sequences. An example for such a vaccinia virus is MVA-BN and its derivatives. Alternatively the virus may be a recombinant vaccinia virus that contains additional nucleotide sequences which are heterologous to the vaccinia virus. As outlined in other sections of the description the heterologous sequences may code for epitopes that induce a response by the immune system. Thus, it is possible to use the recombinant vaccinia virus to vaccinate against the proteins or agents comprising said epitope. The viruses may be formulated as shown below in more detail. The amount of virus that may be used for each vaccination has been defined above.

It is known for a person skilled in the art, how he can obtain Vaccinia viruses having at least one the following properties:

- capability of reproductive replication in chicken embryo fibroblasts (CEF) and in the baby hamster kidney cell line BHK, but no capability of reproductive replication in the human keratinocyte cell line HaCat,
- failure to replicate in vivo,
- induction of a higher immunogenicity compared to the known strain MVA 575 in a lethal challenge model and/or

- induction of at least substantially the same level of immunity in vaccinia virus prime/ vaccinia virus boost regimes when compared to DNA-prime/ vaccinia virus boost regimes.

5 A process to obtain such a virus may comprise the following steps:

- (i) introducing a known vaccinia virus strain, preferably MVA 574 or MVA 575 (ECACC V00120707) into non human cells in which the virus is able to reproductively replicate, 10 wherein the non-human cells are preferably selected from CEF cells and the cell line BHK,
- (ii) isolating/enriching virus particles from these cells and
- (iii) analysing whether the obtained virus has at least one of the desired biological properties as defined above,

15 wherein the above steps can optionally be repeated until a virus with the desired replication characteristics is obtained. The invention further relates to the viruses obtained by this method according to the present invention. Methods how the desired biological properties can be determined are explained in other parts of this description.

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 In applying this method the inventors identified and isolated in several rounds of clone purification a strain according to the present invention starting from the MVA isolate passage 575 (MVA 575). This new strain corresponds to the strain with the accession number 25 ECACC V0083008, mentioned above.

The growth behavior of the vaccinia viruses according to the present invention, in particular the growth behaviour of MVA-BN, indicates that the strains according to the present invention are far superior to any other so far characterized MVA isolate regarding attenuation in human cell lines and failure of in vivo replication. The strains according to the present invention are therefore ideal candidates for the development of safer products such as vaccines or pharmaceuticals as will be described below.

In one embodiment the virus according to the present invention, in particular MVA-BN and its derivatives, is used as a vaccine against human pox virus diseases such as smallpox. In a further embodiment the virus according to the present invention may be recombinant, i.e. may express heterologous genes as, e.g., antigens or epitopes heterologous to the virus and may thus be useful as a vaccine to induce an immune response against heterologous antigens or epitopes.

The term "immune response" means the reaction of the immune system, when a foreign substance or micro-organism enters the organism. Per definition, the immune response is divided into a specific and an unspecific reaction although both are closely cross linked. The unspecific immune response is the immediate defence against a wide variety of foreign substances and infectious agents. The specific immune response is the defence raised after a lag phase, when the organism is challenged with a substance for the first time.

The specific immune response is highly efficient and is responsible for the fact that an individual who recovers from a specific infection is protected against this specific infection. Thus, a second infection with the same or a very similar infectious agent causes much milder symptoms or no symptoms at all, since there is already a “pre-existing immunity” to this agent. Such immunity and the immunological memory, respectively, persists for a long time, in some cases even lifelong. Accordingly, the induction of an immunological memory can be used for vaccination.

The “immune system” means a complex organ involved in the defence of the organism against foreign substances and micro-organisms. The immune system comprises a cellular part comprising several cell types, such as, e.g., lymphocytes and other cells derived from white blood cells, and a humoral part comprising small peptides and complement factors.

“Vaccination” means that an organism is challenged with an infectious agent, e.g., in an attenuated or inactivated form of said infectious agent, to induce a specific immunity. The term vaccination also covers the challenge of an organism with recombinant vaccinia viruses according to the present invention, in particular recombinant MVA-BN and its derivatives, expressing antigens or epitopes that are heterologous to the virus. Examples for such epitopes are given in other parts of the description and cover, e.g., epitopes from proteins derived from other viruses such as the Dengue virus, Hepatitis C

virus, HIV, or epitopes derived from proteins that are associated with the development of tumours and cancer. After the administration of the recombinant vaccinia virus into the body the epitopes are expressed and are presented to the immune system and a specific
5 immune response against these epitope may be induced. The organism, thus, is immunized against the agent/protein containing the epitope that is encoded by the recombinant vaccinia virus.

“Immunity” means partial or complete protection of an
10 organism against diseases caused by an infectious agent due to a successful elimination of a preceding infection with said infectious agent or a characteristic part thereof. Immunity is based on the existence, induction and activation of specialised cells of the immune system.

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As pointed out above in one embodiment of the invention, the recombinant viruses according to the present invention, in particular recombinant MVA-BN and its derivatives, contain at least one heterologous nucleic acid sequence. The term “heterologous” is used
20 hereinafter for any combination of nucleic acid sequences that is not normally found intimately associated with the virus in nature, such virus is also called "recombinant virus" .

According to a further embodiment of the present invention the
25 heterologous sequences are preferably antigenic epitopes, which are selected from any non-vaccinia source. Most preferably, said

recombinant virus expresses one or more antigenic epitopes from Plasmodium falciparum, Mycobacteria, Influenza virus, from viruses selected of the family of Flaviviruses, Paramyxoviruses, Hepatitis viruses, Human immunodeficiency viruses or from viruses causing hemorrhagic fever such as Hantaviruses or Filoviruses, i.e., Ebola or Marburg virus.

According to still a further embodiment, but also in addition to the above-mentioned selection of antigenic epitopes, the heterologous sequences can be selected from another poxviral or a vaccinia source. These viral sequences can be used to modify the host spectrum or the immunogenicity of the virus.

In a further embodiment the virus according to the present invention may code for a heterologous gene/nucleic acid expressing a therapeutic compound. A "therapeutic compound" encoded by the heterologous nucleic acid in the virus can be, e.g., a therapeutic nucleic acid such as an antisense nucleic acid or a peptide or protein with desired biological activity.

According to a further preferred embodiment the expression of heterologous nucleic acid sequence is preferably, but not exclusively, under the transcriptional control of a poxvirus promoter, more preferably of a vaccinia virus promoter.

According to still a further embodiment the insertion of heterologous nucleic acid sequence is preferably into a non-essential region of the virus genome. In another preferred embodiment of the invention, the heterologous nucleic acid sequence is inserted at a naturally occurring deletion site of the MVA genome (disclosed in PCT/EP96/02926). Methods how to insert heterologous sequences into the poxviral genome are known to a person skilled in the art.

According to another further preferred embodiment the invention includes also the genome of the virus, its recombinants or functional parts thereof. Such viral sequences can be used to identify or isolate the virus or its recombinants, e.g., by using PCR, hybridization technologies or by establishing ELISA assays. Furthermore, such viral sequences can be expressed from an expression vector to produce the encoded protein or peptide which then may supplement deletion mutants of a virus that lacks the viral sequence contained in the expression vector.

"Functional part" of the viral genome means a part of the complete genomic sequence, which encodes a physical entity, such as a protein, protein domain, epitope of a protein. Functional part of the viral genome also describes parts of the complete genomic sequence, which code for regulatory elements or parts of such elements with individualizable activity, such as promoter, enhancer, cis- or trans-acting elements.

