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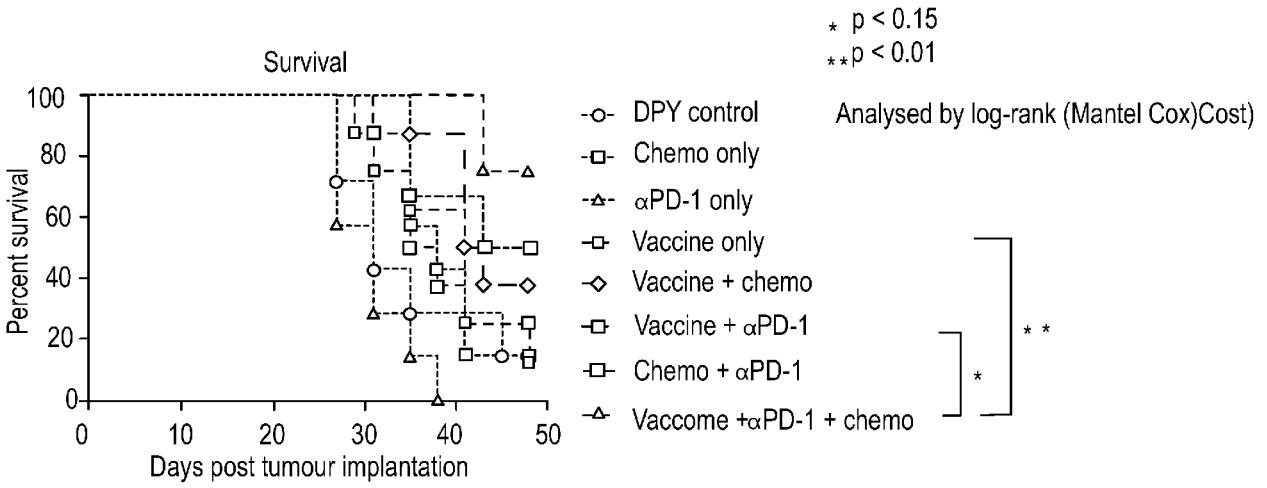

FIG.21

(57) Abstract: Chimpanzee adenovirus (ChAd) and MVA virus vectors containing polynucleotide sequences encoding cancer antigens are administered sequentially to a subject in a suitable adjuvant in order to achieve a prime boost effect. The polynucleotides are expressed in situ following administration to provide a MAGEA3/linker/NY-ESO-1 fusion protein and variants thereof. Also, a hli/MAGEA3/linker/NY-ESO-1 fusion protein and variants thereof. An improved T cell response is found. In a particular synergistic therapeutic approach a triple combination of ChAdOx and MVA vectors together with chemotherapeutic agent and checkpoint inhibitor results in depleted myeloid derived suppressor cells (MDSC) and dramatically improves survival time in a mouse model of cancer.

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VIRAL VECTORS ENCODING CANCER/TESTIS ANTIGENS FOR USE IN A METHOD OF PREVENTION OR TREATMENT OF CANCER

This invention relates to viral vector-based vaccines for the prevention or treatment of cancer, more particularly replication-defective adenovirus (Ad) and Modified Vaccinia Virus Ankara (MVA) vectors comprising a cancer vaccine antigen of interest and for administration to a mammal. The invention therefore concerns the viral particles, immunogenic compositions comprising the viral particles, and host cells containing the viral vectors. The viral vector vaccines are used to treat a subject suffering from a cancer or to prevent a subject from getting a cancer. In a preferred regime the invention involves a prime administration using an Ad vector, followed by a boost administration using an MVA vector. This invention further provides for vaccine compositions comprising the novel replication-defective adenoviral vectors of the present invention.

BACKGROUND

More than 1.6 million Americans are diagnosed with cancer every year, and approximately 600,000 people are expected to die of this disease in 2018 in the United States alone. During the last decades, significant progress has been achieved in the detection, diagnosis, and treatment of cancer. However, still only 67% of people remain alive 5 years after the onset of treatment. (See Siegel, R. L. *et al.* (2017) Cancer J. Clin. 67(1): 7 – 30.)

Current therapeutic options include surgical procedures, radiation, radiofrequency, chemotherapeutics, monoclonal antibodies, etc. Most of these approaches are associated with serious risk, toxic side effects, high cost, and doubtful efficacy.

Cancer immunotherapy though has demonstrated some significant progress in recent years and continues as a developing field of interest. The healthy normal human immune system has an innate capacity to identify and reject tumour cells based on the ability of cytolytic T lymphocytes (CTLs) to recognise tumour-associated antigens (TA). Cancer cells should normally activate an integrated immune response, both cellular and humoral. The cellular response involves $CD8^+$ and $CD4^+$ T cells which participate in the immune response. However, in the genesis of cancer and malignant cancer the normal CTL activity against tumour cells is compromised or lost. Cancer immunotherapy therefore adopts various approaches for restoring or rekindling CTL activity of the human immune system against tumour cells. The immune system of a human cancer patient can be harnessed with the goal of eradicating the malignant cells that express a tumour-associated antigen (TA).

Cytotoxic T cells express CD8 and can specifically kill cancerous cells. $CD4^+$ T cells or T helper cells support the development of the cytotoxic response, produce cytokines, and

also assist in the maturation and proliferation of B cells. During the humoral response, B cells are activated, replicate, differentiate, and produce TA-specific antibodies. For more information, see Murphy, K. & Weaver, C. "Janeway's Immunobiology" 9th Edition (2016): Garland Science/Taylor & Francis: New York, NY.

Adoptive T cell therapies and immune checkpoint modulators are clinical approaches aimed at boosting the ability of the human immune system to reject tumours. However, both approaches have limitations. Adoptive T cell therapy requires expansion and transduction of effector T cells of a required specificity (see Baruch E. N. *et al.* (2017) Cancer 123(S11): 2154 - 62. This complexity currently limits the applicability of this approach. Checkpoint inhibitor treatment, a segment of immune checkpoint modulators, is based on monoclonal antibodies that release brakes on T cells in order to improve their effector functions. Whilst checkpoint inhibitors may induce long-term clinical responses in a fraction of advanced cancer patients, the side effects of autoimmune toxicity caused by this stimulation of all T cells remains a problem. Also, existing checkpoint inhibitor treatments suffer from a lack of efficacy in relation to "cold" tumours which are not infiltrated by T cells.

Another approach representing a promising alternative to the above are cancer vaccines or more specifically therapeutic cancer vaccines which are used to elicit an immune response against tumour cells. This is based on the concept that tumour cells are inherently poorly immunogenic and a vaccine should help serve to overcome this deficiency. Many different types of cancer vaccines have been studied and some have shown promising results. Sahin U. *et al.* (2017) Nature 547(7662): 222 – 226 tried personalized RNA mutanome vaccines which mobilize polyspecific therapeutic immunity against cancer. Also, Ott P. A. *et al.* (2017) Nature 547(7662): 217 - 221 tried personalized immunogenic neoantigen vaccine for patients with melanoma.

However, the potential of cancer vaccines became questionable after failure of several large scale clinical trials, including two large phase III trials by GlaxoSmithKline (GSK). These trials used vaccination approach based on a recombinant tumour-associated protein combined with an adjuvant. This vaccine platform, like many others, had proven to be able to induce good antibody and $CD4^+$ T-helper responses, but was unable to mount consistent CTL responses. Given that CTLs are key effectors of the anti-tumour immune response, this likely explains the clinical failure of those vaccines. A technical challenge is therefore the provision of a new cancer vaccine platform that induces good CD8 responses in humans.

In order to achieve some efficacy, it is believed that a cancer vaccine should have the ability to: i) target antigens that are potentially expressed or expressed solely on cancer

cells and can elicit an integrated immune response; and ii) induce a robust clonal expansion and effector and memory differentiation of antigen-specific T cells (see Coulie, P. G. (2014) Nat. Rev. Cancer, 14(2): 135 – 146.

Traditionally, therapeutic cancer vaccines have comprised a tumour antigen (TA) protein and an adjuvant. For example, the vaccine called Stimuvax (formerly known as BLP25 liposome vaccine (L-BLP25)), is a liposome that encapsulates synthetic peptides derived from the mucin 1 (MUC1) antigen and the adjuvant MPL4, and to which US 6,600,012 (B1) BIOMIRA INC. relates. Also, the MAGRIT vaccine which was assessed in a Phase 3 trial in patients with resected MAGE-A3-positive non-small-cell lung cancer (see Vansteenkiste, J. F. *et al* Lancet Oncol. 17(6): 822 – 835) contained the AS15 adjuvant combined with a recombinant melanoma-associated antigen MAGE-A3 protein. However, as indicated generally above, these Stimuvax and MAGRIT vaccines failed to show efficacy in large phase III trials.

The first "cancer vaccine" to be approved in the United States and Europe is PROVENGE, an autologous cellular vaccine in which patient's antigen presenting cells (APC) are incubated with the prostate acid phosphatase (PAP) antigen. Despite efficacy and an ability to activate proper T cell response, this vaccine requires to be made individually for each patient, thereby involving a complex and expensive manufacturing process. Consequently, the vaccine is of limited practical use. (See US2004/141991 (A1) LAUS *et al.*).

Vector-based cancer vaccines have shown great promise and have generated strong therapeutic interest with several vector technologies, adjuvants and combinations tested in the clinic. The basis for this strategy is to use recombinant viral vectors to deliver tumour antigens. The viral vectors themselves are modified to be replication-defective, and so no longer harmful to patients. The vectors express both the TA as well as other viral antigens that act as adjuvants and potentiate the induction of the immune response. An ideal viral vector should have several properties: i) being safe; ii) enabling efficient antigen presentation; iii) elicit an integrated immune response; and iv) able to be produced on a large scale (see Melief, C. J. M. *et al.* (2015) J. Clin. Invest. 125(9): 3401 – 3412.

Several viral vectors have been proposed for clinical use. For example, replication-defective adenovirus (Ad) have been studied as vaccine vector for infectious diseases such as disclosed in EP 2,130,921 B1 GLAXOSMITHKLINE BIOLOGALS SA for Human Immunodeficiency Virus (HIV)-1 or in US2012/082694 (A1) CRUCELL, for malaria.

In the field of vaccination, vaccine administration is typically followed by one or more boosting injections that are administrated in the same manner as the first injection, but at a later time, or times. During the interval between the first (priming) and the following

(boosting) administrations the immune system responds by eliciting both cellular and humoral response (see Woodland, D. L. (2004) Trends Immunol. 25(2): 98 – 104).

However, repeated administrations with the same vector (homologous boosting) failed to boost tumour antigen-specific T cell responses, because competing immunogenicity is generated against viral antigens, resulting in the production of antibodies that recognized surface antigens of the viral capsid and prevent further infection of antigen-presenting cells by the recombinant vectors. In particular, homologous boosting does not induce CD8 T cells against the inserted tumour antigens. A potential approach to circumvent this problem involves the sequential administration of vaccines that use different antigen-delivery systems such as two different viral vectors (heterologous boosting). EP 2,631,290 (A1) NATIONAL UNIVERSITY CORPORATION discloses a virus vector for prime/boost vaccines which comprises Vaccinia virus vector and Sendai virus vector. Chen, J.-L. *et al.* (2015) Int. J. Cancer 136(6): E590 – 601 describes NY-ESO-1 specific antibody and cellular responses in melanoma patients primed with NY-ESO-1 protein in ISCOMATRIX and boosted with recombinant NY-ESO-1 fowlpox virus.

Many prime/boost vaccines composed of DNA vaccines and various viral vectors have been tried. For example, WO2006/057454 (A1) JAPAN SCIENCE AND TECHNOLOGY AGENCY discloses a heterologous prime/boost HIV vaccine developed against HIV-1 gag E antigen by using a Bacillus Calmette–Guérin (BCG) vector for priming and an attenuated vaccinia virus strain DIs, for boosting. Odunsi, K. *et al.* (2012) Proc. Natl. Acad. Sci. U. S. A. 109(15): 5797 – 5802 describe a limited size phase I study using a prime-boost approach with two different orthopox vectors (vaccinia and fowlpox) and the antigen NY-ESO-1 and showed possible clinical benefits among melanoma and ovarian cancer patients.

Human adenoviruses are widely used by scientists for the development of cancer vaccines because of their properties (e.g. replication-deficiency, stability, high immunogenicity, ability to transduce numerous cell types, etc.). Natural adenoviral infection is endemic in the human population and a majority of humans seroconvert within the first five years of life. Thus, cancer vaccines derived from human adenoviruses will encounter pre-existing humoral and cellular immunity which will limit its efficacy (see Coughlan, L. (2015) *et al.* J. Pharm. Pharmacol. 67(3): 382 – 399 and US 6,140,087 ADVEC INC entitled "Adenovirus Vectors for Gene Therapy").

US 9,714,435 (B2) ISIS INNOVATION entitled "Simian Adenovirus and hybrid Adenoviral vectors" and EP 2,163,260 (A2) ISTITUTO RICHERCHE DI BIOLOGICA MOLECULARE entitled "Chimpanzee Adenovirus Vaccine Carriers" explain how scientists have developed replication-defective adenoviruses derived from non-human primates, that evade any pre-

existing immunity in humans. Chimpanzee adenovirus (ChAd) shows several qualities: i) robust immunogenicity; ii) low seroprevalence in humans; iii) standardized manufacturing production.

Also known is an attenuated non-replicative vaccinia virus Ankara strain (MVA). This viral vector has been shown to elicit an immune response with an excellent safety profile. MVA has been attenuated by more than 570 passages in chicken embryo fibroblasts with a consequent loss of approximately 15% of its genome. Thus, MVA lacks the ability to mature virions in many mammalian cells and is associated with a strong immunogenicity and reduced risk of amplification. WO2011/128704 of Isis Innovation Limited describes a pox virus expression system, including MVA, in which a transgene is inserted into a poxvirus genome and therefore provides poxvirus vectors and uses of this to transfer genes of interest into a target cell for the purposes of vaccines against infection, cancer treatment and gene therapy. There is also EP 2044947 A1 of Isis Innovation Limited which describes MVA viral vectors used for inducing immune responses, particular T cell immune responses against influenza virus.

Aiming a cure for infectious diseases, viral vector-based vaccines in a heterologous prime-boost regime have been developed and optimised to induce strong CTL responses. This vaccine strategy employed a chimpanzee adenovirus (ChAd) for prime and boost with Modified Vaccinia Ankara (MVA) carrying the same immunogen. Coughlan L. *et al.* (2015) J. Pharm. Pharmacol. 67(3): 382 – 99 and Hui E. P. *et al.* (2013) Cancer Res. 73(6): 1676 – 88 report on the individual testing of both viral vectors in preclinical and clinical studies in infectious disease settings and how they have a very high safety profile.

EP 2,044,947 (A1) ISIS INNOVATION discloses vaccines with an adenovirus vector for priming and then MVA for boosting in the prevention of influenza.

Ewer K. J. *et al.* (2013) Nat. Commun. 4: 2836 and Ogwang, C. *et al.* (2015) Sci. Transl. Med. 7(286): 286re5 discloses vaccines with ChAd as priming and MVA as boosting for malaria.

The same prime-boost approach has been described in Cappuccini, F. *et al.* (2017) Oncotarget 8(29): 47474 – 47489 in a cancer mouse model expressing 5T4 antigen, and in Cappuccini, F. *et al.* (2016) Cancer Immunol. Immunother. CII 65(6): 701 – 713 where a cancer mouse model expressed STEAP1 which is a prostate cancer antigen. In all these studies, the heterologous prime-boost vaccine induced a strong immune response toward TA and the activation of antigen-specific $CD8^+$ T cells.

There is also WO2017/120670 A1 (Lichty, B. & Bell, J.) which describes co-administration of a replicative oncolytic rhabdovirus and an immune checkpoint inhibitor in clinically

relevant cancer models results resulting in a stimulation of antigen-specific T lymphocytes and significant survival. Oncolytic rhabdovirus specifically infects, replicates in, and kills malignant cells leaving normal tissues unaffected. The oncolytic rhabdovirus (e.g. VSVdelta5 I or Mamba MG 1) expresses a tumor antigen to which the test animal has a preexisting immunity selected from MAGEA3, Human Papilloma Virus E6/E7 fusion protein, human Six-Transmembrane Epithelial Antigen of the Prostate protein, or Cancer Testis Antigen.

A successful therapeutic cancer vaccine will need to target tumour antigens that are expressed on tumours but not on normal tissues. Cancer-germline antigens are an heterologous group of proteins that are physiologically expressed in several types of cancer, but not in differentiated, normal tissues, except for germline cells that are incapable to present antigens to the immune system due to the lack of MHC I molecules. These antigens are encoded by cancer-germline genes. NY-ESO-1 and MAGE-A3 are prototypical MAGE-type antigens being two of the most representative of the group as described in Gnjatic, S. *et al.* (2006) Cancer Res. 95: 1 – 30. Also, Coulie P. G. *et al.* (2014) *supra* which describes responses shown to occur in a number of patients.

BRIEF SUMMARY OF THE DISCLOSURE

In accordance with the present invention there is provided a chimpanzee adenovirus (ChAd) vector encapsidating a nucleic acid molecule, the nucleic acid molecule comprising a polynucleotide sequence encoding (i) a MAGE cancer antigen and/or NY-ESO-1 cancer antigen, or immunogenic fragments thereof; or (ii) a MAGE cancer antigen and/or LAGE1 cancer antigen, or immunogenic fragments thereof, operably linked to expression control sequences which direct the translation, transcription and/or expression of the cancer antigen or fragment thereof in an animal cell, and an adenoviral packaging signal sequence. Advantageously such ChAd viral vectors are stable and well-studied, not neutralized by antibodies to human adenovirus and are engineered to be replication deficient. They have high capacity for inserted antigens of interest and can be produced in HEK293 cells containing the adenoviral E1 gene.

MAGE-type antigens are tumour-specific shared human tumour antigens known to induce CD8 T cells in cancer patients. They are expressed in many cancer types and are not expressed in normal tissues, except for male germline cells which have no MHC-1 molecules.

NY-ESO-1 (gene name *CTAG1*) induces a strong CD8 response in many cancer patients and numerous CD8 epitopes can be identified, as presented by multiple HLA class I specificities.

In a particular form the ChAd vector may be (a) ChAdOx1 as disclosed in WO2012/172277; preferably encoded by a polynucleotide of SEQ ID NO: 38 as disclosed in WO2012/172277 or a sequence of at least 80% identity therewith; or (b) ChAdOx2 as disclosed in WO2017/221031; preferably encoded by a polynucleotide of SEQ ID NO: 10 as disclosed in WO2017/221031 or a sequence of at least 80% identity therewith.

Also provided by the invention is a modified vaccinia virus Ankara (MVA) vector encapdisating a nucleic acid molecule, the nucleic acid molecule comprising a polynucleotide sequence encoding (i) a MAGE cancer antigen and/or NY-ESO-1 cancer antigen, or immunogenic fragments thereof; or (ii) a MAGE cancer antigen and/or LAGE1 cancer antigen, or immunogenic fragments thereof, operably linked to expression control sequences which direct the translation, transcription and/or expression of the cancer antigen or fragment thereof in an animal cell. Advantageously, such MVA vectors are not able to replicate in humans and have a long safety track record as smallpox vaccines. MVA provides excellent boosting after priming with ChAd. MVA has no virulence and immune system evasion factors and is highly immunogenic and is readily produced in chicken embryonic fibroblasts or immortalized duck embryonic cell lines.

An MVA vector in more particular form may be as disclosed in WO2011/128704 or EP 2044947 A1.

For the ChAd and/or MVA vectors of the invention as herein described, the MAGE antigen is preferably MAGE3A and as such has an amino acid sequence of SEQ ID NO: 1 or a sequence of at least 46%; preferably at least 69%; more preferably at least 95% identity therewith; or any immunogenic fragment thereof.

For the ChAd and/or MVA vectors of the invention as herein described, the NY-ESO-1 cancer antigen has an amino acid sequence of SEQ ID NO: 3 or a sequence of at least 75%; preferably at least 76.7% identity therewith; or any immunogenic fragment thereof.

For the ChAd and/or MVA vectors of the invention as herein described, the LAGE1 antigen has an amino acid sequence of SEQ ID NO: 5, or a sequence of at least 78%; preferably at least 97% identity therewith; or any immunogenic fragment thereof.

In preferred ChAd and/or MVA vectors of the invention, the polynucleotide sequence may further encode a human HLA class II histocompatibility antigen gamma chain (hli or Ii), and Ii may have an amino acid sequence of SEQ ID NO: 6 or a sequence of at least 79% identity therewith, or a fragment thereof, so that the cancer antigen is expressed in an

animal cell as a fusion with Ii or fragment thereof; more preferably wherein the fragment is a transmembrane domain; even more preferably wherein the transmembrane domain comprises amino acid residues 30 to 55 or 30 to 61. In a particularly preferred embodiment the transmembrane domain has the amino acid sequence of SEQ ID NO: 7.

In alternatively preferred ChAd and/or MVA vectors of the invention, the polynucleotide sequence may further encode tPA which has an amino acid sequence of SEQ ID NO: 8 or a sequence of at least 81% identity therewith, or a fragment thereof; so that the cancer antigen is expressed in an animal cell as a fusion with tPA or a fragment thereof; more preferably wherein the fragment comprises a 21 amino acid leader sequence; even more preferably the 21 amino acid leader sequence is SEQ ID NO: 9.

Advantageously, the inclusion of Ii or tPA increases immunogenicity of the viral vector produced antigen. This increases the magnitude, breadth and duration of antigen-specific T cell response.

A ChAd vector of the invention may be constructed so that it has a polynucleotide sequence encoding (i) a MAGE cancer antigen or immunogenic fragment thereof and a NY-ESO-1 cancer antigen or immunogenic fragment thereof, each as herein defined; or (ii) a MAGE cancer antigen or immunogenic fragment thereof and a LAGE1 cancer antigen or immunogenic fragment thereof, each as herein defined, expressed in an animal cell as a fusion protein.

An MVA vector of the invention may be constructed so that it has a polynucleotide sequence encoding (i) a MAGE cancer antigen or immunogenic fragment thereof and/or an NY-ESO-1 cancer antigen or immunogenic fragment thereof each as herein defined; or (ii) a MAGE cancer antigen or immunogenic fragment thereof and/or a LAGE1 cancer antigen or immunogenic fragment thereof each as herein defined, expressed in an animal cell as a fusion protein, wherein at least one of the MAGE cancer antigen, NY-ESO-1 cancer antigen or LAGE1 cancer antigen is a fragment.

The inventors believe that NYESO-1 may be more immunogenic than MAGEA3 in humans. Also, in cancer patients, in certain groups of these, tumours are found more frequently to express MAGEA3 and not NY-ESO-1. Therefore, a possible concern might be in having an MVA boost vector in a prime-boost regimen of the present invention, comprising both MAGEA3 and NY-ESO-1 antigens leading to an immunodominant immune response to NY-ESO-1 and ineffective immunization against MAGEA3. Therefore, at least for such particular patient groups, or groups with higher expression of MAGEA3 compared to NY-ESO-1, an MVA vector comprising just MAGEA3 cancer antigen or immunogenic fragment thereof is preferred in the prime-boost regimen. That is to say, in certain embodiments, the invention does not include an MVA vector comprising

any NY-ESO-1 cancer antigen or immunogenic fragment thereof. In a similar way, in certain embodiments, the invention does not include an MVA vector comprising any LAGE1 cancer antigen or immunogenic fragment thereof.

In preferred embodiments each of MVA vector, each of the MAGE cancer antigen and NY-ESO-1, or MAGE cancer antigen and LAGE1 are immunogenic fragments.

Where the ChAd and/or MVA vectors of the invention are constructed to yield fusions of antigens on expression, the polynucleotide sequence preferably also encodes a suitable polypeptide linker of between 5 and 9 amino acids; more preferably having the amino acid sequence GGGPGGG, which when expressed links the MAGE and NY-ESO-1 or LAGE1 cancer antigens or fragments thereof, in either order, as a fusion protein.

The invention therefore also provides an immunogenic composition comprising a ChAd or MVA vector as hereinbefore and as herein described. Such compositions may further comprise a suitable adjuvant.

The invention further provides an isolated polynucleotide comprising a sequence encoding a fusion protein contained in a ChAd vector or an MVA vector as herein described.

A preferred polynucleotide comprises the nucleic acid sequence SEQ ID NO: 10 encoding a MAGEA3/linker/NY-ESO-1 fusion protein. Also possible are polynucleotides having sequences of at least 70% identity with SEQ ID NO: 10. The translated protein sequence of 501 amino acids is as set forth in SEQ ID NO: 11 or a sequence of at least 70% identity therewith.

Another preferred polynucleotide has the nucleic acid sequence SEQ ID NO: 12 encoding a hli/MAGEA3/linker/NY-ESO-1 fusion protein. Also possible are polynucleotides having sequences of at least 70% identity with SEQ ID NO: 12. The translated protein sequence is set forth in SEQ ID NO: 13 or a sequence of at least 70% identity therewith.

Yet another preferred polynucleotide has the nucleic acid sequence SEQ ID NO: 14 encoding tPA/MAGEA3/linker/NY-ESO-1 fusion protein. Also possible are polynucleotides having sequences of at least 70% identity with SEQ ID NO: 12. The translated protein sequence is set forth in SEQ ID NO: 15 or a sequence of at least 70% identity therewith.

In particular embodiments the isolated polynucleotide consists of any of the aforementioned sequences or variants thereof.

In all aspects of the invention, the polynucleotides encoding the antigens are preferably codon optimised for expression in humans. A person of skill in the art will be familiar with a number of available software packages, including for example those described in US Patent No. 8,326,547, or Puigbo, P. et al. (2007) OPTIMIZER: A web server for optimizing

the codon usage of DNA sequences: Nucleic Acids Research, 35:W126-W131. Also, commercially available services and software such as those offered by Integrated DNA Technologies or GenScript.

The invention also includes a Bacterial Artificial Chromosome (BAC) clone comprising a polynucleotide as described herein. Converting the BAC clones of the viral genomes into viruses ("rescue") can be carried out by a well-known process, as described in WO2012/172277 of Isis Innovation Limited, incorporated herein by reference.

The invention further includes an isolated host cell comprising a ChAd and/or MVA vector as described herein.

Also, the invention provides a method of preventing or treating cancer in an individual, comprising administering an effective amount or a ChAd vector as described herein, and administering an effective amount of an MVA vector as described herein, whereby the adaptive immune system of the individual is stimulated to provide an anti-cancer immune response. Advantageously the method of the invention generates a strong T cell immune response, particularly a strong $CD8^+$ immune response leading to protective immunity which is long lasting.

In a preferred method of preventing or treating cancer in accordance with the invention, the administration of the ChAd and MVA vectors is carried out separately, sequentially or simultaneously.

In particular methods of preventing or treating cancer in accordance with the invention, there is the further administration of an effective amount of one or more immune checkpoint modulators. Such checkpoint modulators may be administered simultaneously, separately or concurrently with the ChAd and MVA vectors.

In the method of preventing or treating cancer aspects of the invention, an individual who is being treated may be one who has received, is receiving or will receive a chemotherapy and/or radiotherapy treatment.

In the methods of preventing or treating cancer in accordance with the invention, the ChAd vector is preferably administered first.

In the cancer prevention or treatment methods of the invention, the ChAd and MVA vectors may be administered more than once each. In preferred aspect when the ChAd is used as a priming immunization then there is just one of these, followed by two MVA booster immunizations. Also possible is methods of cancer treatment or prevention in which the ChAd and MVA vectors are administered in alternation.

The period of time between each administration of a vector of the invention may be in the range 5 days to 8 weeks; preferably though a period of about 1 week is used between prime and subsequent boost or boosts.

In cancer prevention or treatment methods of the invention where a checkpoint modulator is administered and also forms part of the treatment regimen, the checkpoint modulator may be an inhibitor that blocks PD-1, CTLA-4 or PD-L1. Advantageously, using the vectors and immunogenic compositions of the invention together with one or more checkpoint modulators can serve to reduce the dosage of checkpoint modulators needed for equivalent effect (i.e. when used alone). The effect is not simply additive but synergistic as between the viral vector treatment regimen of the present invention and checkpoint modulators.

Particularly preferred checkpoint modulators may be selected from nivolumab (Opdivo®), pembrolizumab (Keytruda®), ipilimumab (Yervoy®), tremelimumab or atezolizumab (Tecentriq®), durvaliumab (Imfinzi®) or avelumab (Bavencio®).

Methods of preventing or treating cancer in accordance with the invention are directed to cancers expressing cancer-germline genes, preferably genes coding MAGE-type, NYESO, and LAGE antigens: preferably directed to particular cancer types, e.g. wherein the cancer is non-small cell lung cancer (NSCLC), melanoma, Hodgkin lymphoma, non-Hodgkin lymphoma, urinary tract (urothelial), esophageal, bladder, small cell lung cancer, renal, head & neck, sarcoma, or breast.

Accordingly, the invention includes a ChAd vector of the invention for use in the prevention or treatment of cancer. Also, an MVA vector of the invention for use in the prevention or treatment of cancer. In respect of such use, each of the various aspects of the method of the invention applies equally.

Further, the invention includes a ChAd vector of the invention as herein defined, and an MVA vector of the invention as herein defined, for separate, sequential or simultaneous administration to a patient for the prevention or treatment of cancer.

ChAd and MVA vectors for use in prevention or treatment of cancer as herein defined, may further including one or more modulators of cancer-immunity cycle or cancer-immunity set-points as described in Chen, D.S. and Mellman, I. (2013) Immunity 39(1):1-10, and Chen, D.S. and Mellman, I. (2017) Nature 541(7637):321-330; preferably checkpoint inhibitors for administration with the ChAd and MVA vectors for the treatment of cancer.

A large proportion of patients with advanced cancer currently do not respond to immunotherapy based on checkpoint modulators. For example, where an anti-PD1 inhibitor is used in melanoma, renal cell carcinoma, head & neck carcinoma and lung

carcinoma. In one aspect the invention uses a ChAd/MVA vaccine to induce CD8 T cells against MAGE-A3 and NY-ESO-1 in combination with anti-PD1 and chemotherapy. Without wishing to be bound by any particular theory, the inventors expect that what would otherwise be "cold" tumours become infiltrated by tumour-specific CD8 T cells that will be boosted by the anti-PD1.

The inventors have also found that a triple combination of vaccine in accordance with the invention, plus chemotherapeutic agent, plus checkpoint inhibitor provides a significantly improved anti-tumour effect, and significant survival times of mice in a mouse model, when compared to vaccine alone or vaccine plus chemotherapeutic agent or vaccine plus checkpoint inhibitor. Indeed the effect of the triple combination is such that it is synergistic. There is a significant depletion of myeloid derived suppressor cell (MDSC) achieved with the triple combination. The invention therefore also provides such a triple combination method of treatment and corresponding medical use. Also the invention provides a ChAd vector as hereinbefore defined, an MVA vector as hereinbefore defined, a chemotherapeutic agent, and a checkpoint inhibitor, for separate, sequential or simultaneous administration to a patient for the prevention or treatment of cancer.

The chemotherapeutic agent may be selected from (but not limited to) (a) carboplatin or cisplatin in combination with (b) one of paclitaxel, docetaxel, vinorelbine, gemcitabine, etoposide or pemetrexed. For the checkpoint inhibitor this may be PD-1. Such particular triple combinations may provide useful treatments for non-small cell lung cancer (NSCLC) or small cell lung cancer (SCLC) melanoma, Hodgkin lymphoma, non-Hodgkin lymphoma, urinary tract (urothelial), bladder, renal, head & neck, sarcoma or breast cancer.

Also provided as part of the invention are kits comprising ChAd and/or MVA vectors as herein described for the prevention or treatment or cancer. Such kits comprise at least one container which holds one of the ChAd and/or MVA vectors of the invention. Kits may comprise two or more, i.e. a multiplicity of containers, each with a different viral vector of the invention. Kits may include a set of instructions in the use of the vectors as a vaccine, including essential information on the vaccine regimen to be used, e.g. prime-boost, and periods between administrations. In more complex embodiments the kits may comprise any of the further therapeutic elements, e.g. checkpoint modulators, in accordance with the invention described herein.

BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments of the invention are further described hereinafter with reference to the accompanying drawings, in which:

Figure 1A shows schematically ChAdOx1 vectors which were prepared encoding mouse P1A antigen.

Figure 1B shows a schematic outline of the ChAdOx1-P1A/MVA-P1A prime-boost immunization of mice from which peripheral blood mononuclear cells (PBMCs) are taken and tested for immune responses.

Figure 2 shows the results of $CD8^+$ T cell response in mice immunized with ChAdOx1/MVA viral vectors encoding P1A, as noted in Figure 1.

Figure 3 shows a schematic outline of the ChAdOx1-P1A/MVA-P1A prime-boost prophylactic vaccination of mice DBA/2 mice against challenge with the syngeneic P1A-expressing cancer cell lines, P815 and 15V4T3.

Figure 4 shows the mean P815 tumour growth over time following prime-boost vaccination of mice as noted in Figure 3 for three P1A antigens versus a phosphate buffered saline (PBS) control.

Figure 5 shows Kaplan-Meier survival curves for the vaccinated mice noted in Figure 4.

Figure 6A shows the mean 15V4T3 tumour growth over time following prime-boost vaccination of ChAdOx1-IiP1A/MVA-P1A, or immunization with the cell line L1210.P1A.B7.1 of mice as noted in Figure 3 versus a phosphate buffered saline (PBS) control.

Figure 6B shows Kaplan-Meier survival curves for the vaccinated mice noted in Figure 6A.

Figure 7 shows schematically the vaccination scheme for testing the prime-boost PIA vaccine in mice in a therapeutic setting, involving rejection of established tumours.

Figure 8A shows the tumour volume growth over time post-vaccination with different ChAdOx1-P1A/MVA-P1A prime-boost vaccination regimes in DBA/2 mice in a therapeutic setting against challenge with the P1A-expressing syngeneic cancer line 15V4T3.

Figure 8B shows mean tumour growth by day 25 following the prime boost vaccination scheme (single prime-boost, high dose (10^8 ChadOx/10^7MVA).

Figure 8C shows Kaplan-Meier survival curves for the vaccinated mice noted in Figure 8.

Figure 9 shows the vaccination scheme used in the experiment to show the effect of combining the prime-boost vaccination of ChAdOx1-IiP1A/MVA-P1A with an anti-PD1 checkpoint inhibitor treatment in a therapeutic setting in mice.

