

A UNIVERSAL VACCINE BASED ON SHARED TUMOR NEOANTIGENS FOR PREVENTION AND
TREATMENT OF MICRO SATELLITE INSTABLE (MSI) CANCERS

This invention relates to a method of selecting a collection of frame-shift peptides (CFSPs) to
5 produce a universal cancer vaccine peptide collection (CVP) for prophylaxis and treatment of
patients with hereditary and sporadic micro-satellite instability (MSI) tumors. This invention
relates as well to a method of producing a CVP by selecting a subset of frame-shift peptides
(FSPs) from the CFSP and optionally modifying the FSP's amino acid (*aa*) sequence to generate
modified FSPs (mFSPs). The invention further relates to nucleic acid collections encoding a
10 CVP of FSPs and/or mFSPs in one or more vaccine vectors that can be used also
simultaneously. These CVPs, nucleic acids and vectors are used for the prophylaxis or treatment
of MSI cancers.

BACKGROUND OF THE INVENTION

15 The field of cancer vaccines has focused for a long time on targeting tumor-associated
and, more recently, tumor-specific antigens. The latter can arise in cancer cells from oncogenic
viral proteins or somatic mutations in coding genes leading to the production of tumor
neoantigens, defined as such because not present in normal cells. While being more appealing
for the lower risk of self-tolerance and autoimmunity, tumor neoantigens vary significantly
20 among the cancerous cells of a given patient and across the human population, hampering the
development of an effective universal cancer vaccine based on shared tumor neoantigens.

There is however a group of cancers that does not follow this general rule due to its
underlying biology: microsatellite instable (MSI) tumors frequently caused by mutations in
DNA mismatch repair genes (MMR). A defective MMR system leads to accumulation of
25 mutations in regions of repetitive nucleotide sequences called microsatellites. Mutations at
microsatellites of coding genes can lead to a shift of the translational reading frame resulting in
chimeric proteins whose C-terminus is composed of a novel non-self peptide, a so-called frame
shift peptide (FSP). Unlike most cancers, mutations in MSI tumors arise preferentially in
microsatellites consisting of mononucleotide repeats (MNRs). Within coding regions, such
30 mutations mostly consist of a 1 nucleotide deletion and affect a limited number of genes, being
therefore shared among patients (Kim, T.M., *et al.* (2013) Cell 155(4): 858-868).

Hence, MSI-associated cancers offer a unique opportunity to design a universal vaccine
based on shared tumor neoantigens. MSI-tumors include both sporadic and inherited cancers
caused by somatic and germline mutations in MMR genes, respectively. The Lynch syndrome

(LS) is a rare disease (ORPHA144) that falls in the second group. In particular, individuals with heterozygous germline mutations in either MSH2 or MLH1 genes of the MMR pathway (~90% of genetic LS carriers) are at higher risk for cancer development. Specifically, they are predisposed to develop colon or endometrial cancer in >50% of cases during their lifespan

5 (Boland, C.R. and A. Goel (2010) *Gastroenterology* 138(6): p. 2073-2087 e3).

In summary, the invention described here relates to the identification of shared FSP neoantigens across MSI tumors and to the development of a universal vaccine based on a subset of FSPs and modified FSPs (defined as CVP) derived from a CFSP for treatment of MSI cancers and for their prevention, particularly in LS carriers. These CVP may provide inter alia the

10 following advantages: (i) good therapeutic and/or prophylactic immune responses for a large variety of MSI cancers; (ii) an off-the-shelf vaccine that is ready to use and effective in a large cohort of patients because it encodes a large set of shared FSPs; (iii) a particular CVP can be selected in such a way to be suitable for treatment and prophylaxis of any MSI cancer, this is particularly useful in a prophylactic setting; (iv) no risk of autoimmune responses due to the

15 exclusion of potential self-epitopes.

To the best knowledge of the inventors, the methods of the invention are characterized by various features unknown before, including:

- (i) A variety of safeguards, such as
- 20 a) selecting frameshift peptides from a gene which is, on average, expressed above a threshold in the selected tumor type,
- b) selecting frameshift peptides that are absent or very rare in tissue of healthy subjects,
- c) excluding segments from frameshift peptides which are identical to segments with length 8 amino acids or more in normal human proteins, and
- c) using a large number of cancer samples.
- 25 (ii) The inclusion of frameshift peptides with a length shorter than that of a minimal putative CD8+ T cell epitope (8mer). This is achieved by the addition of up to 4 wildtype amino acids to generate a peptide of at least 8 amino acids.
- (iii) The selection of an optimal collection of frameshift peptides to be included in the vaccine such that each individual cancer sample (cancer samples represent the population targeted
- 30 by the vaccine) contains a portion of the frameshift peptides encoded by the vaccine and the total length of the frameshift peptides represented in this portion is at least 400 amino acids. Clinical trials on vaccines targeting viral antigens have shown that, on average, 400 amino acid of viral antigen, i.e. non-self antigens just like frameshift peptides, is needed to generate at least 1 immunogenic T cell response in each patient. Although for each cancer sample the

portion of frameshift peptides covered will be different (i.e. each cancer sample contains a different subset of frameshift mutations and, consequently, a different subset of frameshift peptides out of the optimal collection will be present), the optimal collection is selected in such a way that the fraction of frameshift peptides covered in each tumor sample will have a total length of at least 400 amino acids. Incorporating this 400 amino acid rule into the disclosed selection method thus ensures induction of T cells against FSP present in tumors of the vaccine target population.

SUMMARY OF THE INVENTION

In a first aspect, the present invention relates to a method of selecting a collection of frame-shift peptides (CFSP) for producing a universal micro-satellite instability (MSI) cancer vaccine peptide collection (CVP) for prophylaxis or treatment of a patient with a cancer comprising hereditary and sporadic MSI cancer or being at risk of developing such a cancer, comprising the steps of:

(i) selecting a collection of nucleic acids (CFSM), each comprising a frame-shift mutation (FSM), each FSM being present in one or more of at least M cancer samples (CS), each of a different patient, wherein the cancer of the patient comprises cancer cells with an MSI phenotype;

wherein at least 50% of the FSM that are selected fulfill criteria (a), (b), (c) and/or (d):

(a) the FSM is present in a mononucleotide repeat (MNR) of coding genes with a length equal to or longer than 6 nucleotides;

(b) the FSM corresponds to a deletion of 1 nucleotide;

(c) the number of DNA sequencing reads harboring the FSM is significantly higher in the tumor sample as compared to the matched normal sample (FDR-corrected Fisher test p-value equal to or lower than 0.05);

(d) the FSM is present in the matched normal samples with an allele frequency lower than 25%,

(ii) selecting X different frame-shift peptides (FSPs), wherein each selected FSP is the complete translation product of the protein-encoding segment of a nucleic acid comprising a FSM of the CFSM of at least 4 amino acid length, starting from the codon encoding the first amino acid that is different relative to the translation product of the corresponding wild type (wt) nucleic acid without the FSM,

wherein X is at least 20 more preferably at least 35 and M is at least 5.

In a second aspect, the present invention relates to a method of determining the amino acid sequences of peptides comprised in a CVP or of the nucleic acid sequences encoding the peptides comprised in the CVP, comprising the steps of:

- 5 (a) selecting at least Y FSPs or at least 8 amino acid long fragments thereof from the CFSP selected according to the first aspect of the invention;
- (b) modifying the amino acid sequence of one or more or of all of those FSPs which fulfill the following criteria: (i) the FSP has a length of between 4 to 9 amino acids, and/or (ii) the FSP contains one or more identical contiguous stretches of 8 or more amino acids present in more than one FSP encoded by the same FSM and/or (iii) the FSP contains one
10 or more contiguous stretches of 8 or more amino acids also present in wt human proteins, wherein the amino acid sequence of an FSP according to (i) is modified by adding to the N-terminus of the FSP between 1 to 4 amino acids of the wild type (wt) amino acid sequence present immediately upstream of the FSP and wherein the modified FSP (mFSP) has a length of at least 8 amino acids; the amino acid sequence of a FSP according to (ii) is modified by
15 removing these contiguous stretches from all but the longest FSP with the proviso that FSPs with a length of less than 4 amino acids after removal of the contiguous stretch are excluded from the CVP; and/or the amino acid sequence of a FSP according to (iii) is modified by removing these stretches; modified FSPs with a length of less than 4 amino acids after removal of the contiguous stretch are excluded from the CVP, and
20 wherein the amino acid sequences of the CVP comprises the amino acid sequences of the FSPs or fragments thereof selected in step a) and/or modified in step (b);
and wherein Y is at least 20 more preferably at least 35

In a third aspect, the present invention relates to a method of producing a CVP or a collection of nucleic acids encoding the CVP comprising the steps of

- 25 (i) obtaining the amino acid or nucleic acid sequence information determined in the method of the second aspect of the invention; and
- (ii) synthesizing the amino acid sequence of the CVP in one or more polypeptides or a collection of nucleic acids with that sequence and optionally inserting the collection of nucleic acids into one or more expression cassettes and/or a collection of expression
30 vectors.

In a fourth aspect, the present invention relates to a CVP or a collection of nucleic acids encoding the peptides of said CVP producible by the method of the third aspect of the invention.

In a fifth aspect, the CVP comprising or consisting of Y different FSPs and/or mFSPs, wherein each FSP or the FSP which is modified to mFSP is a fragment of or the complete

translation product of the protein-encoding segment of a FSM containing nucleic acid starting from the codon encoding the first amino acid that is different relative to the translation of the corresponding wt nucleic acid without the FSM of in either case at least 4 amino acid length and wherein at least 50% of the FSPs or the FSPs which are modified to mFSPs fulfill one or more of the following criteria:

- (a) the FSP is encoded by a FSM that is observed with a cancer type-specific frequency (CF) observed for a subset of CS of a specific type of cancer that are part of a collection of M different CS that is at least 5% for at least one of the cancer types present in the CS; and/or
- (b) the average mRNA expression level of the gene with the FSM encoding the FSP is in the top 80th percentile of the distribution describing the average mRNA expression values of each protein-encoding gene across the CS; and/or
- (c) the FSM generating the FSP is observed in less than 2% in normal tissues in a cohort of subjects without a cancer

wherein the amino acid sequence of one or more or all those FSPs which fulfill the following criteria: (i) the FSP has a length of between 4 to 9 amino acids, and/or (ii) the FSP contains one or more identical contiguous stretches of 8 or more amino acids present in more than one FSP encoded by the same FSM and/or (iii) the FSP contains one or more contiguous stretches of 8 or more amino acids also present in wt human proteins,

is modified for a FSP according to (i) by adding to the N-terminus of the FSP between 1 to 4 amino acids of the wild type (wt) amino acid sequence present immediately upstream of the FSP and wherein the modified FSP (mFSP) has a length of at least 8 amino acids; for a FSP according to (ii) is modified by removing these contiguous stretches from all but the longest FSP with the proviso that FSPs with a length of less than 4 amino acids after removal of the contiguous stretch are excluded from the CVP; and/or for a FSP according to (iii) is modified by removing these stretches; modified FSPs with a length of less than 4 amino acids after removal of the contiguous stretch are excluded from the CVP; and wherein Y is at least 20 and more preferably at least 35 and M is at least 5.

In a sixth aspect, the present invention relates to a nucleic acid collection encoding the CVP of the fifth aspect of the present invention.

In a seventh aspect, the present invention relates to a collection of one or more expression vectors, each comprising all or part of the nucleic acid collection of the fourth or sixth aspect of the present invention, wherein the entirety of the collection of expression vectors comprise all of the nucleic acid collection of the fourth or sixth aspect of the present invention.

In an eighth aspect, the present invention relates to a CVP of the fourth or fifth aspect of the present invention, a nucleic acid collection of the fourth or sixth aspect of the present invention, an expression vector collection of the seventh aspect of the present invention, for use in prophylaxis or treatment of a patient with a cancer comprising cancer cells with an MSI phenotype or being at risk of developing such cancer, wherein the cancer is preferably selected from the group consisting of colorectal cancer, gastric cancer, endometrial cancer, small intestine cancer, hepatobiliary tract cancer, liver cancer, neuroendocrine cancers, cervical cancer, ovarian cancer, uterine sarcomas, brain cancer and skin cancer

In an eighth aspect, the present invention relates to a nucleic acid collection of the fourth or sixth aspect of the present invention and/or an expression vector collection of the seventh aspect of the present invention for use in prophylaxis or treatment of a patient with a cancer comprising cancer cells with an MSI phenotype or being at risk of developing such cancer, wherein the nucleic acid collection and/or the expression vector collection is administered in a heterologous prime-boost vaccination scheme, preferably the prime is with an adenovirus vector and one or more boosts are with an MVA vector.

FIGURE LEGENDS

- Fig. 1: Antigen length determines the number of vaccine-induced immunogenic epitopes.
- Fig. 2: Immunogenic coverage of Nous-209 in MSI cell lines.
- Fig. 3: Immunogenic coverage of Nous-209 in MSI CRC biopsies.
- Fig. 4: Number of predicted MHC-I binding epitopes arising from Nous-209 in biopsies of MSI patients.
- Fig. 5: The FSP corresponding to SEQ ID NO: 123 included in Nous-209 is immunogenic *in vivo* in HLA.A02 transgenic mice. A representative CD8 T cell response in 5 animals to a HLA-A02 nonamer present in FSP SEQ ID NO: 123, as measured by intracellular staining (ICS) for interferon γ (IFN- γ) (panel A). FACS plot of gating strategy for IFN- γ + CD8 T cells from one of those mice showing a significant percentage (5.6%) of FSP-reactive T cells (panel B).
- Fig. 6: Disorder profiles predicted by IUPRED for the eight artificial polypeptides containing Nous-209 FSPs in layout A and B.
- Fig. 7: Schematic view of the expression cassettes.
- Fig. 8: Immunogenicity of GAd20-209-FSPs/MVA-209-FSPs prime/boost regimen in mice. IFN γ ELISpot responses are measured 2 weeks post GAd20-209-FSPs prime (GAd) and one-week post MVA-209-FSPs boost (GAd/MVA). Shown are the responses

(number of T cells producing IFN γ per millions of splenocytes) to 16 pools of synthetic peptides (P1-P16) covering the polypeptide sequences of the 209 FSPs encoded by the vaccines.