The recombinant virus according to the present invention may be used for the introduction of the heterologous nucleic acid sequence into a target cell, said sequence being either homologous or heterologous to the target cell. The introduction of a heterologous nucleic acid sequence into a target cell may be used to produce *in vitro* heterologous peptides or polypeptides and/or complete viruses encoded by said sequence. This method comprises the infection of a host cell with the recombinant MVA, cultivation of the infected host cell under suitable conditions, and isolation and/or enrichment of the peptide, protein and/or virus produced by said host cell.

Furthermore, the method for introduction of a homologous or of a heterologous sequence to cells may be applied for *in vitro* and preferably *in vivo* therapy. For *in vitro* therapy, isolated cells that have been previously (*ex vivo*) infected with the virus are administered to the living animal body for inducing an immune response. For *in vivo* therapy, the virus or its recombinants are directly administered to the living animal body for inducing an immune response. In this case, the cells surrounding the site of inoculation are directly infected *in vivo* by the virus or its recombinants according to the invention.

Since the virus according to the invention is highly growth restricted in human and monkey cells and, thus, highly attenuated, it is ideal to treat a wide range of mammals including humans. Hence, the present invention also provides a pharmaceutical composition and a vaccine, e.g., for inducing an immune response in a living

animal body, including a human. The virus of the invention is further safe in any other gene therapy protocols.

The pharmaceutical composition may generally include one or
5 more pharmaceutical acceptable and/or approved carriers, additives, antibiotics, preservatives, adjuvants, diluents and/or stabilizers. Such auxiliary substances can be water, saline, glycerol, ethanol, wetting or emulsifying agents, pH buffering substances, or the like. Suitable carriers are typically large, slowly metabolized molecules such as
10 proteins, polysaccharides, polylactic acids, polyglycolic acids, polymeric amino acids, amino acid copolymers, lipid aggregates, or the like.

For the preparation of vaccines, the virus or its recombinants
15 according to the invention is converted into a physiologically acceptable form. This can be done based on the experience in the preparation of poxvirus vaccines used for vaccination against smallpox (as described by Stickl, H. *et al.* [1974] Dtsch. med. Wschr. 99, 2386-2392). For example, the purified virus is stored at -80°C with a
20 titre of 5×10^8 TCID₅₀/ml formulated in about 10mM Tris, 140 mM NaCl pH 7.4. For the preparation of vaccine shots, e.g., 10^2 - 10^8 particles of the virus are lyophilized in 100 ml of phosphate-buffered saline (PBS) in the presence of 2% peptone and 1% human albumin in an ampoule, preferably a glass ampoule. Alternatively, the vaccine
25 shots can be produced by stepwise freeze-drying of the virus in a formulation. This formulation can contain additional additives such as

mannitol, dextran, sugar, glycine, lactose or polyvinylpyrrolidone or other additives such as antioxidants or inert gas, stabilizers or recombinant proteins (e.g. human serum albumin) suitable for *in vivo* administration. The glass ampoule is then sealed and can be stored
5 between 4°C and room temperature for several months. However, as long as no need exists the ampoule is stored preferably at temperatures below -20°C.

For vaccination or therapy the lyophilisate can be dissolved in
10 0.1 to 0.5 ml of an aqueous solution, preferably physiological saline or Tris buffer, and administered either systemically or locally, i.e. by parenterally, intramuscularly or any other path of administration known to the skilled practitioner. The mode of administration, the dose and the number of administrations can be optimized by those skilled in
15 the art in a known manner.

Additionally, according to a further embodiment the virus according to the present invention is particularly useful to induce immune responses in immuno-compromised animals, e.g., monkeys
20 (CD4 < 400/μl of blood) infected with SIV, or in immuno-compromised humans. The term "immuno-compromised" describes the status of the immune system of an individual, which shows only incomplete immune responses or has a reduced efficiency in the defence against infectious agents. Even more interesting and according to still a
25 further embodiment the virus according to the present invention can boost immune responses in immuno-compromised animals or humans,

even in the presence of a pre-existing immunity to poxvirus in these animals or humans. Particularly interesting was, that the virus according to the present invention can boost immune responses also in animals or humans undergoing an antiviral, e.g., antiretroviral therapy. "Antiviral therapy" includes therapeutic concepts in order to eliminate or suppress viral infection including , e.g., (i) the application of nucleotide analogs, (ii) the application of inhibitors for viral enzymatic activity or viral assembling, or (iii) application of cytokins to influence immune responses of the host.

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According to still a further embodiment the vaccine is especially, but not exclusively, applicable in the veterinary field, e.g., for the immunization against animal pox infection. In small animals the inoculation for immunization is preferably performed parenterally or nasally, whereas in larger animals or humans a subcutaneous, intramuscular or oral inoculation is preferred.

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It has been found by the inventors that already a vaccine shot containing an effective dose of only 10^2 TCID₅₀ (tissue culture infectious dose) of the virus according the present invention is sufficient to induce complete immunity against a wild type vaccinia virus challenge in mice. This is particularly surprising since such high degree of attenuation of the virus according to the present invention would be expected to negatively influence and, thereby, reduce its immunogenicity. Such expectation is based on the believe that for induction of an immune response the antigenic epitopes need to be

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presented to the immune system in sufficient quantity. A virus that is highly attenuated and, thus, not replicating can only present a very small amount of antigenic epitopes, that is as much as itself incorporates. This amount of antigen, carried by the viral particles, was not considered sufficient for induction of a potent immune response. However, the virus according to the invention stimulates even with a very low effective dose of only 10^2 TCID₅₀ a potent and protecting immune response in a mouse/vaccinia challenge model. The virus according to the present invention thus shows an unexpected and even increased immunogenicity compared to other so far characterized MVA strains. This high immunogenicity makes the virus according to the present invention and any vaccine derived thereof especially useful for application in immuno-compromised animals or humans.

According to still another embodiment of the invention, the virus is used as an adjuvant. An "adjuvant" in the context of the present description refers to an enhancer of the specific immune response in vaccines. "Using the virus as adjuvant" means including the virus in a pre-existing vaccine to additionally stimulate the immune system of the patient who receives the vaccine. The immunizing effect of an antigenic epitope in most vaccines is often enhanced by the addition of a so-called adjuvant. An adjuvant co-stimulates the immune system by causing a stronger specific immune reaction against an antigenic epitope of a vaccine. This stimulation can be regulated by factors of the unspecific immune system, such as interferon and interleukin.

Hence, in a further embodiment of the invention, the virus is used in mammals including humans to activate, support or suppress the immune system, and preferably to activate the immune response against any antigenic determinant. The virus may also be used to support the immune system in a situation of increased susceptibility against infections such as in the case of stress.

The virus used as an adjuvant may be a non-recombinant virus, i.e. a virus that does not contain heterologous DNA in its genome. An example for this type of virus is MVA-BN. Alternatively the virus that is used as an adjuvant is a recombinant virus containing in its genome heterologous DNA sequences that are not naturally present in the viral genome. For use as a adjuvant the recombinant viral DNA of the virus preferably contains and expresses genes that code for immune stimulatory peptides or proteins such as interleukines.

According to a further embodiment it is preferred that the virus is inactivated, when used as an adjuvant or added to another vaccine. The inactivation of the virus may be performed, e.g., by heat or chemicals, as known in the art. Preferably, the virus is inactivated by β -propiolacton. According to this embodiment of the invention, the inactivated virus may be added to vaccines against numerous infectious or proliferative diseases to increase the immune response of the patient to this disease.