Figure 10 shows tumour volume growth over time for ChAdOx1-IiP1A/MVA-P1A prime-boost vaccination regime in combination with immune checkpoint inhibitors, in DBA/2 mice against challenge with the P1A-expressing syngeneic cancer line 15V4T3.

Figure 11 shows Kaplan-Meier survival curves for the vaccinated mice in Figure 10.

Figure 12 shows a schematic outline for an experiment where outbred CD1 mice are vaccinated with viral vectors encoding MAGE-A3 (M) and NY-ESO-1 (NY) proteins and then the $CD8^+$ T cell responses are determined.

Figure 13 shows induction of CD8 T cells (as measured by IFNγ production) as a result of immunization of outbred CD1 mice with ChAdOx-MAGEA3/NY-ESO-1 fusion, with and without invariant chain Ii or tPA. Isolated PBMCs following immunization were stimulated *ex vivo* with overlapping MAGEA3 or overlapping NY-ESO-1 peptides.

Figure 14 shows the same as in Figure 13 plus the results of immunisation with a boost of MVA-MAGEA3 with or without tPA.

Figure 15 shows the same as in Figure 13 plus the results of immunisation with a boost of MVA-NY-ESO-1 with or without tPA.

Figure 16A shows the MAGE-A3 and NYESO specific responses in PBMCs after prime with ChAdOx-M-NY, ChAdOx-tPA-M-NY or ChAdOx-Ii-M-NY, and boost with MVA-M, MVA-NY MVA-tPA-M, or MVA-tPA-NY vectors.

Figure 16B shows the MAGE-A3 and NYESO specific responses in PBMCs after second boost with either MVA-M,MVA-NY MVA-tPA-M, or MVA-tPA-NY vectors.

Figure 17A shows induction of CD8 T cell responses against MAGE-A3 and NYESO in outbred CD1 mice after the immunization with ChAdOx-Ii-MAGEA3/NY-ESO-1 fusion, and boost with MVA-M, MVA-NY, MVA-tPA-M, or MVA-tPA-NY vectors.

Figure 17B shows the MAGE-A3 and NYESO-specific responses after second boost with MVA-M, MVA-NY, MVA-tPA-M, or MVA-tPA-NY vectors.

Figure 18 shows the time lines of 15V4T3 cell injections into mice and subsequent treatment points in each of 8 experimental groups of mice.

Figure 19 shows a graph of the mean tumour growth results of the experiments shown in Figure 18. Results are analysed by 2-way ANOVA. * = $p < 0.05$. ** = $p < 0.01$. *** = $p < 0.001$. **** = $p < 0.0001$.

Figure 20 shows graphs of tumour volume over time of tumour post-implantation, for each of the 8 experimental groups of mice.

Figure 21 shows Kaplan Meier survival plots for each of the 8 experimental groups of mice. Data was analysed by log-rank (Mantel-Cox) test. * = $p < 0.05$. ** = $p < 0.01$.

Figure 22 is a chart showing the IFNγ response of CD8 cells on bleed at day 27 of the 8 experimental groups of mice

Figure 23 shows the time lines of a repeated experiment of 15V4T3 cell injections into mice and subsequent treatment points in each of 8 experimental groups of mice.

Figure 24 shows graphs of the proportion of $CD45^+$ cells which are (a) CD11b, (b) $CD11b^+$ and $GR1hi^+$; or (c) CD11b and $GR1int^+$, for certain experimental treatments and controls.

Figure 25 shows graphs of the proportion of $CD45^+$ cells which are (a) CD11c, and (b) $CD11b^+$ and $CD11c^+$, for certain experimental treatments and controls.

Figure 26 shows the time line of vaccinations for PBS control, αPD1 only, and two test groups of mice (1) a low dose one week apart prime boost (ChAdOx1-li-P1A + MVA-tPA-P1A) and (2) a low dose one week apart prime boost (ChAdOx1-li-P1A + MVA-tPA-P1A) + αPD1.

Figure 27 shows the mean tumour volume over time for each of the experimental mice and controls shown in Figure 26.

Figure 28 is a chart showing the tumour mass for each of the experimental mice and controls shown in Figure 26.

Figure 29 are graphs of tumour growth rate data for each individual animal for each of the control and experimental groups as shown in Figures 25 to 28.

Figure 30 is a chart showing the proportion of tumour infiltrating lymphocytes (TILs) as a proportion of total cells in tumours in each experimental and control group of mice.

Figure 31 is a chart showing the ratio of CD4:CD8 T cells in each of the experimental and control groups of mice.

Figure 32 shows charts of the ratio of the ratio of $CD4^+$:$CD8^+$ TILs in tumours in each of the experimental and control groups of mice (left hand chart); and the percentage of T cells which are $CD8^+$ cells (right hand chart).

Figure 33 is a chart showing the absolute number of $CD3^+$ $CD8^+$ TIL counts in each of the control and experimental mice groups.

Figure 34 is a chart showing the absolute $P1A_{35-43}$ $tetramer^+$ $H\text{-}2L^d$ $CD8^+$ TIL counts in each of the control and experimental mice groups.

Figure 35 is a diagram showing the correlation between P1A-specific $CD8^+$ TIL infiltrate and tumour mass at harvest.

Figure 36 is a chart showing the CD8 response in blood of mice.

Figures 38 – 40 are charts of data showing the CD8 response in spleen of mice.

Figures 41 – 43 are bar charts of data showing T cell subset analysis. The legend to Figure 43 applies to Figures 41 and 42.

Figures 44 and 45 are bar charts of data showing further T cell subset analysis. The legend to Figure 45 applies to Figure 44.

Figure 46 shows further data of T cell-subset analysis.

Figure 47 shows charts of data for PD1 expression on T cells.

Figure 48 shows further data for PD1 expression on T cells.

Figure 49 shows further data for PD1 expression on T cells.

Figure 50 shows a chart of data for PD1 expression on P1A-specific T cells.

Figure 51 – 53 show charts of further data for PD1 expression on P1A-specific T cells.

DETAILED DESCRIPTION

Suitable chimpanzee adenoviral vectors for use in accordance with the present invention are described in detail in WO2012/17277 Isis Innovations Limited, or WO 2005/071093 Istituto di Ricerche di Biologia Molecolare P. Angeletti S.p.A, or WO2017/221031 of Oxford University Innovation Limited, all of which are incorporated herein by reference.

Particularly preferred adenoviral vectors are the chimpanzee adenovirus Oxford 1 and 2 (ChAdOx1 and ChAdOx2) of Vaccitech Ltd, Oxford. ChAdOx1 is a replication-defective E1/E3 deleted chimpanzee adenovirus vector from wild-type isolate Y25 (species human adenovirus E) and is described in Dicks M.D. *et al.* (2012) PLoS ONE 7: e40385. ChAdOx2 is an E1/E3-deleted vaccine vector derived from ChAd68 with a modified E4 region to increase virus yields in HEK293 cells.

The ChAd vector of the invention may be (a) ChAdOx1 as disclosed in WO2012/172277; preferably encoded by a polynucleotide of SEQ ID NO: 38 as disclosed in WO2012/172277 or a sequence of at least 80% identity therewith; or (b) ChAdOx2 as disclosed in WO2017/221031; preferably encoded by a polynucleotide of SEQ ID NO: 10 as disclosed in WO2017/221031 or a sequence of at least 80% identity therewith. The skilled person will understand that ChAd vectors used in the invention may include homologues, equivalents and derivatives of all of the nucleic acid sequences, as further described herein.

Suitable Modified Vaccinia Ankara (MVA) vectors for use in accordance with the present invention are described in detail in WO2011/128704 or EP 2044947 A1, each of which are incorporated herein by reference.

The cancer antigens, whether separate or in the form of fusions with each other and optionally other polypeptides, as encoded by and expressed by any of the viral vectors of the invention are preferably immunogenic as defined herein, and this includes fragments of cancer antigens and their fusions with each other and other polypeptides.

As used herein, "antigen" generally equates with one or more epitopes of a protein or polypeptide, including fusions and fragments and variants thereof. Such fragments and variants may retain essentially the same biological activity or function as the parent antigen. By "antigenic" is usually meant that the protein or polypeptide or fragment is capable of being used to raise antibodies or T cells and so is capable of inducing an antibody or T cell response in a subject. "Immunogenic" means that a protein or polypeptide or fragment is capable of eliciting a potent and preferably a protective immune response in a subject. Thus, in the latter case, the protein or polypeptide or fragment may be capable of generating an antibody response and a non-antibody based immune response.

As used herein, whenever there is reference to a nucleic acid sequence having identity to a reference sequence, then the degree of identity may be selected from any of the following, wherein the "at least" applies to each percentage figure listed here: at least 46%, 47%, 48%, 49%, 50%, 51%, 52%, 53%, 54%, 55%, 56%, 57%, 58%, 59%, 60%, 61%, 62%, 63%, 64%, 65%, 66%, 67%, 68%, 69%, 70%, 71%, 72%, 73%, 74%, 75%, 76%, 77%, 78%, 79%, 80%, 81%, 82%, 83%, 84%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 98.1%, 98.2%, 98.3%, 98.4%, 98.5%, 98.6%, 98.7%, 98.8%, 98.9%, 99%, 99.1%, 99.2%, 99.3%, 99.4% 99.5%, 99.6%, 99.7%, 99.8% or 99.9%. When comparing nucleic acid sequences for the purposes of determining the degree of homology or identity one can use programs such as BESTFIT and GAP (both from the Wisconsin Genetics Computer Group (GCG) software package). BESTFIT, for example, compares two sequences and produces an optimal alignment of the most similar segments. GAP enables sequences to be aligned along their whole length and finds the optimal alignment by inserting spaces in either sequence as appropriate. Suitably, in the context of the present invention, when discussing identity of nucleic acid sequences, the comparison is made by alignment of the sequences along their whole length. The above applied *mutatis mutandis* to all nucleic acid sequences disclosed in the present application.

Additionally, the skilled person will also appreciate that variation from the particular nucleic acid molecules exemplified herein will be possible in view of the degeneracy of the genetic code. Preferably, such variants have substantial identity to the nucleic acid sequences described herein over their entire length.

Having regard to any amino acid sequence described in connection with the present invention, this includes variants of these amino acid sequences. As will be well known to a person of skill in the art, for a given starting or reference sequence disclosed herein, one or more amino acid residues may be substituted, deleted or added in any combination. Preferred as changes are silent substitutions, additions and deletions, which do not alter the properties and activities of the protein of the present invention. Various amino acids have similar properties, and one or more such amino acids can be substituted by one or more other such amino acids without eliminating a desired immunogenicity or other activity of that substance. Thus, amino acids glycine, alanine, valine, leucine and isoleucine can often be substituted for one another – they have aliphatic side chains. Of these glycine and alanine are preferable used to substitute each other. Also, valine, leucine and isoleucine may be used to substitute for each another - they have larger aliphatic side chains which are hydrophobic). Phenylalanine, tyrosine and tryptophan may substitute for each other – being amino acids having aromatic side chains. Lysine, arginine and histidine may substitute for each other – being amino acids having basic side chains. Aspartate and glutamate may substitute for each other - having acidic side chains. Asparagine and glutamine may substitute for each other – having amide side chains). Cysteine and methionine may substitute for each other – having sulphur-containing side chains.

"Variants" as described herein include naturally occurring or artificial variants. Artificial variants may be generated using mutagenesis or gene engineering or gene editing techniques, including those applied to nucleic acid molecules, cells or organisms. As used herein, whenever there is reference to an amino acid sequence having identity to a reference sequence, then the degree of identity may be selected from any of the following, wherein the "at least" applies to each percentage figure listed here: at least 46%, 47%, 48%, 49%, 50%, 51%, 52%, 53%, 54%, 55%, 56%, 57%, 58%, 59%, 60%, 61%, 62%, 63%, 64%, 65%, 66%, 67%, 68%, 69%, 70%, 71%, 72%, 73%, 74%, 75%, 76%, 77%, 78%, 79%, 80%, 81%, 82%, 83%, 84%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95% 96%, 97%, 98%, 98.1%, 98.2%, 98.3%, 98.4%, 98.5%, 98.6%, 98.7%, 98.8%, 98.9%, 99%, 99.1%, 99.2%, 99.3%, 99.4% 99.5%, 99.6%, 99.7%, 99.8% or 99.9%. A person of skill in the art may use a program such as the CLUSTAL program to compare amino acid sequences. This program compares amino acid sequences and finds the optimal alignment by inserting spaces in either sequence as appropriate. It is possible to calculate amino acid identity or similarity (identity plus conservation of amino acid type) for an optimal alignment. A program like BLASTx will align the longest stretch of similar sequences and assign a value to the fit. It is thus possible to obtain a comparison where

several regions of similarity are found, each having a different score. The above applies *mutatis mutandis* to all amino acid sequences disclosed in the present application.

Particularly preferred MVA vectors are standard MVA produced by Anton Mayr after 570 passages in CEFs as is most commonly used in the art. This is a highly attenuated strain of vaccinia virus that was developed in connection with smallpox eradication. MVA has lost about 10% of the vaccinia genome and with it the ability to replicate efficiently in primate cells.

Regarding the MAGE human cancer antigen, the MAGE family consists of approximately 40 members. MAGE-A proteins share at least 46% of sequence identity, defined biochemical structure and properties. MAGE-A3 is significantly expressed in major forms of cancer and its expression is associated with a negative outcome. Alignment of MAGE-A3 amino acid sequences with other MAGE-A family members gave the following % identity values:

	Identity with MAGEA3
MAGEA1	66.9%
MAGEA2	84.4%
MAGEA4	69.3%
MAGEA5	71.8%
MAGEA6	95.9%
MAGEA8	63.7%
MAGEA9	59.6%
MAGEA10	47.8%
MAGEA11	59.6%
MAGEA12	85.4%

Each of the MAGE antigens noted above may be used in pursuance of the present invention, as may be defined in terms of any percentage identity with the MAGEA3 reference sequence of SEQ ID NO: 1.

Regarding NY-ESO-1 this is a known cancer antigen of 180 amino acids. The sequence has a 76.6% identity to LAGE-1. Several studies have tried to define the immunogenicity of the sequence. The main region spans from aa 79 to 173 of NY-ESO-1. Gnjatic S, *et al.* (2006) Adv. Cancer Res. vol 95:1–30; Sabbatini P, *et al.* (2012) Clin. Cancer Res. Vol 18(23): 6497-508; and Baumgaertner P, *et al.* (2016) Oncoimmunology vol 9:5(10) report how melanoma or ovarian cancer have highlighted specific fragments of interest. These are each options for use in any aspect of the present invention:

- NY-ESO-1 79-173

- NY-ESO-1 79-108
- NY-ESO-1 100-129
- NY-ESO-1 121-150
- NY-ESO-1 42-173

LAGE1 is also a known cancer antigen and it too or fragments thereof may be used together with MAGEA3 in the viral vectors and methods and uses of the present invention.

Adjuvants may be used in compositions for the delivery of the AdCh and/or MVA vectors of the invention described herein. Advantageously these viral vectors may be engineered so that they comprise a polynucleotide construct that encodes a fusion protein between the cancer antigen or fragment and CD74, the MHC class II invariant chain (Ii). This is expected to lead to enhanced $CD8^+$ T cell immunogenicity. More detailed information about how to make such protein fusions and preferred Ii sequences is provided in WO2015/082922 of Isis Innovation Limited, incorporated herein by reference.

The viral vector of the invention may be designed to express the one or more antigen genes as an epitope string. Preferably, the epitopes in a string of multiple epitopes are linked together without intervening sequences such that unnecessary nucleic acid and/or amino acid material is avoided. The creation of the epitope string is preferably achieved using a recombinant DNA construct that encodes the amino acid sequence of the epitope string, with the DNA encoding the one or more epitopes in the same reading frame. Alternatively, the antigens may be expressed as separate polypeptides.

Any fragments of antigens, whether separately or in an epitope string as described, preferably comprise at least n consecutive amino acids from the sequence of the parent antigen, wherein n is preferably at least, or more than, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41 , 42, 43, 44, 45, 46, 47, 48, 49, 50, 51 , 52, 53, 54, 55, 56, 57, 57, 58, 59, 60, 70, 80, 90 or 100 amino acids. Fragments preferably include one or more epitopes of the parent antigen. A fragment may in some situations comprise or consist of just a single epitope of a parental antigen. Usually the fragment will be sufficiently similar to the parent regions or eiptope(s) such that the antigenic/immunogenic properties are maintained.

One or more of the antigens or antigen genes used in the invention may be truncated at the C-terminus and/or the N-terminus. This may facilitate cloning and construction of the vectored vaccine and/or enhance the immunogenicity or antigenicity of the antigen. Methods for truncation will be known to those of skill in the art. For example, various well-known techniques of genetic engineering can be used to selectively delete the encoding

nucleic acid sequence at either end of the antigen gene, and then insert the desired coding sequence into the viral vector. For example, truncations of the candidate protein are created using 3' and/or 5' exonuclease strategies selectively to erode the 3' and/or 5' ends of the encoding nucleic acid, respectively. The wild type gene sequence may be truncated such that the expressed antigen may be truncated by 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20 or more amino acids relative to the parent antigen. In some instances, the antigen gene is truncated by 10 - 20 amino acids (when expressed) at the C- terminus relative to the wild type antigen. In other instances the antigen gene is truncated by 13 - 18 amino acids (when expressed), preferably by 15 amino acids (when expressed) at the C- terminus relative to the wild type antigen.

In some situations, antigen genes may include a leader sequence and this may affect processing of the primary transcript to mRNA, translation efficiency, mRNA stability, and may enhance expression and/or immunogenicity of the antigen. In connection with the invention some preferred leader sequences which also may serve in an adjuvanting capacity are tissue plasminogen activator (tPA) or MHC II chaperone protein invariant chain (Ii). Preferably, the leader sequence is positioned N-terminal to the one or more antigens.

The invention includes a pharmaceutical or immunogenic composition comprising the viral vector or vectors of the invention; optionally in combination with one or more additional active ingredients, a pharmaceutically acceptable carrier, diluent, excipient or adjuvant. Preferably, the composition is an immunogenic and/or antigenic composition.

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

The immunogenic and/or antigenic compositions of the invention may be prophylactic (whereby they induce immune responses which prevent a cancer from forming) or therapeutic (whereby they induce immune responses which have an anti-cancer activity).

The vectors or compositions of the invention are administered to the individual subject either as a single immunisation or multiple immunisations. Preferably, the viral vector or immunogenic composition thereof are administered as part of a single, double or triple immunisation regime. They may also be administered as part of a homologous or heterologous prime-boost immunisation regime.

The immunisation regime may include second or subsequent administrations of the viral vector or immunogenic composition of the present invention. The second administration

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

In terms of administration, the virus vectors of the invention may be administered in amounts of one or more doses of 10, 100, 10^3, 10^4, 10^5, 10^6, 10^7, 10^8, 10^9, 10^{10}, 10^{11}, 10^{12}, 10^{13}, 10^{14} or more viral particles (vp).

Administration may be by intraperitoneal, intravenous, intra-arterial, intramuscular, intradermal, subcutaneous, or intranasal administration. In preferred embodiments, the viral vectors are administered systemically, particularly by intravascular administration, which includes injection, perfusion and the like.

Immune checkpoint modulators (agonists or inhibitors) are an immunotherapy used in the treatment of cancers. They regulate checkpoint proteins, which are proteins known to tune T cells attacking cancer cells. Checkpoint inhibitors, a segment of checkpoint modulators, for use in accordance with the invention block different checkpoint proteins including, CTLA-4 (cytotoxic T lymphocyte associated protein 4), PD-1 (programmed cell death protein 1) or PD-L1 (programmed death ligand 1). CTLA-4 and PD-1 are found on T cells, whereas PD-L1 is found on cancer cells. Suitable checkpoint inhibitors for blocking PD-1 include nivolumab (Opdivo®), pembrolizumab (Keytruda®) and may be used together with the vaccination approach of the present invention for treating patients suffering from cancers such as melanoma, Hodgkin lymphoma, non small cell lung cancer, urinary tract (urothelial), bladder. Suitable checkpoint inhibitors for blocking CTLA-4 include Ipilimumab (Yervoy®) and may be used with the present invention for treatment of melanoma. Suitable checkpoint inhibitors for blocking PD-L1 includes atezolizumab (Tecentriq®) and may be used with the present invention for treatment of cancers including lung, breast and urothelial.

Others suitable targets for immune checkpoint modulators useful in operation of the methods and uses of the invention include, for example any selected from AMHRII, B7-H3, B7-H4, BTLA, BTNL2, Butyrophilin family, CD27, CD28, CD30, CD40, CD40L, CD47, CD48, CD70, CD80, CD86, CD155, CD160, CD226, CD244, CEACAM6, CLDN6, CCR2, CTLA4, CXCR4, GD2, GGG (guanylyl cyclase G), GIRT, GIRT ligand, HHLA2, HVEM, ICOS, ICOS ligand, IFN, IL1, IL1R, IL1RAP, IL6, IL6R, IL7, IL7R, IL12, IL12R, IL15, IL15R, LAG3, LIGHT, LIF, MUC16, NKG2A family, OX40, OX40 ligand, PD1, PDL1, PDL2,

Resokine, SEMA4D, Siglec family, SIRPalpha, STING, TGFbeta family, TIGIT, TIM3, TL1A, TMIGD2, TNFRSF, VISTA, 4-1BB and 4-1BB ligand.

A fuller review of checkpoint modulators is provided by Mahoney, A. M. et al., (2015) Nature Reviews Drug Discovery vol 14: 561 – 584 (see particularly figure 1).

The administration of a checkpoint modulators may be simultaneously together with either the prime or the one or more boost immunizations of the invention. This therefore provides a combination treatment, for prophylactic or therapeutic purposes. As a modification of a simultaneous administration the checkpoint modulator may be administered substantially following the prime and/or boost administrations, in effect at the same time. Or there may be a sequential administration delayed in time from the prime and/or boost administrations. The delay may differ relative to prime and boost administrations and may be long enough such that the checkpoint modulator is administered separately in time in between vaccine administrations. Separate administration of checkpoint modulator from the immunogenic compositions of the invention may result in equal time periods between each administration. In some instances, checkpoint modulator may be administered before the prime vaccination using the ChAd-based immunogenic composition of the invention.

A "combination treatment" in the context of one or more checkpoint modulator envisages the simultaneous, sequential or separate administration of the components of the combination. For example, simultaneous administration of a viral vector of the invention and checkpoint inhibitor. Also possible for example is a sequential administration of a viral vector of the invention and one or more checkpoint inhibitors. Further, there is the example of separate administration of a viral vector of the invention and one or more checkpoint inhibitor. Where the administration of the viral vector and checkpoint inhibitor is sequential or separate, the virus and checkpoint inhibitor may be administered within time intervals that allow that the therapeutic agents show a cooperative e.g., synergistic, effect. In preferred embodiments, a viral vector of the invention and one or more checkpoint inhibitors are administered within 1, 2, 3, 6, 12, 24, 48, 72 hours, or within 4, 5, 6 or 7 days or within 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30 or 31 days of each other. In some embodiments, a first dose of a viral vector of the invention is administered prior to a first dose of a checkpoint inhibitor or *vice versa* and may include a phase where treatment with a viral vector and a checkpoint inhibitor overlap. In other embodiments, a first dose of a viral vector of the invention may be administered on or about the same time as a first dose of a checkpoint inhibitor. In other embodiments, a first dose of viral vector of the invention is administered after a first dose (or second, third or subsequent dose) of a checkpoint inhibitor and may include a phase where treatment with a viral vector and checkpoint inhibitor overlap.

EXAMPLES

Materials and Methods

Viral vector construction

Gene sequences for insertion into the viral vectors, codon optimised for translation efficiency, were synthesized as DNA strings or plasmids by GeneArt (ThermoFisher Scientific). For the construction of chimpanzee adenoviral vectors (ChAdOx), the DNA string inserts and a p1990 backbone (Gateway® entry vector) were digested with the restriction enzymes KpnI / NotI, and then ligated via overnight incubation. Plasmids p1990 encoding the gene sequence of interest were transformed into DH5α™competent *E. coli* and then screened for positive clones via a PCR method. Positive cloned DNA was amplified via midiprep and then Gateway® cloning (ThermoFisher Scientific) was carried out between p1990 containing the gene insert and p2563 [SEQ ID NO: 24], a ChAdOx destination vector, using LR clonase. The p2563 destination vector DNA was amplified via bacterial transformation, maxiprep and gravity column purification. The p2563 destination vectors were digested with Pme1 to linearise the DNA before sending for virus production.

More comprehensive technical information, including nucleic acid sequences and sources of deposited biological material for generating ChAdOx1 vectors is disclosed in WO2012/172277 of Isis Innovation Limited and which is incorporated herein by reference. More comprehensive technical information, including nucleic acid sequences and sources of biological material for generating ChAdOx2 vectors is disclosed in WO2017/221031 of Oxford University Innovation Limited and which is incorporated herein by reference.

Other relevant disclosure incorporated herein by reference and providing more materials and methods information for the production of the ChAdOx viral vectors of the invention are Dicks, M. D. J., *et al.* (2012) "A Novel Chimpanzee Adenovirus Vector with Low Human Seroprevalence: Improved Systems for Vector Derivation and Comparative Immunogenicity" PlosOne e40385.

To generate the Modified Vaccinia Ankara (MVA) vectors, the GeneArt DNA strings or plasmids were amplified via PCR using a Phusion ® polymerase (ThermoFisher Scientific) to ensure correct overhangs for an InFusion reaction. The Gene insert and p4719 [SEQ ID NO: 25], an MVA destination vector were then digested with the restriction enzyme Ale I. The amplified insert and p4719 were then ligated using an InFusion method. Ligated plasmids were transformed into DH5α™ competent *E. coli*. Positive clones were screened and DNA amplified via midiprep. A final digest with Xho1 + Acc651 to linearise the DNA was performed before virus production.

More comprehensive technical information, including nucleic acid sequences and sources of deposited biological material for generating and reproducing the necessary MVA vectors for the present invention are disclosed in WO2011/128704 of Isis Innovation Limited and also EP 2044947 A1, each of which is incorporated in their entirety herein by reference. Other relevant disclosure incorporated herein by reference and providing more materials and methods information for the production of the MVA viral vectors of the invention Pavot V., Sebastian S., Turner A. V., Matthews J., Gilbert S.C. (2017) "Generation and Production of Modified Vaccinia Virus Ankara (MVA) as a Vaccine Vector" In: Ferran M., Skuse G. (eds) Recombinant Virus Vaccines, Methods in Molecular Biology, vol 1581 Humana Press, New York, NY.

Peptide production

Overlapping pools of short peptides of 15 amino acids in length covering the whole of the P1A, MAGE-A3 and NY-ESO-1 proteins were ordered from and produced by Mimotopes of Mulgrave, Victoria, Australia.

Mice

Six to eight-week-old C57BL/6, DBA/2 and CD1 mice were purchased from Envigo, UK and housed at the Functional Genomics Facility, University of Oxford, UK. Mouse care and experimental procedures were carried out in accordance with the terms of the UK Animals Scientific Procedures Act Project License 30/2947

In vivo studies

To assess vaccine immunogenicity, mice were administered with the produced ChAdOx1 and MVA viral vectors at doses indicated in the drawings via intramuscular (i.m.) injection in a total volume of 50µl under general anaesthesia. Vaccinations were administered at time points according to the scheme detailed for each experiment. Immunizations with live L1210.P1A.B7-1 cells were via intra-peritoneal injection. To obtain PBMCs for *ex vivo* assays, blood was sampled via tail vein bleed and processed to remove red blood cells with ACK lysis buffer.

Ten different recombinant viral vaccines (see Table 1 below) were generated and antigen expressions were confirmed in infected cells.

Table 1:

Viral vector	Polynucleotide sequence insert	Antigen amino acid sequence
ChAdOx_MAGEA3_NYESO	SEQ ID NO: 10	SEQ ID NO: 11
ChAdOx_Ii_MAGEA3_NYESO	SEQ ID NO: 12	SEQ ID NO: 13
ChAdOx_tPA_MAGEA3_NYESO	SEQ ID NO: 14	SEQ ID NO: 15
ChAdOx_P1A	SEQ ID NO: 26	SEQ ID NO: 27
ChAdOx_Ii_P1A	SEQ ID NO: 28	SEQ ID NO: 29
MVA_MAGEA3	SEQ ID NO: 16	SEQ ID NO: 17
MVA_NYESO	SEQ ID NO: 18	SEQ ID NO: 19
MVA_tPA_MAGEA3	SEQ ID NO: 20	SEQ ID NO: 21
MVA_tPA_NYESO	SEQ ID NO: 22	SEQ ID NO: 23
MVA_P1A	SEQ ID NO: 30	SEQ ID NO: 31

The immunogenicity of these viral vectored vaccines expressing P1A antigen were tested in three different strains of mice including DBA/2, C57BL/6 and CD1 outbred mice.

Ex vivo peptide stimulation

Isolated mouse PBMCs or splenocytes were suspended in RPMI 1640 medium supplemented with 10% FCS and added to a V-bottom 96-well plate. The cells were stimulated by adding P1A, MAGE-A3 or NY-ESO-1 peptides or DMSO control to the culture medium at a working concentration of 4mg/ml, together with anti-CD28 antibody (2µg/ml) and DNase (20µg/ml). Peptide stimulated cells were incubated at 37 °C in 5% CO_2 for 5 hours, with the addition of Brefaldin A after 1 hour to promote intracellular cytokine accumulation.

Flow cytometry – intracellular cytokine staining

Following peptide stimulation, PBMCs were washed with PBS, and stained for surface markers / viability by incubating with Aqua live/dead fixable dye (Invitrogen) and anti-CD8 / anti-CD4 antibodies in PBS for 20 minutes at 4 °C. To assess the percentage of activated cells producing cytokines, cells were then fixed and permeabalised with CytoFix/CytoPerm (BD Biosciences) and incubated with anti-IFN-γ, anti-TNF-α and anti-IL-2 antibodies in 1x perm buffer (BD Biosciences) for 20 minutes at 4 °C. Samples were acquired on a BD Fortessa and analysis performed using FlowJo software (Tree Star, Inc.).

Statistical analysis

All statistical tests and analyses were performed using GraphPad Prism software. Differences between multiple groups were determined with a Kruskal-Wallis non-parametric ANOVA and between individual groups with a Mann-Whitney non-parametric t-test.

Example 1: Induction of CD8 T cells against P1A by immunization with ChAdOx / MVA

P1A is a murine MAGE-type antigen that can be used to confirm induction of CD8 responses against a non-mutated MAGE-type antigen in a syngeneic host and induce protection against P1A-expressing tumour P815. It is a surrogate for MAGE-A3 and NY-ESO-1.

Figure 1B shows a schematic outline of the prime-boost immunization of mice from which peripheral blood mononuclear cells (PBMCs) are taken and tested for vaccination responses. Figure 2 shows $CD8^+$ T cell response in mice vaccinated with ChAdOx1/MVA viral vectors encoding P1A. According to the vaccination scheme timeline (Figure 1) – BL/6, DBA/2 and CD1 mice were vaccinated with either ChAdOx1.P1A or ChAdOx1.P1A-Ii (prime) followed by MVA.P1A (boost) 4 weeks later. To test the P1A-specific T-cell response, PMBCs were stimulated *ex vivo* with P1A peptide pools and the percentage cells producing type I cytokines analysed by flow cytometry. Percentage of $CD8^+$ cells producing the cytokines IFN-γ (A) and TNF-α (B) (n = 6 per group) was measured. The heterologous prime-boost vaccination induced a strong CD8 response against P1A in all three strains of mice (Figure 2) as illustrated by intracellular staining of IFN-γ and TNF-α. The response was further enhanced when P1A was fused to the MHC II chaperone protein invariant chain (Ii). These results were confirmed by IFN-γ ELISPOT assay and P1A-specific tetramer staining in DBA/2 mice (results not shown).

Overall, what was observed was very strong CD8 responses in DBA/2, B6 and outbred CD1 mice. The CD8 response was increased by adding Ii in the ChAdOx vector. What was found was when CD8 T cells were induced by the overlapping peptides they secreted IFNγ, IL2, and TNFα. There was little in the way of a CD4 response against P1A (no CD4 epitope is known).

Example 2: Assessment of protective efficacy of ChAdOx1 and MVA viral vectors carrying P1A against tumour development

As part of the assessment of vaccine protective efficacy against tumour challenge, mice were injected subcutaneously (s.c.) with tumour cells in serum-free cell culture media in one flank. Upon the development of palpable tumours, growth was recorded and mice euthanized once tumour size reached 10mm in any direction. Tumour volume was measured using the formula length (mm) x width2(mm) x 0.5. Survival curves were made according to the Kaplan-Meier method and differences in survival tested using the log-rank test. P values below 0.05 were considered significant.

In more detail, DBA/2 mice were immunized with either PBS, live L1210.P1A.B7-1 cells or a ChAdOx1-P1A (± Ii) / MVA-P1A prime-boost given 4 weeks apart and then challenged with $1.5x10^6$ P815 cells or $1x10^6$ 15V4T3 cells via subcutaneous injection in the flank. P815 and 15V4T3 are syngeneic P1A-positive mastocytoma cell lines. The 15V4T3 cells are described in Boon T, Van den Eynde B, Hirsch H, Moroni C, De Plaen E, van der Bruggen P, De Smet C, Lurquin C, Szikora JP, De Backer O. (1994) "Genes coding for tumor-specific rejection antigens" Cold Spring Harb Symp Quant Biol. 59: 617 - 22.

Mean tumour growth for each treatment group following P815 challenge (Figure 4) and 15V4T3 (Figure 7A). The Kaplan-Meier survival curves are shown for P815 (Figure 5), 15V4T3 (Figure 7B) n=10 per group.

As shown in Figures 4 and 5, adenovirus prime and MVA boost vaccination with P1A significantly reduced the tumour growth and improved survival in vaccinated mice compared to the PBS control group. Interestingly, the group vaccinated with Ii_P1A had smaller tumour volume and a better survival compared to the positive control group that was immunised with L1210.P1A B7.1 cells. This cell line has previously been shown to induce very strong P1A-specific cytotoxic activity and protection against P1A positive tumour challenge (see Brandle D. *et al.* (1998) Eur. J. Immunol. 28(12): 4010 – 4019 and Naslund T. I. *et al.* (2007) J. Immunol. 178(11): 6761 - 6769. This indicated that the stimulated immune response from vaccination is efficient in protecting the mice from P815 tumours. Figure 6A and 6B show the same results observed using the other P1A positive tumour cell line 15V4T3.