- Fig. 9: Measurement of immune responses against each of the 16 pools covering the 209 FSP sequences. IFN γ ELISpot responses measured post boost on splenocytes of mice vaccinated with GAd20-209-FSPs/MVA-209-FSPs. Shown are the responses (number of T cells producing IFN γ per millions of splenocytes) to each of the 16 pools of synthetic peptides (from P1 to P16) covering the polypeptide sequences of the 209 FSPs encoded by the vaccine.
- Fig. 10: Vaccine-induced immune responses against FSPs encoded by a single vector are not affected by vectors co-administration. IFN γ ELISpot responses are measured post prime (week2, gray bars) and post boost (week3, black bars) in mice immunized with a vector mixture or with single vectors. Shown are the responses (number of T cells producing IFN γ per millions of splenocytes) to the 4 pools of synthetic peptides (P1-P4) covering the sequences of the FSPs encoded by the vector FSPA1 (A) and to the 4 pools of synthetic peptides (P5-P8) covering the sequences of the FSPs encoded by the vector FSPA2 (B). Statistics are calculated by non-parametric Mann-Whitney U test (ns = p>0.05).
- Fig. 11: The FSP corresponding to SEQ ID NO: 123 (FSP-peptide) included in Nous-209 is immunogenic *in vivo* in HLA.A02 transgenic mice. A) Percentage of IFN γ + CD8+ FSP-specific T cells responses and responses observed for the DMSP control. B) FACS plot of gating strategy for IFN- γ + CD8 T cells from one representative mouse sample for the DMSO control (top) and the FSP peptide (bottom).

DETAILED DESCRIPTION OF THE INVENTION

Before the present invention is described in detail below, it is to be understood that this invention is not limited to the particular methodology, protocols and reagents described herein as these may vary. It is also to be understood that the terminology used herein is for the purpose of describing particular embodiments only, and is not intended to limit the scope of the present invention which will be limited only by the appended claims. Unless defined otherwise, all technical and scientific terms used herein have the same meanings as commonly understood by one of ordinary skill in the art.

Preferably, the terms used herein are defined as described in "A multilingual glossary of biotechnological terms: (IUPAC Recommendations)", Leuenberger, H.G.W, Nagel, B. and Klbl, H. eds. (1995), Helvetica Chimica Acta, CH-4010 Basel, Switzerland) and as described in "Pharmaceutical Substances: Syntheses, Patents, Applications" by Axel Kleemann and
5 Jurgen Engel, Thieme Medical Publishing, 1999; the "Merck Index: An Encyclopedia of Chemicals, Drugs, and Biologicals", edited by Susan Budavari et al., CRC Press, 1996, and the United States Pharmacopeia-25/National Formulary-20, published by the United States Pharmacopeial Convention, Inc., Rockville Md., 2001.

Throughout this specification and the claims which follow, unless the context requires
10 otherwise, the word "comprise", and variations such as "comprises" and "comprising", will be understood to imply the inclusion of a stated feature, integer or step or group of features, integers or steps but not the exclusion of any other feature, integer or step or group of integers or steps. In the following passages different aspects of the invention are defined in more detail. Each aspect so defined may be combined with any other aspect or aspects unless clearly
15 indicated to the contrary. In particular, any feature indicated as being preferred or advantageous may be combined with any other feature or features indicated as being preferred or advantageous.

Several documents are cited throughout the text of this specification. Each of the documents cited herein (including all patents, patent applications, scientific publications,
20 manufacturer's specifications, instructions, etc.), whether *supra* or *infra*, are hereby incorporated by reference in their entirety. Nothing herein is to be construed as an admission that the invention is not entitled to antedate such disclosure by virtue of prior invention.

Definitions

25 In the following, some definitions of terms frequently used in this specification are provided. These terms will, in each instance of its use, in the remainder of the specification have the respectively defined meaning and preferred meanings.

As used herein, the term "isolated" refers to a molecule which is substantially free of other molecules with which it is naturally associated with. In particular, isolated means the
30 molecule is not in an animal body or an animal body sample. An isolated molecule is thus free of other molecules that it would encounter or contact in an animal. Isolated does not mean isolated from other components associated with as described herein, e.g. not isolated from other components of a composition the molecule is comprised in, or isolated from a vector or cell it is comprised in.

The terms "polynucleotide" and "nucleic acid" are used interchangeably herein and are understood as a polymeric or oligomeric macromolecule made from nucleotide monomers. Nucleotide monomers are composed of a nucleobase, a five-carbon sugar (such as but not limited to ribose or 2'-deoxyribose), and one to three phosphate groups. Typically, a nucleic acid is formed through phosphodiester bonds between the individual nucleotide monomers. In the context of the present invention preferred nucleic acid molecules include but are not limited to ribonucleic acid (RNA), modified RNA, deoxyribonucleic acid (DNA), and mixtures thereof such as e.g. RNA-DNA hybrids. The nucleic acids, can e.g. be synthesized chemically, e.g. in accordance with the phosphotriester method (see, for example, Uhlmann, E. & Peyman, A. (1990) Chemical Reviews, 90, 543-584). "

The term "open reading frame" abbreviated "ORF" is used in the context of the present invention to refer to a sequence of nucleotides that can be translated into a consecutive string of amino acids. Typically, an ORF contains a start codon, a subsequent region usually having a length which is a multiple of 3 nucleotides, but does not contain a stop codon (TAG, TAA, TGA, UAG, UAA, or UGA) in the given reading frame. An ORF codes for a protein where the amino acids into which it can be translated form a peptide-linked chain.

As used herein, the term "protein", "peptide", "polypeptide", "peptides" and "polypeptides" are used interchangeably throughout. These terms are used in the context of the present invention to refer to both naturally occurring peptides, e.g. naturally occurring proteins and synthesized peptides that may include naturally or non-naturally occurring amino acids. Peptides can be also chemically modified by modifying a side chain or a free amino or carboxy-terminus of a natural or non-naturally occurring amino acid. This chemical modification includes the addition of further chemical moieties as well as the modification of functional groups in side chains of the amino acids, such as a glycosylation. A peptide is a polymer preferably having at least 3, 4, 5, 6, 7, 8, 9, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70, 75, 80, 85, 90, 95, or at least 100 amino acids, most preferably at least 8 or at least 30 amino acids.

The term "frame-shift mutation" abbreviated as "FSM" is used in the context of the present invention to refer to an alteration of the nucleic acid sequence within the ORF encoding a protein, which leads to an alteration of the reading frame downstream of the mutation and, thus to a protein with an altered sequence in comparison to the wild-type protein. A frame-shift mutation results, if a number of nucleotides is inserted or deleted in an ORF that cannot be divided by 3. Typically, FSM result if one or two nucleotides are deleted or inserted. Deletions are more frequent than insertions. If one or two nucleotides are deleted within the codon of an ORF an altered codon will be formed with one or two nucleotides 3' of the affected codon.

Unless this altered codon is a stop codon the translation product of the ORF will be determined by the altered codon and an alternate ORF 3' of the altered codon up to the next stop codon. If one or two nucleotides are inserted into a codon a new codon is generated that will comprise two or one nucleotides of the previous nucleotides and one or two of the inserted nucleotides.

- 5 Unless this new codon is a stop codon the translation product of the ORF will be determined by the new codon and an alternate ORF 3' of the new codon up to the next stop codon.

The term "frame-shift codon" abbreviated as "FC" is used in the context of the present invention to refer to the first codon at the 3' of the FSM that encodes a different amino acid compared to the wt sequence.

- 10 The term "collection of nucleic acids comprising FSMs" abbreviated as "CFSM" is used in the context of the present invention to refer to a list of separate nucleotide sequences each including a FSM that may represent all FSMs observed in a particular MSI cancer type, e.g. colorectal, endometrial or gastric cancer or two or more MSI cancers or a subgroup of FSMs that is selected according to one or more of the criteria outlined in detail below.

- 15 The term "frame-shift peptide" abbreviated as "FSP" is used in the context of the present invention to refer to the complete translation product of the protein-encoding segment of a nucleic acid comprising a FSM of an CFSM starting from the FC.

- The term "a collection of frame-shift peptides" abbreviated as "CFSP" is used in the context of the present invention to refer to a list of amino acid sequences of FSP may represent
20 all FSPs observed in a particular MSI cancer type, e.g. colorectal, endometrial or gastric cancer or two or more MSI cancers or a subgroup of FSPs that is selected according to one or more of the criteria outlined in detail below.

- The term "modified FSP" abbreviated as "mFSP" is used in the context of the present invention to refer to a peptide having an amino acid sequence that is based on a FSP but that is
25 modified compared to the FSP by addition or deletion of amino acids to render that particular FSP more suitable for inclusion into a collection of peptides that form a cancer vaccine peptide collection. The criteria for selecting FSPs that may benefit from modification and the particular modification are outlined in detail below.

- The term "cancer vaccine peptide collection" abbreviated as "CVP" is used in the context
30 of the present invention to refer to FSPs and/or mFSPs either in the form of individual peptides or as linked to each other. Preferably, two or more different FSPs and/or mFSPs are linked to each other by peptide bonds forming polypeptides. The linkage may be directly or through one or more linker amino acids, e.g. small flexible amino acids like Gly, Ser, or Ala. In order to avoid the generation of further antigens its it preferred that the peptides are linked directly to

each other. It is preferred to link the FSPs and/or mFSPs together to form polypeptides. It is known that the translation efficiency of very long mRNAs decreases and, therefore it is preferred that CVPs comprising FSPs and mFSPs of a total length of more than 1.000 amino acids, more preferably of more than 1.500 amino acids are split into separate polypeptides. E.g.
5 if the CVP comprises FSPs and/or mFSPs of about 6.000 amino acid than it is preferred that the FSPs and/or mFSPs are linked to form four separate polypeptides each comprising FSPs and/or mFSPs of a total length of about 1.500 amino acids.

The term “microsatellite instability” abbreviated as “MSI” is defined as alterations in the length of microsatellites due to the deletion or insertion of one or more repeat units in the
10 microsatellite regions. This generates novel microsatellite alleles with altered total length in the genomic DNA of the tumor cells when compared with the genomic DNA in normal/germline cells from the same individual. This condition of genetic hypermutability results from impaired DNA mismatch repair (MMR). MMR is a mechanism that corrects spontaneous mutations that occur in genomic DNA during DNA replication. Typically, the mutations are single base
15 mismatches of short nucleotide insertions or deletions. The latter two may result in a frameshift mutation if occurring in an ORF and if the length of the inserted or deleted nucleotide sequence is not dividable by three (see above definition of FSM).

The term “MSI phenotype” refers to the diagnosis of a change in the length of repeated nucleotides, most often GT/CA repeats. Such repeats occur throughout the genomic DNA of
20 healthy subjects and make up about 3% of the human genome. The skilled person is well aware how to determine MSI phenotype in a sample. A preferred way is the use of a Promega (Madison, WI) MSI Analysis System (v 1.2), comprehensive of 7 markers, according to the guidelines established during the National Cancer Institute (NCI) Workshop on Microsatellite Instability.

25 The term “neo-epitope” is used in the context of the present invention to refer to an epitope encoded by the tumor that is not present in normal/germline cells but occurs in precancerous and/or, cancerous cells, in particular having an MSI phenotype.

The term “expression cassette” is used in the context of the present invention to refer to a nucleic acid molecule which comprises at least one nucleic acid sequence that is to be
30 expressed, e.g. a nucleic acid encoding the CVP of the present invention or a part thereof, operably linked to transcription and translation control sequences. Preferably, an expression cassette includes cis-regulating elements for efficient expression of a given gene, such as promoter, initiation-site and/or polyadenylation-site. Preferably, an expression cassette contains all the additional elements required for the expression of the nucleic acid in the cell of

a patient. A typical expression cassette thus contains a promoter operatively linked to the nucleic acid sequence to be expressed and signals required for efficient polyadenylation of the transcript, ribosome binding sites, and translation termination. Additional elements of the cassette may include, for example enhancers. An expression cassette preferably also contains a
5 transcription termination region downstream of the structural gene to provide for efficient termination. The termination region may be obtained from the same gene as the promoter sequence or may be obtained from a different gene.

The term “operably linked” as used in the context of the present invention refers to an arrangement of elements, wherein the components so described are configured so as to perform
10 their usual function. A nucleic acid is "operably linked" when it is placed into a functional relationship with another nucleic acid sequence. For example, a promoter is operably linked to one or more transgenes, if it affects the transcription of the one or more transgenes. Further, control elements operably linked to a coding sequence are capable of effecting the expression of the coding sequence. The control elements need not be contiguous with the coding sequence,
15 so long as they function to direct the expression thereof. Thus, for example, intervening untranslated yet transcribed sequences can be present between a promoter sequence and the coding sequence and the promoter sequence can still be considered “operably linked” to the coding sequence.

The term “expression vector” refers to a polynucleotide or a mixture of a polynucleotide
20 and proteins capable of being introduced or of introducing the collection of nucleic acids of the present invention or one nucleic acid that is part of the collection of nucleic acids of the invention into a cell, preferably a mammalian cell. Examples of vectors include but are not limited to plasmids, cosmids, phages, viruses or artificial chromosomes. In particular, a vector is used to transport the promoter and the collection of the nucleic acids or one nucleic acid that
25 is part of the collection of nucleic acids of the invention into a suitable host cell. Expression vectors may contain "replicon" polynucleotide sequences that facilitate the autonomous replication of the expression vector in a host cell. Once in the host cell, the expression vector may replicate independently of or coincidental with the host chromosomal DNA, and several copies of the vector and its inserted DNA can be generated. In case that replication incompetent
30 expression vectors are used – which is often the case for safety reasons – the vector may not replicate but merely direct expression of the nucleic acid. Depending on the type of expression vector the expression vector may be lost from the cell, i.e only transiently expresses the CVP encoded by the nucleic acid or may be stable in the cell. Expression vectors typically contain

expression cassettes, i.e. the necessary elements that permit transcription of the nucleic acid into an mRNA molecule.