Summary of the Invention

The invention *inter alia* comprises the following, alone or in combination:

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Vaccinia virus having at least one of the following properties:

- capability of reproductive replication in chicken embryo fibroblasts (CEF) and in the baby hamster kidney cell line BHK, but no capability of reproductive replication in the human keratinocyte cell line HaCat,
- 10 - failure to replicate in vivo,
- induction of a higher immunogenicity compared to the known strain MVA 575 in a lethal challenge model and/or
- induction of at least substantially the same level of immunity in vaccinia virus prime/ vaccinia virus boost regimes when compared to
- 15 DNA-prime/ vaccinia virus boost regimes.

The virus as above, wherein the virus is not capable of reproductively replicating in any of the following human cell lines: the human embryo kidney cell line 293, the human bone osteosarcoma cell line 143B and

20 the human cervix adenocarcinoma cell line HeLa.

The virus as above being deposited at the European Collection of Cell Cultures (ECACC), Salisbury (UK) under number V00083008 and derivatives thereof.

25

The virus as above comprising at least one heterologous nucleic acid sequence.

5 The virus as above, wherein said heterologous nucleic acid sequence being selected from a sequence coding for at least one antigen, antigenic epitope, and/or a therapeutic compound.

Genome or functional parts thereof derived from the virus as defined above.

10

Pharmaceutical composition comprising the virus as above and/or the genome and/or functional part thereof as defined above and a pharmaceutically acceptable carrier, diluent and/or additive.

15

Vaccine comprising the virus as above and/or the genome and/or functional part thereof as defined above.

20

The virus as above, the genome and/or functional part thereof as defined above, the composition as defined above or the vaccine as defined above as drug for affecting, preferably inducing, an immunological response in a living animal, including a human.

25

The virus as above, the pharmaceutical composition as defined above, the vaccine as defined above or the virus as defined above, wherein the virus, the composition or the vaccine is administered in

therapeutically effective amounts in a first inoculation ("priming inoculation") and in a second inoculation ("boosting inoculation").

5 Use of the virus as above, and/or the genome as defined above, for the preparation of a medicament or a vaccine.

Method for introducing homologous and/or heterologous nucleic acid sequences into target cells comprising the infection of the target cells with the virus comprising heterologous sequences as defined above or
10 the transfection of the target cell with the genome as defined above.

Method for producing a peptide, protein and/or virus comprising

- infection of a host cell with the virus as above,
- cultivation of the infected host cell under suitable conditions, and
- 15 - isolation and/or enrichment of the peptide and/or protein and/or viruses produced by said host cell.

Method for affecting, preferably inducing an immunological response in a living animal body including a human comprising administering the
20 virus as above, the genome and/or functional part thereof as defined above, the composition as defined above or the vaccine as defined above to the animal or human to be treated.

The method as above comprising the administration of at least 10^2
25 TCID₅₀ (tissue culture infectious dose) of the virus.

The method as above, wherein the virus, the composition or the vaccine is administered in therapeutically effective amounts in a first inoculation ("priming inoculation") and in a second inoculation ("boosting inoculation").

5

The method as above, wherein the animal is immuno-compromised.

The method as above, wherein the animal has a pre-existing immunity to poxviruses.

10

The method as above, wherein the animal is undergoing an antiviral therapy.

The method wherein the animal is undergoing an antiviral therapy, characterized in that the antiviral therapy is an antiretroviral therapy

15

Use of the virus as above, the genome and/or functional part thereof as defined above as adjuvant.

20

A method for enhancing a specific immune response against an antigen and/or an antigenic epitope included in a vaccine comprising administration of the virus as above or the genome as defined above, as an adjuvant to a living animal body including a human to be treated with the vaccine.

25

The virus as above or the genome as defined above, as adjuvant.

A cell, preferably a human cell, containing the virus as above or the genome or functional part thereof as defined above.

5

Method for obtaining the vaccinia virus as above comprising the following steps:

- introducing a commonly available vaccinia virus strain, preferably MVA 575 into non human cells in which the virus is able to
- 10 reproductively replicate, wherein the non-human cells are preferably selected from CEF cells and the cell line BHK,
- isolating/enriching virus particles from these cells and
- analysing whether the obtained virus has at least one of the biological properties as defined above,

15

wherein the above steps can optionally be repeated until a virus with the desired replication characteristics is obtained

20

Kit for prime/boost immunization comprising a virus as above, a vaccine as above or the virus as drug as defined above for a first inoculation ("priming inoculation") in a first vial/container and for a second inoculation ("boosting inoculation") in a second vial/container.

25

Use of the virus as above, the composition as defined above and/or of the vaccine as defined above for the preparation of a vaccine wherein the virus, the composition or the vaccine is administered in a prime

inoculation and wherein the same virus or vaccine is administered in a boost inoculation.

Short Description of the Figures

5

Figure 1: Growth kinetics of different strains of MVA in different cell lines. In part A) the results are grouped according to the MVA strains tested whereas in part B) the results are grouped according to the cell lines tested. B) The amount of virus recovered from a cell line after four days (D4) of culture was determined by plaque assay and expressed as the ratio of virus recovered after 4 days to the initial inoculum on day 1 (D1)

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Figure 2: Protection provided against a lethal challenge of vaccinia following vaccinations with either MVA-BN or MVA 575. The protection is measured by the reduction in ovary titres determined 4 days post challenge by standard plaque assay.

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Figure 3: Induction of CTL and protection provided against an influenza challenge using different prime-boost regimes.

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3A: Induction of CTL responses to 4 different H-2^d restricted epitopes following vaccinations with different combinations of DNA or MVA-BN vaccines encoding a murine polytope. BALB/c mice (5 per group) were vaccinated with either DNA (intramuscularly) or MVA-BN (subcutaneously) and received booster immunisations three weeks later. CTL responses to 4 different epitopes encoded by the vaccines (TYQRTRALV, influenza; SYIPSAEKI, *P. Berghei*; YPHFMPTNL,

25

Cytomegalovirus; RPQASGVYM, LCV) were determined using an ELISPOT assay 2 weeks post the booster immunisations.

3B: . Induction of CTL responses to 4 different epitopes following vaccinations with different combinations of DNA or MVA-BN vaccines encoding a murine polytope. BALB/c mice (5 per group) were vaccinated with either DNA (intramuscularly) or MVA-BN (intravenously) and received booster immunisations three weeks later. CTL responses to 4 different epitopes encoded by the vaccines (TYQRTRALV, influenza; SYIPSAEKI, *P. Berghei*; YPHFMPTNL, Cytomegalovirus; RPQASGVYM, LCV) were determined using an ELISPOT assay 2 weeks post the booster immunisations.

3C: Frequency of peptide and MVA specific T cells following homologous prime boost using an optimal dose (1×10^8 TCID₅₀) of recombinant MVA-BN, given subcutaneously. Groups of 8 mice were vaccinated with two shots of the combinations as indicated in the figure. Two weeks post the final vaccination the number of peptide specific splenocytes were measured using an IFN-gamma ELISPOT assay. The bars represent the mean number of specific spots plus/minus the standard deviation from the mean.

Figure 4: SIV load of monkeys vaccinated with MVA-BN nef or MVA-BN.

Figure 5: Survival of vaccinated monkeys following infection with SIV.

Figure 6: Monkey serum antibody titres to MVA-BN. The antibody titres for each animal are shown as different shapes, while the mean titre is illustrated as a solid rectangle.

5 **Figure 7:** Levels of SIV in immuno-compromised monkeys (CD4 < 400 ml blood) following vaccinations with MVA-BN encoding tat. Monkeys had previously received three vaccinations with either MVA-BN or MVA-BN nef (week 0, 8, 16) and had been infected with a pathogenic isolate of SIV (week 22). At week 100, 102 and 106 (indicated by
10 arrows) the monkeys were vaccinated with MVA-BN tat.