Overall, what was observed was a CD8 response associated with protection against tumour challenge and increased survival in different P1A-expressing tumour models P815 and 15V4T3 (also V4D6 – data not shown). The prime-boost regimen gave better protection than with a positive control cellular vaccine. Also observed is how invariant chain (Ii)-P1A fusion appears better than P1A alone in the vectors. Where any tumours

escape from the reduced growth effect with the treatment after a long period these have lost P1A expression (data not shown).

Example 3: Assessment of vaccine therapeutic efficacy of ChAdOx1 and MVA viral vectors carrying P1A

Experiments were performed to assess the vaccine therapeutic efficacy. Upon establishment of 15V4T3 tumours, mice were primed with ChAdOx vectors from 5 days later, and then boosted with an MVA vectors at day 26. The vaccination scheme is shown in Figure 7. Three different vaccination schemes were tested. DBA/2 mice were challenged with $1x10^6$ 15V4T3 cells via subcutaneous injection in the flank and then 5 days following challenge received either a single standard dose ChAdOx-P1A (10^8 IU) / MVA-P1A (10^7 PFU) prime-boost vaccination three weeks apart, a single low dose prime-boost vaccination (ChAdOx – 10^7 IU, MVA – 10^6 PFU) three weeks apart, weekly alternating low dose ChAdOx-P1A/MVA-P1A vaccinations or weekly ChAdOx/MVA vaccinations encoding a control antigen, DPY. 15V4T3 tumour growth and survival in each treatment group were then monitored.

As shown in Figure 8 tumour growth was remarkably delayed in vaccinated mice compared to the control group vaccinated with viral vectors expressing an irrelevant protein DPY. Moreover, the single standard dose prime-boost demonstrated the best protection and survival against the tumour challenge. However, the vaccinated mice started to lose their ability to control tumour outgrowth at the later stage (week 6).

Therapeutic efficacy was therefore observed in the 15V4T3 model.

Example 4: Assessing the therapeutic efficacy of ChAdOx1-P1A/MVA-P1A prime-boost vaccination regime in combination with immune checkpoint inhibitors

To achieve a better tumour protection and increase the vaccine efficacy, vaccines were combined with checkpoint inhibitor blocking, using the same 15V4T3 tumour model, DBA/2 mice were inoculated with P1A-expressing syngeneic 15V4T3 tumour cells. DBA/2 mice were challenged with $1x10^6$ 15V4T3 cells via subcutaneous injection in the flank and then randomized into different treatment groups on day 8 post challenge based on tumour size. Mice received either PBS (sham) vaccinations, weekly ChAdOx/MVA vaccinations – alone or in combination with either anti-PD1 or anti-CTLA-4 antibodies (3 doses 3 days apart), or anti-PD1 or anti-CTLA-4 antibodies alone. 15V4T3 tumour growth (Figure 10) and survival (Figure 11) in each treatment group were monitored and recorded throughout the duration. After establishment of a palpable tumours, tumour size was measured and the mice

randomized into different groups. As shown in Figure 10 (left hand graph), the tumour growth of mice receiving the combination therapy was much delayed compared to mice in the control and single therapy groups. Also, 100% of mice receiving the combination therapy of anti-PD1 and the vaccines survived up until day 36 after tumour challenge, and 50% of mice survived in the group of anti-CTLA4 and vaccine treatment, while the other mice all had poor survival.

A synergistic effect of the vaccine + anti-PD1 was observed in the therapeutic setting of the 15V4T3 model.

Example 5: Assessing immunogenicity of MAGE-A3 and NY-ESO-1 in CD1 outbred mice

Having established the response from vectors encoding the mouse P1A gene, vector constructs encoding the human MAGE-type antigens were produced and tested. The immunogenicity of the different forms of the human MAGE-type antigens, MAGE-A3 and NY-ESO-1 was examined in CD1 outbred mice. MAGE-A3 and NY-ESO-1 were cloned in the Chimpanzee adenovirus vector as a fusion protein, while they were cloned in MVA individually. This is due to two main reasons. Firstly, production of adenoviral vectored vaccine is more expensive than MVA. In order to prepare for clinical setting, the aim was to minimise the cost to just include one single adenoviral vectored vaccine expressing the fusion of MAGE-A3 and NY-ESO-1. Secondly, some human tumours express either MAGE-A3 or NY-ESO-1. In order to induce a more specific response against the tumours, the particular antigen that is expressed by the tumours is targeted for boosting. In more detail, mice were vaccinated according to timeline (Figure 12) – prime with ChAdOx1 encoding MAGE-A3-NY-ESO-1 ± Ii or tPA, followed by two boosts with MVA encoding either MAGE-A3 or NY-ESO-1, ± tPA (second MVA boost containing alternate antigen to first MVA boost). Antigen specific T-cell responses were assessed after each vaccination at the indicated time points - PBMCs were harvested and stimulated *ex vivo* with MAGE-A3 (blue circles) or NY-ESO-1 (red squares) peptides and the percentage of IFN-γ^+ responding cells analysed by flow cytometry.

Figure 13 shows the induction of CD8 T cells against MAGE-A3/NY-ESO-1 following priming injection of outbred CD1 mice with ChAdOx1-MAGE-A3/NY-ESO-1 fusion (M-NY), ChAdOx1-MAGE-A3/NY-ESO-1 fusion with tPA (tPA-M-NY) and ChAdOx1-MAGE-A3/NY-ESO-1 fusion with invariant chain (Ii-M-NY). Two weeks later, PBMCs were isolated, and the response to MAGE-A3 overlapping peptides (red circles) and NY-ESO-1 overlapping peptides (blue squares) tested by *ex vivo* intracellular cytokine staining. The CD8 IFNγ

responses following prime shows that a ChAdOx prime containing a fusion protein can elicit specific CD8 T cells to both antigens.

Then, the ChAdOx primed mice were given booster injections with (i) MVA containing MAGEA3 with or without fusion to tPA; and (ii) MVA containing NY-ESO-1 with or without fusion to tPA. PBMCs were then again isolated from these mice and tested for MAGEA3 and NY-ESO-1 responses using *ex vivo* intracellular cytokine staining after stimulation with overlapping peptides. Figure 14 shows the effect of the MVA-MAGEA3 ± tPA boost, and Figure 15 shows the effect of the MVA-NY-ESO-1 ± tPA boost. In each of Figures 14 and 15, Figure 13 is included as the left hand portion for convenient comparison of the boost results with the result of prime only. As can be seen, the initial prime responses are boosted to a much higher magnitude against either antigen of choice using MVA.

The ChAdOx-invariant chain (Ii) as prime and MVA-tPA appears to be the most immunogenic regime, subject to sample sizes and the use of outbred mice which have some degree of variability.

In a dual boost, initial prime responses were increased to a higher magnitude simultaneously (data not shown). The observed responses are broadly matched by other type I cytokines (data not shown).

Given how frequencies of antigen-specific T-cells appear to be boosted to much higher levels and the response directed against an antigen of choice, the invention may allow for a more personalised approach to prevention or treatment following the particular expression pattern of the individual tumour in question.

Figure 16A shows the percentage of IFN-γ^+ cells in CD8+ cells after boost with MVA-M, MVA-NY, MVA-tPA-M, or MVA-tPA-NY vectors. Figure 16B shows the percentage of IFN-γ^+ cells in $CD8^+$ cells after second boost with either MVA-M, MVA-NY, MVA-tPA-M, or MVA-tPA-NY vectors.

When mice were primed with adenovirus expressing fusion MAGE-A3 and NY-ESO-1, and boosted with MVA either expressing MAGE-A3 or NY-ESO-1, the increased CD8 response was directed against the antigen expressed by the MVA (Figures 14 and 15). Also, boosting the mice with both MVAs (MVA_MAGEA3 and MVA_NYESO) induced similar levels of CD8 responses against these two antigens.

The immunogenicity of an antigen can be enhanced by fusing the gene to some molecular adjuvants as described in Bolhassani A. *et al.* (2011) Mol. Cancer. 10:3. Among these, the human tissue plasmogen activator (tPA) signal peptide (see Delogu G. *et al.* (2002) Infect. Immun.70(1): 292 - 302) may increase protein expression within infected cells, thus enhance the T cell responses (e.g. Biswas S. *et al.* (2011) PLoS One 6(6): e20977. Also, fusing antigens to the MHC II associated Ii can strengthen CD8 response (Mikkelsen M. *et al.* (2011) Journal of Immunology 186(4): 2355 -2364; and Sorensen M. R. *et al.* (2009) European Journal of Immunology 39(10): 2725 - 2736.

In summary from the various examples above, the CD8 response to P1A is enhanced when fusing the antigen to Ii (Figure 2). Also shown is how the better stimulated CD8 response translated to a better tumour protection in mice (Figures 4 and 5). The effect of tPA fusion had not hitherto been studied in viral vectored vaccines. The examples show that unlike Ii, tPA fusion to MAGE antigens could not enhance $CD8^+$ T cell response in a single vaccination with adenovirus. Also, an increase in CD8 response was observed when mice were primed with adenovirus expressing antigens fused to Ii, and boosted with MVA encoding antigens fused to tPA, in single prime boost vaccination (see Figures 16A and 16B). However, further analysis shows that tPA fusion to the MAGE antigens in the MVA boost could not enhance the CD8 responses.

Example 6: triple combination of vaccine, checkpoint inhibitor and chemotherapy in effect on 15V4T3 tumour in DBA/2 mice

Figure 18 shows the experimental chronologies for vaccination of test mice together with chemotherapy and checkpoint inhibitor treatment, as well as associated control treatments. Briefly, 1 million 15V4T3 cells were injected subcutaneously into each of DBA/2 mice. The mice were randomly divided into groups based on tumour size on day 6. Treatments including any vaccinations of mice were begun on day 8 after tumour implantation. Where administered, 20mg/kg paclitaxel and 40mg/kg of carboplatin were given to the mice on day 8 by I.P, and 20mg/kg of paclitaxel was given on day 9 by I.P. Where administered, 3 doses of 100µg of aPD1 were given on days 18, 21 and 24 by I.P. The number of mice per group was 6 or 7 or 8.

Figure 19 shows time courses of mean tumour volume in the mice for each of the experimental and control treatments.

Figure 20 shows time courses for the tumour volumes of individual mice in each experimental group or control group. The times of treatment, whether vaccination and/or chemotherapy and/or checkpoint inhibitor are shown. Also indicated are the 48 day end-

point numbers of mice in each group which are found to be tumour free. The triple combination of vaccination, chemotherapy and checkpoint inhibitor clearly inhibits the formation of tumours the most effectively of the various treatments.

Figure 21 shows the survival of mice over time in each experimental and control group. The triple combination of vaccination, chemotherapy and checkpoint inhibitor clearly provides the best survival of the mice compared to the other treatments and controls.

The triple combination of vaccines with aPD1 and chemotherapy significantly inhibited the tumour growth compared to other groups. There were 6 out of 8 tumour-free mice on day 23 after tumour injection, and these mice remained tumour-free up till day 48. Also as shown in Figure 22, the triple combination group also has the highest periphery P1A-specific CD8 responses on day 27 after tumour injection.

Example 7: triple combination of vaccine, checkpoint inhibitor and chemotherapy in effect on 15V4T3 tumour in DBA/2 mice

Figure 23 shows the time lines for each experimental group of mice and controls. 1 million 15V4T3 cells (early passage) were injected simultaneously into DBA/2 mice. Mice were randomly divided into groups based on tumour size on day 11 and vaccinations of mice begun on day 11 after tumour implantation. Where administered, 20mg/kg paclitaxel and 40mg/kg of carboplatin were given on day 11 by I.P, and 20mg/kg of paclitaxel was given on day 12 by I.P. Where administered, 3 doses of 100µg of aPD1 was given on day 21, 24 and 27 by I.P. n = 6 or 7 per group. A naïve group without tumour challenge was also included in this experiment. Bleeding was carried out on day 14 and samples were used to check myeloid derived suppressor cell (MDSC) depletion.

Figures 24 and 25 show how mice treated with chemotherapy only or chemotherapy plus vaccine had lower MDSC frequency.

Example 8: 15V4T3 tumour in DBA/2 mice – vaccination with CPI increases tumour T cell infiltration

1 million 15V4T3 cells were injected subcutaneously in DBA/2 mice. The vaccination schedules are shown in Figure 26 for PBS control, aPD1 only, and the two test groups of mice (1) a low dose one week apart prime boost (ChAdOx1-li-P1A + MVA-**tPA**-P1A) and (2) a low dose one week apart prime boost (ChAdOx1-li-P1A + MVA-**tPA**-P1A) + aPD1. Vaccination of mice was begun on day 10 after tumour implantation. CPI (αPD1) was given 3 days after prime, with 3 doses of 100µg on day 13, 16 and 19 after tumour

injection. All mice were bled on day 20 and sacrificed on day 21. The immune profiles of the tumour microenvironment were studied by FACS. The results are set forth in Figures 27 – 53.

In more detail, Figure 27 shows an even spread of tumour size in all groups of mice at sacrifice. Figure 28 shows a reduction in tumour mass in a subset of mice in the vaccine + anti-PD-1 combination group, indicating beginnings of tumour clearance in these mice.

Figure 29 shows individual tumour growth curves for each of the mice in each group.

Figure 30 shows the percentage of $CD8^+$ tumour infiltrating lymphocytes (TILs) in the tumours of vaccine and control groups of mice. Vaccination increases $CD3^+CD8^+$ TILs as a proportion of total cells in the tumour.

Figures 33 and 34 show absolute TIL numbers calculated and normalized to cell number and tumour weight.

Figures 36 and 37 show how addition of αPD-1 treatment appears to boost P1A-specific response primed by ChAdOx/MVA vaccination when evaluated at an early time-point of day 11 post ChAdOx prime.

Figure 46 shows how infiltration of P1A-specific T_{EM} $CD8^+$s in the tumour follows the same pattern as P1A-specific CD8s.

Overall, the results of Figures 27 – 53 show how vaccine increases T cell infiltration of tumours, with an increase in $CD3^+CD8^+$ TIL and an increase in P1A-specific TIL in the vaccine groups of mice compared to controls.

Also, the $CD3^+CD8^+$ TIL are mainly effector memory cells $T_{EM}(CD62L^-CD44^+)$ and $T_{CM}(CD62L^+CD44^+)$.

Further, the P1A-specific TILs express PD-1 in the vaccine groups, but the expression decrease with αPD1 blockade.

Nucleotide and amino acid sequences referred to herein

Certain proteins or polypeptides are referred to herein and reference nucleotide and/or amino acid sequences for these are provided in the accompanying sequence listing filed as part of the present description. Some of the sequences are annotated to provide further information as follows:

Human HLA class II histocompatibility antigen gamma chain (Ii) UniProtKB/Swiss-Prot: P04233.3. The underlined sequence portions represents the transmembrane domain used in vectors:

MHRRRSRSCR EDQKPVMDDQ RDLISNNEQL PMLGRRPGAP ESKCSRGALY TGFSILVTLL LAGQATTAYF LYQQQGRLDK LTVTSQNLQL ENLRMKLPKP PKPVSKMRMA TPLLMQALPM GALPQGPMQN ATKYGNMTED HVMHLLQNAD PLKVYPPLKG SFPENLRHLK NTMETIDWKV FESWMHHWLL FEMSRHSLEQ KPTDAPPKVL TKCQEEVSHI PAVHPGSFRP KCDENGNYLP LQCYGSIGYC WCVFPNGTEV PNTRSRGHHN CSESLELEDP SSGLGVTKQD LGPVPM **[SEQ ID NO: 6]**

Human Tissue-type plasminogen activator (tPA). The underlined sequence portion shown is the leader sequence used in vectors.

MDAMKRGLCCVLLLCGAVFVSPSQEIHARFRRGARSYQVICRDEKTQMIYQQHQSWLRP VLRSNRVEYCWCNSGRAQCHSVPVKSCSEPRCFNGGTCQQALYFSDFVCQCPEGFAG KCCEIDTRATCYEDQGISYRGTWSTAESGAECTNWNSSALAQKPYSGRRPDAIRLGLGN HNYCRNPDRDSKPWCYVFKAGKYSSEFCSTPACSEGNSDCYFGNGSAYRGTHSLTESG ASCLPWNSMILIGKVYTAQNPSAQALGLGKHNYCRNPDGDAKPWCHVLKNRRLTWEYC DVPSCSTCGLRQYSQPQFRIKGGLFADIASHPWQAAIFAKHRRSPGERFLCGGILISSCWI LSAAHCFQERFPPHHLTVILGRTYRVVPGEEEQKFEVEKYIVHKEFDDDTYDNDIALLQLK SDSSRCAQESSVVRTVCLPPADLQLPDWTECELSGYGKHEALSPFYSERLKEAHVRLYP SSRCTSQHLLNRTVTDNMLCAGDTRSGGPQANLHDACQGDSGGPLVCLNDGRMTLVGII SWGLGCGQKDVPGVYTKVTNYLDWIRDNMRP **[SEQ ID NO: 8]**

Polynucleotide construct for vector ChAdOx1_MAGE_NYESO. MAGEA3 in underlined. Linker is in bold type. NY-ESO-1 is in italics.

ATGCCCCTGGAACAGCGGAGCCAGCACTGCAAGCCTGAGGAAGGCCTGGAAGCCAG AGGCGAAGCTCTGGGACTCGTGGGAGCACAGGCTCCAGCCACCGAAGAACAGGAAG CCGCCAGCAGCAGCTCCACCCTGGTGGAAGTGACACTGGGCGAAGTGCCTGCCGCC GAGTCTCCTGATCCTCCTCAGTCTCCTCAGGGCGCCAGCTCTCTGCCCACCACCATG AACTACCCCCTGTGGTCCCAGTCCTACGAGGACAGCAGCAACCAGGAAGAAGAGGG CCCCAGCACCTTCCCCGACCTGGAATCTGAATTCCAGGCCGCCCTGAGCCGGAAGG TGGCCGAACTGGTGCACTTCCTGCTGCTGAAGTACCGGGCCAGAGAACCCGTGACC AAGGCCGAGATGCTGGGCAGCGTCGTGGGCAACTGGCAGTACTTCTTCCCCGTGAT CTTCTCCAAGGCCAGCTCCAGCCTGCAGCTGGTGTTCGGCATCGAGCTGATGGAAGT GGACCCCATCGGACACCTGTACATCTTCGCCACCTGTCTGGGCCTGAGCTACGATGG CCTGCTGGGCGACAACCAGATCATGCCCAAAGCCGGCCTGCTGATCATCGTGCTGG CCATCATTGCCCGCGAGGGCGATTGTGCCCCCGAGGAAAAGATCTGGGAGGAACTG

AGCGTGCTGGAAGTGTTCGAGGGAAGAGAGGACTCCATCCTGGGCGACCCCAAGAA
GCTGCTGACCCAGCACTTCGTGCAGGAAAACTACCTGGAGTATAGACAGGTGCCCG
GCAGCGACCCTGCCTGCTACGAATTTCTGTGGGGCCCTAGAGCACTGGTGGAAACC
AGCTACGTGAAAGTGCTGCACCACATGGTCAAGATCAGCGGCGGACCCCACATCAG
CTACCCCCCTCTGCATGAATGGGTGCTGAGAGAGGGCGAGGAA**GGCGGAGGACCT**
GGCGGAGGA*ATGCAGGCTGAAGGCAGAGGCACAGGCGGCTCTACAGGCGACGCTG*
ATGGACCAGGCGGACCCGGAATTCCAGATGGCCCTGGCGGAAATGCTGGCGGGCCT
GGCGAAGCTGGCGCTACAGGCGGAAGAGGACCTAGAGGCGCTGGCGCCGCTAGAG
CTTCTGGACCAGGGGGAGGCGCTCCTAGAGGACCTCATGGCGGAGCTGCCTCTGGC
CTGAACGGCTGCTGTAGATGTGGCGCCAGAGGCCCCGAAAGCAGACTGCTGGAATT
CTACCTGGCCATGCCTTTCGCCACCCCCATGGAAGCTGAGCTGGCCAGAAGAAGCCT
GGCCCAGGACGCTCCTCCACTGCCTGTGCCAGGCGTGCTGCTGAAAGAATTCACCG
TGTCCGGCAACATCCTGACCATCCGGCTGACAGCCGCCGACCACAGACAGCTGCAG
CTGAGCATCAGCAGCTGCCTGCAGCAGCTGTCCCTGCTGATGTGGATCACCCAGTGC
TTTCTGCCCGTGTTTCTGGCCCAGCCTCCTAGCGGACAGCGGAGATGA **[SEQ ID NO: 10]**

Translated protein of ChAdOx1_MAGE_NYESO. MAGEA3 in underlined. Linker is in bold. NY-ESO-1 is in italics:

MPLEQRSQHCKPEEGLEARGEALGLVGAQAPATEEQEAASSSSTLVEVTLGEVPAAESP
DPPQSPQGASSLPTTMNYPLWSQSYEDSSNQEEEGPSTFPDLESEFQAALSRKVAELVH
FLLLKYRAREPVTKAEMLGSVVGNWQYFFPVIFSKASSSLQLVFGIELMEVDPIGHLYIFAT
CLGLSYDGLLGDNQIMPKAGLLIIVLAIIAREGDCAPEEKIWEELSVLEVFEGREDSILGDPK
KLLTQHFVQENYLEYRQVPGSDPACYEFLWGPRALVETSYVKVLHHMVKISGGPHISYPP
LHEWVLREGEE**GGGPGGG***MQAEGRGTGGSTGDADGPGGPGIPDGPGGNAGGPGEAG*
ATGGRGPRGAGAARASGPGGGAPRGPHGGAASGLNGCCRCGARGPESRLLEFYLAMP
FATPMEAELARRSLAQDAPPLPVPGVLLKEFTVSGNILTIRLTAADHRQLQLSISSCLQQLS
LLMWITQCFLPVFLAQPPSGQRR **[SEQ ID NO: 11]**

Polynucleotide construct for vector ChAdOx1_hIi_MAGE_NY-ESO-1. Ii sequence in bold and italics type. MAGEA3 is underlined. Sequence linker is in bold. NY-ESO-1 is in italics:

ATG***GGCGCCCTGTACACCGGCTTTAGCATCCTCGTGACCCTGCTGCTGGCCGGACA***
GGCTACCACCGCCTACTTTCTGTACCCCCTGGAACAGCGGAGCCAGCACTGCAAGC
CTGAGGAAGGCCTGGAAGCCAGAGGCGAAGCTCTGGGACTCGTGGGAGCACAGGC
TCCAGCCACCGAAGAACAGGAAGCCGCCAGCAGCTCTAGCACCCTGGTGGAAGTGA

CACTGGGCGAAGTGCCTGCCGCCGAGTCTCCTGATCCTCCTCAGTCTCCTCAGGGC
GCCAGCTCTCTGCCCACCACCATGAACTACCCCCTGTGGTCCCAGTCCTACGAGGAC
AGCAGCAACCAGGAAGAAGAGGGCCCCAGCACCTTCCCCGACCTGGAATCTGAATT
CCAGGCCGCCCTGAGCCGGAAGGTGGCCGAACTGGTGCACTTTCTGCTGCTGAAGT
ACCGGGCCAGAGAACCCGTGACCAAGGCCGAGATGCTGGGCAGCGTCGTGGGCAA
CTGGCAGTACTTCTTCCCCGTGATCTTCTCCAAGGCCAGCTCCAGCCTGCAGCTGGT
GTTCGGCATCGAGCTGATGGAAGTGGACCCCATCGGACACCTGTACATCTTCGCCAC
CTGTCTGGGCCTGAGCTACGATGGCCTGCTGGGCGACAACCAGATCATGCCCAAAG
CCGGCCTGCTGATCATCGTGCTGGCCATCATTGCCCGCGAGGGCGATTGTGCCCCC
GAGGAAAAGATCTGGGAGGAACTGAGCGTGCTGGAAGTGTTCGAGGGAAGAGAGGA
CTCCATCCTGGGCGACCCCAAGAAGCTGCTGACCCAGCACTTCGTGCAGGAAAACTA
CCTGGAGTATAGACAGGTGCCCGGCAGCGACCCTGCCTGCTACGAATTTCTGTGGG
GCCCTAGAGCACTGGTGGAAACCAGCTACGTGAAAGTGCTGCACCACATGGTCAAGA
TCAGCGGCGGACCCCACATCAGCTACCCCCCTCTGCATGAATGGGTGCTGAGAGAG
GGCGAGGAA**GGCGGAGGACCTGGCGGAGGA***ATGCAGGCTGAAGGCAGAGGCACA*
GGCGGCTCTACAGGCGACGCTGATGGACCAGGCGGACCCGGAATTCCAGATGGCCC
TGGCGGAAATGCTGGCGGGCCTGGCGAAGCTGGCGCTACAGGCGGAAGAGGACCT
AGAGGCGCTGGCGCCGCTAGAGCATCTGGACCAGGGGGAGGCGCTCCTAGAGGAC
CTCATGGCGGAGCTGCCTCTGGCCTGAACGGCTGCTGTAGATGTGGCGCCAGAGGC
CCCGAAAGCAGACTGCTGGAATTCTACCTGGCCATGCCTTTCGCCACCCCCATGGAA
GCTGAGCTGGCCAGAAGAAGCCTGGCCCAGGACGCTCCTCCACTGCCTGTGCCAGG
CGTGCTGCTGAAAGAATTCACCGTGTCCGGCAACATCCTGACCATCCGGCTGACAGC
CGCCGACCACAGACAGCTGCAGCTGAGCATCAGCAGCTGCCTGCAGCAGCTGTCCC
TGCTGATGTGGATCACCCAGTGCTTTCTGCCCGTGTTTCTGGCCCAGCCTCCTAGCG
GACAGCGGAGATGA **[SEQ ID NO: 12]**

Translated protein sequence of ChAdOx1_hli_MAGE_NY-ESO-1. li sequence in bold and italics type. MAGEA3 is underlined. Linker is in bold. NY-ESO-1 is in italics:

M***GALYTGFSILVTLLLAGQATTAYFLY***PLEQRSQHCKPEEGLEARGEALGLVGAQAPAT
EEQEAASSSSTLVEVTLGEVPAAESPDPPQSPQGASSLPTTMNYPLWSQSYEDSSNQEE
EGPSTFPDLESEFQAALSRKVAELVHFLLLKYRAREPVTKAEMLGSVVGNWQYFFPVIFS
KASSSLQLVFGIELMEVDPIGHLYIFATCLGLSYDGLLGDNQIMPKAGLLIIVLAIIAREGDCA
PEEKIWEELSVLEVFEGREDSILGDPKKLLTQHFVQENYLEYRQVPGSDPACYEFLWGPR
ALVETSYVKVLHHMVKISGGPHISYPPLHEWVLREGEE**GGGPGGG***MQAEGRGTGGSTG*
DADGPGGPGIPDGPGGNAGGPGEAGATGGRGPRGAGAARASGPGGGAPRGPHGGAA
SGLNGCCRCGARGPESRLLEFYLAMPFATPMEAELARRSLAQDAPPLPVPGVLLKEFTV

*SGNILTIRLTAADHRQLQLSISSCLQQLSLLMWITQCFLPVFLAQPPSGQRR** **[SEQ ID NO: 13]**

Polynucleotide construct for vector ChAdOx1_tPA_MAGE_NY-ESO-1. tPA sequence in bold and italics type. MAGEA3 is underlined. Linker is in bold. NY-ESO-1 is in italics:

ATG***GACGCCATGAAGCGGGGCCTGTGTTGCGTGCTGCTGCTGTGTGGCGCTGTGTT CGTGTCCCCC***CCACTGGAACAGAGAAGCCAGCACTGCAAGCCCGAGGAAGGCCTGG AAGCCAGAGGCGAAGCTCTGGGACTCGTGGGAGCACAGGCTCCAGCCACCGAAGAA CAGGAAGCCGCCAGCAGCTCTAGCACCCTGGTGGAAGTGACACTGGGCGAAGTGCC TGCCGCCGAGTCTCCTGATCCTCCTCAGTCTCCTCAGGGCGCCAGCTCTCTGCCCAC CACCATGAACTACCCCCTGTGGTCCCAGTCCTACGAGGACAGCAGCAACCAGGAAGA AGAGGGCCCCAGCACCTTCCCCGACCTGGAATCTGAATTCCAGGCCGCCCTGAGCC GGAAGGTGGCCGAACTGGTGCACTTCCTGCTGCTGAAGTACCGGGCCAGAGAACCC GTGACCAAGGCCGAGATGCTGGGCAGCGTCGTGGGCAACTGGCAGTACTTCTTCCC CGTGATCTTCTCCAAGGCCAGCTCCAGCCTGCAGCTGGTGTTCGGCATCGAGCTGAT GGAAGTGGACCCCATCGGACACCTGTACATCTTCGCCACCTGTCTGGGCCTGAGCTA CGATGGCCTGCTGGGCGACAACCAGATCATGCCCAAAGCCGGCCTGCTGATCATCG TGCTGGCCATCATTGCCCGCGAGGGCGATTGTGCCCCCGAGGAAAAGATCTGGGAG GAACTGAGCGTGCTGGAAGTGTTCGAGGGAAGAGAGGACTCCATCCTGGGCGACCC CAAGAAGCTGCTGACCCAGCACTTCGTGCAGGAAAACTACCTGGAGTATAGACAGGT GCCCGGCAGCGACCCTGCCTGCTACGAATTTCTGTGGGGCCCTAGAGCACTGGTGG AAACCAGCTACGTGAAAGTGCTGCACCACATGGTCAAGATCAGCGGCGGACCCCACA TCAGCTACCCACCTCTGCACGAATGGGTGCTGAGAGAGGGCGAAGAA**GGCGGAGGA** **CCTGGCGGAGGA***ATGCAGGCTGAAGGCAGAGGCACAGGCGGCTCTACAGGCGACG CTGATGGACCAGGCGGACCCGGAATTCCAGATGGCCCTGGCGGAAATGCTGGCGGG CCTGGCGAAGCTGGCGCTACAGGCGGAAGAGGACCTAGAGGCGCTGGCGCCGCTA GAGCATCTGGACCAGGGGGAGGCGCTCCTAGAGGACCTCATGGCGGAGCTGCCTCT GGCCTGAATGGCTGCTGTAGATGTGGCGCCAGAGGCCCCGAAAGCAGACTGCTGGA ATTCTACCTGGCCATGCCTTTCGCCACCCCCATGGAAGCTGAGCTGGCCAGAAGAAG CCTGGCCCAGGACGCTCCTCCACTGCCTGTGCCAGGGGTGCTGCTGAAAGAATTCA CCGTGTCCGGCAACATCCTGACCATCCGGCTGACAGCCGCCGACCACAGACAGCTG CAGCTGAGCATCAGCAGCTGCCTGCAGCAGCTGTCCCTGCTGATGTGGATCACCCA GTGCTTTCTGCCCGTGTTTCTGGCCCAGCCTCCTAGCGGACAGCGGAGATGA* **[SEQ ID NO: 14]**

Translated protein of ChAdOx1_tPA_MAGE_NY-ESO-1. tPA sequence in bold and italics type. MAGEA3 is underlined. Linker is in bold. NY-ESO-1 is in italics:

M***DAMKRGLCCVLLLCGAVFVSP***PLEQRSQHCKPEEGLEARGEALGLVGAQAPATEEQE
AASSSSTLVEVTLGEVPAAESPDPPQSPQGASSLPTTMNYPLWSQSYEDSSNQEEEGPS
TFPDLESEFQAALSRKVAELVHFLLLKYRAREPVTKAEMLGSVVGNWQYFFPVIFSKASS
SLQLVFGIELMEVDPIGHLYIFATCLGLSYDGLLGDNQIMPKAGLLIIVLAIIAREGDCAPEEK
IWEELSVLEVFEGREDSILGDPKKLLTQHFVQENYLEYRQVPGSDPACYEFLWGPRALVE
TSYVKVLHHMVKISGGPHISYPPLHEWVLREGEE**GGGPGGG***MQAEGRGTGGSTGDAD*
GPGGPGIPDGPGGNAGGPGEAGATGGRGPRGAGAARASGPGGGAPRGPHGGAASGL
NGCCRCGARGPESRLLEFYLAMPFATPMEAELARRSLAQDAPPLPVPGVLLKEFTVSGNI
LTIRLTAADHRQLQLSISSCLQQLSLLMWITQCFLPVFLAQPPSGQRR **[SEQ ID NO: 15]**

Polynucleotide construct for vector MVA_tPA_MAGEA3. tPA underlined:

ATGGACGCCATGAAGCGGGGCCTGTGCTGCGTGCTGCTGCTGTGTGGCGCTGTGTT
CGTGTCCCCCCCACTGGAACAGAGAAGCCAGCACTGCAAGCCCGAGGAAGGCCTGG
AAGCCAGAGGCGAAGCTCTGGGACTCGTGGGAGCACAGGCTCCAGCCACCGAAGAA
CAGGAAGCCGCCAGCAGCTCTAGCACCCTGGTGGAAGTGACACTGGGCGAAGTGCC
TGCCGCCGAGTCTCCTGATCCTCCTCAGTCTCCTCAGGGCGCCAGCTCTCTGCCCAC
CACCATGAACTACCCCCTGTGGTCCCAGTCCTACGAGGACAGCAGCAACCAGGAAGA
AGAGGGCCCCAGCACCTTCCCCGACCTGGAATCTGAATTCCAGGCCGCCCTGAGCC
GGAAGGTGGCCGAACTGGTGCACTTCCTGCTGCTGAAGTACCGGGCCAGAGAACCC
GTGACCAAGGCCGAGATGCTGGGCAGCGTCGTGGGCAACTGGCAGTACTTCTTCCC
CGTGATCTTCTCCAAGGCCAGCTCCAGCCTGCAGCTGGTGTTCGGCATCGAGCTGAT
GGAAGTGGACCCCATCGGACACCTGTACATCTTCGCCACCTGTCTGGGCCTGAGCTA
CGATGGCCTGCTGGGCGACAACCAGATCATGCCCAAAGCCGGCCTGCTGATCATCG
TGCTGGCCATCATTGCCCGCGAGGGCGATTGTGCCCCCGAGGAAAAGATCTGGGAG
GAACTGAGCGTGCTGGAAGTGTTCGAGGGAAGAGAGGACTCCATCCTGGGCGACCC
CAAGAAGCTGCTGACCCAGCACTTCGTGCAGGAAAACTACCTGGAGTATAGACAGGT
GCCCGGCAGCGACCCTGCCTGCTACGAATTTCTGTGGGGCCCTAGAGCACTGGTGG
AAACCAGCTACGTGAAAGTGCTGCACCACATGGTCAAGATCAGCGGCGGACCCCACA
TCAGCTACCCACCTCTGCACGAATGGGTGCTGCGGGAAGGCGAAGAGTGA **[SEQ ID NO: 20]**