The term “antigen” is used in the context of the present invention to refer to any structure recognized by molecules of the immune response, e.g. antibodies, T cell receptors (TCRs) and the like. Preferred antigens are cellular proteins that are associated with a particular disease. Antigens are recognized by highly variable antigen receptors (B-cell receptor or T-cell receptor) of the adaptive immune system and may elicit a humoral or cellular immune response. Antigens that elicit such a response are also referred to as immunogen. A fraction of the proteins inside cells, irrespective of whether they are foreign or cellular, are processed into smaller peptides and presented to by the major histocompatibility complex (MHC). A cellular immune response is elicited, if the small peptide fragment is bound by a T-cell receptor.

The term “epitope”, also known as antigenic determinant, is used in the context of the present invention to refer to the segment of an antigen, preferably peptide that is bound by molecules of the immune system, e.g. B-cell receptors, T-cell receptors or antibodies. The epitopes bound by antibodies or B cells are referred to as “B cell epitopes” and the epitopes bound by T cells are referred to as “T cell epitopes”. In this context, the term “binding” preferably relates to a specific binding, which is defined as a binding with an association constant between the antibody or T cell receptor (TCR) and the respective epitope of 1×10^5 M⁻¹ or higher, preferably of 1×10^6 M⁻¹, 1×10^7 M⁻¹, 1×10^8 M⁻¹ or higher. The skilled person is well aware how to determine the association constant (see e.g. Caoili, S.E. (2012) *Advances in Bioinformatics* Vol. 2012). Preferably, the specific binding of antibodies to an epitope is mediated by the Fab (fragment, antigen binding) region of the antibody, specific binding of a B-cell is mediated by the Fab region of the antibody comprised by the B-cell receptor and specific binding of a T-cell is mediated by the variable (V) region of the T-cell receptor. T cell epitopes are presented on the surface of an antigen presenting cell, where they are bound to Major Histocompatibility (MHC) molecules. There are at least three different classes of MHC molecules termed MHC class I, II and III molecules, respectively. Epitopes presented through the MHC-I pathway elicit a response by cytotoxic T lymphocytes (CD8+ cells), while epitopes presented through the MHC-II pathway elicit a response by T-helper cells (CD4+ cells). T cell epitopes presented by MHC Class I molecules are typically peptides between 8 and 11 amino acids in length and T cell epitopes presented by MHC Class II molecules are typically peptides between 13 and 17 amino acids in length. MHC Class III molecules also present non-peptidic epitopes such as glycolipids. Accordingly, the term “T cell epitope” preferably refers to a 8 to 11 or 13 to 17 amino acid long peptide that can be presented

by either a MHC Class I or MHC Class II molecule. Epitopes usually consist of chemically active surface groupings of amino acids, which may or may not carry sugar side chains and usually have specific three-dimensional structural characteristics, as well as specific charge characteristics. Conformational and non-conformational epitopes are distinguished in that the binding to the former but not the latter is lost in the presence of denaturing solvents.

The term “junctional epitope” as used in the context of the present invention refers to an epitope that is not present in an isolated FSP, mFSP and/or antigenic fragment thereof of a given CVP but comprises an amino acid sequence formed upon linking two peptides, e.g. two FSPs by a peptide bond. For example, a list of all potential junction epitopes of the assembled peptides with 8 consecutive amino acids may be created wherein 1 to 7 amino acids of the first peptide and 7 to 1 amino acids from the second peptide are included encompassing the linking peptide bond. This list is then compared to the amino acid sequence of all FSPs and mFSPs of the CVP in order to identify all potential junctional epitopes.

The term “non-MSI cancer epitope” refers to an epitope of a protein that is specifically expressed in cancer cells but which is not due to a FSM. Such an epitope is considered specific if it is at least 10-fold more abundant in cancer cells than in healthy cells. Examples of such epitopes are proteins whose expression is upregulated in cancer cells like, e.g. tyrosinase in melanomas or Her-2 receptor in breast cancer, or that are mutated in certain cancers like e.g. p53.

The term “immunogenic coverage” refers to the expected number of immunogenic epitopes that the vaccine is likely to elicit in a patient. A vaccine encoding a set of FSPs that are present in a patient’s tumor for a cumulative length of 400 amino acids is expected to elicit on average 3 immunogenic epitopes and is providing good immunogenic coverage.

The term “an antigenic fragment thereof” as used in the context of the present invention refers to a fragment of an antigen, preferably a FSP or mFSP, wherein the fragment is also antigenic, i.e. is capable of eliciting a B and/or T cell immune response in a mammal. Preferably the antigenic “fragments of FSPs and/or mFSPs” are at least 8 amino acid long continuous stretches of the FSPs and mFSPs as defined above and in more detail below. Fragments of a mFSP comprises at least 4 amino acids of the FSP on which the mFSP is based.

The term “collection of nucleic acids encoding the CVP” is used in the context of the present invention to refer to one or more consecutive nucleic acid sequences encoding a polypeptide comprising all FSPs and/or mFSPs or antigenic fragments thereof of the CVP, encoding 2, 3, 4, 5, 6, 7, 8, 9, or 10 or more, preferably four polypeptides comprising all FSPs and/or mFSPs of the CVP. Thus, the term comprises in one embodiment a single nucleic acid

encoding the CVP and in the other most extreme embodiment the collection of nucleic acid comprises a separate nucleic acid for each FSP and/or mFSP or antigenic fragment thereof.

The terms "preparation" and "composition" as used in the context of the present invention are intended to include the formulation of the active compound, e.g. the VLPs of the present invention with a carrier and/or excipient.

"Pharmaceutically acceptable" as used in the context of the present invention means approved by a regulatory agency of the Federal or a state government or listed in the U.S. Pharmacopeia or other generally recognized pharmacopeia for use in animals, and more particularly in humans.

The term "carrier", as used herein, refers to a pharmacologically inactive substance such as but not limited to a diluent, excipient, surfactants, stabilizers, physiological buffer solutions or vehicles with which the therapeutically active ingredient is administered. Such pharmaceutical carriers can be liquid or solid. Liquid carrier include but are not limited to sterile liquids, such as saline solutions in water and oils, including but not limited to those of petroleum, animal, vegetable or synthetic origin, such as peanut oil, soybean oil, mineral oil, sesame oil and the like. Saline solutions and aqueous dextrose and glycerol solutions can also be employed as liquid carriers, particularly for injectable solutions. A saline solution is a preferred carrier when the pharmaceutical composition is administered intravenously. Examples of suitable pharmaceutical carriers are described in "Remington's Pharmaceutical Sciences" by E. W. Martin.

Suitable pharmaceutical "excipients" include starch, glucose, lactose, sucrose, gelatine, malt, rice, flour, chalk, silica gel, sodium stearate, glycerol monostearate, talc, sodium chloride, dried skim milk, glycerol, propylene, glycol, water, ethanol and the like.

"Surfactants" include anionic, cationic, and non-ionic surfactants such as but not limited to sodium deoxycholate, sodium dodecylsulfate, Triton X-100, and polysorbates such as polysorbate 20, polysorbate 40, polysorbate 60, polysorbate 65 and polysorbate 80.

"Stabilizers" include but are not limited to mannitol, sucrose, trehalose, albumin, as well as protease and/or nuclease antagonists.

"Physiological buffer solution" that may be used in the context of the present invention include but are not limited to sodium chloride solution, demineralized water, as well as suitable organic or inorganic buffer solutions such as but not limited to phosphate buffer, citrate buffer, tris buffer (tris(hydroxymethyl)aminomethane), HEPES buffer ([4 (2 hydroxyethyl)piperazino]ethanesulphonic acid) or MOPS buffer (3 morpholino-1

propanesulphonic acid). The choice of the respective buffer in general depends on the desired buffer molarity. Phosphate buffer are suitable, for example, for injection and infusion solutions.

The term "adjuvant" refers to agents that augment, stimulate, activate, potentiate, or modulate the immune response to the active ingredient of the composition at either the cellular or humoral level, e.g. immunologic adjuvants stimulate the response of the immune system to the actual antigen, but have no immunological effect themselves. Examples of such adjuvants include but are not limited to inorganic adjuvants (e.g. inorganic metal salts such as aluminium phosphate or aluminium hydroxide), organic adjuvants (e.g. saponins or squalene), oil-based adjuvants (e.g. Freund's complete adjuvant and Freund's incomplete adjuvant), cytokines (e.g. IL-1 β , IL-2, IL-7, IL-12, IL-18, GM-CSF, and INF- γ) particulate adjuvants (e.g. immunostimulatory complexes (ISCOMS), liposomes, or biodegradable microspheres), virosomes, bacterial adjuvants (e.g. monophosphoryl lipid A, or muramyl peptides), synthetic adjuvants (e.g. non-ionic block copolymers, muramyl peptide analogues, or synthetic lipid A), or synthetic polynucleotides adjuvants (e.g. polyarginine or polylysine).

An "effective amount" or "therapeutically effective amount" is an amount of a therapeutic agent sufficient to achieve the intended purpose. The effective amount of a given therapeutic agent will vary with factors such as the nature of the agent, the route of administration, the size and species of the animal to receive the therapeutic agent, and the purpose of the administration. The effective amount in each individual case may be determined empirically by a skilled artisan according to established methods in the art.

As used herein, "treat", "treating", "treatment" or "therapy" of a disease or disorder means accomplishing one or more of the following: (a) reducing the severity of the disorder; (b) limiting or preventing development of symptoms characteristic of the disorder(s) being treated; (c) inhibiting worsening of symptoms characteristic of the disorder(s) being treated; (d) limiting or preventing recurrence of the disorder(s) in an individual that has previously had the disorder(s); and (e) limiting or preventing recurrence of symptoms in individuals that were previously symptomatic for the disorder(s).

Aspects of the invention and preferred embodiments

In a first aspect, the present invention relates to a method of selecting a collection of frame-shift peptides (CFSP) for producing a universal micro-satellite instability (MSI) cancer vaccine peptide collection (CVP) for prophylaxis or treatment of a patient with a cancer

comprising hereditary and sporadic MSI cancer or being at risk of developing such a cancer, comprising the steps of:

- (i) selecting a collection of nucleic acids (CFSM) each comprising a frame-shift mutation (FSM) each FSM being present in one or more of at least M cancer samples (CS) each of a different patient, wherein the cancer of the patient comprises cancer cells with an MSI phenotype;

wherein at least 50% of the FSM that are selected fulfill criteria (a), (b), (c) and/or (d):

(a) the FSM is present in a mononucleotide repeat (MNR) of coding genes with a length equal to or longer than 6 nucleotides;

(b) the FSM corresponds to a deletion of 1 nucleotide;

(c) the number of DNA sequencing reads harboring the FSM is significantly higher in the tumor sample as compared to the matched normal sample (FDR-corrected Fisher test p-value equal to or lower than 0.05);

(d) the FSM is present in the matched normal samples with an allele frequency lower than 25%,

- (ii) selecting X different frame-shift peptides (FSPs), wherein each selected FSP is the complete translation product of the protein-encoding segment of a nucleic acid comprising a FSM of the CFSM of at least 4 amino acid length, starting from the codon encoding the first amino acid that is different relative to the translation product of the corresponding wild type (wt) nucleic acid without the FSM,

wherein X is at least 20 more preferably at least 35 and M is at least 5.

By selecting a certain number and types of FSPs according to the method of the first aspect, induction of T cells against a number of FSP is ensured by the vaccination. The expected number of T cell immunogenic epitopes based on the 400 aa rule is at least one immunogenic epitope every 400aa and therefore at least 16 for a vaccine encoding for a total length of 6021aa. The inventors have indeed demonstrated in the mouse model that vaccination with 209 FSP for a total length of 6021aa was able to induce a T cell response against at least 16 different FSP, corresponding to at least 1 every 376 aa (Figure 9), this confirms the immunogenic rule. The selected vaccination platform based on genetic vectors, differently from peptide vaccination, ensured that the immunogenicity of an individual FSP is not suppressed by another FSP present in the vaccine. The inventors have demonstrated in a mouse model that competition is not occurring, by showing that administration of only one of the four vaccine vectors generates virtually identical responses compared to administration of a mix of four vaccine vectors.

In one embodiment, the FSPs selected in step (ii) can be described as candidate FSPs for producing a universal MSI CVP for prophylaxis or treatment of a patient with a cancer comprising hereditary and sporadic MSI cancer or being at risk of developing such a cancer. “Candidate” means that the FSPs potentially have a prophylactic or therapeutic effect. This can
5 be expected based on the selection process and their structure.

The selection criterion (c) requires that the prevalence of a given FSM is significantly higher, i.e. more prevalent in the genomic DNA of one or more tumor samples than in matched normal samples from a healthy subject or healthy subjects. In this context the term “significantly higher” means that the prevalence of a given FSM relative to the prevalence of
10 the wt un-mutated MNR is significantly higher in the tumor sample as compared to the normal sample according to a false-discovery-rate (FDR) corrected Fisher-test p-value equal to or smaller than 0.1, more preferably smaller than 0.05, more preferably smaller than 0.01 and even more preferably smaller than 0.005. The lower the value the more suited the FSM is for inclusion in the CFSM, since the likelihood of the stimulation of an unwanted immune reaction
15 against healthy tissue decreases. This criterion is assessed by sequencing either genomic DNA or cDNA from the samples. It is preferred that 50% of the FSMs selected for the CFSM fulfill criterion (c), more preferably at least 60%, more preferably at least 70%, more preferably at least 80%, more preferably at least 90%, more preferably at least 95% and most preferably at least 100%.