Figure 8: SIV levels in monkeys undergoing anti-retroviral therapy and therapeutic vaccinations using MVA-BN. Three groups of monkeys (n =6) were infected with SIV and treated daily with PMPA (indicated
15 by black line). At week 10 and 16 animals were vaccinated (indicated by arrows) with either mixtures of recombinant MVA or saline.

Figure 9: Humoral response generated to SIV following infection and vaccinations with recombinant MVA. Three groups (n = 6) of monkeys
20 were infected with a pathogenic isolate of SIV (week 0) and then treated with the anti-retroviral therapy (PMPA; indicated by bold line). Monkeys were vaccinated with mixtures of recombinant MVA or saline at week 10 and 16. Antibodies to SIV were determined using infected T cell lysates as antigen in a standard ELISA.

Figure 10: Humoral response generated to MVA in SIV infected monkeys undergoing anti-retroviral therapy. Three groups (n = 6) of monkeys were infected with a pathogenic isolate of SIV (week 0) and then treated with the anti-retroviral therapy (PMPA; indicated by bold line). Monkeys were vaccinated with mixtures of recombinant MVA or saline at week 10 and 16. Antibodies to MVA were determined using a standard capture ELISA for MVA.

Figure 11: Induction of antibodies to MVA following vaccination of mice with different smallpox vaccines. The levels of antibodies generated to MVA following vaccinations with MVA-BN (week 0 and 4), was compared to conventional vaccinia strains, Elstree and Wyeth, given via tail scarification (week 0), MVA 572 (week 0 and 4) and MVA-BN and MVA 572 given as a pre-Elstree vaccine. MVA 572 has been deposited at the European Collection of Animal Cell Cultures as ECACC V94012707. The titres were determined using a capture ELISA and calculated by linear regression using the linear part of the graph and defined as the dilution that resulted in an optical density of 0.3. * MVA-BN : MVA-BN is significantly ($p > 0.05$) different to MVA 572 : MVA 572.

Examples

The following examples will further illustrate the present invention. It will be well understood by a person skilled in the art that the provided examples in no way may be interpreted in a way that

limits the applicability of the technology provided by the present invention to this examples.

Example 1

5 Growth kinetics of a new strain of MVA in selected cell lines and replication in vivo

(i) Growth kinetics in cell lines:

10 To characterize a newly isolated strain according to the present invention (further referred to as MVA-BN) the growth kinetics of this new strain were compared to those of other MVA strains, which have already been characterized.

15 The experiment was done by comparing the growth kinetics of the following viruses in the subsequently listed primary cells and cell lines:

 MVA-BN (Virus stock #23, 18. 02. 99 crude, titrated at $2,0 \times 10^7$ TCID₅₀/ml);

20 MVA as characterized by Altenburger (US patent 5, 185, 146) and further referred to as MVA-HLR;

25 MVA (passage 575) as characterized by Anton Mayr (Mayr, A., *et al.* [1975] Infection 3; 6-14) and further referred to as MVA-575 (ECACC V00120707); and

MVA-Vero as characterized in the International Patent Application PCT/EP01/02703 (WO 01/68820)(Virus stock, passage 49, #20, 22.03.99 crude, titred at $4,2 \times 10^7$ TCID₅₀/ml).

5

The used primary cells and cell lines were:

CEF Chicken embryo fibroblasts (freshly prepared from SPF eggs);

10

HeLa Human cervix adeocarcinoma (epithelial), ATCC No. CCL-2;

143B Human bone osteosarcoma TK-, ECACC No. 91112502;

HaCaT Human keratinocyte cell line, Boukamp *et al.* 1988, J Cell Biol 106(3): 761-771;

15

BHK Baby hamster kidney, ECACC 85011433;

Vero African green monkey kidney fibroblasts, ECACC 85020299;

CV1 African green monkey kidney fibroblasts, ECACC 87032605.

20

25

For infection the different cells were seeded into 6-well-plates at a concentration of 5×10^5 cells/well and incubated over night at 37°C, 5% CO₂ in DMEM (Gibco, Cat. No. 61965-026) plus 2% FCS. Cell culture medium was removed and cells were infected at approximately moi 0.05 for one hour at 37°C, 5% CO₂ (for infection it is assumed that cell numbers doubled over night). The amount of

virus used for each infection of the different cell types was 5×10^4 TCID₅₀ and this will be referred to as Input. Cells were then washed 3 times with DMEM and finally 1 ml DMEM, 2% FCS was added and the plates were left to incubate for 96 hours (4 days) at 37°C, 5% CO₂. These infections were stopped by freezing the plates at -80°C ready for titration analysis.

Titration analysis (immunostaining with a vaccinia virus specific antibody)

For titration of amount of virus test cells (CEF) were seeded on 96-well-plates in RPMI (Gibco, Cat. No. 61870-010), 7% FCS, 1% Antibiotic/ Antimycotic (Gibco, Cat. No. 15240-062) at a concentration of 1×10^4 cells/well and incubated over night at 37°C, 5% CO₂. The 6-well-plates containing the infection experiments were frozen/thawed 3 times and dilutions of 10^{-1} to 10^{-12} were prepared using RPMI growth medium. Virus dilutions were distributed onto test cells and incubated for five days at 37°C, 5% CO₂ to allow CPE (cytopathic effect) development. Test cells were fixed (Aceton/Methanol 1:1) for 10 min, washed with PBS and incubated with polyclonal vaccinia virus specific antibody (Quartett Berlin, Cat. No. 9503-2057) at a 1:1000 dilution in incubation buffer for one hour at RT. After washing twice with PBS (Gibco, Cat. No. 20012-019) the HPR-coupled anti-rabbit antibody (Promega Mannheim, Cat. No. W4011) was added at a 1:1000 dilution in incubation buffer (PBS containing 3% FCS) for one hour at RT. Cells were again washed twice with PBS and incubated with staining solution (10 ml PBS + 200 µl

saturated solution of o-dianisidine in 100% ethanol + 15 µl H₂O₂ freshly prepared) until brown spots were visible (two hours). Staining solution was removed and PBS was added to stop staining reaction. Every well showing a brown spot was marked as positive for CPE and titer was calculated using the formula of Kaerber (TCID₅₀ based assay) (Kaerber, G. 1931. Arch. Exp. Pathol. Pharmacol. 162, 480).

The viruses were used to infect duplicate sets of on the one hand CEF and BHK, which were expected to be permissive for MVA, and on the other hand CV-1, Vero, Hela, 143B and HaCat which were expected to be non-permissive for MVA, at a low multiplicity of infection, i.e., 0.05 infectious units per cell (5×10^4 TCID₅₀). After this, the virus inoculum was removed and the cells washed three times to remove any remaining unabsorbed viruses. Infections were left for a total of 4 days where viral extracts were prepared and then titred on CEF cells. Table 1 and Figure 1 show the results of the titration assays where the values are given as total amount of virus produced after 4 days infection.

It was shown that all viruses amplified well in CEF cells (Chicken embryo fibroblasts) as expected since this is a permissive cell line for all MVAs. Additionally it was shown that all viruses amplified well in BHK (Hamster kidney cell line). MVA-Vero performed the best, since BHK is a permissive cell line.

Concerning replication in Vero cells (Monkey kidney cell line) MVA-Vero amplified well as expected namely 1000 fold above Input. MVA-HLR and also MVA-575 amplified well with 33 fold and 10 fold increase above Input, respectively. Only MVA-BN was found to not
5 amplified as well in these cells as compared to the others, namely only 2 fold increase above Input.