Translated protein of MVA_tPA_MAGEA3. tPA is underlined:

MDAMKRGLCCVLLLCGAVFVSPPLEQRSQHCKPEEGLEARGEALGLVGAQAPATEEQE
AASSSSTLVEVTLGEVPAAESPDPPQSPQGASSLPTTMNYPLWSQSYEDSSNQEEEGPS
TFPDLESEFQAALSRKVAELVHFLLLKYRAREPVTKAEMLGSVVGNWQYFFPVIFSKASS
SLQLVFGIELMEVDPIGHLYIFATCLGLSYDGLLGDNQIMPKAGLLIIVLAIIAREGDCAPEEK
IWEELSVLEVFEGREDSILGDPKKLLTQHFVQENYLEYRQVPGSDPACYEFLWGPRALVE
TSYVKVLHHMVKISGGPHISYPPLHEWVLREGEE **[SEQ ID NO: 21]**

Polynucleotide construct for vector MVA_tPA_NYESO. tPA is underlined:

ATGGACGCCATGAAGCGGGGCCTGTGCTGCGTGCTGCTGCTGTGTGGCGCTGTGTT
CGTGAGCCCTCAGGCCGAGGGAAGAGGCACAGGCGGATCTACAGGCGACGCTGAT
GGACCTGGCGGCCCTGGAATTCCTGATGGCCCAGGCGGAAATGCTGGCGGACCAG
GCGAAGCTGGCGCTACAGGCGGAAGAGGACCTAGAGGCGCTGGCGCCGCTAGAGC
TTCTGGACCTGGGGGAGGCGCTCCTAGAGGACCTCATGGCGGAGCTGCCTCTGGCC
TGAATGGCTGCTGTAGATGTGGCGCCAGAGGCCCCGAAAGCCGGCTGCTGGAATTC
TACCTGGCCATGCCCTTCGCCACCCCCATGGAAGCTGAGCTGGCCAGAAGAAGCCT
GGCCCAGGACGCTCCTCCACTGCCTGTGCCAGGGGTGCTGCTGAAAGAATTCACCG
TGTCCGGCAACATCCTGACCATCCGGCTGACAGCCGCCGACCACAGACAGCTGCAG
CTGAGCATCAGCAGCTGCCTGCAGCAGCTGTCCCTGCTGATGTGGATCACCCAGTGC
TTTCTGCCCGTGTTTCTGGCCCAGCCTCCTAGCGGCCAGCGGCGCTAA **[SEQ ID NO: 22]**

Translated protein of MVA_tPA_NYESO. tPA is underlined:

MDAMKRGLCCVLLLCGAVFVSPQAEGRGTGGSTGDADGPGGPGIPDGPGGNAGGPGE
AGATGGRGPRGAGAARASGPGGGAPRGPHGGAASGLNGCCRCGARGPESRLLEFYLA
MPFATPMEAELARRSLAQDAPPLPVPGVLLKEFTVSGNILTIRLTAADHRQLQLSISSCLQ
QLSLLMWITQCFLPVFLAQPPSGQRR **[SEQ ID NO: 23]**

Polynucleotide construct for vector ChAdOx1_mli_P1A. The li sequence is underlined:

ATGGGCGCTCTGTATACTGGCGTGTCCGTGCTGGTGGCCCTGCTGCTGGCTGGACA
GGCTACAACCGCCTACTTCCTGTACAGCGACAACAAGAAGCCCGACAAGGCCCACTC
TGGCAGCGGCGGAGATGGCGACGGCAACAGATGTAACCTGCTGCACAGATACAGCC
TGGAAGAGATCCTGCCCTACCTGGGCTGGCTGGTGTTCGCCGTCGTGACAACAAGCT
TCCTGGCCCTGCAGATGTTCATCGACGCCCTGTACGAGGAACAGTACGAGAGGGAC

GTGGCCTGGATCGCCAGACAGAGCAAGAGAATGAGCAGCGTGGACGAGGACGAGG
ATGATGAGGACGACGAAGATGACTACTACGACGATGAGGATGACGACGACGACGCC
TTCTACGATGACGAGGACGATGAAGAGGAAGAACTGGAAAACCTGATGGACGACGAG
TCCGAGGATGAGGCCGAGGAAGAGATGAGCGTGGAAATGGGCGCTGGCGCCGAAG
AGATGGGAGCCGGCGCTAACTGTGCTTGCGTGCCAGGACACCACCTGAGAAAGAAC
GAAGTGAAGTGCCGGATGATCTACTTCTTCCACGACCCCAACTTTCTGGTGTCCATCC
CCGTGAACCCCAAAGAACAGATGGAATGCAGATGCGAGAACGCCGACGAAGAGGTG
GCCATGGAAGAAGAAGAGGAAGAGGAAGAAGAAGAAGAGGAAGAAATGGGCAA
CCCCGACGGCTTCAGCCCCTGA **[SEQ ID NO: 28]**

Translated protein ChAdOx1_mli_P1A. The li sequence is underlined:

MGALYTGVSVLVALLLAGQATTAYFLYSDNKKPDKAHSGSGGDGDGNRCNLLHRYSLEE
ILPYLGWLVFAVVTTSFLALQMFIDALYEEQYERDVAWIARQSKRMSSVDEDEDDEDDED
DYYDDEDDDDDAFYDDEDDEEEELENLMDDESEDEAEEEMSVEMGAGAEEMGAGANC
ACVPGHHLRKNEVKCRMIYFFHDPNFLVSIPVNPKEQMECRCENADEEVAMEEEEEEEE
EEEEEEMGNPDGFSP **[SEQ ID NO: 29]**

Throughout the description and claims of this specification, the words "comprise" and "contain" and variations of them mean "including but not limited to", and they are not intended to (and do not) exclude other moieties, additives, components, integers or steps. Throughout the description and claims of this specification, the singular encompasses the plural unless the context otherwise requires. In particular, where the indefinite article is used, the specification is to be understood as contemplating plurality as well as singularity, unless the context requires otherwise.

Features, integers, characteristics, compounds, chemical moieties or groups described in conjunction with a particular aspect, embodiment or example of the invention are to be understood to be applicable to any other aspect, embodiment or example described herein unless incompatible therewith. All of the features disclosed in this specification (including any accompanying claims, abstract and drawings), and/or all of the steps of any method or process so disclosed, may be combined in any combination, except combinations where at least some of such features and/or steps are mutually exclusive. The invention is not restricted to the details of any foregoing embodiments. The invention extends to any novel one, or any novel combination, of the features disclosed in this specification (including any accompanying claims, abstract and drawings), or to any novel one, or any novel combination, of the steps of any method or process so disclosed.

The reader's attention is directed to all papers and documents which are filed concurrently with or previous to this specification in connection with this application and which are open to public inspection with this specification, and the contents of all such papers and documents are incorporated herein by reference.

CLAIMS

1. A chimpanzee adenovirus (ChAd) vector encapsidating a nucleic acid molecule, the nucleic acid molecule comprising a polynucleotide sequence encoding (i) a MAGE cancer antigen and/or NY-ESO-1 cancer antigen, or immunogenic fragments thereof; or (ii) a MAGE cancer antigen and/or LAGE1 cancer antigen, or immunogenic fragments thereof, operably linked to expression control sequences which direct the translation, transcription and/or expression of the cancer antigen or fragment thereof in an animal cell, and an adenoviral packaging signal sequence.

2. A ChAd vector as claimed in claim 1, wherein the ChAd vector is (a) ChAdOx1 as disclosed in WO2012/172277; preferably encoded by a polynucleotide of SEQ ID NO: 38 as disclosed in WO2012/172277 or a sequence of at least 80% identity therewith; or (b) ChAdOx2 as disclosed in WO2017/221031; preferably encoded by a polynucleotide of SEQ ID NO: 10 as disclosed in WO2017/221031 or a sequence of at least 80% identity therewith.

3. A modified vaccinia virus Ankara (MVA) vector encapdisating a nucleic acid molecule, the nucleic acid molecule comprising a polynucleotide sequence encoding (i) a MAGE cancer antigen and/or NY-ESO-1 cancer antigen, or immunogenic fragments thereof; or (ii) a MAGE cancer antigen and/or LAGE1 cancer antigen, or immunogenic fragments thereof, operably linked to expression control sequences which direct the translation, transcription and/or expression of the cancer antigen or fragment thereof in an animal cell.

4. An MVA vector as claimed in claim 3, wherein the MVA vector is as disclosed in WO2011/128704 or EP 2044947 A1.

5. A ChAd or MVA vector as claimed in any of claims 1 to 4, wherein the MAGE antigen is MAGE 3A having an amino acid sequence of SEQ ID NO: 1 or a sequence of at least 46%; preferably at least 69%; more preferably at least 95% identity therewith; or any immunogenic fragment thereof.

6. A ChAd or MVA vector as claimed in any of claims 1 to 5, wherein the NY-ESO-1 cancer antigen has an amino acid sequence of SEQ ID NO: 3 or a sequence of at least 75%; preferably at least 76.7% identity therewith; or any immunogenic fragment thereof.

7. A ChAd or MVA vector as claimed in any of claims 1 to 5, wherein the LAGE1 cancer antigen has an amino acid sequence of SEQ ID NO: 5, or a sequence of at least 78%; preferably at least 97% identity therewith; or any immunogenic fragment thereof.

8. A ChAd or MVA vector as claimed in any preceding claim, wherein the polynucleotide sequence further encodes a human HLA class II histocompatibility antigen gamma chain (Ii) with an amino acid sequence of SEQ ID NO: 6 or a sequence of at least 79% identity therewith, or a fragment thereof, so that the cancer antigen is expressed in an animal cell as a fusion with Ii or fragment thereof; preferably wherein the fragment is a transmembrane domain; more preferably wherein the transmembrane domain comprises amino acid residues 30 to 55 or 30 to 61, even more preferably wherein the transmembrane domain has the amino acid sequence of SEQ ID NO: 7.

9. A ChAd or MVA vector as claimed in any preceding claim, wherein the polynucleotide sequence further encodes tPA with an amino acid sequence of SEQ ID NO: 8 or a sequence of at least 81% identity therewith, or a fragment thereof; so that the cancer antigen is expressed in an animal cell as a fusion with tPA or a fragment thereof; preferably wherein the fragment comprises a 21 amino acid leader sequence; more preferably the 21 amino acid leader sequence is SEQ ID NO: 9.

10. A ChAd vector as claimed in any preceding claim, wherein the polynucleotide sequence encodes (i) a MAGE cancer antigen or immunogenic fragment thereof and a NY-ESO-1 cancer antigen or immunogenic fragment thereof; or (ii) a MAGE cancer antigen or immunogenic fragment thereof and a LAGE1 cancer antigen or immunogenic fragment thereof, expressed in an animal cell as a fusion protein.

11. An MVA vector as claimed in any of claims 1 to 9, wherein the polynucleotide sequence encodes (i) a MAGE cancer antigen or immunogenic fragment thereof and/or an NY-ESO-1 cancer antigen or immunogenic fragment thereof; or (ii) a MAGE cancer antigen or immunogenic fragment thereof and/or a LAGE1 cancer antigen or immunogenic fragment thereof, expressed in an animal cell as a fusion protein, wherein at least one of the MAGE cancer antigen, NY-ESO-1 cancer antigen or LAGE1 cancer antigen is a fragment.

12. An MVA vector as claimed in claim 11, wherein the MAGE cancer antigen and NY-ESO-1 or MAGE cancer antigen and LAGE1 are immunogenic fragments.

13. A ChAd or MVA vector as claimed in any of claims 10 to 12, wherein the polynucleotide sequence encodes a linker of between 5 and 9 amino acids; preferably having the amino acid sequence GGGPGGG, which when expressed links the MAGE and NY-ESO-1 or LAGE1 cancer antigens or fragments thereof, in either order, as a fusion protein.

14. An immunogenic composition comprising a ChAd or MVA vector as claimed in any preceding claim.

15. A composition of claim 14 further comprising an adjuvant.

16. An isolated polynucleotide comprising a sequence encoding a ChAd vector of any of claims 1 to 10 or 13, or an MVA vector of any of claims 3 to 9 or 11 to 13.

17. An isolated polynucleotide as claimed in claim 16, codon optimised for human codon usage.

18. A Bacterial Artificial Chromosome (BAC) clone comprising a polynucleotide of claim 16 or claim 17.

19. An isolated host cell comprising a ChAd and/or MVA vector as set forth in any of claims 1 to 13.

20. A method of preventing or treating cancer in an individual, comprising administering an effective amount of a ChAd vector as set forth in any of claims 1 to 10 or 13, and administering an effective amount of an MVA vector as set forth in any of claims 3 to 9 or 11 to 13, whereby the adaptive immune system of the individual is stimulated to provide an anti-cancer immune response.

21. A method of preventing or treating cancer as claimed in claim 20, wherein the administration of the ChAd and MVA vectors is carried out separately, sequentially or simultaneously.

22. A method as claimed in claim 20 or claim 21, further comprising administration of an effective amount of one or more checkpoint inhibitors.

23. A method as claimed in any of claim 20 to 22, wherein the checkpoint inhibitor is administered simultaneously, separately or concurrently with the ChAd and MVA vectors.

24. A method as claimed in any of claims 20 to 23, wherein the individual has received, is receiving or will receive a chemotherapy and/or radiotherapy treatment.

25. A method as claimed in any of claims 20 to 24, wherein the ChAd vector is administered first.

26. A method as claimed in any of claims 20 to 25, wherein the ChAd and MVA vectors are administered more than once each.

27. A method as claimed in any of claims 20 to 26, wherein the ChAd and MVA vectors are administered in alternation.

28. A method as claimed in any of claims 20 to 27, wherein the period of time between each administration of a vector is in the range 5 days to 8 weeks; preferably 1 week.

29. A method as claimed in any of claims 22 to 28, wherein the checkpoint inhibitor blocks PD-1, CTLA-4 or PD-L1.

30. A method as claimed in any of claims 22 to 28, wherein the checkpoint inhibitor is selected from nivolumab, pembrolizumab, ipilimumab, tremelimumab or atezolizumab, durvaliumab or avelumab.

31. A method as claimed any of claims 22 to 28, wherein the cancer is non-small cell lung cancer (NSCLC), melanoma, Hodgkin lymphoma, non-Hodgkin lymphoma, urinary tract (urothelial), bladder, small cell lung cancer, renal, head & neck, sarcoma, or breast.

32. A ChAd vector as claimed in any of claims 1, 2, 5 to 10 or 13 for use in the prevention or treatment of cancer.

33. An MVA vector as claimed in any of claims 3 to 9 or 11 to 13 for use in the prevention or treatment of cancer.

34. A ChAd vector as set forth in any of claims 1, 2, 5 to 10 or 13 and an MVA vector as set forth in any of claims 3 to 9 or 11 to 13, for separate, sequential or simultaneous administration to a patient for the prevention or treatment of cancer.

35. ChAd and MVA vectors for use in prevention or treatment of cancer as claimed in claim 34, further including one or more checkpoint inhibitors for administration with the ChAd and MVA vectors for the treatment of cancer.

36. ChAd and MVA vectors for use in prevention or treatment of cancer as claimed in claim 35, wherein the checkpoint inhibitor is administered simultaneously, separately or concurrently with a vector.

37. ChAd and MVA vectors for use in prevention or treatment of cancer as claimed in any of claims 31 to 33, wherein the patient has received, is receiving or will receive chemotherapy.

38. ChAd and MVA vectors for use in prevention or treatment of cancer as claimed in any of claims 34 to 36, wherein the ChAd vector is administered first.

39. ChAd and MVA vectors for use in prevention or treatment of cancer as claimed in any of claims 34 to 38, wherein the ChAd and MVA vectors are administered more than once each.

40. ChAd and MVA vectors for use in prevention or treatment of cancer as claimed in any of claims 34 to 39, wherein the ChAd and MVA vectors are administered in alternation.

41. ChAd and MVA vectors for use in prevention or treatment of cancer as claimed in any of claims 34 to 40, wherein the period of time between each administration of a vector is in the range 5 days to 8 weeks, preferably 1 week.

42. ChAd and MVA vectors for use in prevention or treatment of cancer as claimed in any of claims 35 to 41, wherein the checkpoint inhibitor blocks PD-1, CTLA-4 or PD-L1.

43. ChAd and MVA vectors for use in prevention or treatment of cancer as claimed in any of claims 35 to 41, wherein the checkpoint inhibitor is selected from nivolumab, pembrolizumab, ipilimumab, tremelimumab or atezolizumab , durvaliumab or avelumab.

44. ChAd and MVA vectors for use in prevention or treatment of cancer as claimed in any of claims 35 to 41, wherein the cancer is non-small cell lung cancer (NSCLC), melanoma, Hodgkin lymphoma, non-Hodgkin lymphoma, urinary tract (urothelial), bladder, small cell lung cancer, renal, head & neck, sarcoma or breast.

45. A ChAd vector as set forth in any of claims 1, 2, 5 to 10 or 13, an MVA vector as set forth in any of claims 3 to 9 or 11 to 13, a chemotherapeutic agent, and a checkpoint inhibitor, for separate, sequential or simultaneous administration to a patient for the prevention or treatment of cancer.

46. A ChAd vector, an MVA vector, a chemotherapeutic agent and a checkpoint inhibitor as claimed in claim 45, wherein the chemotherapeutic agent is selected from (a) carboplatin or cisplatin in combination with (b) one of paclitaxel, docetaxel, vinorelbine, gemcitabine, etoposide or pemetrexed.

47. A ChAd vector, an MVA vector, a chemotherapeutic agent and a checkpoint inhibitor as claimed in claim 45 or claim 46, wherein the checkpoint inhibitor is PD-1.

48. A ChAd vector, an MVA vector, a chemotherapeutic agent and a checkpoint inhibitor as claimed in any of claims 45 to 47, wherein the cancer is selected from: non-small cell lung cancer (NSCLC) or small cell lung cancer (SCLC), melanoma, Hodgkin lymphoma, non-Hodgkin lymphoma, urinary tract (urothelial), bladder, small cell lung cancer, renal, head & neck, sarcoma or breast cancer.

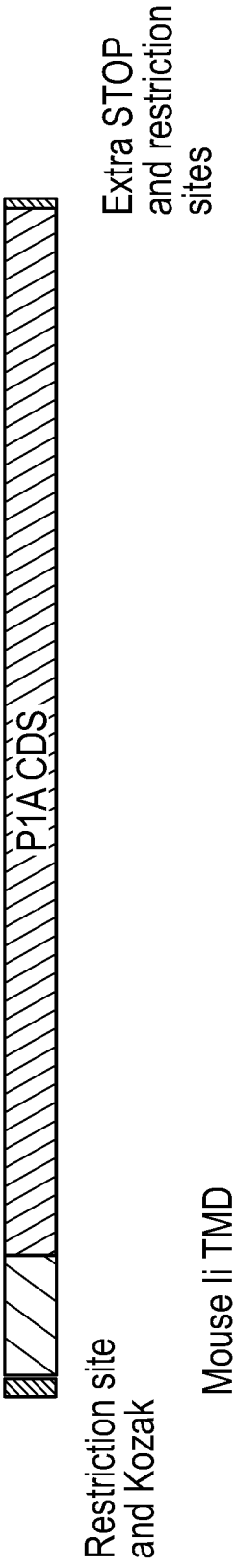
Extra STOP
and restriction
sites
P1A CDS
Restriction site
and Kozak
Mouse Ii TMD

FIG.1A

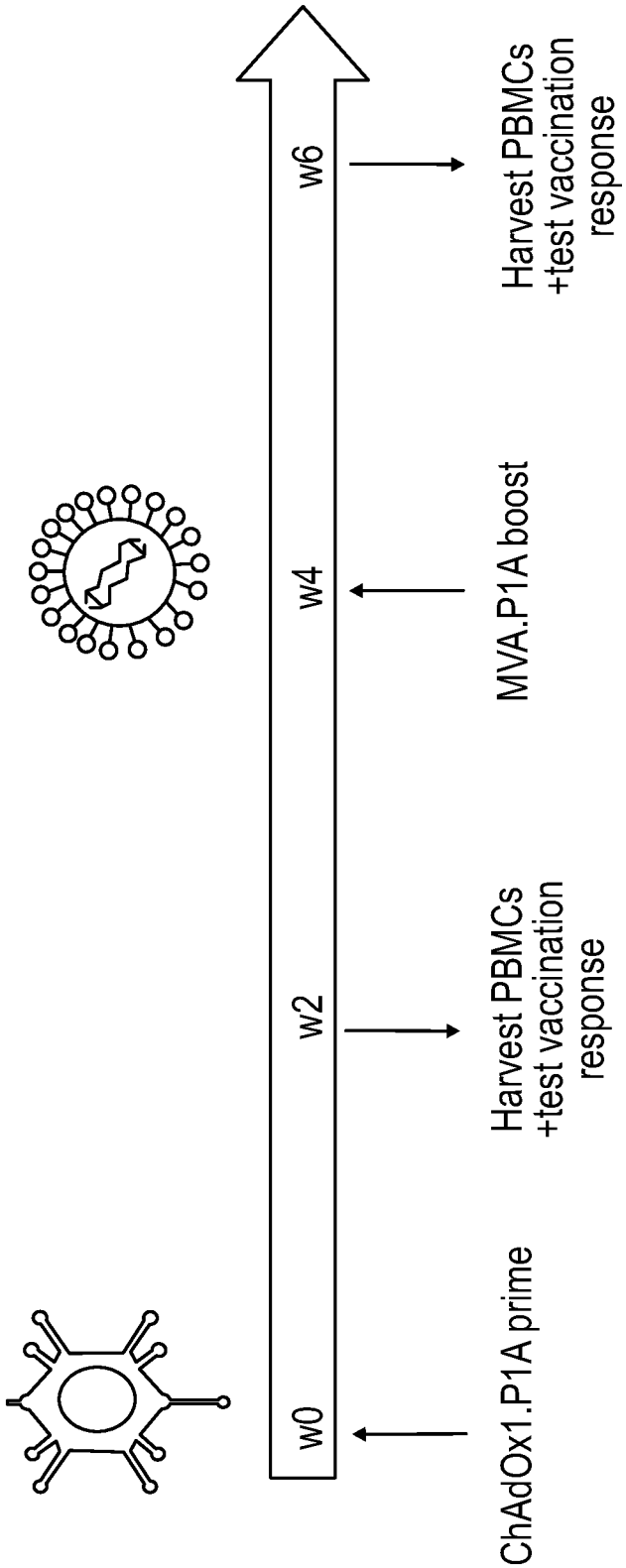
w0
w2
w4
w6
ChAdOx1.P1A prime
Harvest PBMCs
+test vaccination
response
MVA.P1A boost
Harvest PBMCs
+test vaccination
response

FIG.1B

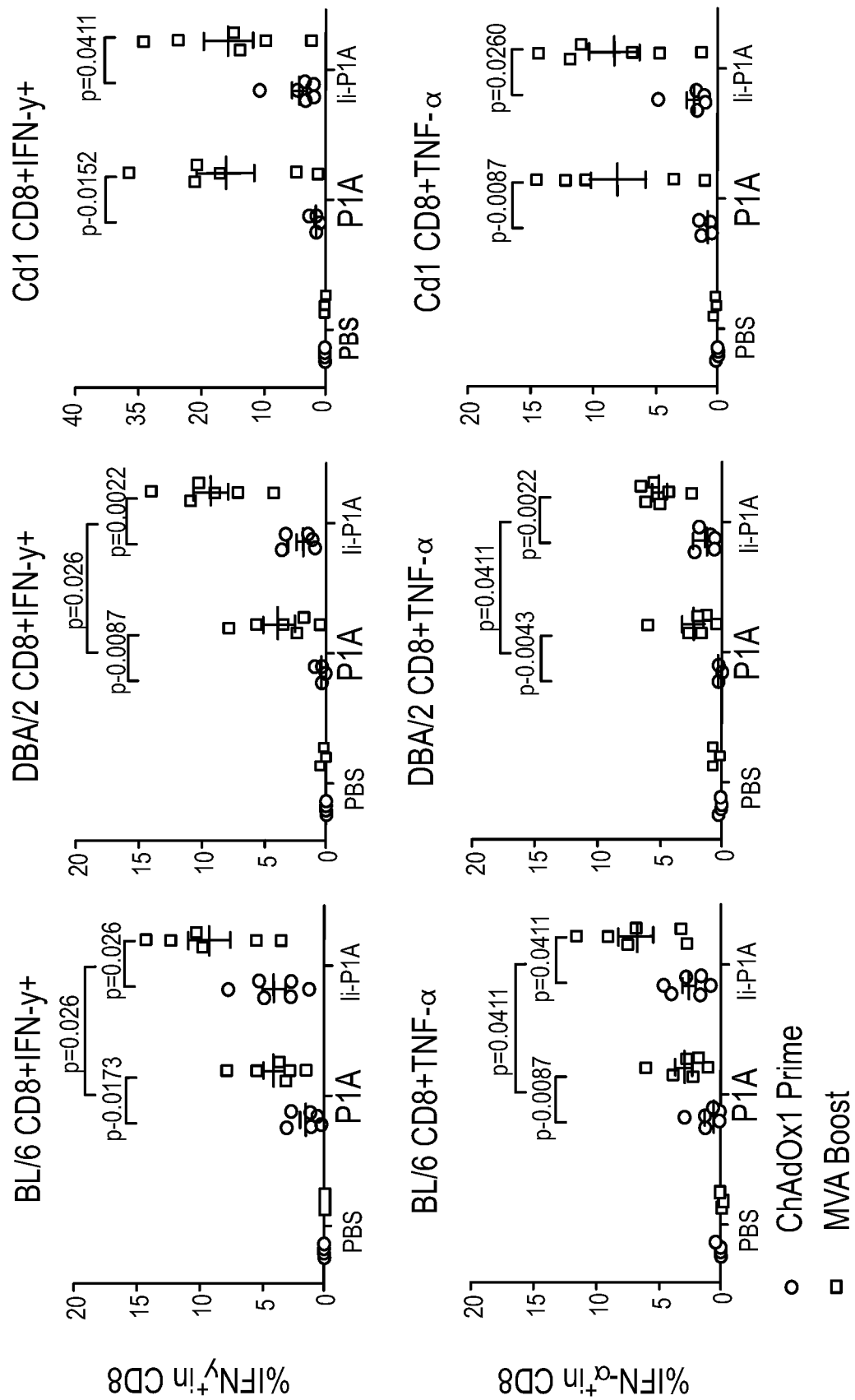
BL/6 CD8+IFN-γ+
DBA/2 CD8+IFN-γ+
Cd1 CD8+IFN-γ+
BL/6 CD8+TNF-α
DBA/2 CD8+TNF-α
Cd1 CD8+TNF-α
%IFNγ+in CD8
%IFN-α+in CD8
p=0.026
p-0.0173
p=0.026
p=0.026
p-0.0087
p=0.0022
p-0.0152
p=0.0411
p=0.0411
p-0.0087
p=0.0411
p=0.0411
p=0.0043
p=0.0022
p-0.0087
p=0.0260
PBS
P1A
li-P1A
ChAdOx1 Prime
MVA Boost

FIG.2

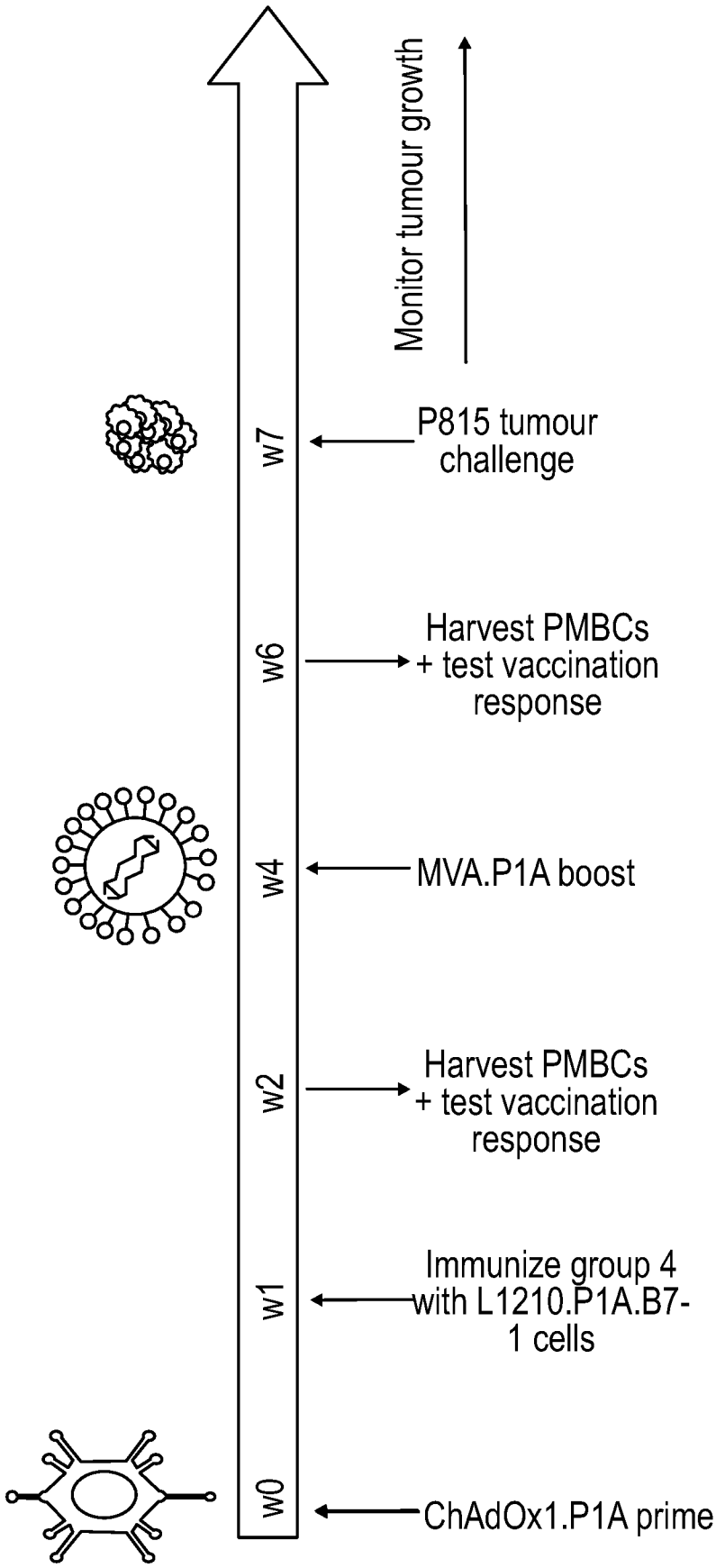
Monitor tumour growth
w7
P815 tumour challenge
w6
Harvest PMBCs + test vaccination response
w4
MVA.P1A boost
w2
Harvest PMBCs + test vaccination response
w1
Immunize group 4 with L1210.P1A.B7-1 cells
w0
ChAdOx1.P1A prime

FIG.3

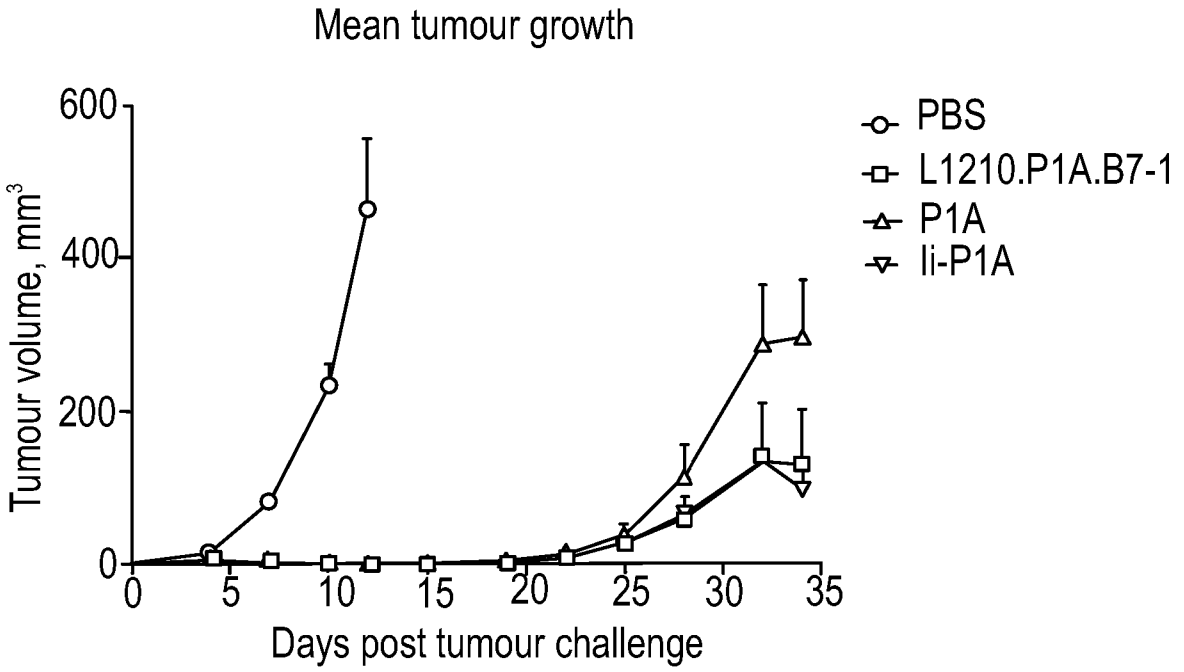
Mean tumour growth
Tumour volume, mm3
600
400
200
0
0
5
10
15
20
25
30
35
Days post tumour challenge
PBS
L1210.P1A.B7-1
P1A
Ii-P1A