While criterion (c) relates to the relative prevalence of a given FSM, criterion (d) relates to the absolute prevalence of a given FSM in the alleles of normal samples. It is preferred that the FSM selected for the CFSM has a low overall prevalence in the alleles of normal samples. Preferably, the allele frequency in normal samples is lower than 40%, more preferably lower than 35%, more preferably lower than 30%, more preferably lower than 25%, more preferably
25 lower than 20% and even more preferably lower than 10%. It is preferred that 50% of the FSMs selected for the CFSM fulfill criterion (d), more preferably at least 60%, more preferably at least 70%, more preferably at least 80%, more preferably at least 90%, more preferably at least 95% and most preferably at least 100%.

It is preferred that the FSMs selected for the CFSM fulfill both criterions (c) and (d). It is
30 preferred that 50% of the FSMs selected for the CFSM fulfill criterion (c) and (d), more preferably at least 60%, more preferably at least 70%, more preferably at least 80%, more preferably at least 90%, more preferably at least 95% and most preferably at least 100%. Preferably, at least 50% also fulfill criterions (a) and/or (b).

In another preferred embodiment the FSMs selected for the CFSM fulfill criterion (a). It is preferred that 50% of the FSMs selected for the CFSM fulfill criterion (a), more preferably at least 60%, more preferably at least 70%, more preferably at least 80%, more preferably at least 90%, more preferably at least 95% and most preferably at least 100%.

5 In another preferred embodiment the FSMs selected for the CFSM fulfill criterion (b). It is preferred that 50% of the FSMs selected for the CFSM fulfill criterion (b), more preferably at least 60%, more preferably at least 70%, more preferably at least 80%, more preferably at least 90%, more preferably at least 95% and most preferably at least 100%.

10 In another preferred embodiment the FSMs selected for the CFSM fulfill criterion (a), (c) and (d). It is preferred that 50% of the FSMs selected for the CFSM fulfill criterion (a), (c) and (d), more preferably at least 60%, more preferably at least 70%, more preferably at least 80%, more preferably at least 90%, more preferably at least 95% and most preferably at least 100%.

15 In another preferred embodiment the FSMs selected for the CFSM fulfill criterion (b), (c) and (d). It is preferred that 50% of the FSMs selected for the CFSM fulfill criterion (b), (c) and (d), more preferably at least 60%, more preferably at least 70%, more preferably at least 80%, more preferably at least 90%, more preferably at least 95% and most preferably at least 100%.

20 In another preferred embodiment the FSMs selected for the CFSM fulfill criterion (a), (b), (c) and (d). It is preferred that 50% of the FSMs selected for the CFSM fulfill criterion (a), (b), (c) and (d), more preferably at least 60%, more preferably at least 70%, more preferably at least 80%, more preferably at least 90%, more preferably at least 95% and most preferably at least 100%.

The method of the invention provides a CVP that is suitable to treat MSI cancer of not only a particular patient but of many different patients with MSI cancer, i.e. is a universal CVP for the treatment of MSI cancers. For the same reason, it will also be suitable to have a prophylactic effect against the development of MSI cancers. Accordingly, the selection of FSMs in the method of the present invention is not based on the analysis of a cancer sample from just one patient but uses the information of several cancer samples from different patients. To obtain an appropriate diversity at least 5 cancer samples (CS) of different patients are analyzed to determine FSMs. As outlined above, this is preferably done by whole genome sequencing, by exome sequencing or by sequencing cDNAs generated from mRNA isolated from the samples. Cancer samples are used from patients that have a MSI cancer. This may be ascertained by detecting an MSI phenotype in cells comprised in the cancer sample. The CS may be of the same MSI cancer, i.e. originate from the same tissue, or from two or more different MSI cancers. It is particularly preferred and provides a particularly broadly usable

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CVP if a CS of MSI cancers of two or more different MSI cancers are used in the selection process. Preferred MSI cancers from which samples are derived are colorectal cancer and gastric cancer, colorectal cancer and endometrial cancer, gastric cancer and endometrial cancer and gastric cancer, colorectal cancer and endometrial cancer.

- 5 The selection process outlined on the basis of the FSMs can also be carried out on the basis of the FSP encoded by a particular nucleic acid comprising a FSM, i.e. criteria (c) and (d) can also be assessed by comparing the respectively encoded amino acid sequences rather than the nucleic acid sequences. It is immediately apparent to the skilled person that the presence of a FSM in a cancer or normal sample can also be assessed by determining the number
10 of the encoded protein amino acid sequence comprising a FSP at their C-terminus rather than the C-terminus of the wild-type protein sequence.

The present inventors further envision to select the FSPs that are included in the CFSP by using one or more of the following criteria:

- (a) the FSP is encoded by a FSM that is observed with a cancer type-specific frequency (CF)
15 observed for a subset of CS of a specific type of cancer that are part of the collection of M different CSs that is at least 5% for at least one of the cancer types present in the CS; and/or
- (b) the average mRNA expression level of the gene with the FSM encoding the FSP is in the top 80th percentile of the distribution describing the average mRNA expression values of
20 each protein-encoding gene across the CS; and/or
- (c) the FSM generating the FSP is observed in less than 2% in normal tissues in a cohort of subjects without a cancer.

- Preferably, at least 50% of the FSPs included in the CFSP fulfill criterion (a), (b), (c), (a)+(b), (a)+(c), (b)+(c) or (a)+(b)+(c). It is preferred that 60% of the FSPs selected for the
25 CFSP fulfill criterion (a), (b), (c), (a)+(b), (a)+(c), (b)+(c) or (a)+(b)+(c), more preferably at least 70% of the FSPs selected for the CFSP fulfill criterion (a), (b), (c), (a)+(b), (a)+(c), (b)+(c) or (a)+(b)+(c), more preferably at least 80% of the FSPs selected for the CFSP fulfill criterion (a), (b), (c), (a)+(b), (a)+(c), (b)+(c) or (a)+(b)+(c), more preferably at least 90% of the FSPs selected for the CFSP fulfill criterion (a), (b), (c), (a)+(b), (a)+(c), (b)+(c) or (a)+(b)+(c), more
30 preferably at least 95% of the FSPs selected for the CFSP fulfill criterion (a), (b), (c), (a)+(b), (a)+(c), (b)+(c) or (a)+(b)+(c) and most preferably at least 100% of the FSPs selected for the CFSP fulfill criterion (a), (b), (c), (a)+(b), (a)+(c), (b)+(c) or (a)+(b)+(c).

Regarding criterion (a) it is preferred that the FSP is encoded by a FSM that is observed with a CF observed for a subset of CS of a specific type of cancer that are part of the collection

of M different CSs that is at least 5% for at least one or all of the cancer types present in the CS, preferably at least 10%, preferably at least 15%, preferably at least 20%, preferably at least 25%, preferably at least 30%, more preferably at least 35%, more preferably at least 40% for at least one or all of the cancer types present in the CS.

- 5 Regarding criterion (b) it is preferred that the average mRNA expression level of the gene with the FSM encoding the FSP is in the top 75th percentile, preferably top 70th percentile, preferably top 65th percentile, preferably top 60th percentile, preferably top 55th percentile, more preferably top 50th percentile, more preferably top 40th percentile, more preferably top 30th percentile of the distribution describing the average mRNA expression values of each protein-
10 encoding gene across the CS, preferably of a specific type of cancer. The higher the relative abundance of the FSP the more likely the induction of an immune response is effective in treatment or prophylaxis of MSI cancers. Just for clarity the phrase “top 80th percentile” refers to all FSMs that have an expression level within including the highest expressed mRNA and only excludes the lowest expressed 19% of the mRNAs. Accordingly, the “top 30th percentile”
15 refers to all FSMs that have an expression level including the highest expressed mRNA and excludes the lowest expressed 69% of the mRNAs.

- Preferred combinations of criteria (a) and (b) are CF of at least 5% and mRNA expression level of the gene with the FSM is in the top 75th percentile, preferably top 70th percentile, preferably top 65th percentile, preferably top 60th percentile, preferably top 55th
20 percentile, more preferably top 50th percentile, more preferably top 40th percentile, more preferably top 30th percentile of the distribution describing the average mRNA expression values of each protein-encoding gene across the CS, preferably of a specific type of cancer. Other preferred combinations of criteria (a) and (b) are CF of at least 10% and mRNA expression level of the gene with the FSM is in the top 75th percentile, preferably top 70th
25 percentile, preferably top 65th percentile, preferably top 60th percentile, preferably top 55th percentile, more preferably top 50th percentile, more preferably top 40th percentile, more preferably top 30th percentile of the distribution describing the average mRNA expression values of each protein-encoding gene across the CS, preferably of a specific type of cancer. Other preferred combinations of criteria (a) and (b) are CF of at least 15% and mRNA
30 expression level of the gene with the FSM is in the top 75th percentile, preferably top 70th percentile, preferably top 65th percentile, preferably top 60th percentile, preferably top 55th percentile, more preferably top 50th percentile, more preferably top 40th percentile, more preferably top 30th percentile of the distribution describing the average mRNA expression values of each protein-encoding gene across the CS, preferably of a specific type of cancer.

Other preferred combinations of criteria (a) and (b) are CF of at least 20% and mRNA expression level of the gene with the FSM is in the top 75th percentile, preferably top 70th percentile, preferably top 65th percentile, preferably top 60th percentile, preferably top 55th percentile, more preferably top 50th percentile, more preferably top 40th percentile, more preferably top 30th percentile of the distribution describing the average mRNA expression values of each protein-encoding gene across the CS, preferably of a specific type of cancer.

Regarding criterion (c) it is preferred the FSM generating the FSP is observed in less than 2% in normal tissues in a cohort of subjects without a cancer, more preferably in less than 1.9%, less than 1.8%, less than 1.7%, less than 1.6%, less than 1.5%, less than 1.4%, less than 1.3%, less than 1.2%, less than 1.1%, less than 1.0% or less.

In a preferred embodiment of the method of the first aspect of the invention:

- (i) the CS are derived from patients having a MSI tumor, preferably colorectal cancer and/or gastric cancer and/or endometrial cancer, more preferably colorectal cancer, gastric cancer and endometrial cancer; and/or
- (ii) M is at least 30, preferably at least 50, more preferably at least 100, more preferably at least 200, most preferably at least 300; and/or
- (iii) X is at least 50, preferably at least 100, more preferably at least 200, and more preferably at least 300.

Preferably, M is at least 30 and X is at least 50, preferably at least 100, more preferably at least 200, and more preferably at least 300, preferably, M is at least 50 and X is at least 50, preferably at least 100, more preferably at least 200, and more preferably at least 300, M is at least 100 and X is at least 50, preferably at least 100, more preferably at least 200, and more preferably at least 300, M is at least 200 and X is at least 50, preferably at least 100, more preferably at least 200, and more preferably at least 300, even more preferably M is at least 300 and X is at least 50, preferably at least 100, more preferably at least 200, and more preferably at least 300.

The increase of the sample number M ascertains a broader, i.e. more universal, applicability of the CVP. However, due to the statistic distribution of FSMs, the completeness of the determination of all FSMs occurring in a particular MSI cancer type will asymptotically reach a maximum for a given number of samples. Thus, no significant improvement will be obtained, when more than 400 samples of a particular MSI cancer type are included. To improve the broad coverage of the FSMs present in MSI cancer type it is preferred to use CS of two or more MSI cancers. Preferred MSI cancers which are amenable to treatment and prophylaxis at the same time are colorectal cancer, and gastric cancer, colorectal cancer and endometrial

cancer, gastric cancer and endometrial cancer, and colorectal cancer, gastric cancer and endometrial cancer.

In a second aspect, the present invention relates to a method of determining the amino acid sequences of peptides comprised in a CVP or of the nucleic acid sequences encoding the peptides comprised in the CVP, comprising the steps of:

- (a) selecting at least Y FSPs or antigenic fragments thereof from the CFSP selected according to the first aspect of the invention;
- (b) modifying the amino acid sequence of one or more or of all of those FSPs which fulfill the following criteria: (i) the FSP has a length of between 4 to 9 amino acids, and/or (ii) the FSP contains one or more identical contiguous stretches of 8 or more amino acids present in more than one FSP encoded by the same FSM and/or (iii) the FSP contains one or more contiguous stretches of 8 or more amino acids also present in wt human proteins, wherein the amino acid sequence of a FSP according to (i) is modified by adding to the N-terminus of the FSP between 1, 2, 3, or 4, preferably 4 amino acids of the wild type (wt) amino acid sequence present immediately upstream of the FSP and wherein the modified FSP (mFSP) has a length of at least 8 amino acids; the amino acid sequence of a FSP according to (ii) is modified by removing these contiguous stretches from all but the longest FSP with the proviso that FSPs with a length of less than 4 amino acids after removal of the contiguous stretch are excluded from the CVP; and/or the amino acid sequence of a FSP according to (iii) is modified by removing these stretches; modified FSPs with a length of less than 4 amino acids after removal of the contiguous stretch are excluded from the CVP, and

wherein the amino acid sequences of the CVP comprises the amino acid sequences of the FSPs or antigenic fragments thereof selected in step a) and/or modified in step (b);

and wherein Y is at least 20 more preferably at least 35.

In the context of the second aspect, it is noted that the term “determining” is used, as is immediately apparent from step (b), not in the sense of “identifying” the sequence of peptides (e.g. by sequencing), but in the sense of “defining”, “fixing”, “codifying” or “modifying”.

In one embodiment, at least one of the FSPs modified in step (b) is, or is expected to be, i) immunogenic and ii) present in the patient tumor. Preferably, the immunogenicity of this FSP is not suppressed by another FSP selected or modified.

In a further embodiment, the FSPs modified in step (b) are candidate FSPs for producing a universal MSI CVP for prophylaxis or treatment of a patient with a cancer comprising hereditary and sporadic MSI cancer or being at risk of developing such a cancer.