Also concerning replication in CV1 cells (Monkey kidney cell line) it was found, that MVA-BN is highly attenuated in this cell line. It
10 showed a 200 fold decrease below Input. Also MVA-575 did not amplify above the Input level also showed a slightly negative amplification, namely 16 fold decrease below Input. MVA-HLR amplified the best with 30 fold increase above Input, followed by MVA-Vero with 5 fold increase above Input.

Most interesting is to compare the growth kinetics of the various viruses in human cell lines. Regarding reproductive replication in 143B cells (human bone cancer cell line) it was shown that MVA-Vero was the only one to show amplification above Input (3 fold
20 increase). All other viruses did not amplify above Input but there was a big difference between the MVA-HLR and both MVA-BN and MVA-575. MVA-HLR was "borderline" (1 fold decrease below Input), were as MVA-BN shows the greatest attenuation (300 fold decrease below Input) followed by MVA-575 (59 fold decrease below Input). To
25 summarize MVA-BN is superior regarding attenuation in human 143B cells.

Furthermore, concerning replication in HeLa cells (human cervix cancer cells) it was shown that MVA-HLR amplified well in this cell line, and even better than it did in the permissive BHK cells (Hela = 125 fold increase above Input; BHK = 88 fold increase above Input) MVA-Vero also amplified in this cell line (27 fold increase above Input). However, MVA-BN and also to a lesser extend MVA-575 were attenuated in these cell lines (MVA-BN = 29 fold decrease below Input and MVA-575 = 6 fold decrease below Input).

Concerning the replication in HaCat cells (human keratinocyte cell line) it was shown that MVA-HLR amplified well in this cell line (55 fold increase above Input). Both MVA-Vero adapted and MVA-575 showed amplification in this cell line (1.2 and 1.1 fold increase above Input respectively). However, MVA-BN was the only one to demonstrate attenuation (5 fold decrease below Input).

In conclusion it can be stated that MVA-BN is the most attenuated virus strain in this group of virus: MVA-BN demonstrates to be extremely attenuated in human cell lines by showing an amplification ratio of 0.05 to 0.2 in Human embryo kidney cells (293: ECACC No. 85120602)(data not incorporated in Table 1), it shows further an amplification ratio of about 0.0 in 143B cells; an amplification ratio of about 0.04 in HeLa cells; an amplification ratio of about 0.22 in HaCat cells. Additionally, MVA-BN is showing an amplification ratio of about 0.0 in CV1 cells. Only in Vero cells

amplification can be observed (ratio of 2.33), however, not to the same extent as it in the permissive cell lines such as BHK and CEF (compare to Table 1). Thus, MVA-BN is the only known MVA strain showing an amplification ratio of less than 1 in all of the human cell lines 143B, HeLa, HaCat and 293.

MVA-575 shows a similar profile as MVA-BN but is not as attenuated as MVA-BN.

MVA-HLR amplified well in all cell lines tested (except for 143B cells), it thus can be regarded as replication competent in all cell lines tested with exception in 143B cells. In one case it even amplified better in a human cell line (HeLa) than in a permissive cell line (BHK).

MVA-Vero does show amplification in all cell lines but to a lesser extent than demonstrated by MVA-HLR (ignoring the 143B result). Nevertheless it cannot be considered as being in the same "class", with regards to attenuation, as MVA-BN or MVA-575.

2. Replication in vivo

Given that some MVA strains clearly replicate *in vitro* the ability of different MVA strains was examined to replicate *in vivo* using a transgenic mouse model AGR129. This mouse strain has gene targeted disruptions in the IFN receptor type I (IFN- α/β) and type II (IFN- γ) genes and in *RAG*. Due to these disruptions the mice have no

IFN system and are incapable of producing mature B and T cells and as such are severely immune compromised and highly susceptible to a replicating virus. Groups of six mice were immunised (i.p) with 10^7 pfu of either MVA-BN, MVA-HLR or MVA 572 (used in 120,000 people in Germany) and monitored daily for clinical signs. All mice vaccinated with MVA HLR or MVA 572 died within 28 and 60 days, respectively. At necropsy there were general signs of a severe viral infection in the majority of organs and by a standard plaque assay MVA (10^8 pfu) was recovered from the ovaries. In contrast, mice vaccinated with the same dose of MVA-BN (corresponding to the deposited strain ECACC V00083008) survived for more than 90 days and no MVA could be recovered from organs or tissues.

When taken together the data from the *in vitro* and *in vivo* studies clearly demonstrate that MVA-BN is more highly attenuated than the parental and commercial MVA-HLR strain.

Example 2

Immunological and in vivo Data

These experiments were set up to compare different dose and vaccination regimens of MVA-BN compared to other MVAs.

2.1. Different Strains of MVA Differ in their Ability to Stimulate the Immune Response.

Replication competent strains of vaccinia induce potent immune responses in mice and at high doses are lethal. Although MVA are highly attenuated and have a reduced ability to replicate on mammalian cells, there are differences in the attenuation between different strains of MVA. Indeed, MVA BN appears to be more attenuated than other MVA strains, even the parental strain MVA 575. To determine whether this difference in attenuation affects the efficacy of MVA to induce protective immune responses, different doses of MVA BN and MVA 575 were compared in a lethal vaccinia challenge model. The levels of protection were measured by a reduction in ovary vaccinia titres determined 4 days post challenge, as this allowed a quantitative assessment of different doses and strains of MVA.

Lethal Challenge Model

Specific pathogen-free 6-8-week-old female BALB/c (H-2^d) mice (n=5) were immunized (i.p.) with different doses (10^2 , 10^4 or 10^6 TCID₅₀/ml) of either MVA BN or MVA 575. MVA-BN and MVA-575 had been propagated on CEF cells, and had been sucrose purified and formulated in Tris pH 7.4. Three weeks later the mice received a boost of the same dose and strain of MVA, which was followed two weeks later by a lethal challenge (i.p.) with a replication competent strain of vaccinia. As replication competent vaccinia virus (abbreviated as "rVV") either the strain WR-L929 TK+ or the strain IHD-J were used. Control mice received a placebo vaccine. The protection was measured by the reduction in ovary titres determined 4 days post challenge by standard plaque assay. For this the mice

were sacrificed on day 4 post the challenge and the ovaries were removed, homogenized in PBS (1ml) and viral titres determined by standard plaque assay using VERO cells (Thomson *et al.*, 1998, J. Immunol. 160: 1717)..

5

Mice vaccinated with two immunizations of either 10^4 or 10^6 TCID₅₀/ml of MVA-BN or MVA-575 were completely protected as judged by a 100% reduction in ovary rVV titres 4 days post challenge (Fig. 2). The challenge virus was cleared. However, differences in the levels of protection afforded by MVA-BN or MVA-575 were observed at lower doses. Mice that received two immunizations of 10^2 TCID₅₀/ml of MVA 575 failed to be protected as judged by the high ovary rVV titres (mean 3.7×10^7 pfu $\pm$ 2.11 $\times 10^7$). In contrast, mice vaccinated with the same dose of MVA-BN induced a significant reduction (96%) in ovary rVV titres (mean 0.21×10^7 pfu $\pm$ 0.287 $\times 10^7$). The control mice that received a placebo vaccine had a mean viral titre of 5.11×10^7 pfu ($\pm$ 3.59 $\times 10^7$) (Fig. 2).

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Both strains of MVA induce protective immune responses in mice against a lethal rVV challenge. Although both strains of MVA are equally efficient at higher doses, differences in their efficacy are clearly evident at sub-optimal doses. MVA-BN is more potent than its parent strain MVA-575 at inducing a protective immune response against a lethal rVV challenge, which may be related to the increased attenuation of MVA-BN compared to MVA-575.