FIG.4

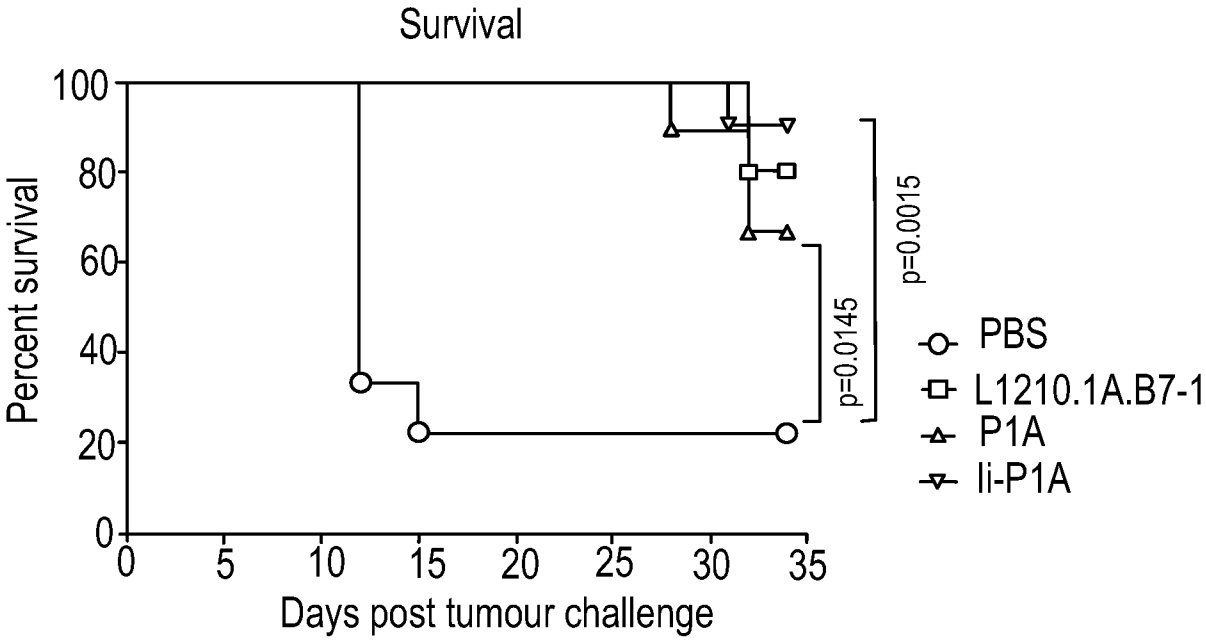
Survival
Percent survival
100
80
60
40
20
0
0
5
10
15
20
25
30
35
Days post tumour challenge
p=0.0015
p=0.0145
PBS
L1210.1A.B7-1
P1A
Ii-P1A

FIG.5

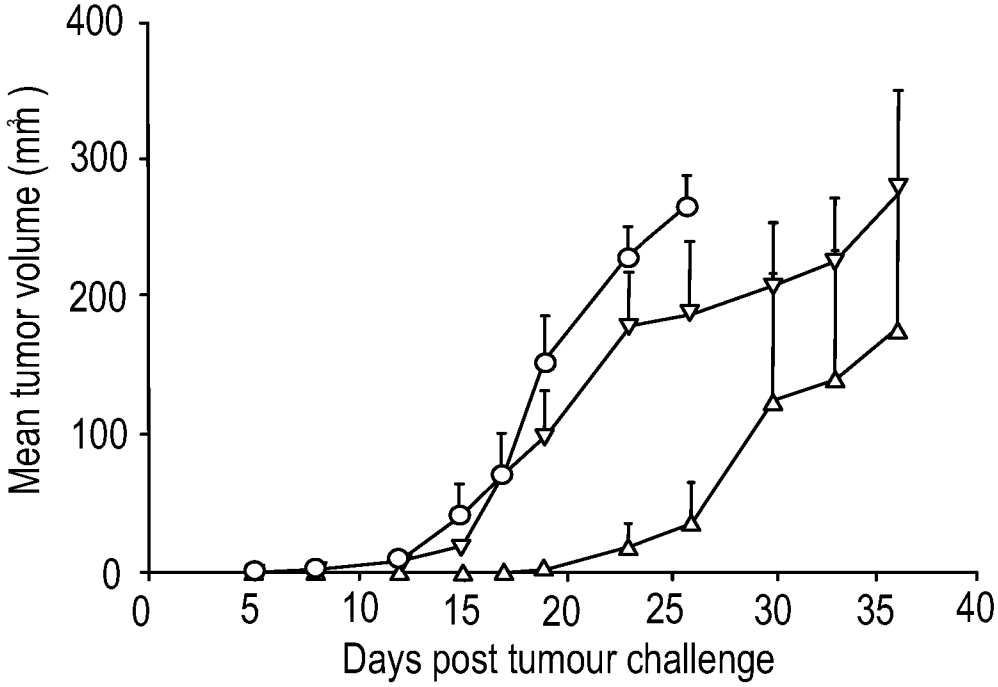
Mean tumor volume (mm3)
400
300
200
100
0
0
5
10
15
20
25
30
35
40
Days post tumour challenge

FIG.6A

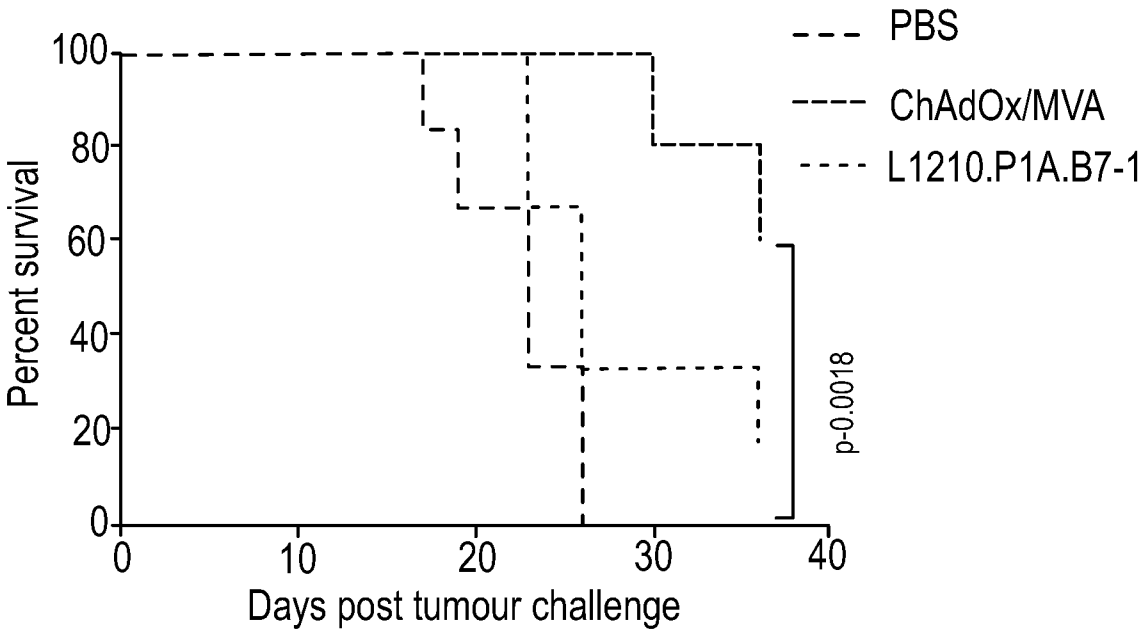
PBS
ChAdOx/MVA
L1210.P1A.B7-1
Percent survival
100
80
60
40
20
0
0
10
20
30
40
Days post tumour challenge
p-0.0018

FIG.6B

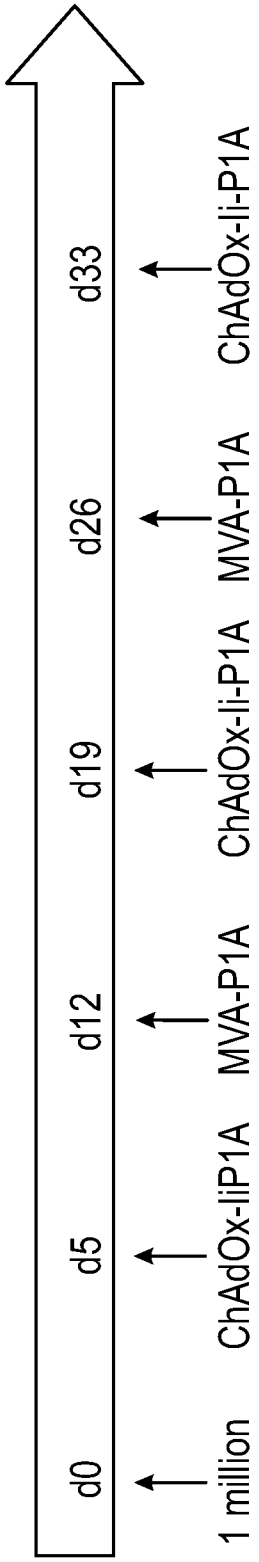
d0
d5
d12
d19
d26
d33
1 million 15V4T3 cells injected s.c.
ChAdOx-liP1A
MVA-P1A
ChAdOx-li-P1A
MVA-P1A
ChAdOx-li-P1A

FIG.7

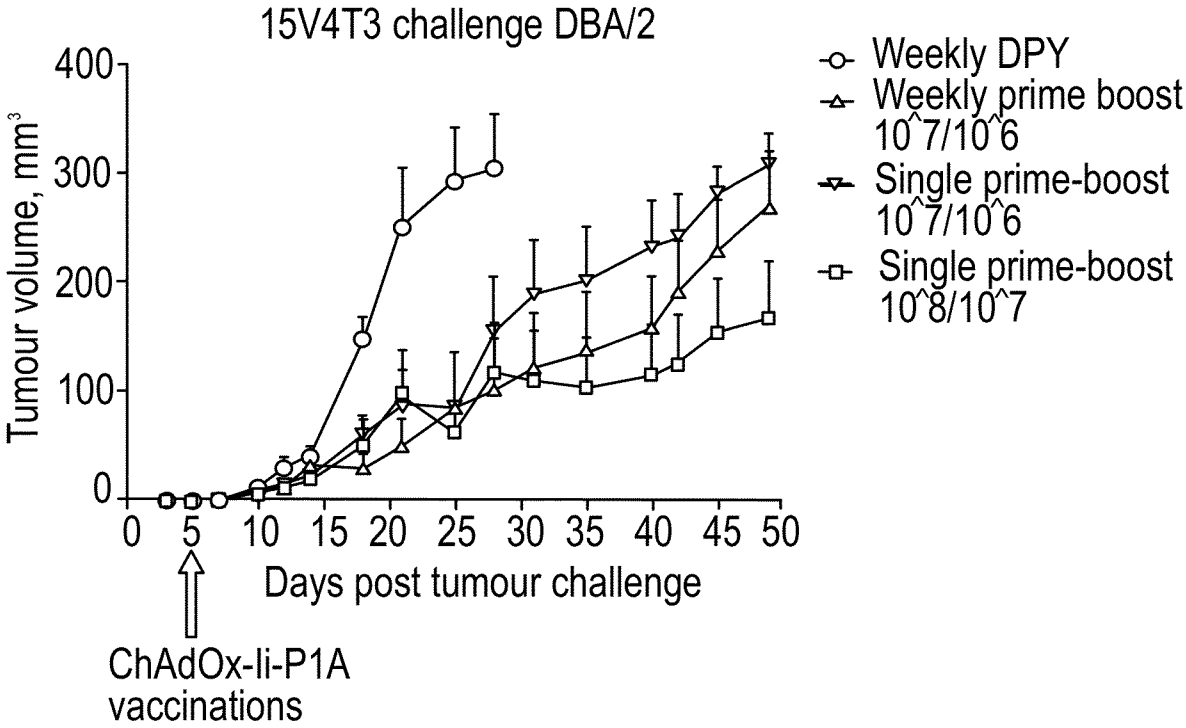
15V4T3 challenge DBA/2
Tumour volume, mm3
400
300
200
100
0
0 5 10 15 20 25 30 35 40 45 50
Days post tumour challenge
ChAdOx-li-P1A
vaccinations
Weekly DPY
Weekly prime boost
10^7/10^6
Single prime-boost
10^7/10^6
Single prime-boost
10^8/10^7

FIG.8A

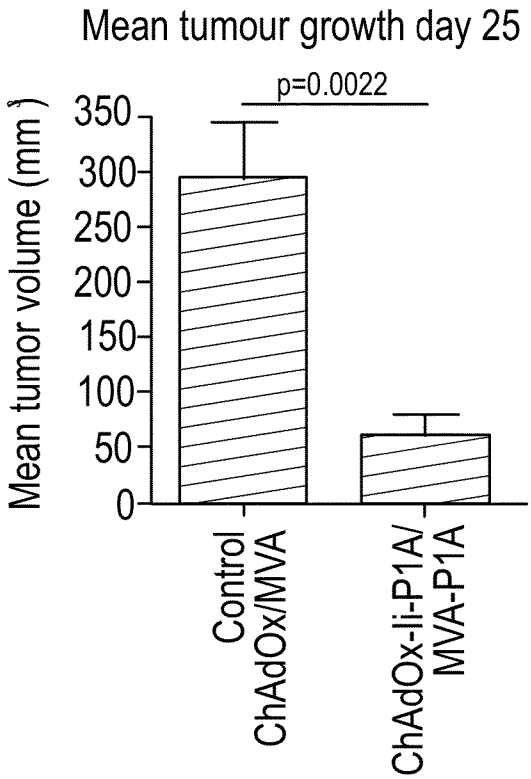
Mean tumour growth day 25
p=0.0022
Mean tumor volume (mm3)
350
300
250
200
150
100
50
0
Control
ChAdOx/MVA
ChAdOx-li-P1A/
MVA-P1A

FIG.8B

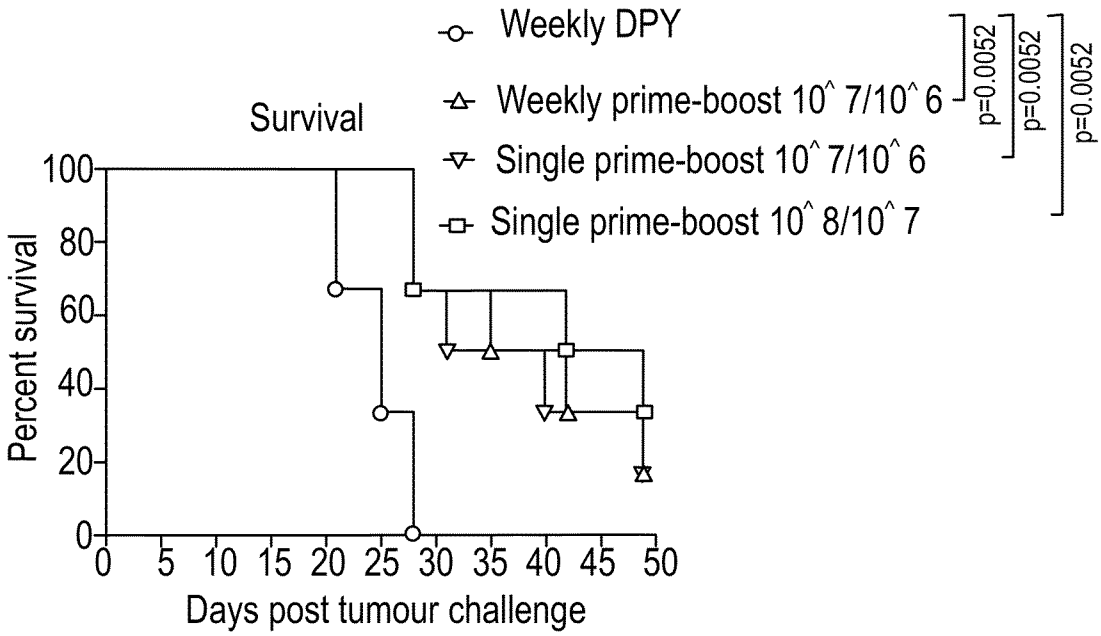
Weekly DPY
Weekly prime-boost 10^ 7/10^ 6
Single prime-boost 10^ 7/10^ 6
Single prime-boost 10^ 8/10^ 7
p=0.0052
p=0.0052
p=0.0052
Survival
Percent survival
100
80
60
40
20
0
0 5 10 15 20 25 30 35 40 45 50
Days post tumour challenge

FIG.8C

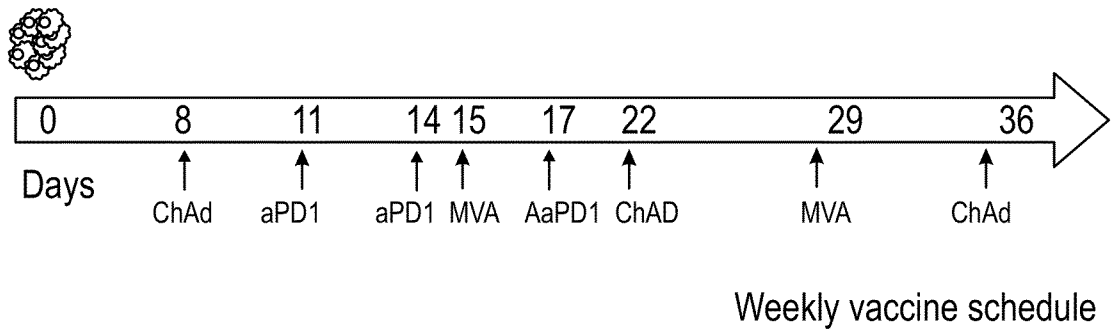
0 8 11 14 15 17 22 29 36
Days
ChAd aPD1 aPD1 MVA AaPD1 ChAD MVA ChAd
Weekly vaccine schedule

FIG.9

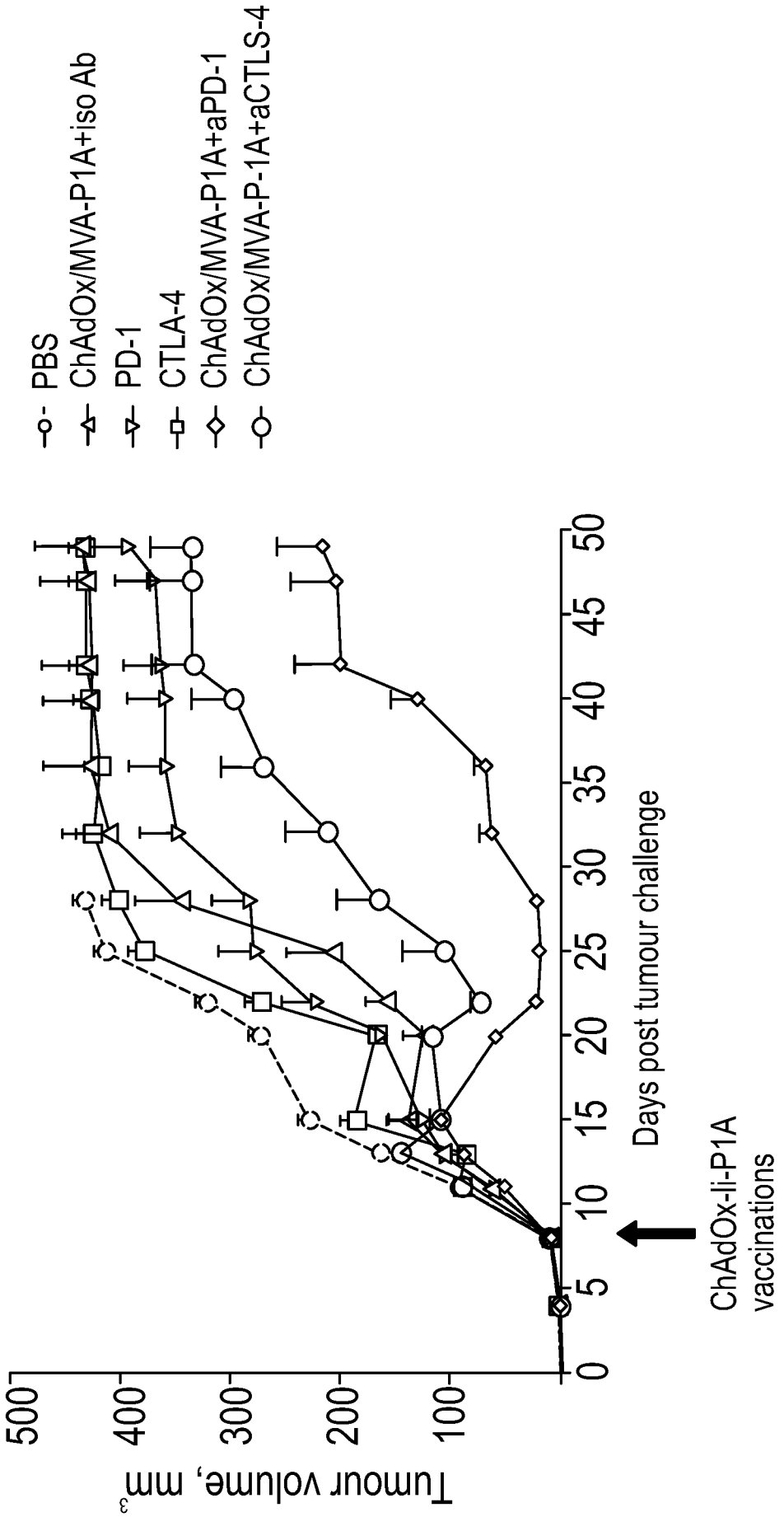
PBS
ChAdOx/MVA-P1A+iso Ab
PD-1
CTLA-4
ChAdOx/MVA-P1A+aPD-1
ChAdOx/MVA-P-1A+aCTLS-4
Tumour volume, mm3
500
400
300
200
100
0
5
10
15
20
25
30
35
40
45
50
Days post tumour challenge
ChAdOx-li-P1A
vaccinations

FIG. 10

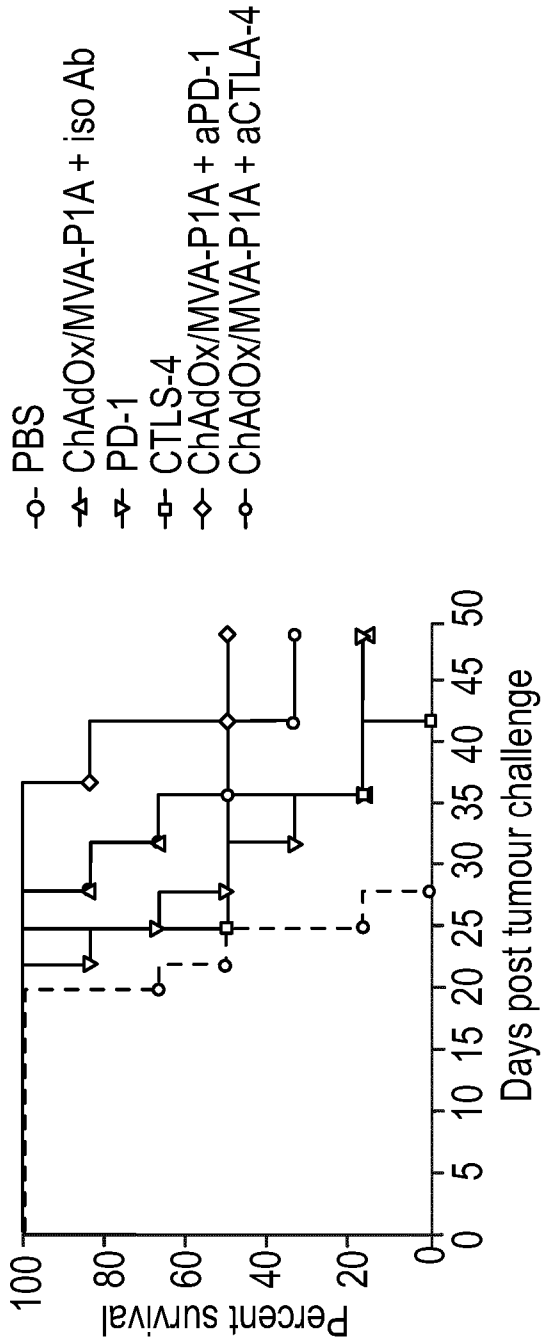
PBS
ChAdOx/MVA-P1A + iso Ab
PD-1
CTLS-4
ChAdOx/MVA-P1A + aPD-1
ChAdOx/MVA-P1A + aCTLA-4
Percent survival
100
80
60
40
20
0
0
5
10
15
20
25
30
35
40
45
50
Days post tumour challenge

FIG.11

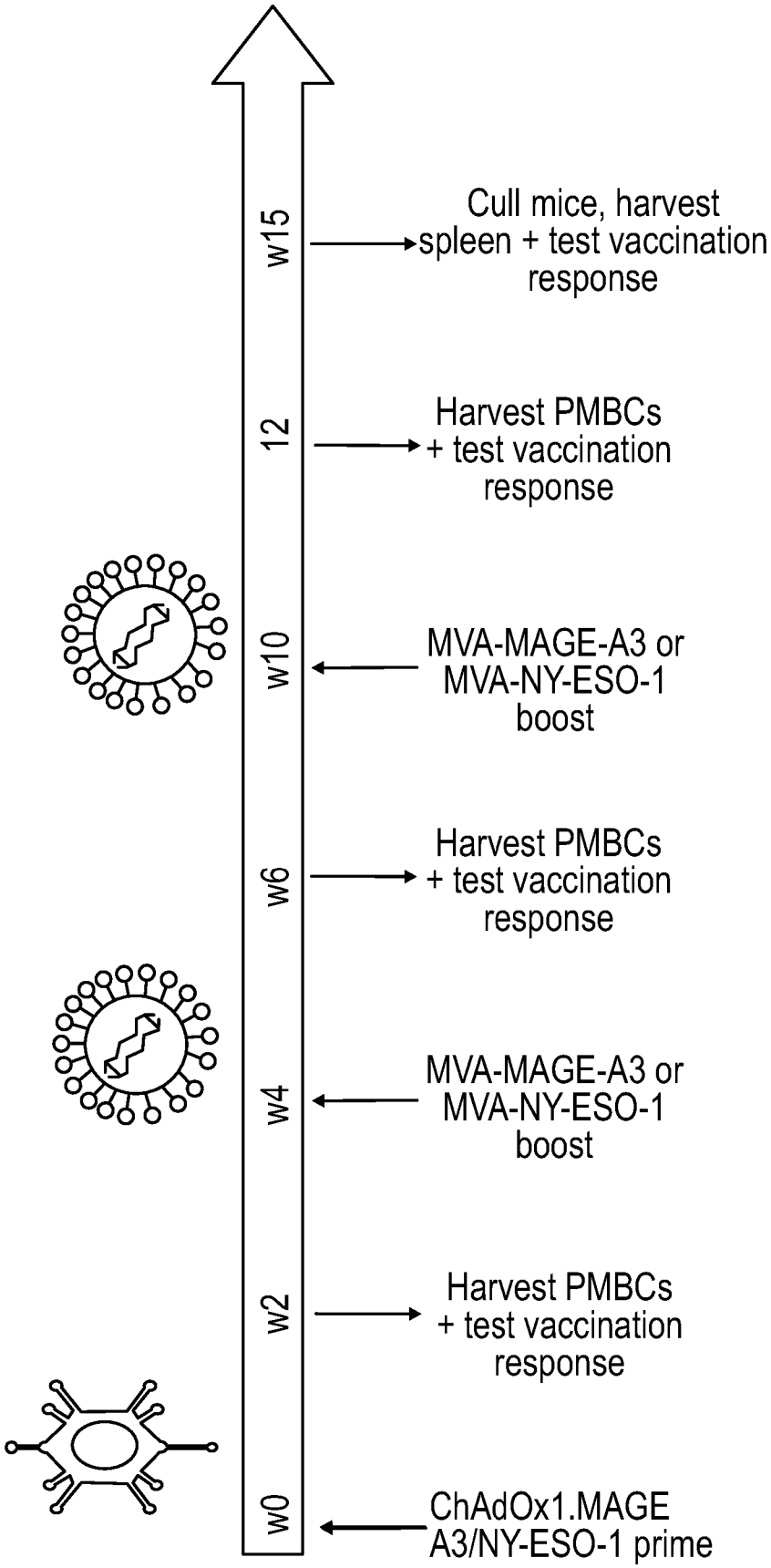
w15
Cull mice, harvest spleen + test vaccination response
12
Harvest PMBCs + test vaccination response
w10
MVA-MAGE-A3 or MVA-NY-ESO-1 boost
w6
Harvest PMBCs + test vaccination response
w4
MVA-MAGE-A3 or MVA-NY-ESO-1 boost
w2
Harvest PMBCs + test vaccination response
w0
ChAdOx1.MAGE A3/NY-ESO-1 prime

FIG.12

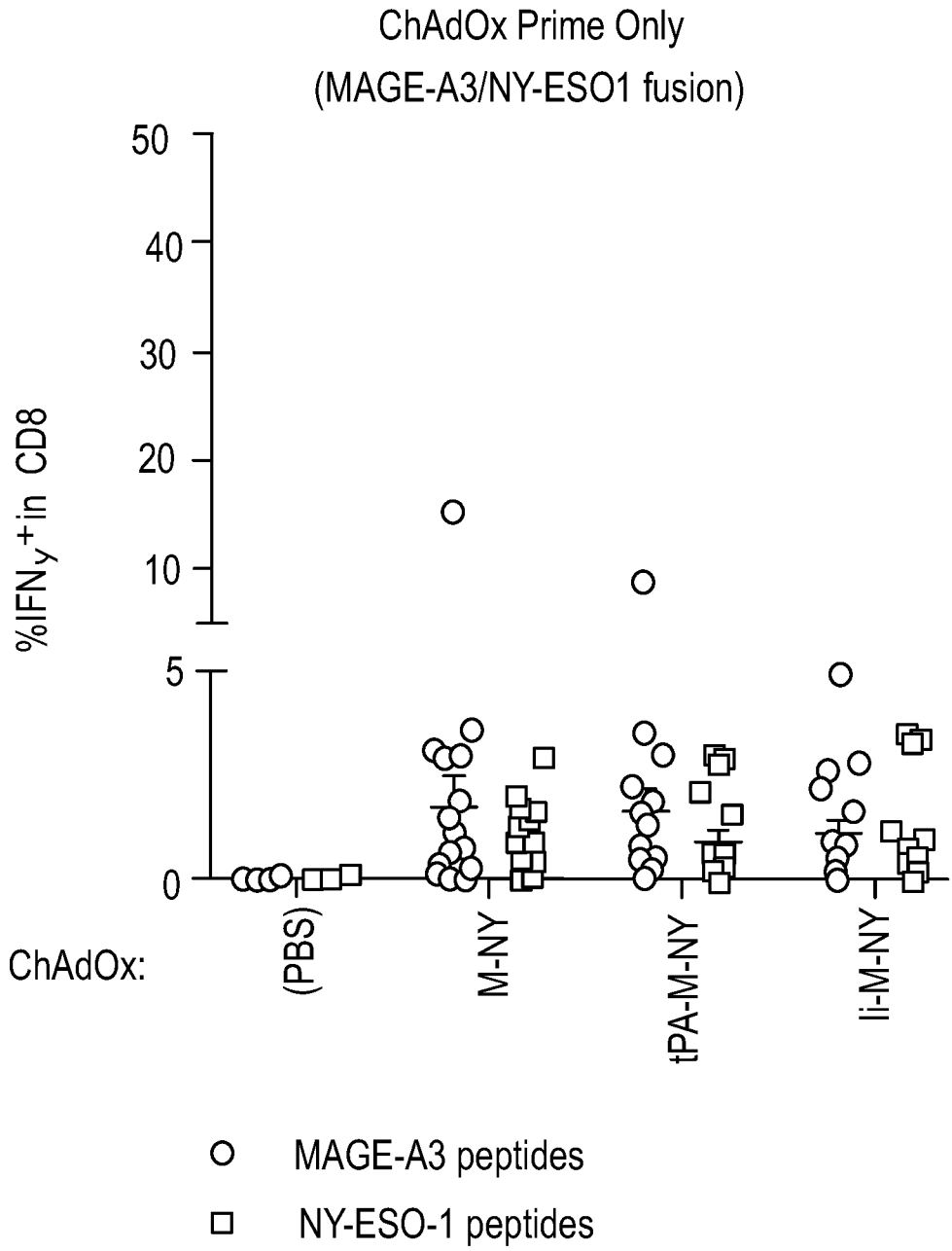
ChAdOx Prime Only
(MAGE-A3/NY-ESO1 fusion)
%IFNγ+ in CD8
50
40
30
20
10
5
0
ChAdOx:
(PBS)
M-NY
tPA-M-NY
li-M-NY
MAGE-A3 peptides
NY-ESO-1 peptides