The modification of FSPs according to step (b) serves the purpose to improve the antigenicity of the FSPs. It is preferred that at least 50% of the FSPs that fulfill criteria (i), (ii), (iii), (i)+(ii), (i)+(iii), (ii)+(iii), or (i)+(ii)+(iii) are modified, more preferably at least 60% of the FSPs that fulfill criteria (i), (ii), (iii), (i)+(ii), (i)+(iii), (ii)+(iii), or (i)+(ii)+(iii) are modified, at least 70% of the FSPs that fulfill criteria (i), (ii), (iii), (i)+(ii), (i)+(iii), (ii)+(iii), or (i)+(ii)+(iii) are modified, more preferably at least 80% of the FSPs that fulfill criteria (i), (ii), (iii), (i)+(ii), (i)+(iii), (ii)+(iii), or (i)+(ii)+(iii) are modified, more preferably at least 90% of the FSPs that fulfill criteria (i), (ii), (iii), (i)+(ii), (i)+(iii), (ii)+(iii), or (i)+(ii)+(iii) are modified, more preferably at least 95% of the FSPs that fulfill criteria (i), (ii), (iii), (i)+(ii), (i)+(iii), (ii)+(iii), or (i)+(ii)+(iii) are modified, and most preferably 100% of the FSPs that fulfill criteria (i), (ii), (iii), (i)+(ii), (i)+(iii), (ii)+(iii), or (i)+(ii)+(iii) are modified.

In a preferred embodiment of the second aspect of the present invention the selection of FSPs and mFSPs is carried out in step (a) in that the FSPs are successively selected from the CFSP and in each selection step a new FSP is selected from the CFSP that increases the cumulative amount of total FSP amino acid length (CAFSPL) to reach a threshold value in the maximal number of cancer samples which are below that threshold value and, optionally, if more than one FSP increases the CAFSPL for the maximal number of cancer samples for which the CAFSPL is still below the threshold value the FSP with the highest score is selected.

In a preferred embodiment of the second aspect of the present invention:

- (i) the CAFSPL for each cancer sample is determined by summing up the amino acid length of the FSPs that are already part of the CVP and the new FSP from the CFSP for which the corresponding FSMs are present in the cancer sample; and/or
- (ii) wherein the threshold value is defined separately for each subset of samples out of the CS that belong to a particular cancer type; and/or
- (iii) wherein the score is defined as the product between the amino acid length of the FSP and the overall frequency with which the FSM generating the FSP is observed in the CS, optionally without counting the FSM in CS from a cancer type for which CF is below 5%, more preferably below 4%, more preferably below 3%, and/or
- (iv) wherein the subset of cancer samples comprises all cancer samples from tumor types where the FSM is present with a CF greater than or equal to 5%, more preferably greater than or equal to 10% greater than or equal to 15%; and/or
- (v) wherein FSPs generated by a FSM with an overall frequency lower than 5% more preferably below 4%, more preferably below 3% are excluded from the selection; and/or

- (vi) wherein addition of new FSPs and/or modified FSPs proceeds until no further FSP is available whose inclusion in the CVP would increase the CAFSPL of any cancer sample whose CAFSPL is still below a threshold value (TV) or the cumulative length of all FSPs present in the CVP has reached a maximal value of V amino acids; and/or
- 5 (vii) wherein FSPs originating from the same FSM are treated as one FSP with a combined score calculated as the sum of the scores of the individual FSPs.

The criteria (i) to (vii) serve the purpose to improve the universality of the FSPs selected for the CVP by providing high immunogenic coverage to a cohort of patients with one or more types of MSI cancers. In addition criterion (vi) also allows to select a CVP that is

10 practically feasible by limiting the total amount of antigens that can be encoded in the vaccine. The use of the scoring system ensures that FSPs with a higher observed frequency (therefore expected to be present in a large number of patients) and with a longer total amino acid length (i.e. FSPs with a higher overall immunogenic potential), are preferably included in the CVP.

In a preferred embodiment criteria (i)+(iii)+(vi) are fulfilled for at least 50%, more

15 preferably at least 60%, at least 70%, at least 80%, at least 90%, at least 95% of the FSPs.

It is thus preferred that at least 50% FSPs are selected preferably based on criteria (i)+(iii)+(vi), more preferably based on criteria (i)+(ii)+(iii)+(vi), (i)+(iii)+(iv)+(vi), (i)+(iii)+(v)+(vi) or (i)+(iii)+(vi)+(vii), more preferably based on criteria (i)+(ii)+(iii)+(iv)+(vi), (i)+(ii)+(iii)+(v)+(vi), (i)+(ii)+(iii)+(vi)+(vii), (i)+(iii)+(iv)+(v)+(vi),

20 (i)+(iii)+(iv)+(vi)+(vii) or (i)+(iii)+(v)+(vi)+(vii), more preferably based on criteria (i)+(ii)+(iii)+(iv)+(v)+(vi), (i)+(ii)+(iii)+(iv)+(vi)+(vii), (i)+(ii)+(iii)+(v)+(vi)+(vii) or (i)+(iii)+(iv)+(v)+(vi)+(vii), most preferably based on criteria (i)+(ii)+(iii)+(iv)+(v)+(vi)+(vii), more preferably at least 60% FSPs are selected preferably based on criteria (i)+(iii)+(vi), more preferably based on criteria (i)+(ii)+(iii)+(vi),

25 (i)+(iii)+(iv)+(vi), (i)+(iii)+(v)+(vi) or (i)+(iii)+(vi)+(vii), more preferably based on criteria (i)+(ii)+(iii)+(iv)+(vi), (i)+(ii)+(iii)+(v)+(vi), (i)+(ii)+(iii)+(vi)+(vii), (i)+(iii)+(iv)+(v)+(vi), (i)+(iii)+(iv)+(vi)+(vii) or (i)+(iii)+(v)+(vi)+(vii), more preferably based on criteria (i)+(ii)+(iii)+(iv)+(v)+(vi), (i)+(ii)+(iii)+(iv)+(vi)+(vii), (i)+(ii)+(iii)+(v)+(vi)+(vii) or (i)+(iii)+(iv)+(v)+(vi)+(vii), most preferably based on criteria

30 (i)+(ii)+(iii)+(iv)+(v)+(vi)+(vii), more preferably at least 70% FSPs are selected preferably based on criteria (i)+(iii)+(vi), more preferably based on criteria (i)+(ii)+(iii)+(vi), (i)+(iii)+(iv)+(vi), (i)+(iii)+(v)+(vi) or (i)+(iii)+(vi)+(vii), more preferably based on criteria (i)+(ii)+(iii)+(iv)+(vi), (i)+(ii)+(iii)+(v)+(vi), (i)+(ii)+(iii)+(vi)+(vii), (i)+(iii)+(iv)+(v)+(vi), (i)+(iii)+(iv)+(vi)+(vii) or (i)+(iii)+(v)+(vi)+(vii), more preferably based on

5 criteria(i)+(ii)+(iii)+(iv)+(v)+(vi), (i)+(ii)+(iii)+(iv)+(vi)+(vii), (i)+(ii)+(iii)+(v)+(vi)+(vii)
 or (i)+(iii)+(iv)+(v)+(vi)+(vii), most preferably based on
 criteria(i)+(ii)+(iii)+(iv)+(v)+(vi)+(vii), more preferably at least 80% FSPs are selected
 preferably based on criteria (i)+(iii)+(vi), more preferably based on criteria
 10 (i)+(ii)+(iii)+(vi), (i)+(iii)+(iv)+(vi), (i)+(iii)+(v)+(vi) or (i)+(iii)+(vi)+(vii), more preferably
 based on criteria (i)+(ii)+(iii)+(iv)+(vi), (i)+(ii)+(iii)+(v)+(vi), (i)+(ii)+(iii)+(vi)+(vii),
 (i)+(iii)+(iv)+(v)+(vi), (i)+(iii)+(iv)+(vi)+(vii) or (i)+(iii)+(v)+(vi)+(vii), more preferably
 based on criteria (i)+(ii)+(iii)+(iv)+(v)+(vi), (i)+(ii)+(iii)+(iv)+(vi)+(vii),
 (i)+(ii)+(iii)+(v)+(vi)+(vii) or (i)+(iii)+(iv)+(v)+(vi)+(vii), most preferably based on criteria
 15 (i)+(ii)+(iii)+(iv)+(v)+(vi)+(vii), more preferably at least 90% FSPs are selected preferably
 based on criteria (i)+(iii)+(vi), more preferably based on criteria (i)+(ii)+(iii)+(vi),
 (i)+(iii)+(iv)+(vi), (i)+(iii)+(v)+(vi) or (i)+(iii)+(vi)+(vii), more preferably based on criteria
 (i)+(ii)+(iii)+(iv)+(vi), (i)+(ii)+(iii)+(v)+(vi), (i)+(ii)+(iii)+(vi)+(vii), (i)+(iii)+(iv)+(v)+(vi),
 (i)+(iii)+(iv)+(vi)+(vii) or (i)+(iii)+(v)+(vi)+(vii), more preferably based on criteria
 20 (i)+(ii)+(iii)+(iv)+(v)+(vi), (i)+(ii)+(iii)+(iv)+(vi)+(vii), (i)+(ii)+(iii)+(v)+(vi)+(vii) or
 (i)+(iii)+(iv)+(v)+(vi)+(vii), most preferably based on criteria
 (i)+(ii)+(iii)+(iv)+(v)+(vi)+(vii), and most preferably 100% FSPs are selected preferably based
 on criteria (i)+(iii)+(vi), more preferably based on criteria (i)+(ii)+(iii)+(vi),
 (i)+(iii)+(iv)+(vi), (i)+(iii)+(v)+(vi) or (i)+(iii)+(vi)+(vii), more preferably based on criteria
 25 (i)+(ii)+(iii)+(iv)+(vi), (i)+(ii)+(iii)+(v)+(vi), (i)+(ii)+(iii)+(vi)+(vii), (i)+(iii)+(iv)+(v)+(vi),
 (i)+(iii)+(iv)+(vi)+(vii) or (i)+(iii)+(v)+(vi)+(vii), more preferably based on criteria
 (i)+(ii)+(iii)+(iv)+(v)+(vi), (i)+(ii)+(iii)+(iv)+(vi)+(vii), (i)+(ii)+(iii)+(v)+(vi)+(vii) or
 (i)+(iii)+(iv)+(v)+(vi)+(vii), most preferably based on criteria
 30 (i)+(ii)+(iii)+(iv)+(v)+(vi)+(vii).

25 It is immediately apparent to the skilled person that the score can also be defined in
 alternative ways, for example based only on the overall frequency of the FSM generating the
 FSP, the length or the reciprocal length of the FSP or as the sum of cancer-specific scores, or
 after excluding one or more cancer types from the calculation of the score. An alternative score
 may further include or be exclusively based on the number of predicted MHC class I and/or
 30 class II epitopes within each FSP. It is also immediately apparent to the skilled person that
 criterion (vii) might be modified if the expression levels of the specific mRNA isoforms
 comprising the FSM are known. In that case, one or more of the FSPs generated by the same
 FSM could be excluded from the selection or the score of the FSPs arising from the individual

mRNA isoforms comprising the FSM can be weighted according to the observed relative expression levels of the isoforms.

In a preferred embodiment of the second aspect of the present invention:

- (i) addition of new FSPs proceeds until no further FSP is available whose inclusion in the CVP would increase the CAFSPL of any cancer sample whose CAFSPL is still below TV; and/or
- (ii) FSPs originating from the same FSM are treated as one FSP with a combined score calculated as the sum of the scores of the individual FSPs.

In a preferred embodiment of the second aspect of the present invention

- (a) the TV is at least 400 amino acids, preferably at least 600 amino acids, more preferably at least 800 amino acids; or
- (b) the TV is:
 - (i) at least 400 amino acids, preferably at least 600 amino acids, more preferably at least 800 amino acids for colorectal and gastric cancer; and
 - (ii) at least 200 amino acids, preferably at least 300 amino acids, more preferably at least 400 amino acids for endometrial cancer.

It is immediately clear to the skilled person that the values of TV can be extended to any situation where the selection is performed on a CS that includes different types of cancers, e.g. combinations of samples from colorectal cancer, gastric cancer, endometrial cancer, small intestine cancer, hepatobiliary tract cancer, liver cancer, neuroendocrine cancers, cervical cancer, ovarian cancer, uterine sarcomas, brain cancer and/or skin cancer.

In a preferred embodiment of the second aspect of the present invention:

- (i) the CVP comprises at least 4 amino acids of each FSP selected from the CFSP; and/or
- (ii) Y is selected in such that the cumulative amino acid length V of all peptides that are part of the CVP is at least 280 amino acids, preferably at least 6000;
- (iii) Y is at least 35, preferably at least 50, preferably at least 100, more preferably at least 200, and/or
- (iv) the CVP comprises FSPs and/or mFSPs selected from the group of FSPs and/or mFSPs according to SEQ ID NO: 1 to 1087, preferably selected from the group of FSPs and/or mFSPs according to SEQ ID NO: 1 to 209.

In a third aspect, the present invention relates to a method of producing a CVP or a collection of nucleic acids encoding the CVP comprising the steps of

- (i) obtaining the amino acid or nucleic acid sequence information determined in the method of the second aspect of the invention; and

- (ii) synthesizing the amino acid sequence of the CVP in one or more polypeptides or a collection of nucleic acids with that sequence and optionally inserting the collection of nucleic acids into one or more expression cassettes and/or a collection of expression vectors.

5 The synthesizing of the FSPs and, if modified the mFSPs, or antigenic fragments thereof of the CVP may be carried out by recombinant expression of a collection of nucleic acids encoding the FSPs and, if modified the mFSPs or antigenic fragments thereof or by chemical synthesis. Similarly, the synthesis of the collection of nucleic acids encoding the peptides of the CVP can be carried out by known methods including chemical synthesis on a solid phase.