2.2. MVA-BN in Prime-Boost Vaccination Regimes

2.2.1.: Induction of antibodies to MVA following vaccination of mice with different smallpox vaccines

5 The efficacy of MVA-BN was compared to other MVA and vaccinia strains previously used in the eradication of smallpox. These included single immunisations using the Elstree and Wyeth vaccinia strains produced in CEF cells and given via tail scarification and immunisations using MVA 572 that was previously used in the
10 smallpox eradication program in Germany. In addition, both MVA-BN and MVA 572 were compared as a pre-vaccine followed by Elstree via scarification. For each group eight BALB/c mice were used and all MVA vaccinations (1×10^7 TCID₅₀) were given subcutaneously at week 0 and week 3. Two weeks following the boost immunisation the mice
15 were challenged with vaccinia (IHD-J) and the titres in the ovaries was determined 4 days post challenge. All vaccines and regimes induced 100% protection.

20 The immune responses induced using these different vaccines or regimes were measured in animals prior to challenge. Assays to measure levels of neutralising antibodies, T cell proliferation, cytokine production (IFN- γ vs IL-4) and IFN- γ production by T cells were used. The level of the T cell responses induced by MVA-BN, as measured by ELIspot, was generally equivalent to other MVA and
25 vaccinia viruses demonstrating bio-equivalence. A weekly analysis of the antibody titres to MVA following the different vaccination regimes

revealed that vaccinations with MVA-BN significantly enhanced the speed and magnitude of the antibody response compared to the other vaccination regimes (Fig. 11). Indeed the antibody titres to MVA were significantly higher ($p > 0.05$) at weeks 2, 4 and 5 (1 week post boost at week 4) when vaccinated with MVA-BN compared to mice vaccinated with MVA 572. Following the boost vaccination at week 4 the antibody titres were also significantly higher in the MVA-BN group compared to the mice receiving a single vaccination of either the vaccinia strains Elstree or Wyeth. These results clearly demonstrate that 2 vaccinations with MVA-BN induced a superior antibody response compared to the classical single vaccination with traditional vaccinia strains (Elstree and Wyeth) and confirm the findings from section 1.5 that MVA-BN is more immunogenic than other MVA strains.

2.2.2.: MVA-prime and boost regimes generate the same level of protection as DNA-prime MVA-boost regimes in a influenza challenge model.

The efficacy of MVA prime-boost regimes to generate high avidity CTL responses was assessed and compared to DNA prime/MVA boost regimes that have been reported to be superior. The different regimes were assessed using a murine polytope construct encoded by either a DNA vector or MVA-BN and the levels of CTL induction were compared by ELISPOT, while the avidity of the response was measured as the degree of protection afforded following a challenge with influenza.

Constructs

The DNA plasmid encoding the murine polytope (10 CTL epitopes including influenza, ovalbumin) was described previously (Thomson *et al.*, 1998, J. Immunol. 160: 1717). This murine polytope was inserted into deletion site II of MVA-BN, propagated on CEF cells, sucrose purified and formulated in Tris pH 7.4.

Vaccination protocols

In the current study specific pathogen free 6-8 week old female BALB/c (H-2d) mice were used. Groups of 5 mice were used for ELISPOT analysis while 6 mice per group were used for the influenza challenge experiments. Mice were vaccinated with different prime-boost regimes using MVA or DNA encoding the murine polytope as detailed in the results. For immunizations with DNA, mice were anesthetized and then given a single injection of 50 µg of endotoxin-free plasmid DNA (in 50 µl of PBS) in the quadriceps muscle under anaesthesia. Primary immunizations using MVA were done either by intravenous administration of 10⁷ pfu MVA-BN per mouse or by subcutaneous administration of 10⁷ pfu or 10⁸ pfu MVA-BN per mouse. Boost immunizations were given three weeks post the primary immunizations. Boosting with plasmid DNA was done in the same way than the primary immunization with DNA (see above). In order to establish CTL responses standard ELISPOT assays (Schneider *et al.*, 1998, Nat. Med. 4; 397-402) were performed on splenocytes 2 weeks post the last booster immunization using the

influenza CTL epitope peptide (TYQRTRALV), the P.Berghei epitope peptide (SYIPSAEKI), the Cytomegalovirus peptide epitope (YPHFMPNTL) and/or the LCV peptide epitope (RPQASGVYM).

For the challenge experiments mice were anesthetized and infected i.n. with a sub-lethal dose of the reassortant influenza virus, Mem71 (4.5 x10⁵ pfu in 50ml PBS). At day 5 post infection, the lungs were removed and viral titres were determined in duplicate on Madin-Darby canine kidney cell line using a standard influenza plaque assay.

Results:

Using the DNA vaccine alone the induction of CTL to the 4 H-2^d epitopes encoded by the murine polytope was poor and only weak responses could be detected to two of the epitopes for *P.Berghei* (SYIPSAEKI) and lymphocytic choriomeningitis virus (RPQASGVYM). In contrast, using a DNA prime MVA boost regime (10⁷ pfu MVA-BN given subcutaneously) there were significantly more CTL induced to SLY (8-fold increase) and RPQ (3-fold increase) and responses were also observed to a third epitope for murine cytomegalovirus (YPHFMPNTL) (Fig. 3A). However, using 10⁷ pfu MVA-BN given subcutaneously in a homologous prime boost regime induced the same level of responses as DNA followed by MVA-BN (Fig. 3A). Surprisingly, there was no significant difference in the numbers of CTLs induced to the three epitopes when one immunisation of MVA-BN (10⁷ TCID₅₀) was used, indicating that a secondary immunisation with MVA-BN did not significantly boost CTL responses.

The subcutaneous administration of 10^7 pfu MVA has previously been shown to be the most inefficient route and virus concentration for vaccination using other strains of MVA, particularly if compared to intravenous immunisations (Schneider et al 1998). In order to define optimal immunization regimes the above experiment was repeated by changing either the amount of virus or by changing the mode of administration. In one experiment 10^7 pfu MVA-BN vaccinations were given intravenously (Fig. 3B). In a further experiment 10^8 pfu MVA-BN were administered subcutaneously (Fig.3C). In these experiments MVA-BN prime-boost immunisations induced higher mean CTL numbers to all three CTL epitopes compared to DNA prime MVA boost regimes. Also unlike 10^7 pfu MVA-BN given subcutaneously the immunisation with 10^7 pfu MVA-BN given intravenously and the immunization with 10^8 pfu given subcutaneously significantly boosted the CTL responses, clearly indicating that MVA-BN can be used to boost CTL responses in the presence of a pre-existing immunity to the vector.

2.2.3.: Efficacy of a MVA-BN nef Vaccine in SIV Infected Rhesus Monkeys.

To determine the efficacy of a MVA-BN nef vaccine by assessing the viral load and delay of disease following a challenge with a virulent primary isolate of SIV. Furthermore, the study will determine whether MVA-BN can be used to safely boost immune responses in immuno-compromised monkeys with a pre-existing immunity to MVA.

Vaccination protocols

Two groups (n = 6) of rhesus monkeys (*Macaca mulatta*) were vaccinated with a bolus intramuscular injection with either MVA-BN alone or a recombinant MVA-BN nef at week 0, 8 and 16. On week 22 all monkeys were challenged with 50 MID₅₀ of a pathogenic cell-associated SIV stock (1XC) from primary, uncultured rhesus monkey PBMC by the intravenous route. The clinical status of the animals was frequently monitored and regular blood samples were taken for the measurement of viremia, immune parameters, and a full range of hematology and blood clinical chemistry parameters. Animals were sacrificed that developed AIDS like disease and the surviving monkeys were monitored for 99 weeks post vaccination. At week 100 the surviving monkeys were all immunized i.m. with MVA-BN tat and received further immunizations with the same MVA-BN tat at weeks 102 and 106.