FIG.13

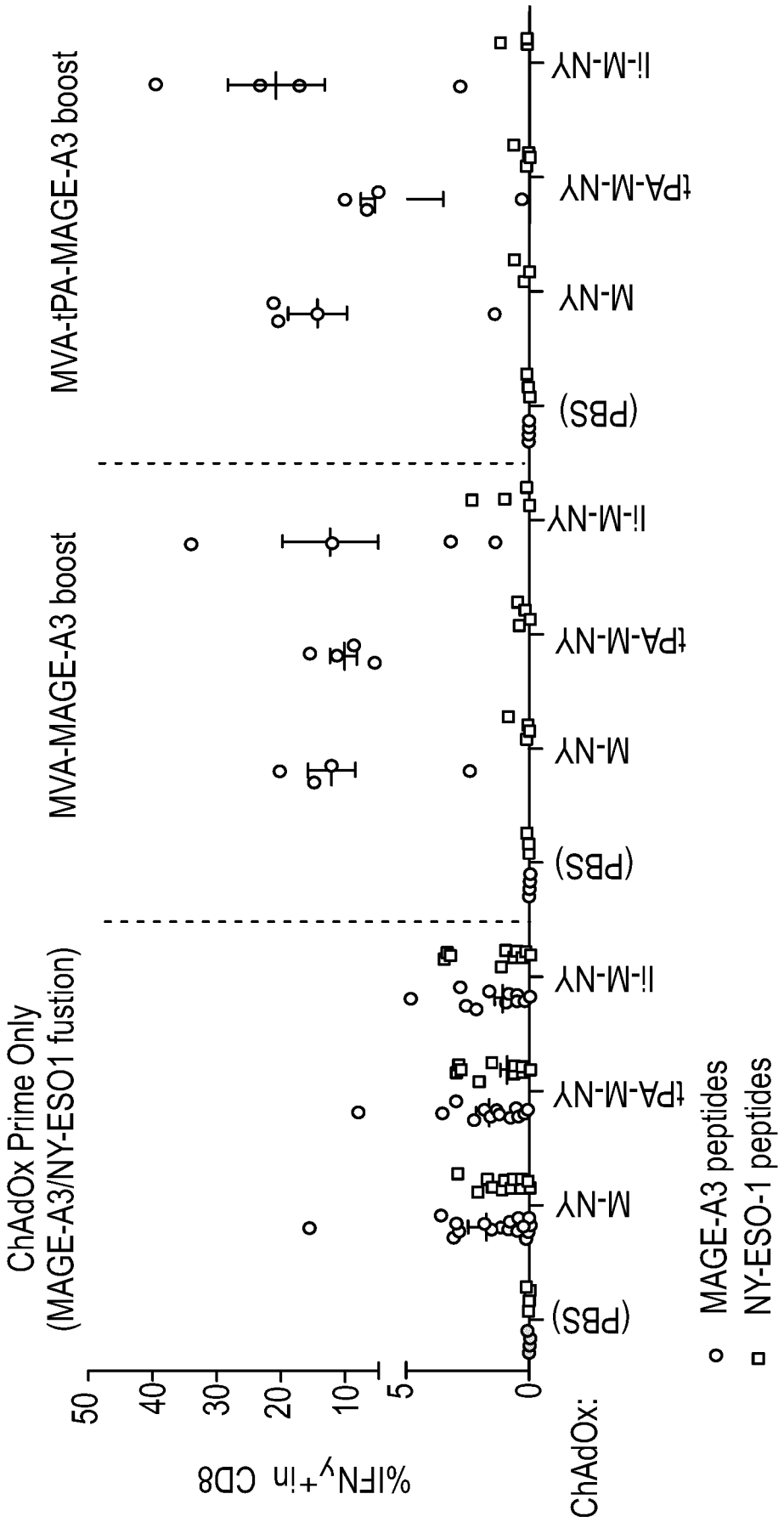
%IFNγ+in CD8
50
40
30
20
10
5
0
ChAdOx:
(PBS)
M-NY
tPA-M-NY
li-M-NY
ChAdOx Prime Only
(MAGE-A3/NY-ESO1 fustion)
MVA-MAGE-A3 boost
MVA-tPA-MAGE-A3 boost
MAGE-A3 peptides
NY-ESO-1 peptides

FIG.14

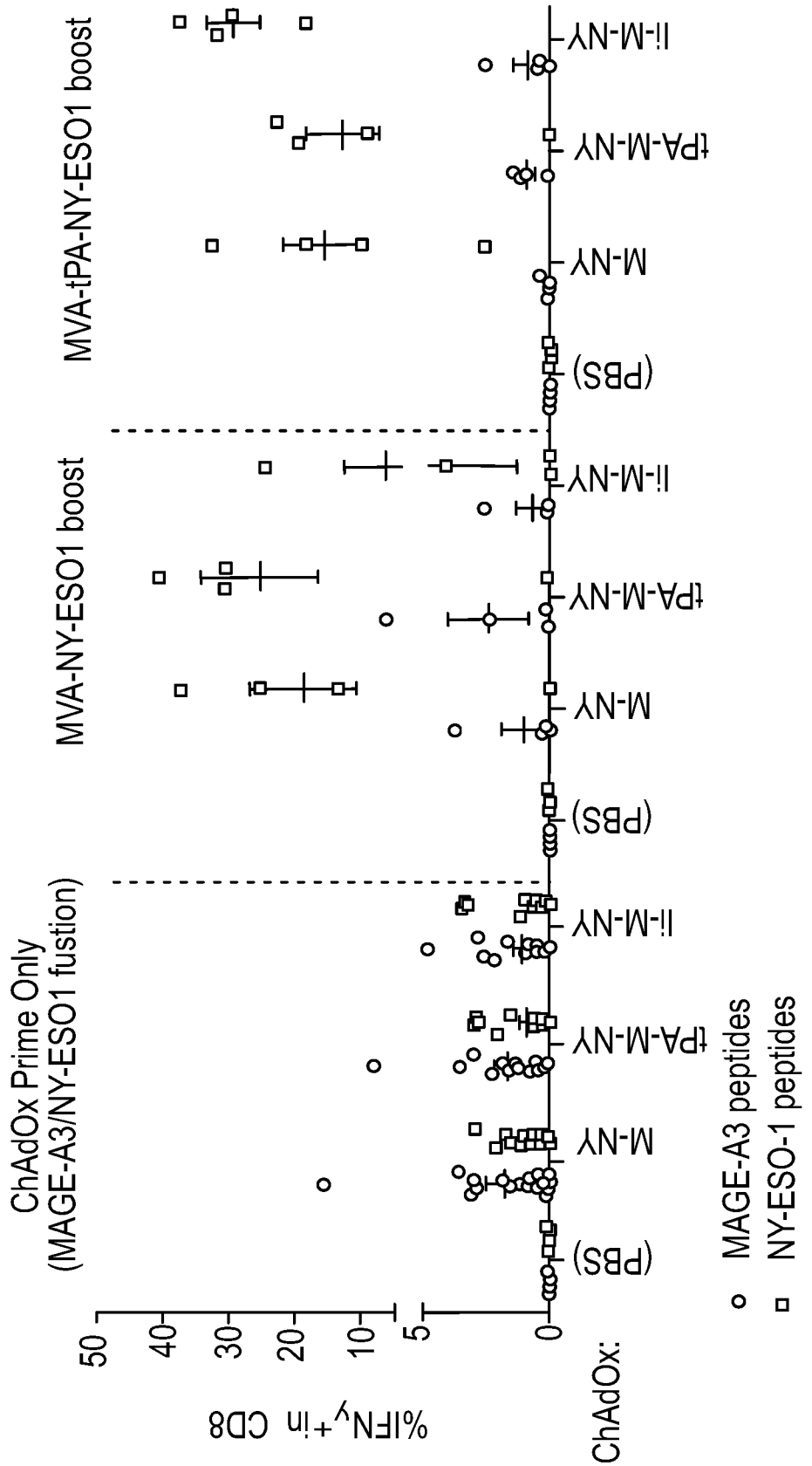
%IFNγ+ in CD8
50
40
30
20
10
5
0
ChAdOx:
(PBS)
M-NY
tPA-M-NY
Ii-M-NY
(PBS)
M-NY
tPA-M-NY
Ii-M-NY
(PBS)
M-NY
tPA-M-NY
Ii-M-NY
ChAdOx Prime Only
(MAGE-A3/NY-ESO1 fustion)
MVA-NY-ESO1 boost
MVA-tPA-NY-ESO1 boost
MAGE-A3 peptides
NY-ESO-1 peptides

FIG.15

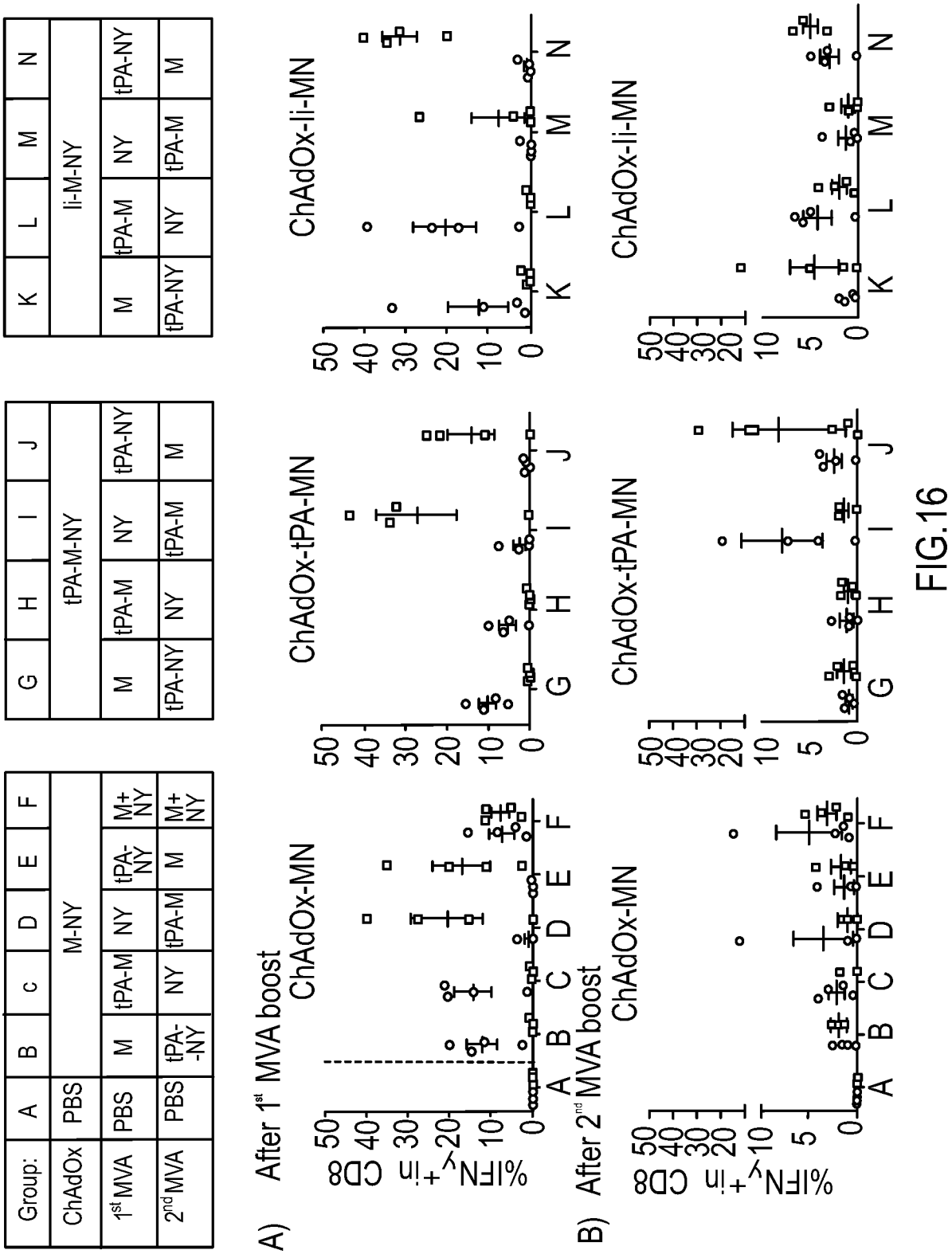
Group:
ChAdOx
1st MVA
2nd MVA
A
PBS
PBS
PBS
B
M-NY
M
tPA-NY
tPA-NY
c
tPA-M
NY
NY
D
NY
tPA-M
tPA-M
E
tPA-NY
M
M
F
M+NY
M+NY
G
tPA-M-NY
M
tPA-NY
H
tPA-M
NY
NY
I
NY
tPA-M
tPA-M
J
tPA-NY
M
M
K
li-M-NY
M
tPA-NY
L
tPA-M
NY
NY
M
NY
tPA-M
tPA-M
N
tPA-NY
M
M
MAGE-A3 peptides
NYESO peptides
A) After 1st MVA boost
B) After 2nd MVA boost
ChAdOx-MN
ChAdOx-tPA-MN
ChAdOx-li-MN
%IFNγ+in CD8
A B C D E F G H I J K L M N

FIG.16

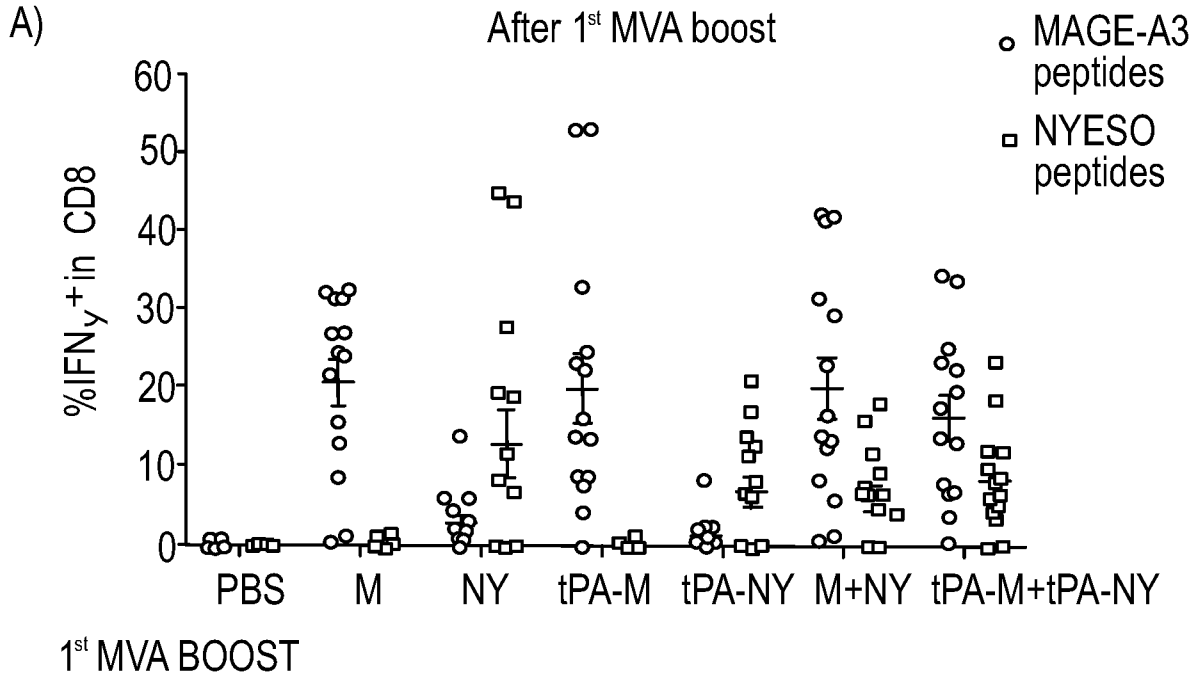

FIG.17A

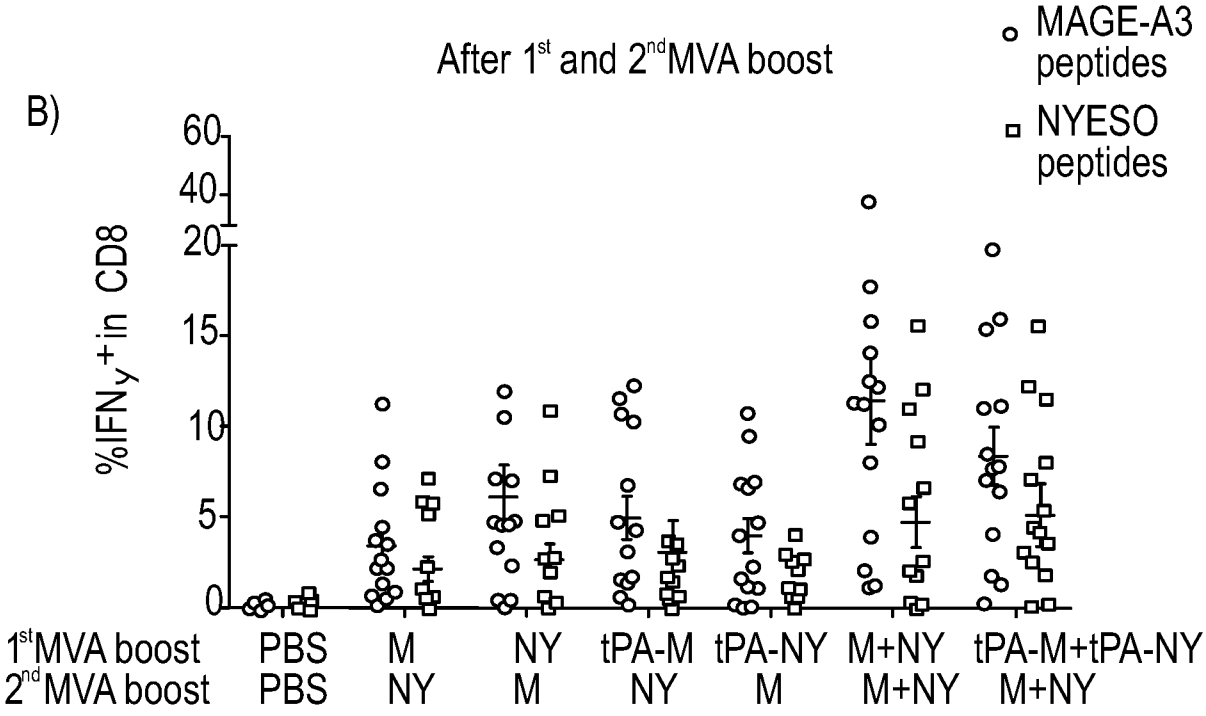

FIG.17B

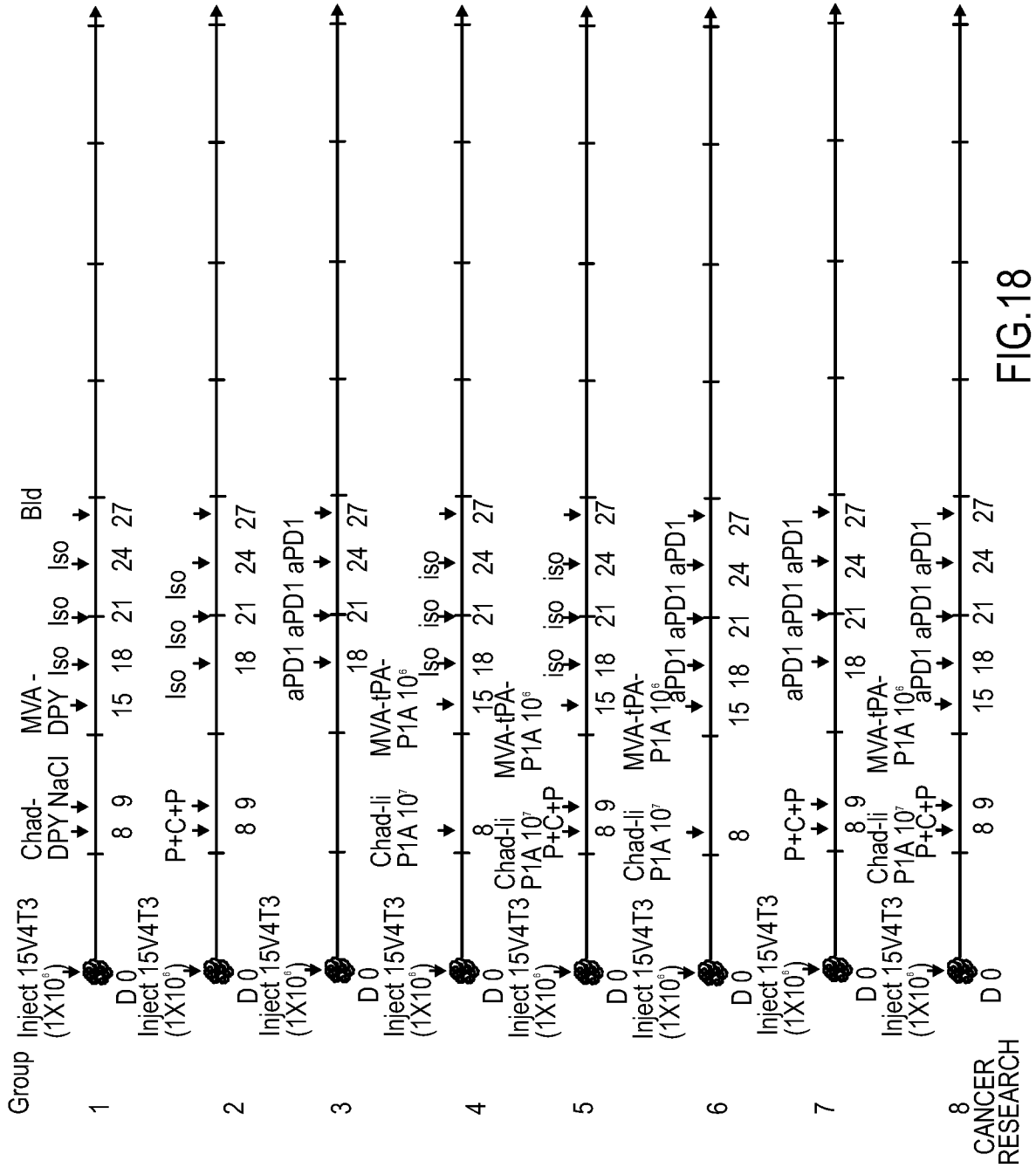
Group
Control Group
Chemo onlly (Paclitaxel and carboplatin(
aPD1 only
Vaccine only (ChAd)x1-li+P1A+MVA=-rPA-P1A)
Chemo + Vaccine (ChAdOx1-li-P1A+MVA-tPA-P1A)+ (Paclitaxel and carboplatin)
Vaccine + CPI (ChAdOx1-li-1A+MVA=tPA-P1A)+aPD1
Chemo + CPI (Paclitaxel and carboplatin) +aPDI
Vaccine +CPI+Chemo (ChAdOx1li-P1A+MVA-tPA-P1A)+aPDI+ (Paclitaxel and carboplatin)
Inject 15V4T3 (1X10⁶)
Chad-DPY NaCl
MVA-DPY
Bld
P+C+P
Chad-li P1A 10⁷
MVA-tPA-P1A 10⁶
Iso
aPD1
D 0
8 9
15 18
21 24 27
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FIG.18

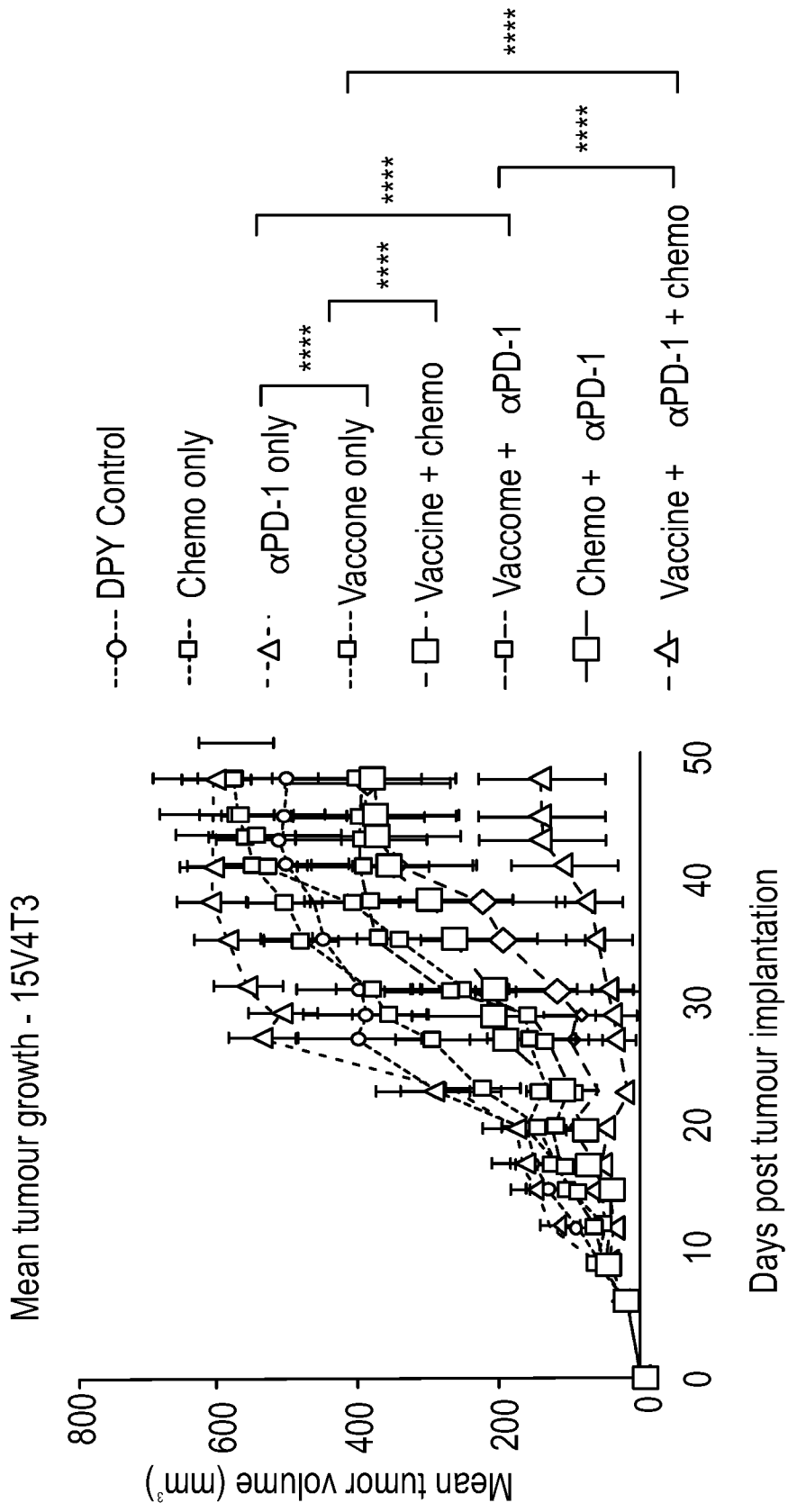

Mean tumour growth - 15V4T3
Mean tumor volume (mm³)
800
600
400
200
0
0
10
20
30
40
50
Days post tumour implantation
DPY Control
Chemo only
αPD-1 only
Vaccone only
Vaccine + chemo
Vaccome + αPD-1
Chemo + αPD-1
Vaccine + αPD-1 + chemo
****
****
****
****

FIG.19

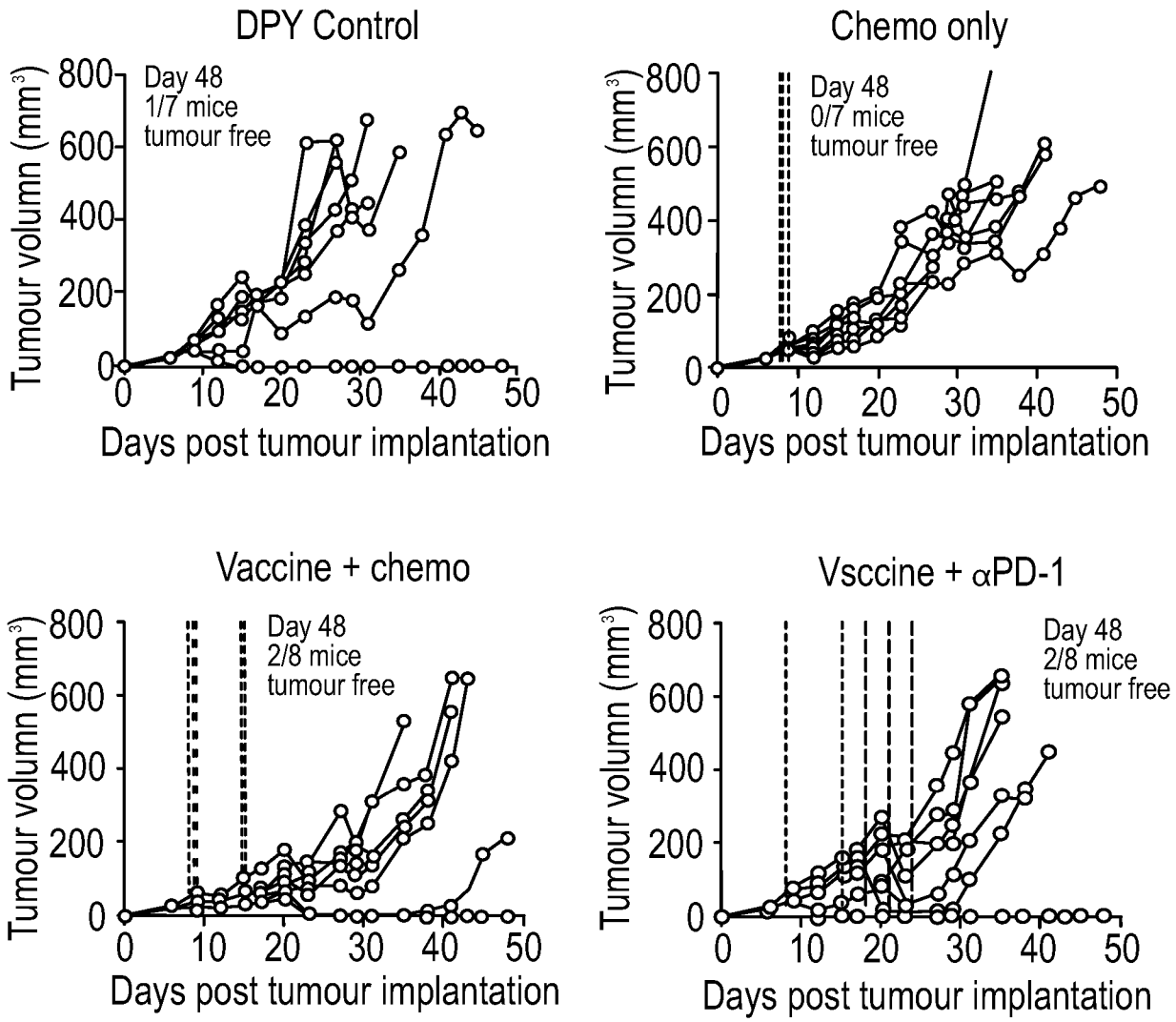

DPY Control
Day 48
1/7 mice
tumour free
Tumour volumn (mm³)
Days post tumour implantation
Chemo only
Day 48
0/7 mice
tumour free
Tumour volumn (mm³)
Days post tumour implantation
Vaccine + chemo
Day 48
2/8 mice
tumour free
Tumour volumn (mm³)
Days post tumour implantation
Vsccine + αPD-1
Day 48
2/8 mice
tumour free
Tumour volumn (mm³)
Days post tumour implantation
---- Vaccination
---- Chemotherapy
– – α PD-1

FIG.20

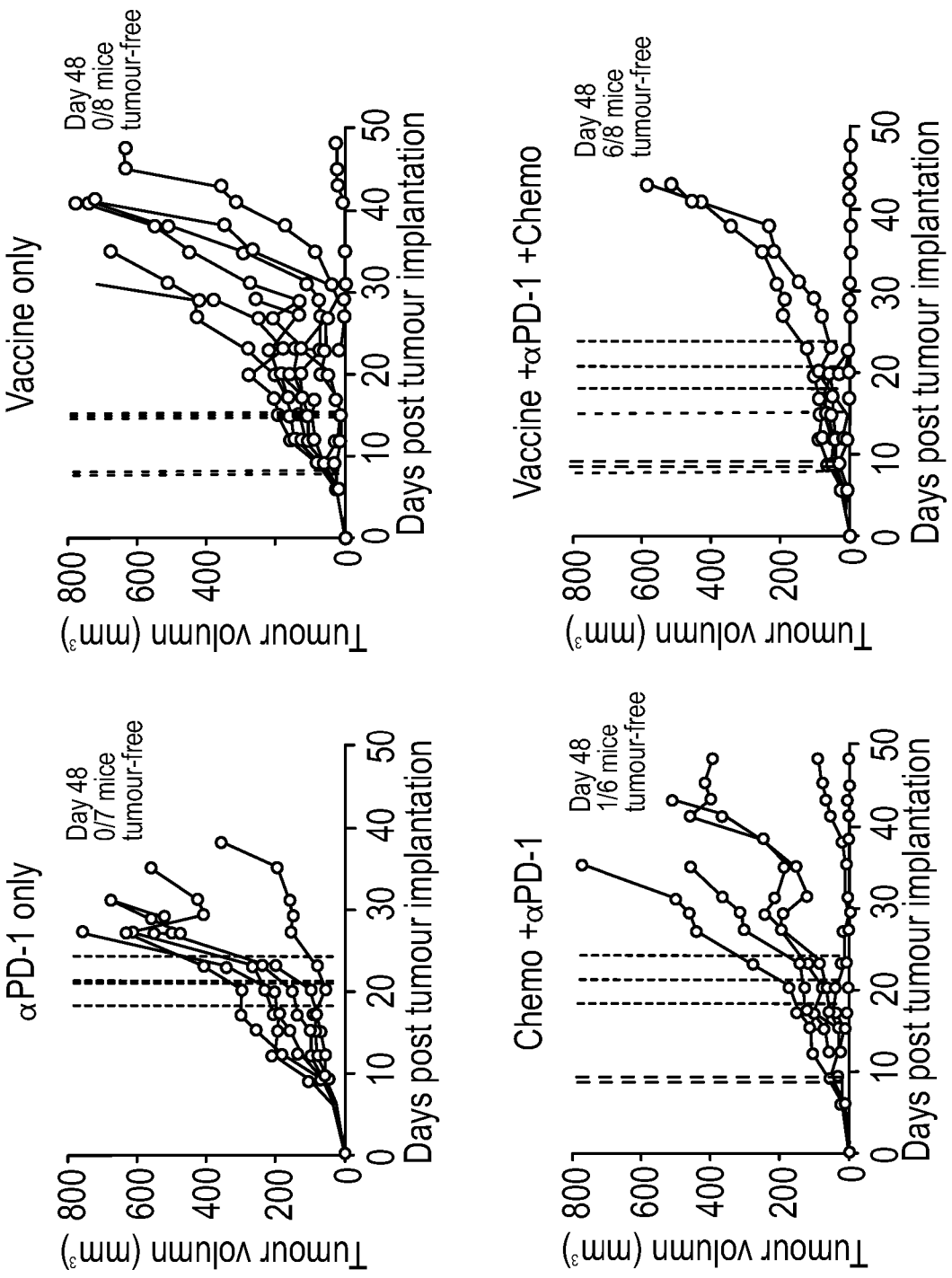


FIG.20 Continue.