10 In a fourth aspect, the present invention relates to a CVP producible by the method of the second aspect of the invention or a collection of nucleic acids encoding the peptides of said CVP.

In a fifth aspect, the CVP comprises or consists of Y different FSPs and/or mFSPs or antigenic fragment of the FSP and/or mFSP with a length of at least 8 amino acids, wherein
15 each FSP or the FSPs which are modified to mFSP is the complete translation product of the protein-encoding segment of a FSM containing nucleic acid starting from the codon encoding the first amino acid that is different relative to the translation of the corresponding wt nucleic acid without the FSM of in either case at least 4 amino acid length and wherein at least 50% of the FSPs or the FSPs which are modified to mFSPs fulfill one or more of the following criteria:

- 20 (a) the FSP is encoded by a FSM that is observed with a cancer type specific frequency (CF) observed for a subset of CS of a specific type of cancer that are part of a collection of M different CSs that is at least 5% for at least one of the cancer types present in the CS; and/or
(b) the average mRNA expression level of the gene with the FSM encoding the FSP is in the
25 top 80th percentile of the distribution describing the average mRNA expression values of each protein-encoding gene across the CS; and/or
(c) the FSM generating the FSP is observed in less than 2% in normal tissues in a cohort of subjects without a cancer

wherein the amino acid sequence of one or more or all those FSPs which fulfill the following
30 criteria: (i) the FSP encoded by a nucleic acid comprising a FSM starting from the amino acid encoded by the FC has a length between 4 to 9 amino acids, and/or (ii) the FSP contains one or more identical contiguous stretches of 8 or more amino acids present in more than one FSP encoded by the same FSM and/or (iii) the FSP contains one or more contiguous stretches of 8 or more amino acids also present in wt human proteins,

are modified for a FSP according to (i) by adding to the N-terminus of the FSP between 1 to 4 amino acids of the wild type (wt) amino acid sequence present immediately upstream of the FSP and wherein the modified FSP (mFSP) has a length of at least 8 amino acids; for a FSP according to (ii) is modified by removing these contiguous stretches from all but the longest
 5 FSP with the proviso that FSPs with a length of less than 4 amino acids after removal of the contiguous stretch are excluded from the CVP; and/or for a FSP according to (iii) is modified by removing these stretches; modified FSPs with a length of less than 4 amino acids after removal of the contiguous stretch are excluded from the CVP;
 and wherein Y is at least 20 more preferably at least 35 and M is at least 5.

10 Preferably, at least 50% of the FSPs included in the CVP fulfill criterion (a), (b), (c), (a)+(b), (a)+(c), (b)+(c) or (a)+(b)+(c). It is preferred that 60% of the FSPs selected for the CFSP fulfill criterion (a), (b), (c), (a)+(b), (a)+(c), (b)+(c) or (a)+(b)+(c), more preferably at least 70% of the FSPs selected for the CFSP fulfill criterion (a), (b), (c), (a)+(b), (a)+(c), (b)+(c) or (a)+(b)+(c), more preferably at least 80% of the FSPs selected for the CFSP fulfill criterion
 15 (a), (b), (c), (a)+(b), (a)+(c), (b)+(c) or (a)+(b)+(c), more preferably at least 90% of the FSPs selected for the CFSP fulfill criterion (a), (b), (c), (a)+(b), (a)+(c), (b)+(c) or (a)+(b)+(c), more preferably at least 95% of the FSPs selected for the CFSP fulfill criterion (a), (b), (c), (a)+(b), (a)+(c), (b)+(c) or (a)+(b)+(c) and most preferably at least 100% of the FSPs selected for the CFSP fulfill criterion (a), (b), (c), (a)+(b), (a)+(c), (b)+(c) or (a)+(b)+(c).

20 Regarding criterion (a) it is preferred that the FSP is encoded by a FSM that is observed with a CF observed for a subset of CS of a specific type of cancer that are part of the collection of M different CSs that is at least 10% for at least one or all of the cancer types present in the CS, preferably at least 15%, preferably at least 20%, preferably at least 25%, preferably at least 30%, more preferably at least 35%, more preferably at least 40% for at least one or all of the
 25 cancer types present in the CS.

Regarding criterion (b) it is preferred that the average mRNA expression level of the gene with the FSM encoding the FSP is in the top 75th percentile, preferably top 70th percentile, preferably top 65th percentile, preferably top 60th percentile, preferably top 55th percentile, more preferably top 50th percentile, more preferably top 40th percentile, more preferably top 30th
 30 percentile of the distribution describing the average mRNA expression values of each protein-encoding gene across the CS. The higher the relative abundance of the FSP the more likely the induction of an immune response is effective in treatment or prophylaxis of MSI cancers. Just for clarity the phrase “top 80th percentile” refers to all FSMs that have an expression level within including the highest expressed mRNA and only excludes the lowest expressed 19% of the

mRNAs. Accordingly, the “top 30th percentile” refers to all FSMs that have an expression level including the highest expressed mRNA and excludes the lowest expressed 69% of the mRNAs.

Preferred combinations of criteria (a) and (b) are CF of at least 5% and mRNA expression level of the gene with the FSM is in the top 75th percentile, preferably top 70th percentile, preferably top 65th percentile, preferably top 60th percentile, preferably top 55th percentile, more preferably top 50th percentile, more preferably top 40th percentile, more preferably top 30th percentile of the distribution describing the average mRNA expression values of each protein-encoding gene across the CS, preferably of a specific type of cancer. Other preferred combinations of criteria (a) and (b) are CF of at least 10% and mRNA expression level of the gene with the FSM is in the top 75th percentile, preferably top 70th percentile, preferably top 65th percentile, preferably top 60th percentile, preferably top 55th percentile, more preferably top 50th percentile, more preferably top 40th percentile, more preferably top 30th percentile of the distribution describing the average mRNA expression values of each protein-encoding gene across the CS, preferably of a specific type of cancer. Other preferred combinations of criteria (a) and (b) are CF of at least 15% and mRNA expression level of the gene with the FSM is in the top 75th percentile, preferably top 70th percentile, preferably top 65th percentile, preferably top 60th percentile, preferably top 55th percentile, more preferably top 50th percentile, more preferably top 40th percentile, more preferably top 30th percentile of the distribution describing the average mRNA expression values of each protein-encoding gene across the CS, preferably of a specific type of cancer. Other preferred combinations of criteria (a) and (b) are CF of at least 20% and mRNA expression level of the gene with the FSM is in the top 75th percentile, preferably top 70th percentile, preferably top 65th percentile, preferably top 60th percentile, preferably top 55th percentile, more preferably top 50th percentile, more preferably top 40th percentile, more preferably top 30th percentile of the distribution describing the average mRNA expression values of each protein-encoding gene across the CS, preferably of a specific type of cancer.

Regarding criterion (c) it is preferred the FSM generating the FSP is observed in less than 2% in normal tissues in a cohort of subjects without a cancer, more preferably in less than 1.9%, less than 1.8%, less than 1.7%, less than 1.6%, less than 1.5%, less than 1.4%, less than 1.3%, less than 1.2%, less than 1.1%, less than 1.0% or less.

In a preferred embodiment the CVP of the fifth aspect of the present invention:

- (i) the CS are derived from patients having a MSI tumor, preferably colorectal cancer and/or gastric cancer and/or endometrial cancer, more preferably colorectal cancer, gastric cancer and endometrial cancer; and/or

- (ii) M is at least 10, preferably at least 20, preferably at least 30, preferably at least 50, more preferably at least 100, more preferably at least 200, most preferably at least 300; and/or
- (iii) Y is at least 35, preferably at least 50, preferably at least 100, more preferably at least 200; and/or
- 5 (iv) the CVP comprises at least 4 preferably at least 6, more preferably at least 8 amino acids of each FSP; and/or
- (v) Y is selected in such that the cumulative amino acid length V of all FSPs and/or mFSPs or antigenic fragments thereof that are part of the CVP is at least 280 amino acids, preferably at least 500 amino acids, preferably at least 1.000 amino acids, preferably at least 1.500 amino acids, preferably at least 2.000 amino acids, preferably at least 2.500 amino acids, preferably at least 3.000 amino acids preferably at least 3.500 amino acids, preferably at least 4.000 amino acids, preferably at least 4.500 amino acids, preferably at least 5.000 amino acids, preferably at least 5.500 amino acids, more preferably at least 6000; and/or
- 10 (vi) the FSPs and/or mFSPs of the CVP are selected from the group of FSPs and/or mFSPs according to SEQ ID NO: 1 to 1087, preferably selected from the group of FSPs and/or mFSPs according to SEQ ID NO: 1 to 209.

Preferably, M is at least 30 and Y is at least 50, preferably at least 100, more preferably at least 200, and more preferably at least 300, preferably, M is at least 50 and Y is at least 50, preferably at least 100, more preferably at least 200, and more preferably at least 300, M is at least 100 and Y is at least 50, preferably at least 100, more preferably at least 200, and more preferably at least 300, M is at least 200 and Y is at least 50, preferably at least 100, more preferably at least 200, and more preferably at least 300, even more preferably M is at least 300 and Y is at least 50, preferably at least 100, more preferably at least 200, and more preferably at least 300.

In one embodiment of the present invention the CVP of the fifth aspect of the invention further comprises one or more non-MSI cancer specific antigens. Preferably, such antigens are specific also to one or more of the cancer types to be treated.

In a preferred embodiment at least 35, preferably at least 50, preferably at least 100, more preferably at least 200, more preferably at least 209 FSPs and/or mFSPs or antigenic fragments thereof of the CVP are selected from the group of FSPs and/or mFSPs according to SEQ ID NO: 1 to 1087, preferably selected from the group of FSPs and/or mFSPs according to SEQ ID NO: 1 to 209.

The FSPs and mFSPs according to SEQ ID NO: 1 to 1087 are ordered from 1 to 1087 in decreasing order of relevance for prophylaxis or treatment of MSI tumors, in particular of colorectal carcinoma, gastric cancer and endometrial cancer. Particular suitable subsets comprise or consist of FSPs and mFSPs with the amino acid sequences of SEQ ID NO: 1 to 50, 1 to 75, 1 to 100, 1 to 125, 1 to 150, 1 to 175, 1 to 200, particularly preferably of 1 to 209, 1 to 225, 1 to 250, 1 to 275, 1 to 300, 1 to 325, 1 to 350, 1 to 375, 1 to 400, 1 to 450, 1 to 500, 1 to 550, 1 to 600, 1 to 650, 1 to 700, 1 to 750, 1 to 800, 1 to 850, 1 to 900, 1 to 950, 1 to 1000, 1 to 1050 or 1 to 1087. While it is preferred that the subset comprise or consists of exactly the respectively indicated FSPs and/or mFSPs, it is understood by the skilled person that between 1 to 10% of these FSPs and/or mFSPs may be omitted from the set without any substantial loss in its activity. Similarly, and as implied by the “comprising” language a subset that comprises, e.g. the amino acid sequences of SEQ ID NO: 1 to 200 may additionally comprise 1 to 100 or more FSPs or mFSP of SEQ ID NO: 201 to 1087 and/or one or more other FSP or mFSP or a non-MSI cancer specific antigen.

In a preferred embodiment the CVP of the fifth aspect of the present invention the FSPs of the CVP have been successively selected from a CFSP and wherein in each selection step a new FSP or antigenic fragment thereof is selected from the CFSP to increase the CAFSPL to reach a threshold value in the maximal number of cancer samples which are below that threshold value and optionally, if more than one FSP increases the CAFSPL for the maximal number of cancer samples for which the CAFSPL is still below the threshold value, the FSP with the highest score is selected.

In a preferred embodiment the CVP of the fifth aspect of the present invention:

(i) the CAFSPL for each cancer sample is determined by summing up the amino acid length of the FSPs that are already part of the CVP and the new FSP from the CFSP for which the corresponding FSMs are present in the cancer sample; and/or

(ii) the threshold value is defined separately for each subset of samples out of the CS that belong to a particular cancer type; and/or

(iii) the score is defined as the product between the amino acid length of the FSP and the overall frequency with which the FSM generating the FSP is observed in the CS; and/or

(iv) addition of new FSPs proceeds until no further FSP is available whose inclusion in the CVP would increase the CAFSPL of any cancer sample whose CAFSPL is still below a threshold value (TV); and/or

(v) wherein FSPs originating from the same FSM are treated as one FSP with a combined score calculated as the sum of the scores of the individual FSPs.

In a preferred embodiment the CVP of the fifth aspect of the present invention,

- (i) wherein the CAFSPL for each cancer sample is determined by summing up the amino acid length of the FSPs that are already part of the CVP and the new FSP from the CFSP for the corresponding FSM are present in the cancer sample; and/or
- 5 (ii) wherein the threshold value is defined separately for each subset of samples out of the CS that belong to a particular cancer type; and/or
- (iii) wherein the score is defined as the product between the amino acid length of the FSP and the overall frequency of the FSM generating the FSP without counting the FSM in cancer samples from a cancer type for which CF is below 5%, more preferably below 4% and
- 10 more preferably below 3%; and/or
- (iv) wherein the subset of cancer samples comprises all cancer samples from tumor types where the FSM is present with a CF greater than or equal to 5%, more preferably greater than or equal to 10% greater than or equal to 15%; and/or
- (v) wherein FSPs generated by a FSM with an overall frequency lower than 5%
- 15 more preferably below 4% and more preferably below 3% are excluded from the selection; and/or
- (vi) wherein addition of new FSPs proceeds until no further FSP is available whose inclusion in the CVP would increase the CAFSPL of any cancer sample whose CAFSPL is still below a TV or the cumulative length of all FSPs present in the CVP has reached a maximal
- 20 value of V amino acids; and/or
- (vii) and wherein FSPs originating from the same FSM are treated as one FSP with a combined score calculated as the sum of the scores of the individual FSPs.