No adverse effects were observed following any of the vaccinations with either MVA-BN or MVA-BN nef. Following the infection of the monkeys with SIV the levels of viremia rose sharply and peaked two weeks post infection (Fig. 4). Due to the large standard deviations within the groups there was no significant difference in the mean levels of SIV between the groups vaccinated with MVA-BN nef or MVA-BN. However, there was a general 10 fold lower SIV load in the group vaccinated with the MVA-BN nef compared to the control (MVA-BN) group. Furthermore, after 35 weeks following infection (the initial observation period) only 1 out of

the six monkeys vaccinated with MVA-BN nef had to be euthanised due to the severity of the disease, compared to 4 out of the 6 animals in the control group (Fig. 5). The development of disease clearly correlated with a higher virus load and as such the animals were observed for an additional 29 weeks post infection. The MVA-BN nef vaccine appeared to delay the progression of the disease, compared to the control group and even at week 46-post infection 5 out of the 6 MVA-BN nef animals survived (Fig. 5). However, by week 59-post infection two further animals in the nef vaccinated group were euthanised leaving five surviving animals (three from the MVA-BN nef group and two vaccinated with MVA-BN). An examination of the antibody titres generated to MVA-BN in these 12 monkeys clearly demonstrated that MVA-BN could boost the immune response even in the presence of a pre-existing immunity to MVA (Fig. 6). Following the primary immunization with either MVA-BN or MVA-BN nef all monkeys generated an antibody response to MVA with a mean titre of 1000. This antibody response was significantly boosted following the secondary immunization, clearly demonstrating that MVA can be used to prime-boost immune response in healthy monkeys. These antibody titres gradually declined, although by week 49 post immunization the titres plateaued, such that the mean titres to MVA at week 99 were 2000.

The five surviving monkeys were SIV infected and immuno-compromised with CD4 counts lower than 400/ μ l blood. To investigate the impact of using MVA-BN in immuno-compromised

monkeys the five animals were vaccination three times with MVA-BN tat at week 100, 102 and 106 post the initial vaccination. The first immunization with MVA-BN tat significantly boosted the antibody response to MVA in these immuno-compromised monkeys that was further boosted with the third immunization six weeks later (Fig. 6). These results further demonstrate that MVA-BN can boost immune responses in the presence of a significant pre-existing immunity to MVA, even in immuno-compromised monkeys. Although the monkeys immune response was boosted following the immunizations with MVA-BN tat the levels of SIV remained stable, indicating that immunizations with MVA-BN are safe and do not affect SIV levels in immuno-compromised monkeys (Fig. 7).

This study has demonstrated that MVA-BN can prime-boost immune responses in immuno-compromised rhesus monkeys and that MVA-BN immunizations are safe and do not affect the levels of viremia in SIV infected animals. The delay in the progression of AIDS like disease in the animals vaccinated with the MVA-BN nef vaccine, indicates that an immune response was successfully generated to nef.

2.2.4.: Therapeutic Vaccination of SIV-Infected Monkeys Undergoing Anti-Retroviral Treatment

An MVA-BN based therapeutic HIV vaccine is likely to be used in individuals undergoing anti-retroviral therapy. Therefore this study investigated the safety (effect on SIV levels) and efficacy of

recombinant MVA's encoding a variety of SIV antigens (gag, pol, env, rev, tat, and nef) in SIV infected monkeys treated with PMPA. PMPA is a nucleoside analogue and is effective against HIV and SIV (Rosenwirth, B. *et al.*, 2000, J Virol 74,1704-11).

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Constructs

All the recombinant MVA constructs were propagated on CEF cells, sucrose purified and formulated in Tris pH 7.4.

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Vaccination Protocol

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Three groups (n = 6) of rhesus monkeys (*Macaca mulatta*) were infected with 50 MID₅₀ of a pathogenic primary SIV isolated (1XC) and then treated daily with PMPA (60 mg/kg given s.c.) for 19 weeks. At week 10, animals were vaccinated with recombinant MVA-BN (i.m.), or saline and received identical vaccinations 6 weeks later. Group 1 received a mixture of MVA gag-pol and MVA-env, group 2 received MVA-tat, MVA-rev and MVA-nef, while group 3 received saline. The clinical status of the animals was frequently monitored and regular blood samples were taken for the measurement of viremia, immune parameters, and a full range of hematology and blood clinical chemistry parameters.

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All animals established high SIV loads that peaked 2 weeks post infection (Fig. 8). Following daily treatment with PMPA the SIV levels decreased and stabilized to low levels by week 9. As in the previous study vaccinations with MVA at week 10 and 16 had no

effect on the SIV levels, indicating that MVA-BN is a safe vaccine vector for immuno-compromised animals. Once the animals came off PMPA treatment (week 21) the SIV levels increased. Although three animals in group 1 had reduced levels of SIV compared to the control group 3, there was no significant difference in the mean SIV load between any of the groups following the end of PMPA treatment (Fig. 8). Using an ELISA to SIV infected T-cell lysates animals in all groups generated an antibody response to SIV by week 4 following infection (Fig. 9). The SIV antibody titre in the control group (saline) dropped during the PMPA treatment and increased rapidly when PMPA treatment stopped, reflecting the drop and subsequent increase in SIV levels during anti-retroviral therapy (Fig. 9). A similar pattern in SIV antibody titre was observed in group 2 that received MVA-tat, MVA-rev and MVA-nef, possibly reflecting the under-expression of these regulatory proteins in the SIV infected T cell lysates used in the ELISA. In contrast however, the anti-SIV antibody titres in group 1 increased following the vaccinations with MVA gag-pol and MVA-env at week 10, indicating that recombinant MVA-BN can boost the immune response to SIV in (SIV) infected animals undergoing anti-retroviral therapy. Importantly, the anti-SIV antibody titres were boosted following the secondary immunization at week 16 again demonstrating that MVA can boost immune responses in immuno-compromised animals, even in the presence of a pre-existing immunity to MVA (Fig. 8). The anti-MVA antibody titres in group 1 also reflected this pattern with the generation of a antibody response

following the primary immunization and this was significantly boosted following the secondary vaccination (Fig. 10).

References

- 5 Schneider, J., Gilbert, SC., Blanchard, TJ., Hanke, T., Robson, KJ., Hannan, CM., Becker, M., Sinden, R., Smith, GL., and Hill, AVS. 1998. Enhanced immunogenicity for CD8+ T cell induction and complete efficacy of malaria DNA vaccination by boosting with modified vaccinia virus Ankara. *Nat. Med.* 4; 397-402.
- 10 Thomson, SA., Sherritt, MA., Medveczky, J., Elliott, SL., Moss, DJ., Fernando, GJP., Brown, LE., and Suhrbier, A. 1998. Delivery of multiple CD8 cytotoxic T cell epitopes by DNA vaccination. *J. Immunol.* 160: 1717.

Table 1:

	CEF	Hela	HaCat	143B	BHK	Vero	CV-1
MVA-BN	579.7 3	0.04	0.22	0.00	65.88	2.33	0.00
MVA-575	796.5 3	0.15	1.17	0.02	131.2 2	10.66	0.06
MVA-HLR	86.68	124.9 7	59.09	0.83	87.86	34.97	29.7 0
MVA-Vero	251.8 9	27.41	1.28	2.91	702.7 7	1416.4 6	4.48

- 5 Virus amplification above the input level after 4 days infection
 Amplification ratio = output TCID₅₀ · input TCID₅₀.
 Values are in TCID₅₀.