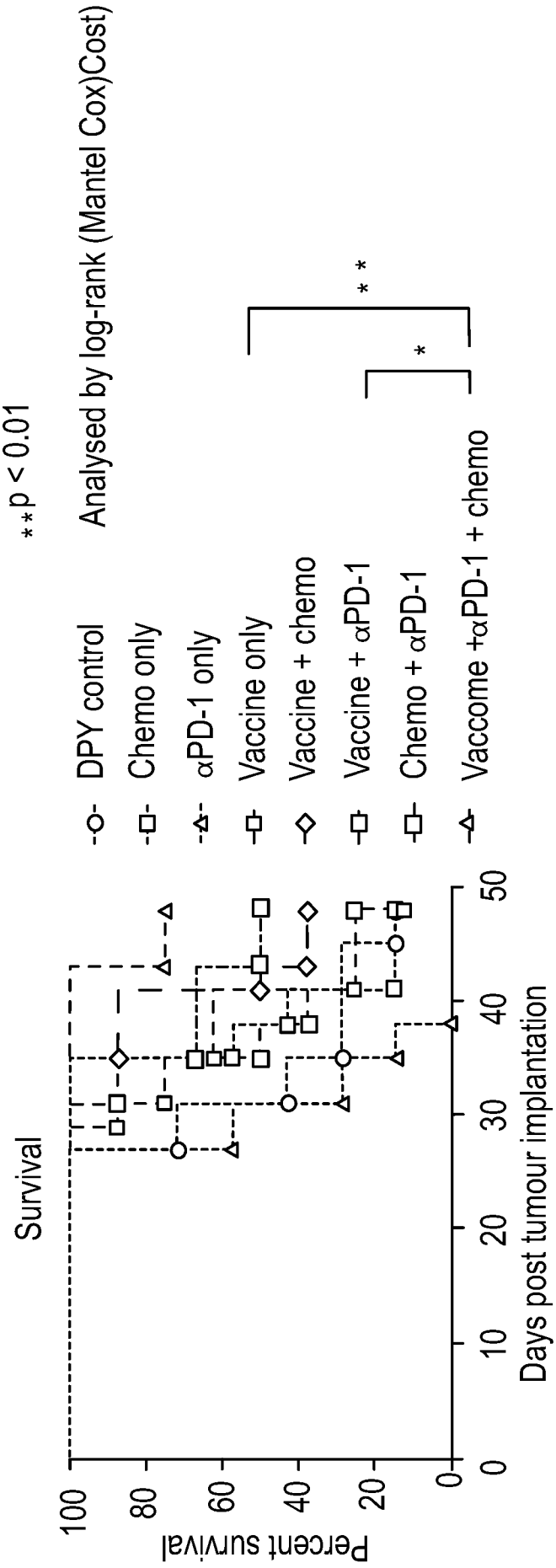

Survival
Percent survival
Days post tumour implantation
0
20
40
60
80
100
0
10
20
30
40
50
DPY control
Chemo only
αPD-1 only
Vaccine only
Vaccine + chemo
Vaccine + αPD-1
Chemo + αPD-1
Vaccome +αPD-1 + chemo
Analysed by log-rank (Mantel Cox)Cost)
* p < 0.15
** p < 0.01
*
**

FIG.21

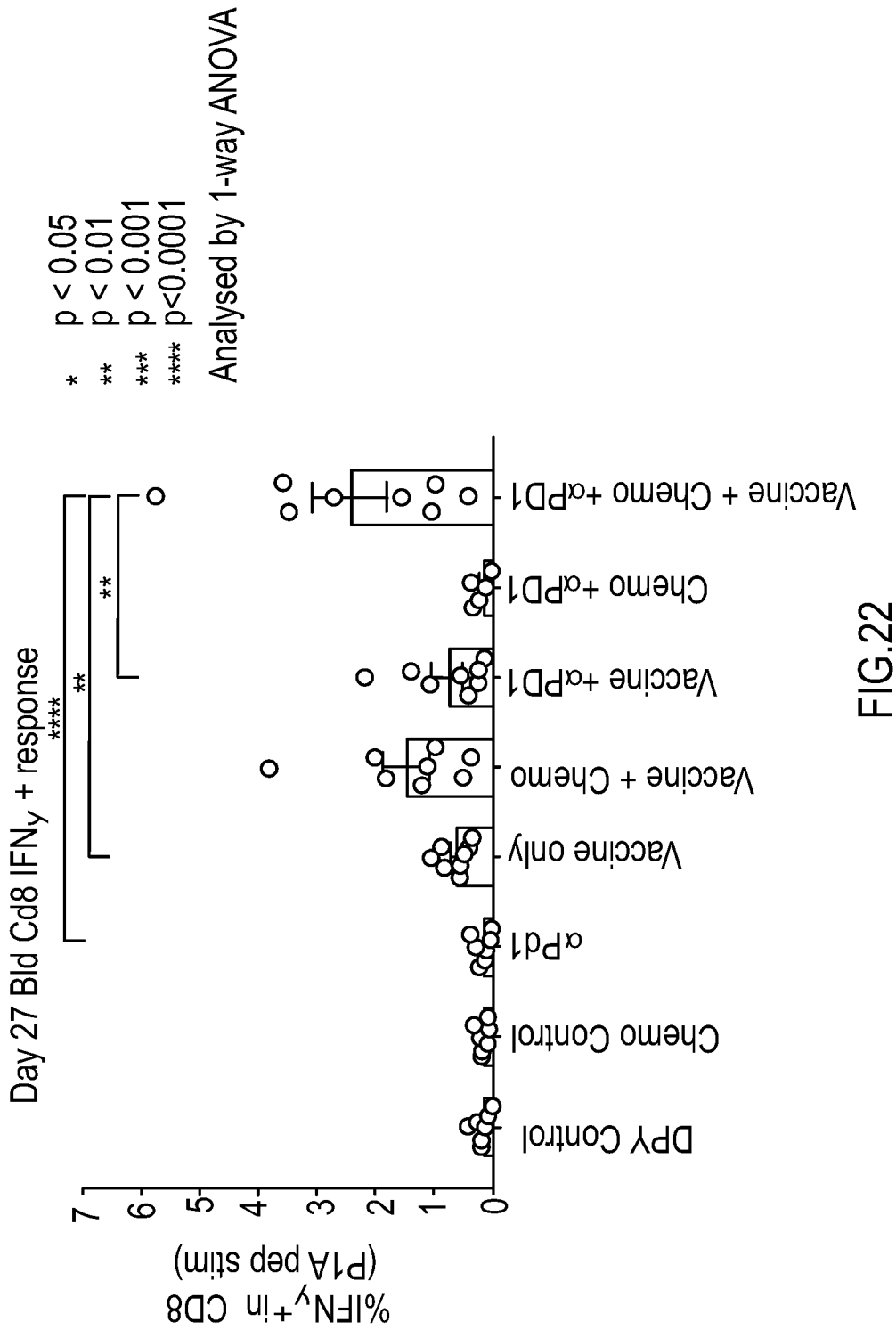

Day 27 Bld Cd8 IFNy + response
%IFNy+in CD8
(P1A pep stim)
0
1
2
3
4
5
6
7
DPY Control
Chemo Control
αPd1
Vaccine only
Vaccine + Chemo
Vaccine +αPD1
Chemo +αPD1
Vaccine + Chemo +αPD1
****
**
**
* p < 0.05
** p < 0.01
*** p < 0.001
**** p<0.0001
Analysed by 1-way ANOVA

FIG.22

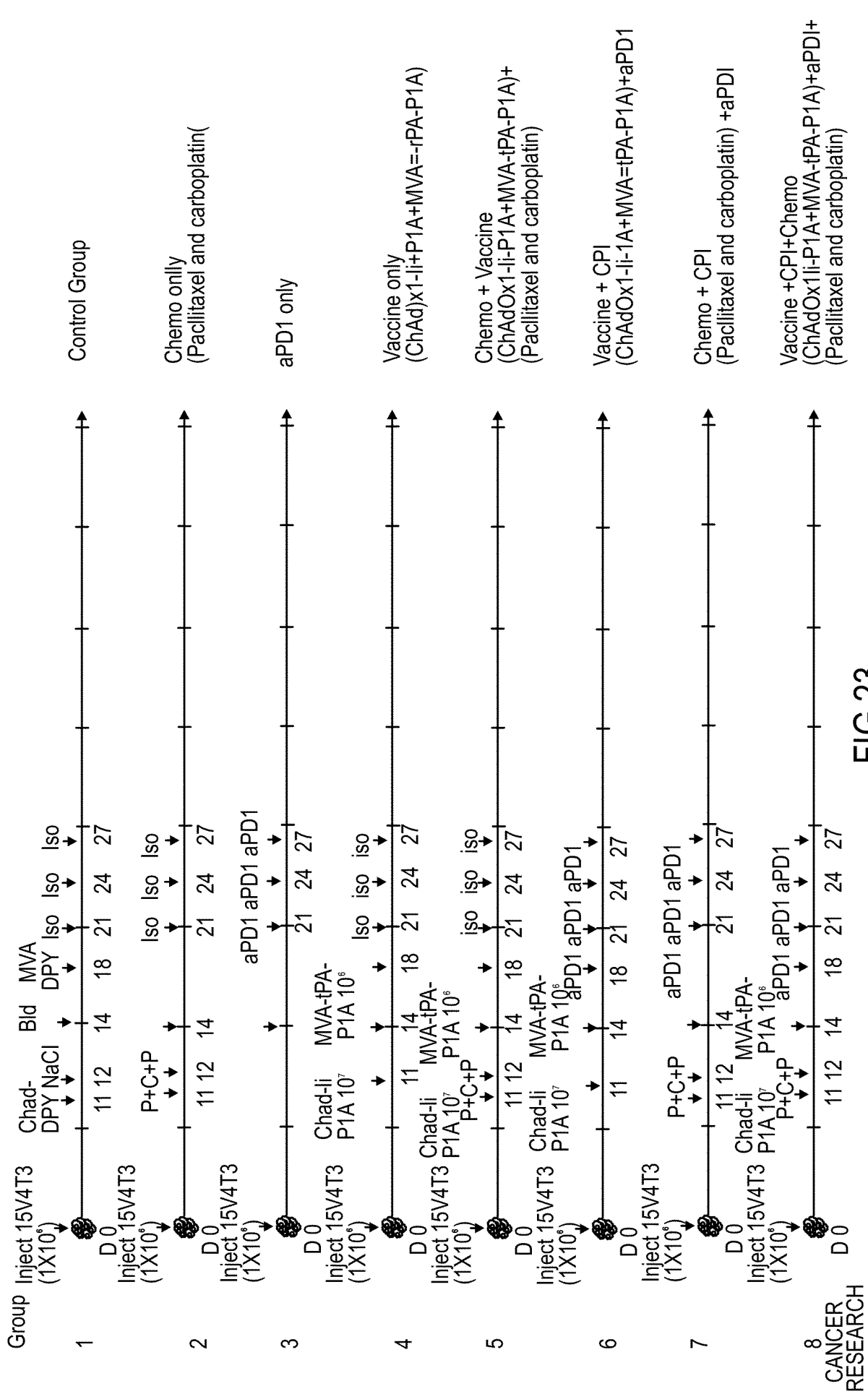

Group
Inject 15V4T3 (1X10^6)
Chad-DPY NaCl
Bld
MVA DPY
P+C+P
Chad-li P1A 10^7
MVA-tPA-P1A 10^6
aPD1
iso
D 0
11 12 14 18 21 24 27
1
2
3
4
5
6
7
8
Control Group
Chemo onlly (Paclitaxel and carboplatin(
aPD1 only
Vaccine only (ChAd)x1-li+P1A+MVA=-rPA-P1A)
Chemo + Vaccine (ChAdOx1-li-P1A+MVA-tPA-P1A)+ (Paclitaxel and carboplatin)
Vaccine + CPI (ChAdOx1-li-1A+MVA=tPA-P1A)+aPD1
Chemo + CPI (Paclitaxel and carboplatin) +aPDI
Vaccine +CPI+Chemo (ChAdOx1li-P1A+MVA-tPA-P1A)+aPDI+ (Paclitaxel and carboplatin)
CANCER RESEARCH

FIG.23

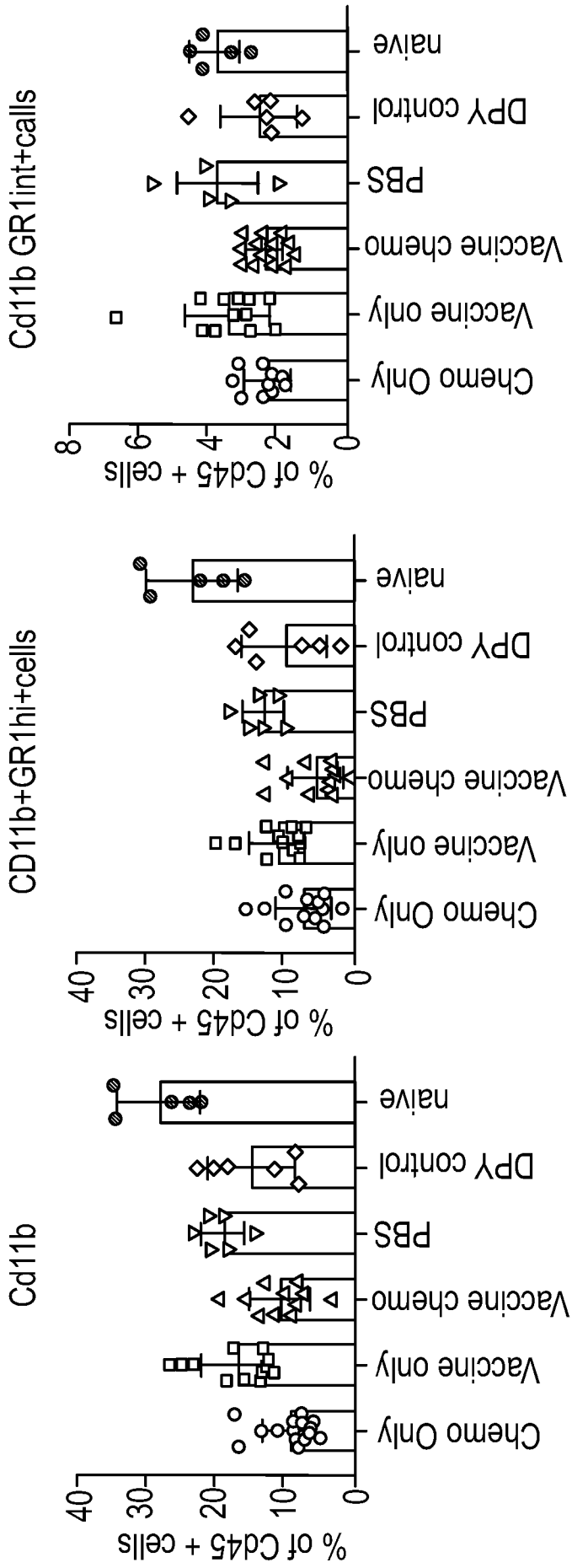

Cd11b
% of Cd45 + cells
0
10
20
30
40
Chemo Only
Vaccine only
Vaccine chemo
PBS
DPY control
naive
CD11b+GR1hi+cells
% of Cd45 + cells
0
10
20
30
40
Chemo Only
Vaccine only
Vaccine chemo
PBS
DPY control
naive
Cd11b GR1int+calls
% of Cd45 + cells
0
2
4
6
8
Chemo Only
Vaccine only
Vaccine chemo
PBS
DPY control
naive

FIG.24

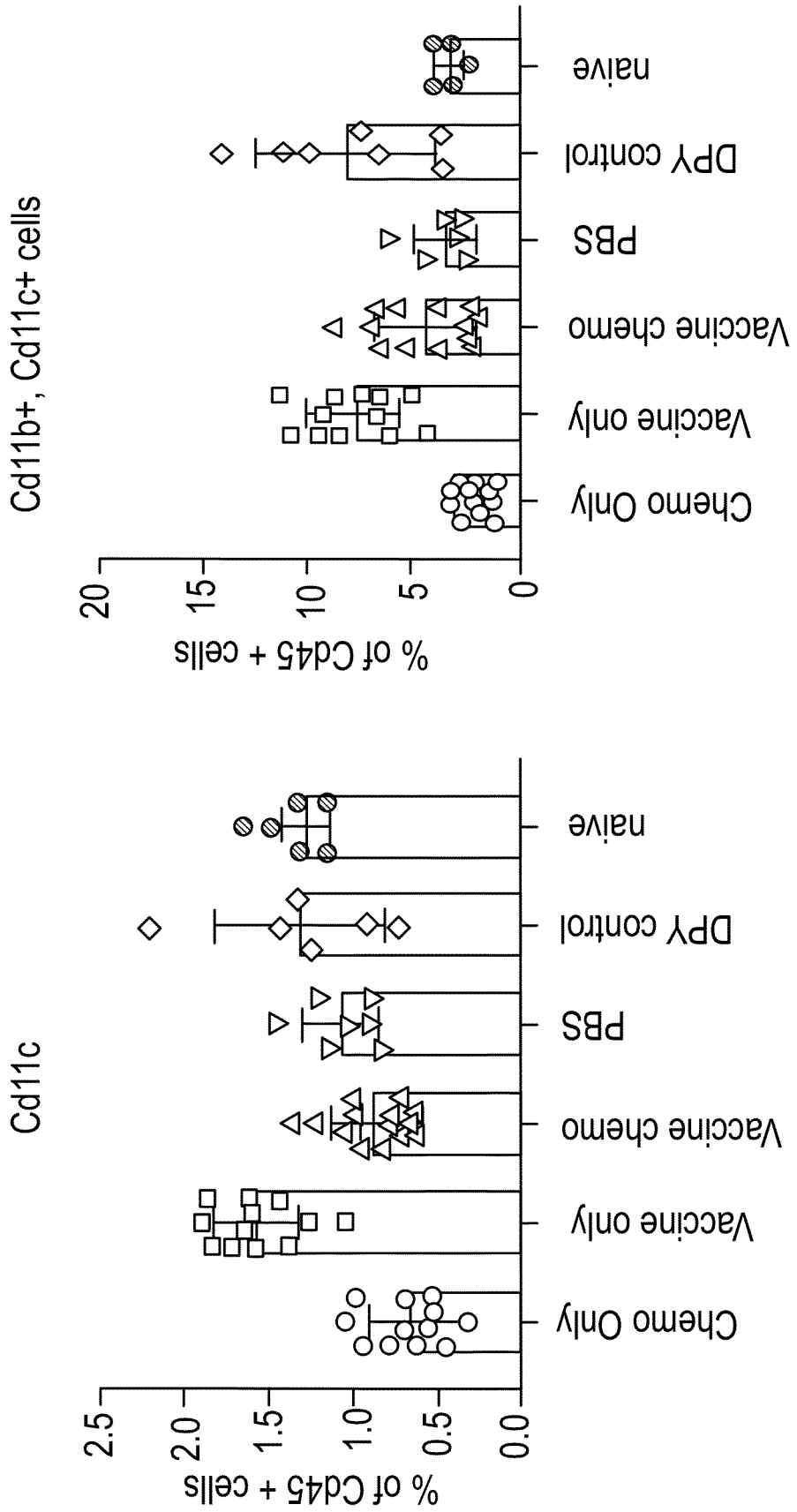

Cd11c
% of Cd45 + cells
2.5
2.0
1.5
1.0
0.5
0.0
Chemo Only
Vaccine only
Vaccine chemo
PBS
DPY control
naive
Cd11b+, Cd11c+ cells
% of Cd45 + cells
20
15
10
5
0
Chemo Only
Vaccine only
Vaccine chemo
PBS
DPY control
naive

FIG.25

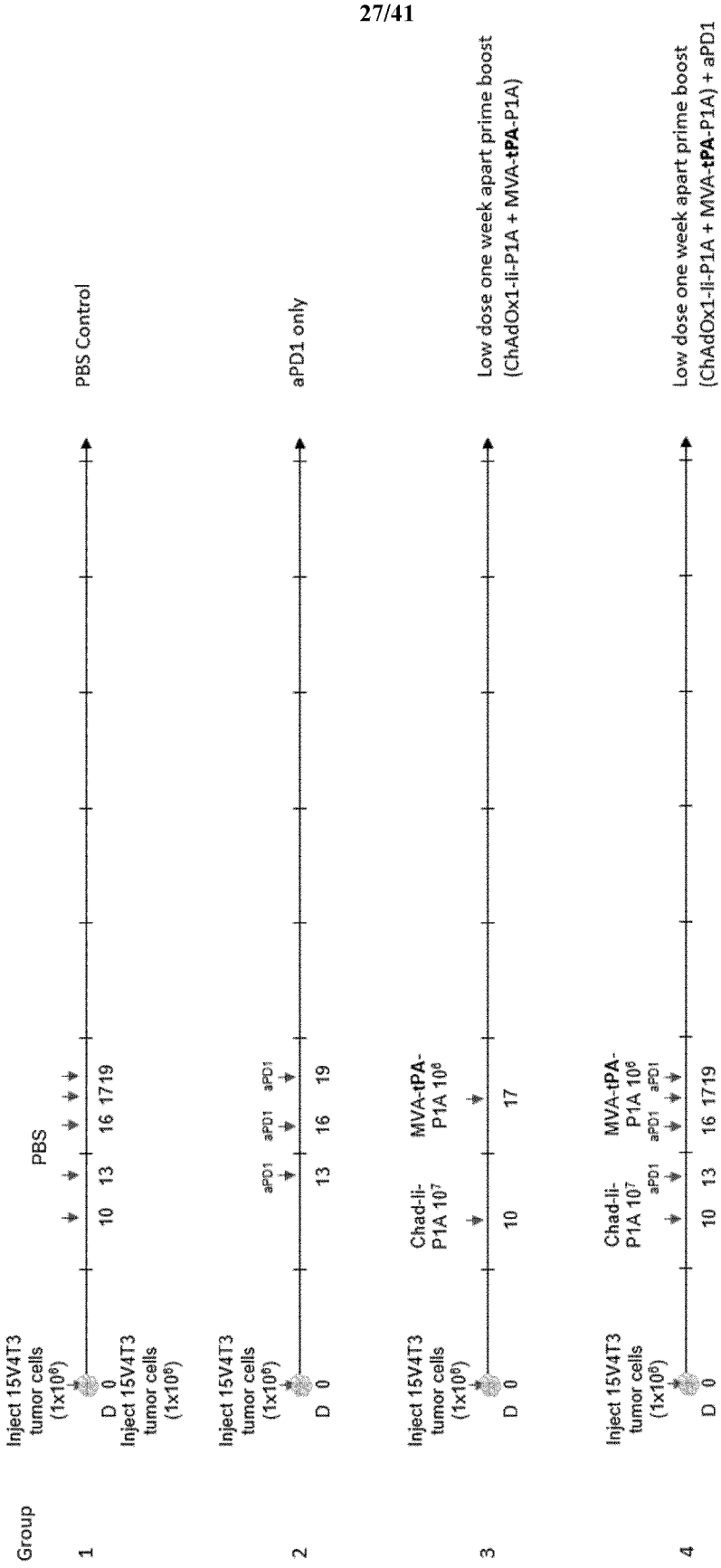

Group
1
PBS Control
Inject 15V4T3 tumor cells (1x10⁶)
D 0
PBS
10 13 16 1719
Inject 15V4T3 tumor cells (1x10⁶)
2
aPD1 only
Inject 15V4T3 tumor cells (1x10⁶)
D 0
aPD1 aPD1 aPD1
13 16 19
3
Low dose one week apart prime boost (ChAdOx1-li-P1A + MVA-tPA-P1A)
Inject 15V4T3 tumor cells (1x10⁶)
D 0
Chad-li-P1A 10⁷
MVA-tPA-P1A 10⁸
10 17
4
Low dose one week apart prime boost (ChAdOx1-li-P1A + MVA-tPA-P1A) + aPD1
Inject 15V4T3 tumor cells (1x10⁶)
D 0
Chad-li-P1A 10⁷
aPD1
MVA-tPA-P1A 10⁸
aPD1 aPD1
10 13 16 1719

FIGURE 26

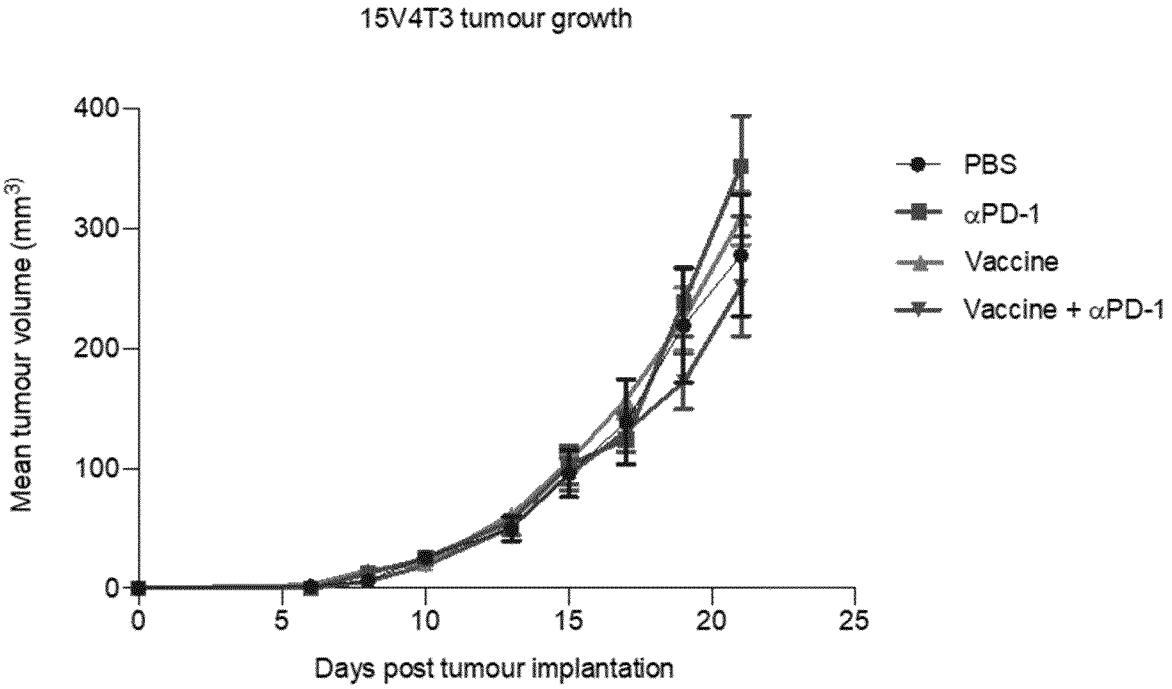


FIGURE 27

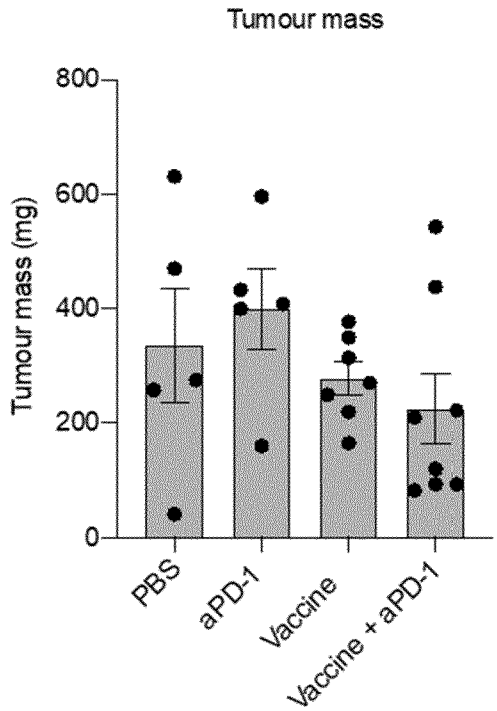
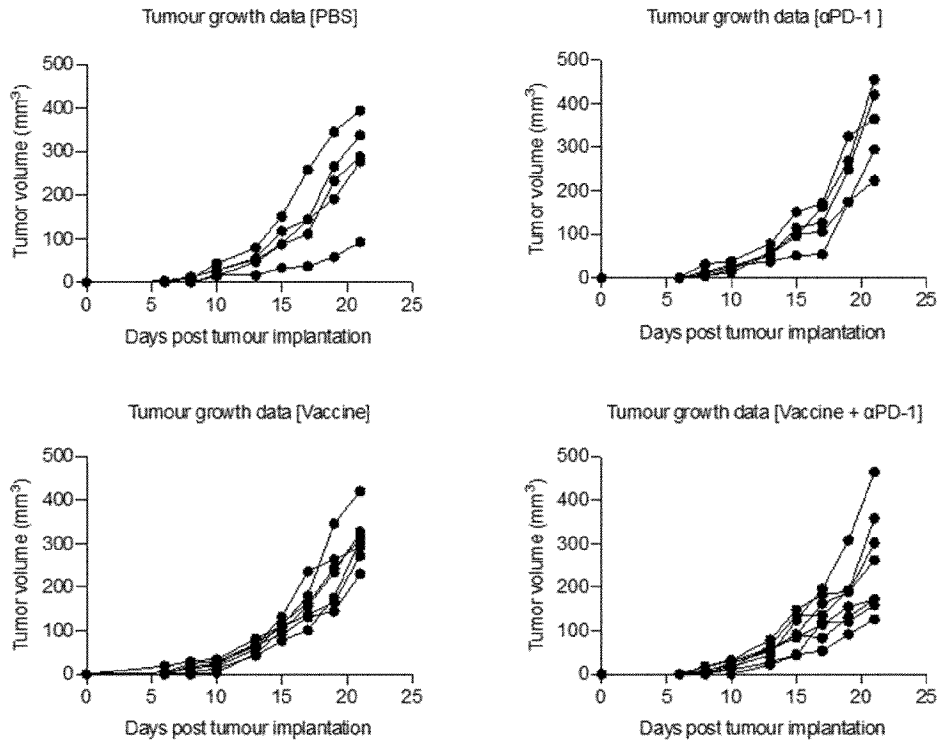


FIGURE 28



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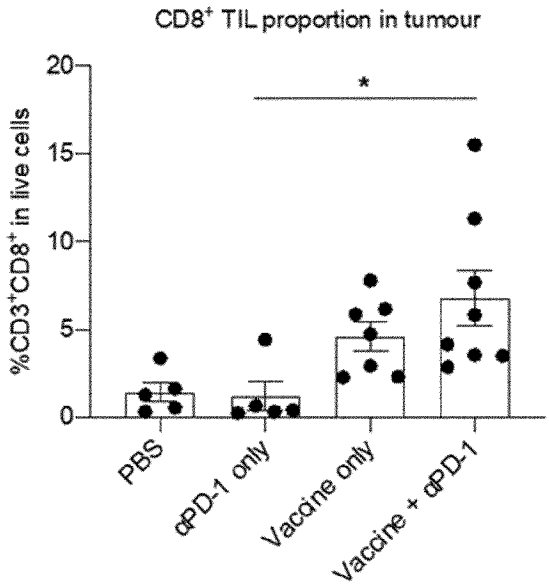

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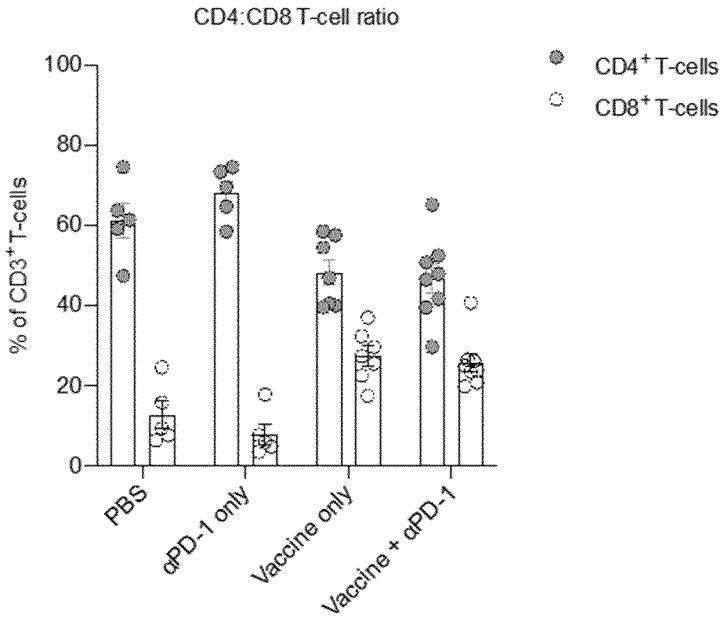
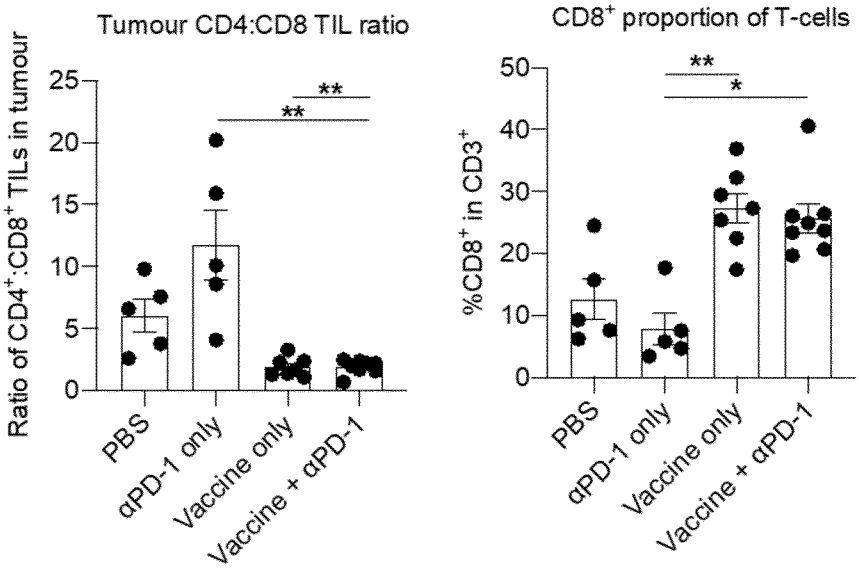


FIGURE 31



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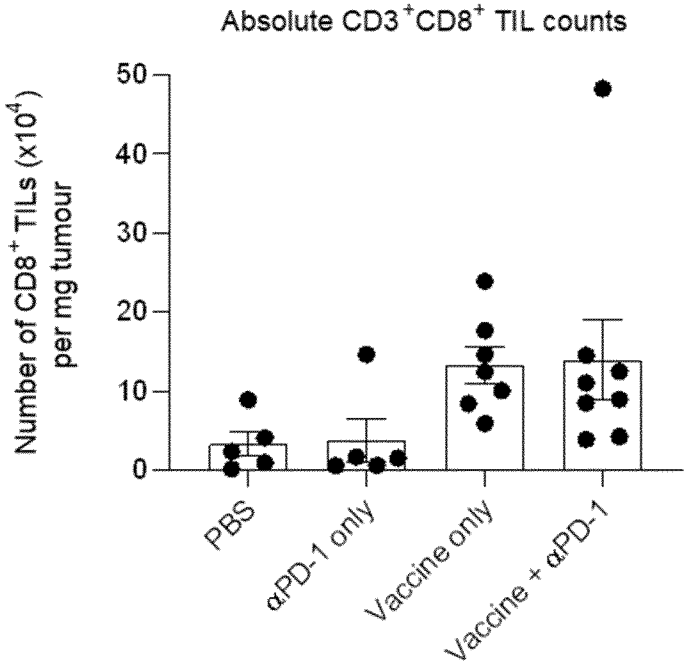