It is understood by the skilled person that the CVP according to the fifth aspect may be designed by the method of the first and second aspect and accordingly the selection steps and

25 criteria outlined regarding the first and second aspect may equally be used to characterize the CVP of the fifth aspect. Accordingly, in a preferred embodiment criteria (i)+(iii)+(vi) are fulfilled for at least 50%, more preferably at least 60%, at least 70%, at least 80%, at least 90%, at least 95% of the FSPs.

It is thus preferred that at least 50% FSPs are selected preferably based on criteria

30 (i)+(iii)+(vi), more preferably based on criteria (i)+(ii)+(iii)+(vi), (i)+(iii)+(iv)+(vi), (i)+(iii)+(v)+(vi) or (i)+(iii)+(vi)+(vii), more preferably based on criteria (i)+(ii)+(iii)+(iv)+(vi), (i)+(ii)+(iii)+(v)+(vi), (i)+(ii)+(iii)+(vi)+(vii), (i)+(iii)+(iv)+(v)+(vi), (i)+(iii)+(iv)+(vi)+(vii) or (i)+(iii)+(v)+(vi)+(vii), more preferably based on criteria (i)+(ii)+(iii)+(iv)+(v)+(vi), (i)+(ii)+(iii)+(iv)+(vi)+(vii), (i)+(ii)+(iii)+(v)+(vi)+(vii) or

[illegible]

(i)+(ii)+(iii)+(iv)+(v)+(vi), (i)+(ii)+(iii)+(iv)+(vi)+(vii), (i)+(ii)+(iii)+(v)+(vi)+(vii) or (i)+(iii)+(iv)+(v)+(vi)+(vii), most preferably based on criteria (i)+(ii)+(iii)+(iv)+(v)+(vi)+(vii).

5 In a preferred embodiment the CVP of the fifth aspect of the present invention the TV is:
(a) the TV is at least 400 amino acids, preferably at least 600 amino acids, more preferably at least 800 amino acids; or

(b) the TV is:

(i) at least 400 amino acids, preferably at least 600 amino acids, more preferably at
10 least 800 amino acids for colorectal and gastric cancer; and
(ii) at least 200 amino acids, preferably at least 300 amino acids, more preferably at least 400 amino acids for endometrial cancer.

In a preferred embodiment the CVP of the fifth aspect of the present invention the peptides of the CVP are separate or at least two FSPs and/or mFSPs are comprised in one or
15 more polypeptides. When linking two or more FSPs and/or mFSPs to a polypeptide it is preferred that the linkage is direct with a peptide bond, i.e. without an amino acid linker.

It is also preferred that it is assessed before linking two FSPs and/or mFSPs within a polypeptide whether the resulting junction sequence contains one or more contiguous stretches of 8 or more amino acids also present in wt human proteins. If that is the case those two peptides
20 are not linked in this way. Accordingly, the resulting polypeptide of linked FSPs and/or mFSPs will not contain one or more contiguous stretches of 8 or more amino acids also present in wt human proteins. Depending on the total length of the FSPs and/or mFSPs comprised in the CVP the FSPs and/or mFSPs may be comprised in two, three, four, five, six or more polypeptides.

The present inventors have assembled the 209 FSPs and mFSPs of SEQ ID NO: 1 to 209
25 or antigenic fragments thereof in four polypeptides and have found that this a particularly suitable way of providing these antigens. Preferred arrangements of the FSPs and mFSPs of SEQ ID NO: 1 to 209 in four polypeptides consists of or comprises the following four polypeptides with amino acid sequences according to SEQ ID NO: 1088 to 1091 (layout A), SEQ ID NO: 1092 to 1095 (layout B), SEQ ID NO: 1155 to 1158 (layout C) or SEQ ID NO:
30 1159 to 1162 (layout D).

It is preferred that in subsequent rounds of administration of the same CVP, i.e. comprising the same FSPs and mFSPs, the polypeptides comprising the FSPs and mFSPs, e.g. according to SEQ ID NO: 1 to 209, are arranged in different order. This minimizes unwanted immune reactions against junctional epitopes. For example, it is preferred to combine

administration of the CVP in polypeptide layout A with polypeptide layout B, layout A with layout C, layout A with layout D, layout B with layout C, layout B with layout D, layout C with layout D, layout A with layout B and layout C, layout A with layout B and layout D, layout B with layout C and layout D, layout A with layout B, layout C and layout D.

5 Accordingly, the present invention also comprises 2, 3, 4, 5, 6, or more different layouts of polypeptides, wherein each set comprises one or more, preferably 2, 3, 4, 5, 6, 7, 8, 9, or 10 or more polypeptides comprising or consisting of the same FSPs and mFSPs or antigenic fragments thereof, i.e. are the same CVP. The difference between each set is thus not the amino acid sequence of the FSPs, mFSPs or antigenic fragments thereof, but the arrangement of the
10 FSPs, mFSPs or antigenic fragments thereof in the respective number of polypeptides. It is particularly, preferred that a given CVP is provided in two different layouts and comprises one or more, preferably 2, 3, 4, 5, 6, 7, 8, 9, or 10 or more polypeptides, most preferably 4 polypeptides comprising or consisting of the same FSPs and mFSPs or antigenic fragments thereof, three different layouts and comprises one or more, preferably 2, 3, 4, 5, 6, 7, 8, 9, or 10
15 or more polypeptides, most preferably 4 polypeptides comprising or consisting of the same FSPs and mFSPs or antigenic fragments thereof, four different layouts and comprises one or more, preferably 2, 3, 4, 5, 6, 7, 8, 9, or 10 or more polypeptides, most preferably 4 polypeptides comprising or consisting of the same FSPs and mFSPs or antigenic fragments thereof, five different layouts and comprises one or more, preferably 2, 3, 4, 5, 6, 7, 8, 9, or 10 or more
20 polypeptides, most preferably 4 polypeptides comprising or consisting of the same FSPs and mFSPs or antigenic fragments thereof. Preferably, each different layout is distinguished from the other layouts by different junction sequences, i.e. two layouts do not comprise a link between the same N- to C-terminal link of one FSP or mFSP to the next FSP or mFSP.

Each layout will typically be administered separately to a patient and, thus, the different
25 layouts can also be viewed as separate compositions of the same CVP.

In a preferred embodiment the CVP of the fifth aspect of the present invention one or more FSPs and/or mFSPs or polypeptides comprising two or more FSPs and/or mFSPs of the CVP are linked, preferably by peptide bonds, to one or more of the following elements that enhance immunogenicity of the CVP: an invariant chain sequence or fragment thereof; a tissue-type plasminogen activator; a PEST sequence; a cyclin destruction box; an ubiquitination
30 signal; a SUMOylation signal; an Interleukin, preferably an Interleukin 2, Interleukin 12, or Interleukin 15; a checkpoint protein specific ligand, preferably an anti-PD1 antibody or PD1-binding fragment thereof, an anti-CTLA4 antibody or an anti-CTLA4-binding fragment

thereof, an anti-LAG3 antibody or an anti-LAG3-binding fragment, an anti-TIM3 antibody or an anti-TIM3-binding fragment thereof.

In a preferred embodiment a sorting signal (either the human tissue plasminogen activator signal peptide (hTPA; SEQ ID NO: 1104 or a functional fragment thereof that is sorted as the hTPA) or the human invariant chain (hINV; SEQ ID NO: 1105 or a functional fragment thereof that is sorted as the hINV) is added at the N-terminus and, optionally an influenza HA-tag sequence (SEQ ID NO: 1106) at the C-terminus of the polypeptides of SEQ ID NO: 1088 to 1091 (layout A), SEQ ID NO: 1092 to 1095 (layout B), SEQ ID NO: 1155 to 1158 (layout C) or SEQ ID NO: 1159 to 1162 (layout D).

Preferred amino acid sequence of so constructed polypeptides are provided as SEQ ID NO: 1107 to 1110 (layout A), SEQ ID NO: 1111 to 1114 (layout B), SEQ ID NO: 1171 to 1174 (layout C) and SEQ ID NO: 1179 to 1182 (layout D) for hTPA and by SEQ ID NO: 1115 to 1118 (layout A), SEQ ID NO: 1119 to 1122 (layout B), SEQ ID NO: 1175 to 1178 (layout C) and SEQ ID NO: 1183 to 1186 (layout D) for hINV.

In a sixth aspect, the present invention relates to a collection of nucleic acids encoding the CVP of the fifth aspect of the present invention. The nucleic acid may preferably be DNA, RNA or RNA modified to increase its serum half-life.

For the reasons set out above regarding the CVP it is preferred to use 2, 3, 4, 5, 6, 7, 8, 9, 10 or more, preferably 4 different layouts of the 1, 2, 3, 4, 5, 6, 7, 8, 9, or 10 or more polypeptides comprising the FSPs, mFSPs or antigenic fragments thereof. Consistently, the collection of nucleic acids encoding the respective number of polypeptides have different layouts. In a preferred embodiment the collection of nucleic acids encoding the FSB and/or mFSB encode the four polypeptides according to SEQ ID NO: 1088 to 1091 (layout A), SEQ ID NO: 1092 to 1095 (layout B), SEQ ID NO: 1155 to 1158 (layout C) or SEQ ID NO: 1159 to 1162 (layout D) and are codon-optimized based on human codon usage.

When a CVP is administered in the form of a collection of nucleic acids encoding the given CVP it is preferred to use 2, 3, 4, 5, 6, or more different layouts of the nucleic acids, wherein each layout comprises one or more, preferably 2, 3, 4, 5, 6, 7, 8, 9, or 10 or more nucleic acids encoding polypeptides comprising or consisting of the same FSPs and mFSPs or antigenic fragments thereof, i.e. encode the same CVP. It is particularly, preferred that a given collection of nucleic acids encoding the CVP of the fourth or fifth aspect of the invention is provided in two different layouts and comprises one or more, preferably 2, 3, 4, 5, 6, 7, 8, 9, or 10 or more nucleic acids encoding polypeptides, most preferably 4 nucleic acids encoding polypeptides comprising or consisting of the same FSPs and mFSPs or antigenic fragments

thereof, three different layouts and comprises one or more, preferably 2, 3, 4, 5, 6, 7, 8, 9, or 10 or more nucleic acids encoding polypeptides, most preferably 4 nucleic acids encoding polypeptides comprising or consisting of the same FSPs and mFSPs or antigenic fragments thereof, four different layouts and comprises one or more, preferably 2, 3, 4, 5, 6, 7, 8, 9, or 10
5 or more nucleic acids encoding polypeptides, most preferably 4 nucleic acids encoding polypeptides comprising or consisting of the same FSPs and mFSPs or antigenic fragments thereof, five different layouts and comprises one or more, preferably 2, 3, 4, 5, 6, 7, 8, 9, or 10 or more nucleic acids encoding polypeptides, most preferably 4 nucleic acids encoding polypeptides comprising or consisting of the same FSPs and mFSPs or antigenic fragments thereof, or six different layouts and comprises one or more, preferably 2, 3, 4, 5, 6, 7, 8, 9, or
10 10 or more nucleic acids encoding polypeptides, most preferably 4 nucleic acids encoding polypeptides comprising or consisting of the same FSPs and mFSPs or antigenic fragments thereof.

Further examples of such nucleic acid collections encoding FSPs and mFSPs of SEQ ID
15 NO: 1 to 209, encoding the same CVP, but with different layout are provided in SEQ ID NO: 1123 to 1126 for layout A and SEQ ID NO: 1187 to 1190 for layout C with hTPA; SEQ ID NO: 1127 to 1130 for layout B and SEQ ID NO: 1191 to 1194 for layout D with hTPA; SEQ ID NO: 1131 to 1134 for layout A and SEQ ID NO: 1195 to 1198 for layout C with hINV and SEQ ID NO: 1135 to 1138 for layout B and SEQ ID NO: 1199 to 1202 for layout D with hINV.

20 In a preferred embodiment, a Kozak sequence (CGCGACTTCGCCGCC) may be placed immediately upstream of the start codon of the collection nucleic acid according to the fourth or sixth aspect of the invention to allow for efficient initiation of translation and a TAA stop codon was placed downstream of the HA tag. Finally, it is preferred that the collection of nucleic acid comprises two flanking segments comprising unique restriction sites to facilitate
25 the sub-cloning of the cassettes were added at the 5'- and 3'-end of the nucleotide sequence, respectively (Figure 7).

The collection of nucleic acids of the fourth and sixth aspect of the present invention may also be comprised in an expression cassette.

In a seventh aspect the invention relates to a collection of one or more expression vectors
30 each comprising all or part of the collection of nucleic acids of the fourth or sixth aspect of the invention, wherein the entirety of the collection of expression vectors comprise all of the collection of nucleic acids of the fourth or sixth aspect of the invention, i.e. wherein the collection of expression comprises nucleic acids encoding all FSPs, mFSP or antigenic fragments thereof of a given CVP.

It is preferred that the collection of expression vectors of comprise one or more elements that enhance immunogenicity of the expression vector. Preferably such elements are expressed as a fusion to the FSPs, mFSPs or antigenic fragments thereof or are encoded by another nucleic acid comprised in the vector, preferably in an expression cassette.

5 In a preferred embodiment the element that enhances immunogenicity of the CVP are selected from the group consisting of an invariant chain sequence or immune stimulatory fragment thereof; a tissue-type plasminogen activator; a PEST sequence; a cyclin destruction box; an ubiquitination signal; a SUMOylation signal; an Interleukin, preferably an Interleukin 2, Interleukin 12, or Interleukin 15; a checkpoint protein specific ligand, preferably an anti-PD1
10 antibody or PD1-binding fragment thereof, an anti-CTLA4 antibody or an anti-CTLA4-binding fragment thereof, an anti-LAG3 antibody or an anti-LAG3-binding fragment, an anti-TIM3 antibody or an anti-TIM3-binding fragment thereof.