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(PCT Rule 13bis)

A. The indications made below relate to the microorganism referred to in the description on page <u>5</u> , line <u>24</u> .	
B. IDENTIFICATION OF DEPOSIT Further deposits are identified on an additional sheet ☐	
Name of depositary institution ECACC European Collection of Cell Cultures	
Address of depositary institution (including postal code and country) Centre for Applied Microbiology & Research Salisbury Wiltshire SP4 0JG, United Kingdom	
Date of deposit August 30, 2000	Accession Number 00083008
C. ADDITIONAL INDICATIONS (leave blank if not applicable) This information is continued on an additional sheet ☐	
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 microorganism be made available only by the issue thereof to an independent expert, in accordance with the relevant patent legislation, e.g., EPC Rule 28 (4); UK Patent Rules 1995, Schedule 2, Paragraph 3; Australian Regulation 3.25(3); Danish Patents Act Sections 22 and 33(3) and generally similar provisions mutatis mutandis for any other designated State.	
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Address of depositary institution (including postal code and country) Centre for Applied Microbiology & Research Salisbury Wiltshire SP4 0JG, United Kingdom	
Date of deposit December 7, 2000	Accession Number 00120707
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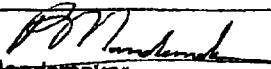
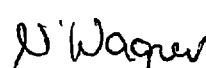
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Name of depositary institution PHLS Public Health Laboratory Service, Centre for Applied Microbiology and Research ECACC European Collection of Cell Cultures, CAMR	
Address of depositary institution (including postal code and country) ECACC European Collection of Cell Cultures, CAMR Porton Down Salisbury, SP4, OJG, UK	
Date of deposit January 27, 1994	Accession Number V94012707
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CLAIMS

- (1) Vaccinia virus having at least one of the following properties:
- (i) capability of reproductive replication in chicken embryo fibroblasts (CEF) and in the baby hamster kidney cell line BHK, but no capability of reproductive replication in the human keratinocyte cell line HaCat,
 - (ii) failure to replicate in vivo,
 - (iii) induction of a higher immunogenicity compared to the known strain MVA 575 in a lethal challenge model and/or
 - (iv) induction of at least substantially the same level of immunity in vaccinia virus prime/ vaccinia virus boost regimes when compared to DNA-prime/ vaccinia virus boost regimes.
- (2) The virus according to claim 1, wherein the virus is not capable of reproductively replicating in any of the following human cell lines: the human embryo kidney cell line 293, the human bone osteosarcoma cell line 143B and the human cervix adenocarcinoma cell line HeLa.
- (3) The virus according to claim 1 or 2 being deposited at the European Collection of Cell Cultures (ECACC), Salisbury (UK) under number V00083008 and derivatives thereof.
- (4) The virus according to anyone of the claims 1 to 3 comprising at least one heterologous nucleic acid sequence.

- (5) The virus according to claim 4, wherein said heterologous nucleic acid sequence is selected from a sequence coding for at least one antigen, antigenic epitope, and/or a therapeutic compound.
- 5
- (6) Genome or functional parts thereof derived from the virus according to anyone of the claims 1 to 5.
- (7) Pharmaceutical composition comprising the virus according to anyone of the claims 1 to 5 and/or the genome and/or functional part thereof according to claim 6 and a pharmaceutically acceptable carrier, diluent and/or additive.
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- (8) Vaccine comprising the virus according to anyone of the claims 1 to 5 and/or the genome and/or functional part thereof according to claim 6.
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- (9) The virus according to anyone of the claims 1 to 5, the genome and/or functional part thereof according to claim 6, the composition according to claim 7 or the vaccine according to claim 8 as drug for affecting, preferably inducing, an immunological response in a living animal, including a human.
- 20
- (10) The virus according to anyone of claims 1 to 5, the pharmaceutical composition according to claim 7, the vaccine according to claim 8 or the virus according to claim 9, wherein the virus, the composition or the vaccine is administered in therapeutically effective amounts in a first
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inoculation ("priming inoculation") and in a second inoculation ("boosting inoculation").

- 5 (11) Use of the virus according to anyone of the claims 1 to 5, and/or the genome according to claim 6, for the preparation of a medicament or a vaccine.
- 10 (12) Method for introducing a homologous and/or a heterologous nucleic acid sequence into target cells comprising the infection of the target cells with the virus according to claim 4 or 5 or the transfection of the target cell with the genome according to claim 6.
- 15 (13) Method for producing a peptide, protein and/or virus comprising
- a) infection of a host cell with the virus according to claims 1 or 5,
- b) cultivation of the infected host cell under suitable conditions, and
- 20 c) isolation and/or enrichment of the peptide and/or protein and/or viruses produced by said host cell.
- 25 (14) Method for affecting, preferably inducing an immunological response in a living animal body including a human comprising administering the virus according to anyone of the claims 1 to 5, the genome and/or functional part thereof according to claim 6, the composition according to claim 7 or

the vaccine according to claim 8 to the animal or human to be treated.

- 5 (15) The method according to claim 14 comprising the administration of at least 10^2 TCID₅₀ (tissue culture infectious dose) of the virus.
- 10 (16) Method according to claim 14 or 15, wherein the virus, the composition or the vaccine is administered in therapeutically effective amounts in a first inoculation ("priming inoculation") and in a second inoculation ("boosting inoculation").
- 15 (17) The method according to anyone of the claims 14 to 16, wherein the animal is immuno-compromised.
- (18) The method according to anyone of the claims 14 to 17, wherein the animal has a pre-existing immunity to poxviruses.
- 20 (19) The method according to anyone of the claims 14 to 18, wherein the animal is undergoing an antiviral therapy.
- (20) The method according to claim 19, wherein the antiviral therapy is an antiretroviral therapy .
- 25 (21) Use of the virus according to anyone of the claims 1 to 5, the genome and/or functional part thereof according to claim 6 as adjuvant.

(22) A method for enhancing a specific immune response against an antigen and/or an antigenic epitope included in a vaccine comprising administration of the virus according to anyone of the claims 1 to 5 or the genome according to claim 6 as an adjuvant to a living animal body including a human to be treated with the vaccine.

(23) The virus according to anyone of claims 1 to 5 or the genome according to claim 6 as adjuvant.

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(24) A cell, preferably a human cell, containing the virus according to any of claims 1 to 5 or the genome or functional part thereof of claim 6.

(25) Method for obtaining the vaccinia virus according to anyone of claims 1 to 3 comprising the following steps:

- introducing a commonly available vaccinia virus strain, preferably MVA 575 into non-human cells in which the virus is able to reproductively replicate, wherein the non-human cells are preferably selected from CEF cells and the cell line BHK,
- isolating/enriching virus particles from these cells and
- analysing whether the obtained virus has at least one of the biological properties as defined in claim 1,

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wherein the above steps can optionally be repeated until a virus with the desired replication characteristics is obtained

(26) Kit for prime/boost immunization comprising a virus according to anyone of claims 1 to 5, a composition according to claim 7, a vaccine according to claim 8 or a virus according to claim 9 for a first inoculation ("priming inoculation") in a first vial/container and for a second inoculation ("boosting inoculation") in a second vial/container.

(27) Use of the virus according to anyone of claims 1 to 5, the composition according to claim 7, the vaccine according to claim 8 or the virus according to claim 9 for the preparation of a vaccine wherein the virus, the composition or the vaccine is administered in therapeutically effective amounts in a first inoculation and in a second inoculation.