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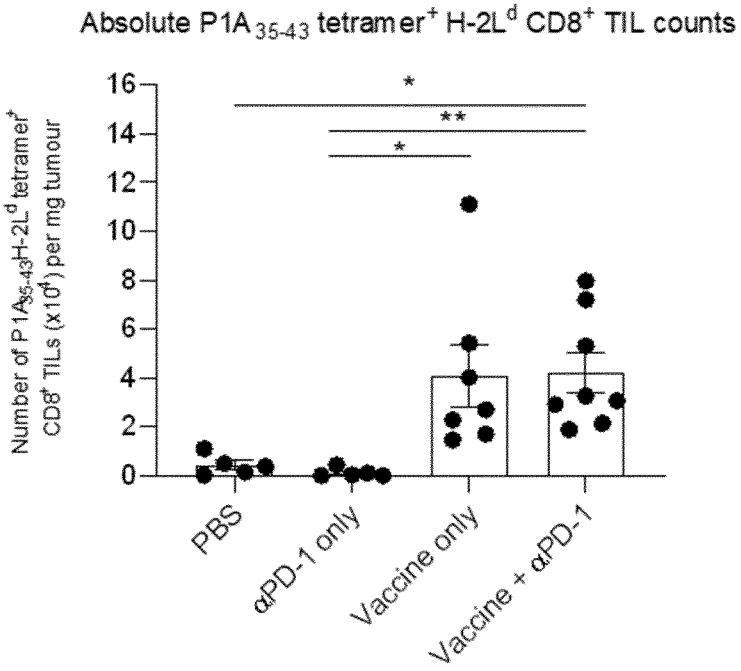
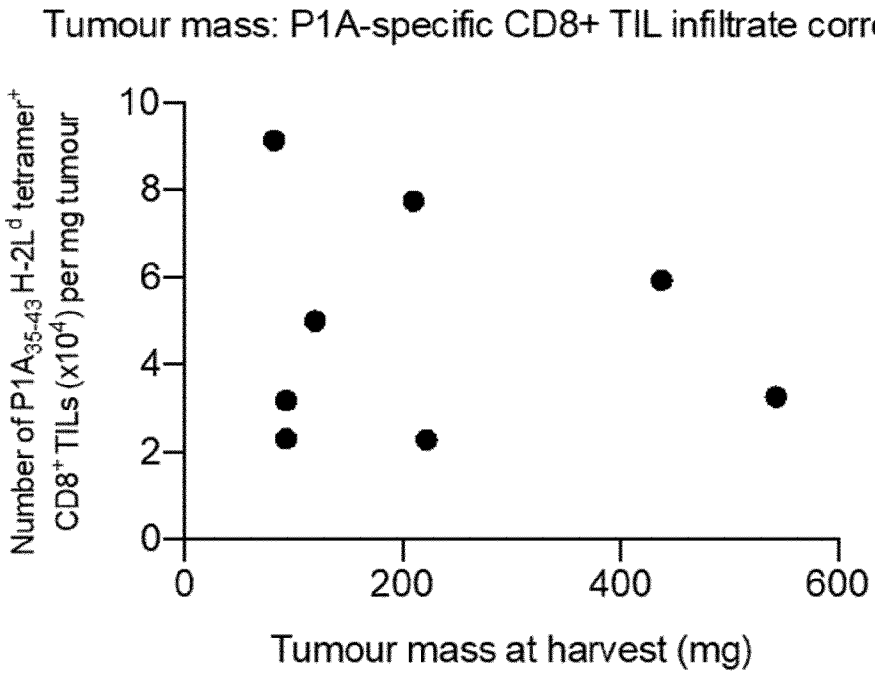


FIGURE 34



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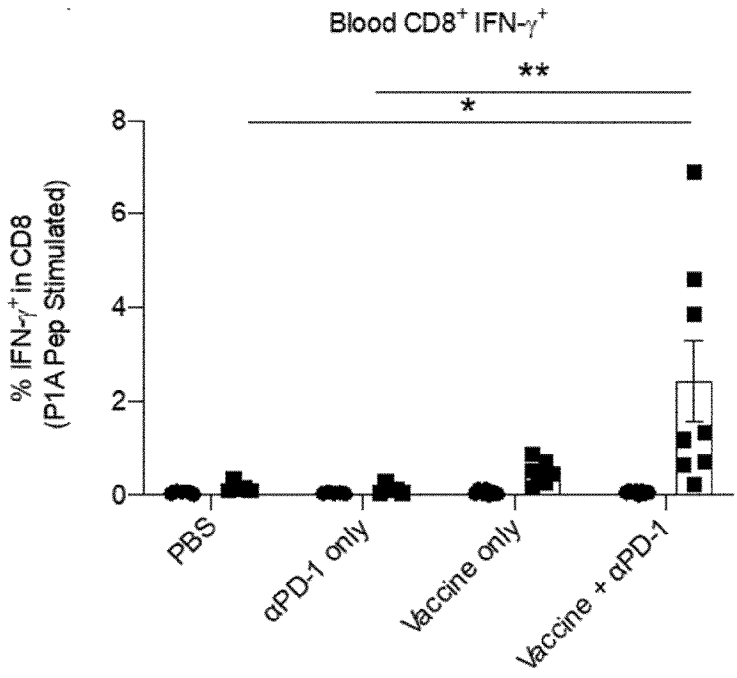

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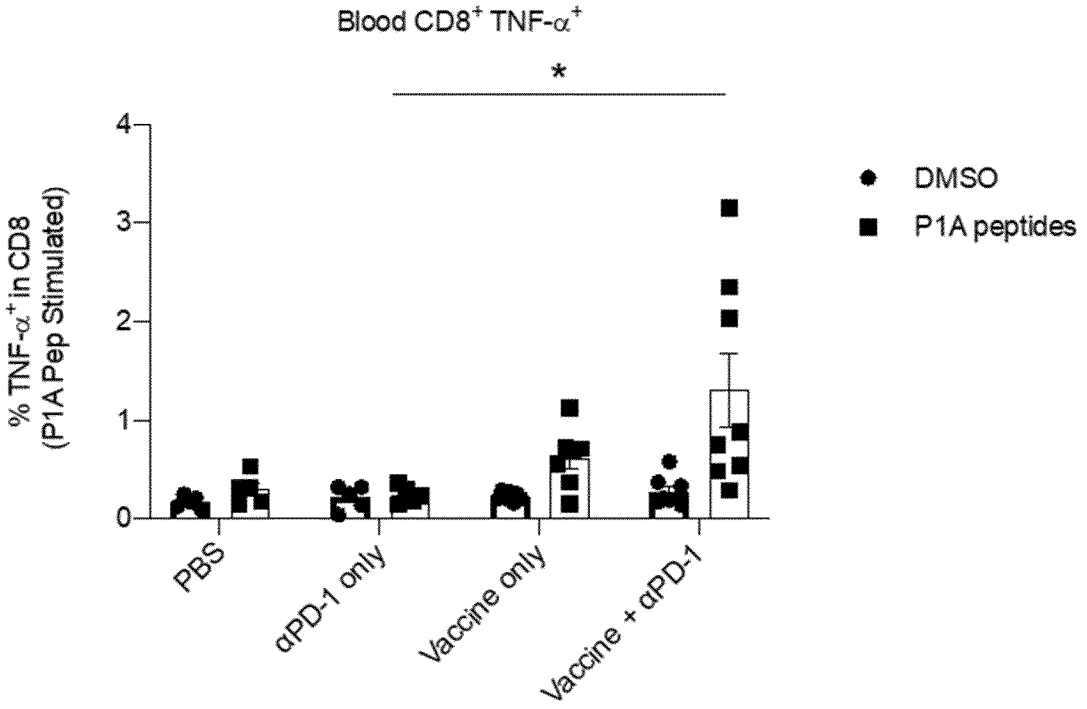

FIGURE 37

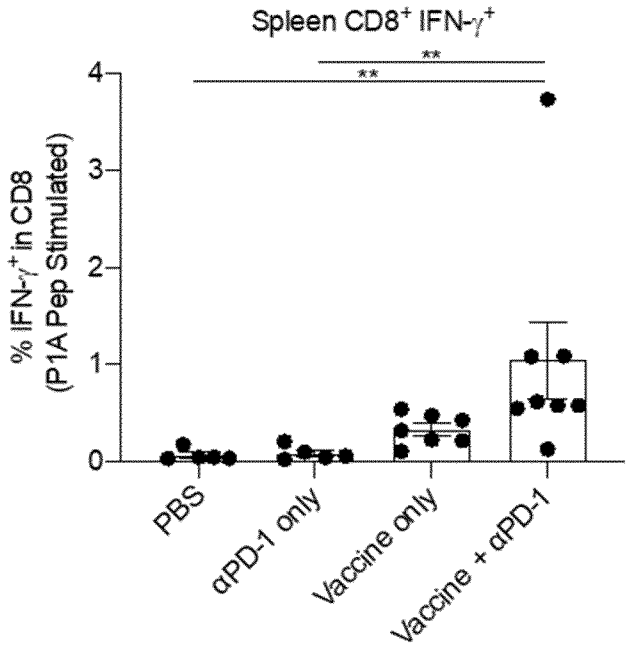

FIGURE 38

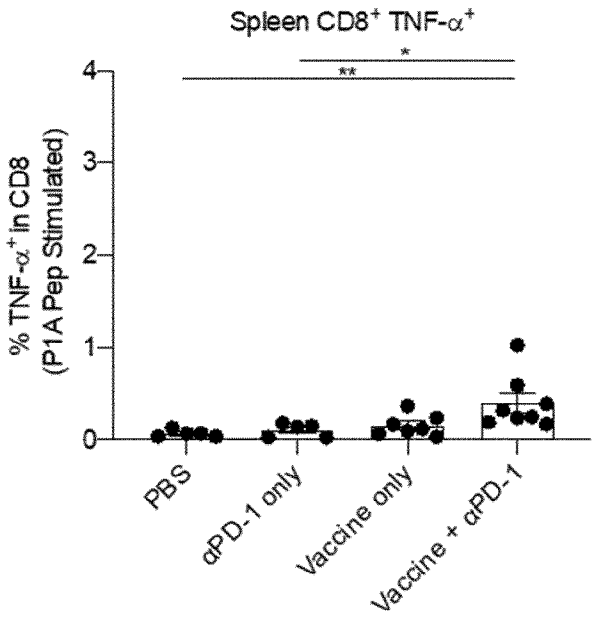

FIGURE 39

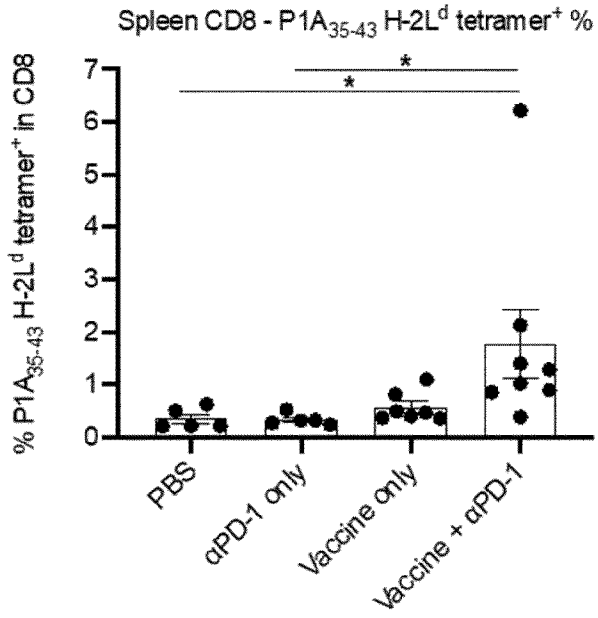

FIGURE 40

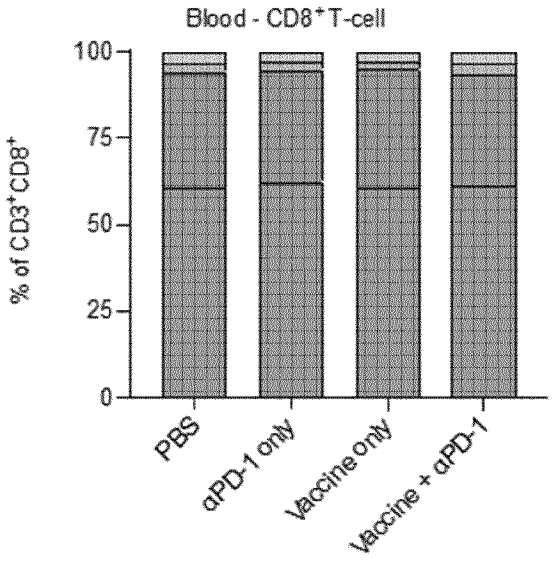

FIGURE 41

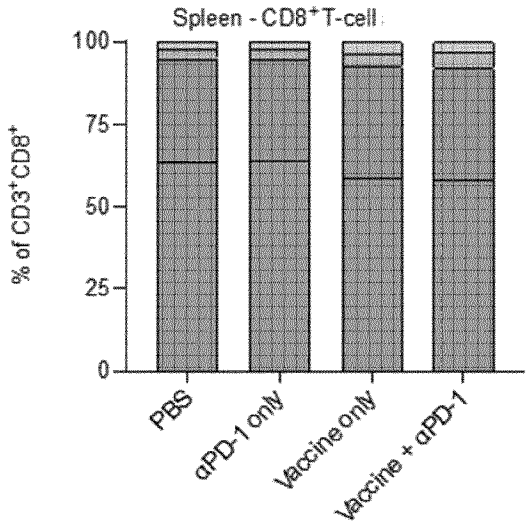

FIGURE 42

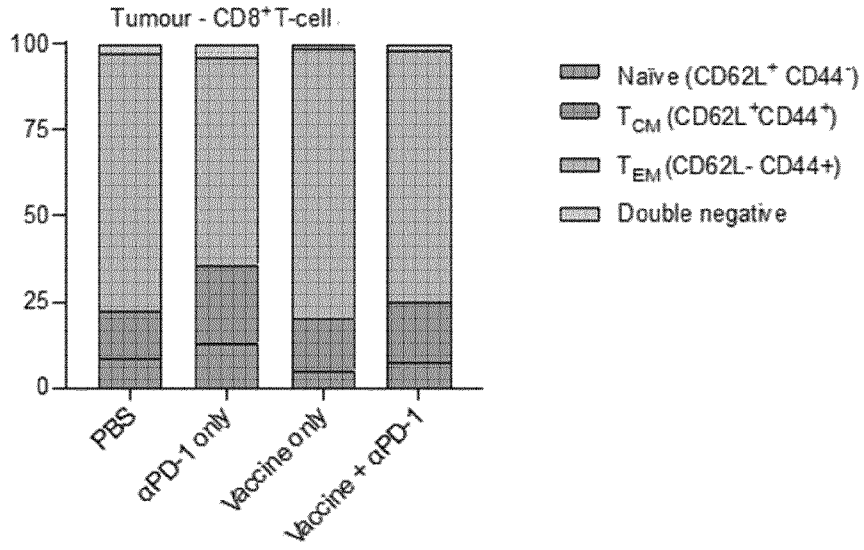

FIGURE 43

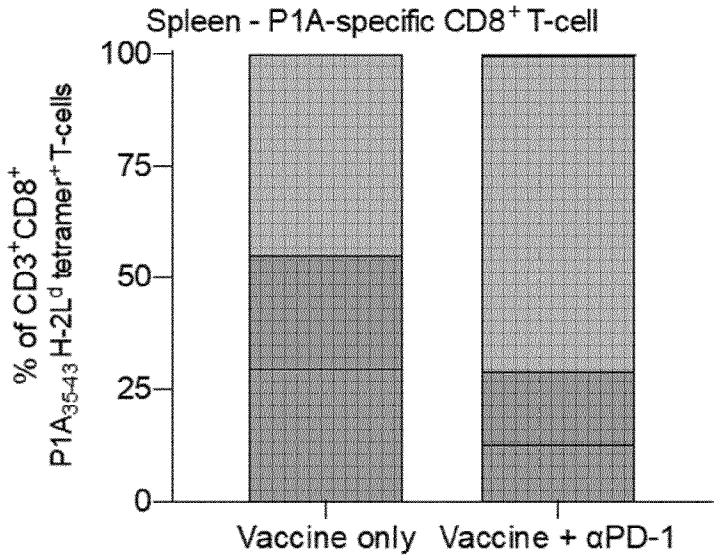

FIGURE 44

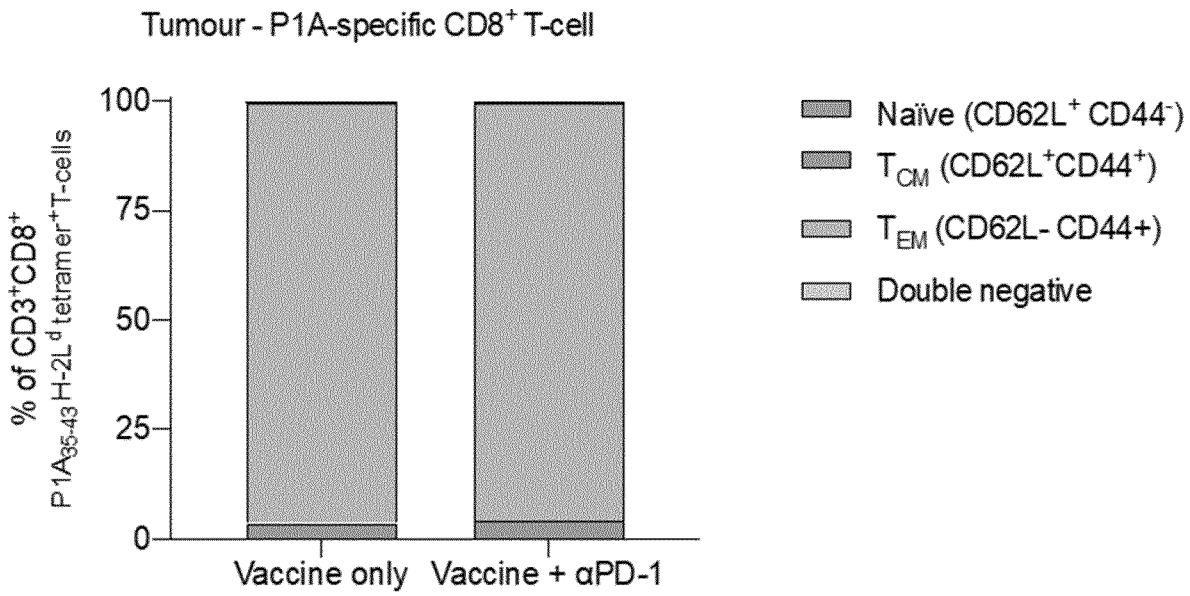

FIGURE 45

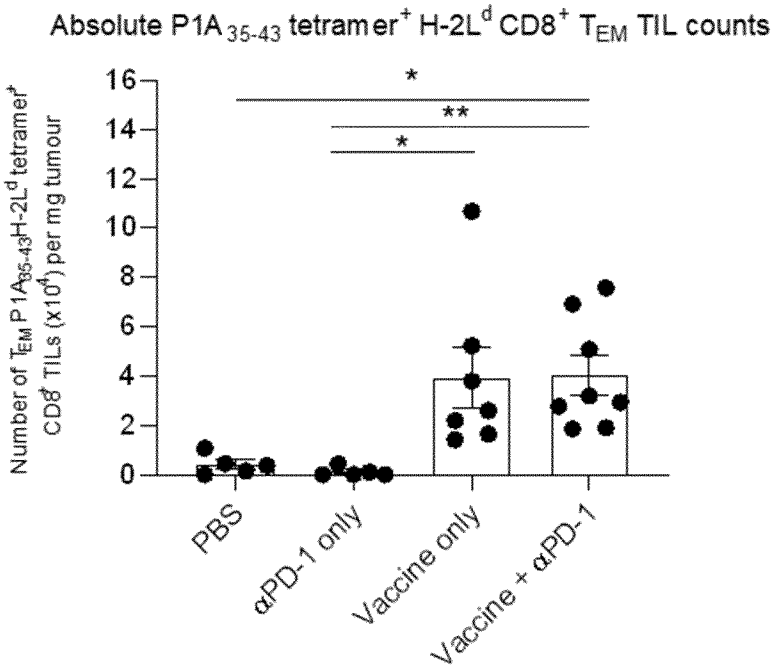

FIGURE 46

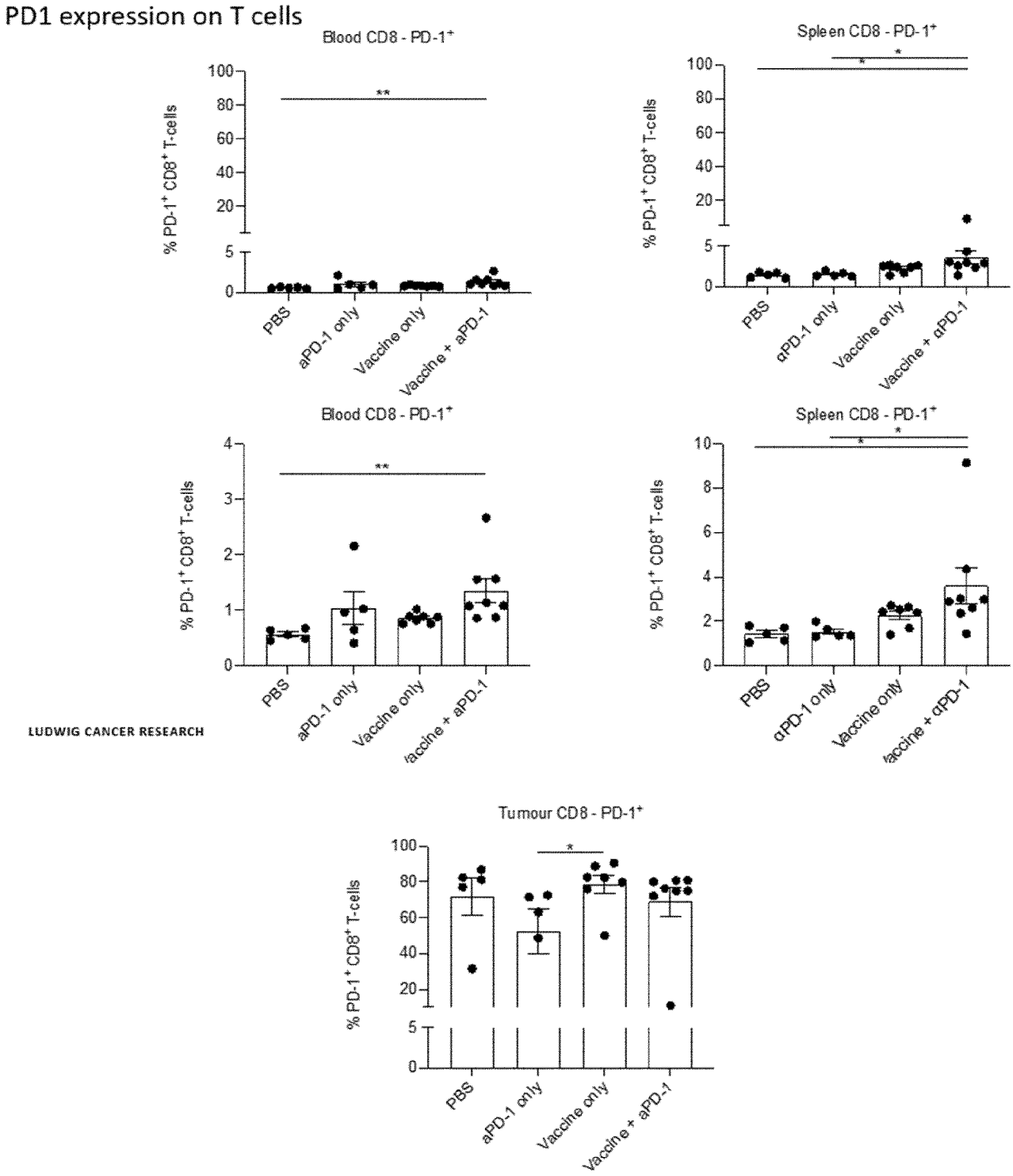
PD1 expression on T cells
Blood CD8 - PD-1+
Spleen CD8 - PD-1+
Blood CD8 - PD-1+
Spleen CD8 - PD-1+
Tumour CD8 - PD-1+
% PD-1+ CD8+ T-cells
PBS
aPD-1 only
Vaccine only
Vaccine + aPD-1
LUDWIG CANCER RESEARCH

FIGURE 47

PD1 expression on T cells

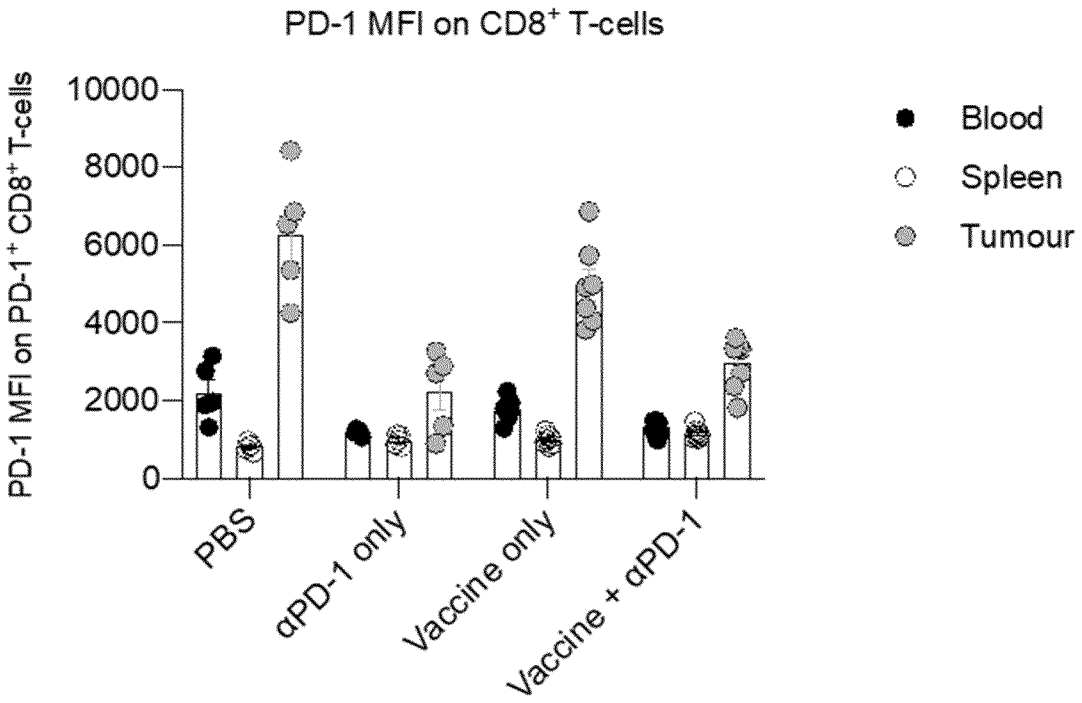

FIGURE 48

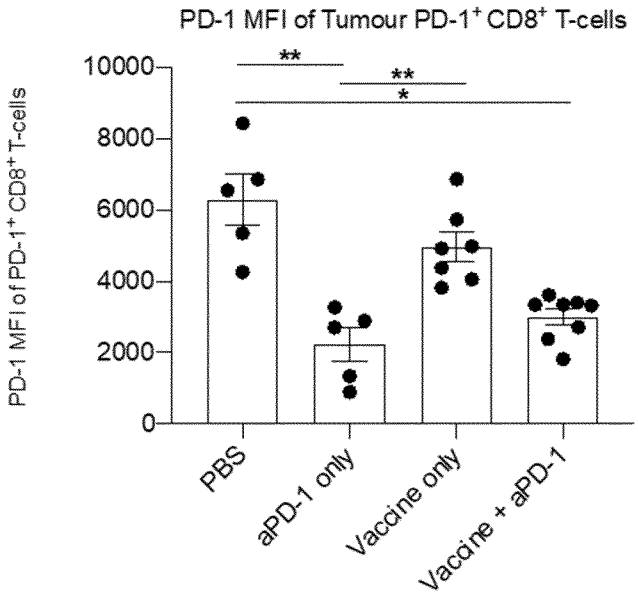

FIGURE 49

PD1 expression on P1A-specific T cells

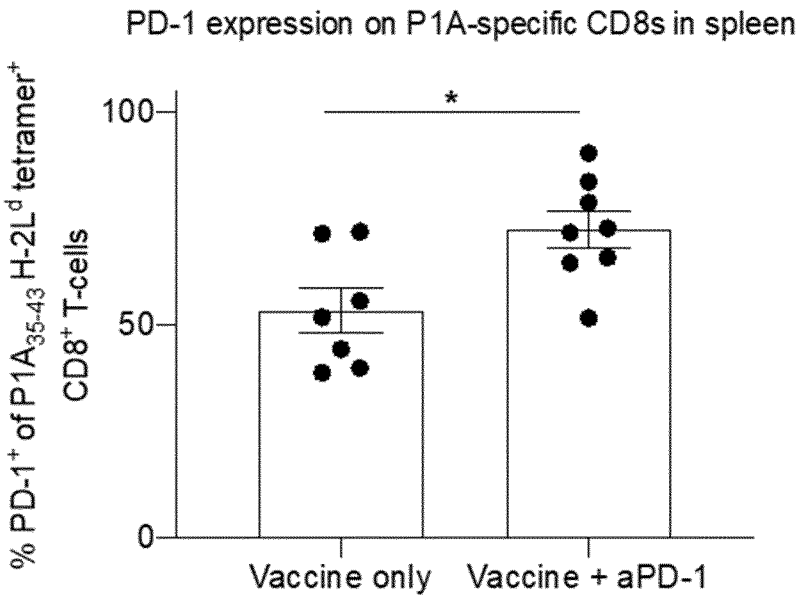

FIGURE 50

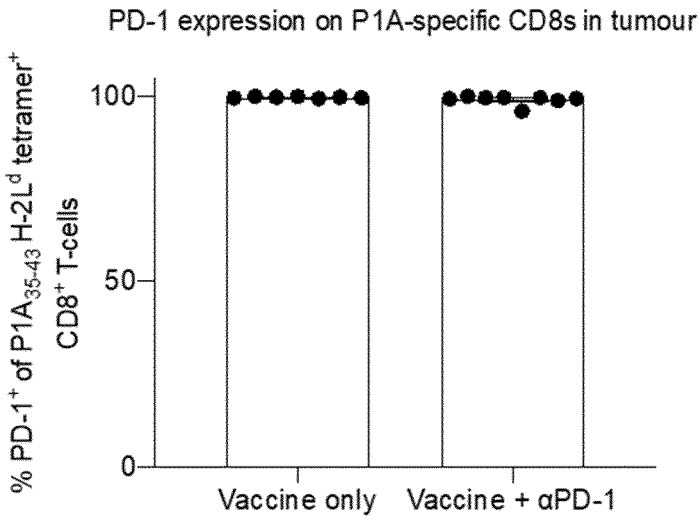

FIGURE 51

PD1 expression on P1A-specific T cells

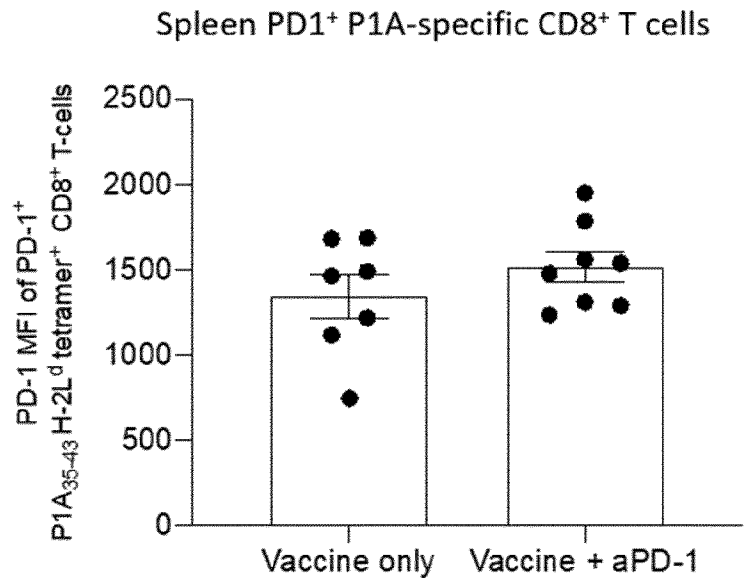

FIGURE 52

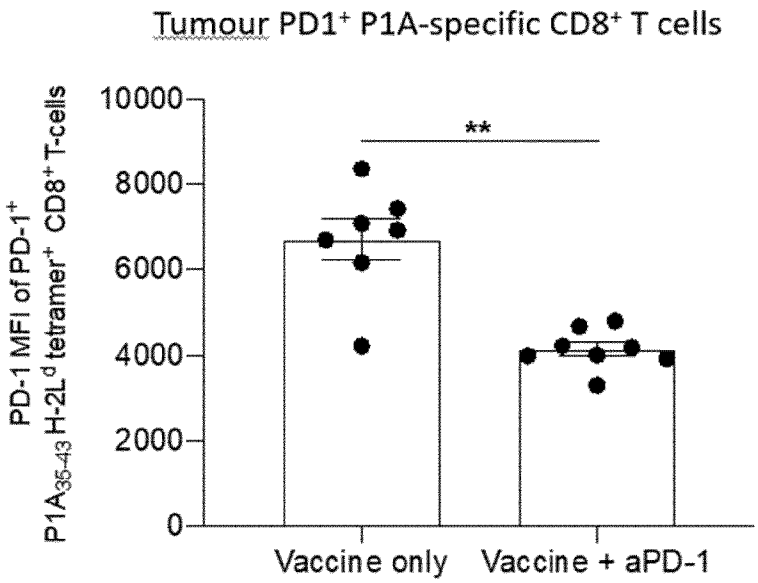

FIGURE 53