In a preferred embodiment of the collection of expression vectors of the seventh aspect each expression vector of the collection is independently selected from the group consisting of
15 a plasmid; a cosmid; an RNA; an RNA-formulated with an adjuvant; an RNA formulated in liposomal particles; a self-amplifying RNA (SAM); a SAM formulated with an adjuvant; a SAM formulated in liposomal particles; a viral vector; preferably an alphavirus vector, a venezuelan equine encephalitis (VEE) virus vector, a sindbis (SIN) virus vector, a semliki forest virus (SFV) virus vector, also preferably a replication competent or incompetent adenoviral
20 vector preferably derived from chimpanzee or bonobo or gorilla, a poxvirus vector, a vaccinia virus vector or a modified vaccinia ankara (MVA) vector, a simian or human cytomegalovirus (CMV) vector, a Lymphocyte choriomeningitis virus (LCMV) vector, a retroviral or lentiviral vector. It is preferred that all expression vectors used in one collection are of the same type, e.g. replication incompetent adenoviral vectors.

25 The most preferred expression vectors are adenoviral vectors, in particular adenoviral vectors derived from human or non-human great apes. Preferred great apes from which the adenoviruses are derived are Chimpanzee (Pan), Gorilla (Gorilla) and orangutans (Pongo), preferably Bonobo (Pan paniscus) and common Chimpanzee (Pan troglodytes). Typically, naturally occurring non-human great ape adenoviruses are isolated from stool samples of the
30 respective great ape. The most preferred vectors are non-replicating adenoviral vectors based on hAd5, hAd11, hAd26, hAd35, hAd49, ChAd3, ChAd4, ChAd5, ChAd6, ChAd7, ChAd8, ChAd9, ChAd10, ChAd11, ChAd16, ChAd17, ChAd19, ChAd20, ChAd22, ChAd24, ChAd26, ChAd30, ChAd31, ChAd37, ChAd38, ChAd44, ChAd55, ChAd63, ChAd73, ChAd82, ChAd83, ChAd146, ChAd147, PanAd1, PanAd2, and PanAd3 vectors or replication-competent

Ad4 and Ad7 vectors. The human adenoviruses hAd4, hAd5, hAd7, hAd11, hAd26, hAd35 and hAd49 are well known in the art. Vectors based on naturally occurring ChAd3, ChAd4, ChAd5, ChAd6, ChAd7, ChAd8, ChAd9, ChAd10, ChAd11, ChAd16, ChAd17, ChAd19, ChAd20, ChAd22, ChAd24, ChAd26, ChAd30, ChAd31, ChAd37, ChAd38, ChAd44, ChAd63 and ChAd82 are described in detail in WO 2005/071093. Vectors based on naturally occurring PanAd1, PanAd2, PanAd3, ChAd55, ChAd73, ChAd83, ChAd146, and ChAd147 are described in detail in WO 2010/086189.

In a particular embodiment, the adenovector is Gad20 (also termed GADNOU20, SEQ ID NO: 1219) or is derived therefrom. In one embodiment, derived therefrom means that the adenovector has at least 85%, and preferably at least 90%, 95%, 96%, 97%, 98% or 99% sequence identity to SEQ ID NO: 1219. In a preferred embodiment, however, it means the following:

The adenovector encodes an adenovirus hexon protein comprising:

- (i) a first hypervariable region HVR1 comprising an amino acid (aa) sequence encoded by nucleotides 19386-19472 of SEQ ID NO: 1219, or a variant thereof having at least 85% aa sequence identity and with no A and preferably with a V at aa position 27,
- (ii) a second hypervariable region HVR2 comprising an aa sequence encoded by nucleotides 19527-19571 of SEQ ID NO: 1219, or a variant thereof having at least 85% aa sequence identity and with no L and preferably with an I at aa position 1,
- (iii) a third hypervariable region HVR3 comprising an aa sequence encoded by nucleotides 19623-19643 of SEQ ID NO: 1219, or a variant thereof having at least 85% aa sequence identity and with no V and preferably with an A at aa position 7,
- (iv) a fourth hypervariable region HVR4 comprising an aa sequence encoded by nucleotides 19737-19772 of SEQ ID NO: 1219, or a variant thereof having at least 85% aa sequence identity,
- (v) a fifth hypervariable region HVR5 comprising an aa sequence encoded by nucleotides 19794-19838 of SEQ ID NO: 1219, or a variant thereof having at least 85% aa sequence identity,
- (vi) a sixth hypervariable region HVR6 comprising an aa sequence encoded by nucleotides 19908-19934 of SEQ ID NO: 1219, or a variant thereof having at least 85% aa sequence identity, and
- (vii) a seventh hypervariable region HVR7 comprising an aa sequence encoded by nucleotides 20259-20336 of SEQ ID NO: 1219, or a variant thereof having at least 85% aa sequence identity with no I and preferably with a V at aa position 1.

In a preferred embodiment, the HVR variants have at least 90%, and more preferably at least 95% sequence identity. Alternative to the definition by a percentage level of sequence identity, the HVR variants can be defined to have a certain number of amino acid mutations compared to the encoded sequence. The number of mutations is then as follows: instead of at least 85% sequence identity, up to 4 mutations in HVR1, up to 2 mutations in HVR2, up to 1 mutation in HVR3, up to 1 mutation in HVR4, up to 2 mutations in HVR5, up to 1 mutations in HVR6, and up to 3 mutations in HVR7; instead of at least 90% sequence identity, up to 2 mutations in HVR1, up to 1 mutation in HVR2, up to 1 mutation and preferably no mutation in HVR3, up to 1 mutation in HVR4, up to 1 mutation in HVR5, up to 1 mutation and preferably no mutation in HVR6, and up to 2 mutations in HVR7; instead of at least 95% sequence identity, up to 1 mutation in HVR1, up to 1 mutation and preferably no mutation in HVR2, up to 1 mutation and preferably no mutation in HVR3, up to 1 mutation and preferably no mutation in HVR4, up to 1 mutation and preferably no mutation in HVR5, up to 1 mutation and preferably no mutation in HVR6, and up to 1 mutation in HVR7.

As known in the art, e.g. from Bradley et al. (J Virol., 2012 Jan;86(2):1267-72), adenovirus neutralizing antibodies target the hexon hypervariable regions, and by replacing the HVR regions of an adenovirus with serumprevalence, that adenovirus can evade the immune system in the immune host. Thus, while the above HVRs can be used with the respective hexon proteins defined below, they have utility independent from those hexon proteins and also from the below penton and fiber proteins, namely by replacing the hexon HVRs in a different adenovirus having other hexon, penton and/or fiber proteins.

In a preferred embodiment, the hexon protein comprises an amino acid sequence encoded by nucleotides 18981-21845 of SEQ ID NO: 1219, or a variant thereof having at least 85% sequence identity,

In a preferred embodiment, the hexon variants have at least 90%, and preferably at least 95%, 96%, 97%, 98% or 99% sequence identity. Alternative to the definition by a percentage level of sequence identity, the hexon variants can be defined to have a certain number of amino acid mutations compared to the encoded sequence. The number of mutations is then as follows: instead of at least 85% sequence identity, up to 143 mutations; instead of at least 90% sequence identity, up to 95 mutations; instead of at least 95% sequence identity, up to 47 mutations; instead of at least 96% sequence identity, up to 38 mutations; instead of at least 97% sequence identity, up to 28 mutations; instead of at least 98% sequence identity, up to 19 mutations; instead of at least 99% sequence identity, up to 9 mutations. It is to be understood that the hexon

variants do not have less sequence identity to or more mutations in their HVRs than defined for the respective HVRs above.

In one embodiment, the adenovector further encodes an adenoviral penton protein comprising an amino acid sequence encoded by nucleotides 14021-15973 of SEQ ID NO: 1219, or a variant thereof having at least 85% sequence identity. In a preferred embodiment, the penton variants have at least 90%, and preferably at least 95%, 96%, 97%, 98% or 99% sequence identity compared to the encoded sequence. Alternative to the definition by a percentage level of sequence identity, the penton variants can be defined to have a certain number of amino acid mutations. The number of mutations is then as follows: instead of at least 85% sequence identity, up to 97 mutations; instead of at least 90% sequence identity, up to 65 mutations; instead of at least 95% sequence identity, up to 32 mutations; instead of at least 96% sequence identity, up to 26 mutations; instead of at least 97% sequence identity, up to 19 mutations; instead of at least 98% sequence identity, up to 13 mutations; instead of at least 99% sequence identity, up to 6 mutations.

Preferably, the penton variants have no D and preferably a G at amino acid position 289 and no D and preferably an N at amino acid position 341.

In another embodiment, the adenovector further (i.e. next to the hexon and possibly the penton protein) encodes an adenoviral fiber protein comprising an amino acid sequence encoded by nucleotides 32163-33956 of SEQ ID NO: 1219, or a variant thereof having at least 85% sequence identity. In a preferred embodiment, the fiber variants have at least 90%, and preferably at least 95%, 96%, 97%, 98% or 99% sequence identity. Alternative to the definition by a percentage level of sequence identity, the fiber variants can be defined to have a certain number of amino acid mutations compared to the encoded sequence. The number of mutations is then as follows: instead of at least 85% sequence identity, up to 89 mutations; instead of at least 90% sequence identity, up to 59 mutations; instead of at least 95% sequence identity, up to 29 mutations; instead of at least 96% sequence identity, up to 23 mutations; instead of at least 97% sequence identity, up to 17 mutations; instead of at least 98% sequence identity, up to 11 mutations; instead of at least 99% sequence identity, up to 5 mutations.

Preferably, the fiber variants have no A and preferably a P at amino acid position 181, no V and preferably an I at amino acid position 474, and/or no insertion of an S and preferably no amino acid insertion between amino acid positions 4 and 5.

In another embodiment, the adenovector further (i.e. next to the hexon and possibly the penton and/or fiber protein) encodes a VA RNA II non-coding RNA comprising a nucleotide sequence according to nucleotides 10724-10897 of SEQ ID NO: 1219, or a variant of the

nucleotide sequence having at least 85% sequence identity. Alternatively or in addition, it may encode a VA RNA I non-coding RNA comprising a nucleotide sequence according to nucleotides 10492-10659 of SEQ ID NO: 1219, or a variant of the nucleotide sequence having at least 85% sequence identity. In a preferred embodiment, the VA RNA variants have at least
5 90%, and preferably at least 95%, 96%, 97%, 98% or 99% sequence identity. Alternative to the definition by a percentage level of sequence identity, the VA RNA variants can be defined to have a certain number of nucleotide mutations. The number of mutations is then as follows: instead of at least 85% sequence identity, up to 25 mutations in VA RNA I and up to 26 mutations in VA RNA II; instead of at least 90% sequence identity, up to 16 mutations in VA
10 RNA I and up to 17 mutations in VA RNA II; instead of at least 95% sequence identity, up to 8 mutations in any VA RNA; instead of at least 96% sequence identity, up to 6 mutations in any VA RNA; instead of at least 97% sequence identity, up to 5 mutations in any VA RNA; instead of at least 98% sequence identity, up to 3 mutations in any VA RNA; instead of at least 99% sequence identity, up to 1 mutation in any VA RNA.

15 Preferably, the VA RNA II variant (a) no C at position 79 and/or no A at position 80, and preferably a T at position 79 and/or a G at position 80, and (b) no A at position 81, and preferably a G at position 81. The VA RNA I variant preferably has no G at position 80 and preferably has an A at position 80.

A VA RNA according to the invention leads to an improved adenovirus production.

20 It is preferred that the adenovector further comprises other adenoviral genes and nucleotide segments, which are adjacent to the hexon, penton and/or fiber gene in the adenovirus genome, using SEQ ID NO: 1219 as a reference. It is particularly preferred that the adenovector also comprises sequences required for packaging of the polynucleotide into an adenoviral particle.

25 Generally, it is preferred that the adenovector comprises at least one of the following:

- (a) an adenoviral 5'-end, preferably an adenoviral 5' inverted terminal repeat;
- (b) an adenoviral Ela region, or a fragment thereof selected from among the 13S, 12S and 9S regions;
- (c) an adenoviral Elb region, or a fragment thereof selected from among the group consisting
30 of the small T, large T and IX regions;
- (d) an adenoviral VA RNA region; or a fragment thereof selected from among the group consisting of the VA RNA I and VA RNA II regions;
- (e) an adenoviral E2b region; or a fragment thereof selected from among the group consisting of the small pTP, Polymerase and IVa2 regions;

- (f) an adenoviral L1 region, or a fragment thereof, said fragment encoding an adenoviral protein selected from the group consisting of the 28.1 kD protein, polymerase, agnoprotein, 52/55 kDa protein, and IIIa protein;
- (g) an adenoviral L2 region, or a fragment thereof, said fragment encoding an adenoviral protein selected from the group consisting of the penton protein as defined above, VII, V, and X protein;
- (h) an adenoviral L3 region, or a fragment thereof, said fragment encoding an adenoviral protein selected from the group consisting of the VI protein, hexon protein as defined above, and endoprotease;
- (i) an adenoviral E2a region, or a fragment thereof, said fragment encoding an adenoviral protein consisting of the DBP protein;
- (j) an adenoviral L4 region, or a fragment thereof said fragment encoding an adenoviral protein selected from the group consisting of the 100 kD protein, the 22 kD homolog, the 33 kD homolog, and protein VIII;
- (k) an adenoviral E3 region, or a fragment thereof selected from the group consisting of E3 ORF1, E3 ORF2, E3 ORF3, E3 ORF4, E3 ORF5, E3 ORF6, E3 ORF7, E3 ORF8 and E3 ORF9;
- (l) an adenoviral L5 region, or a fragment thereof said fragment encoding the fiber protein as defined above;
- (m) an adenoviral E4 region, or a fragment thereof selected from the group consisting of E4 ORF6/7, E4 ORF6, E4 ORF5, E4 ORF4, E4 ORF3, E4 ORF2, and E4 ORF1;
- (n) an adenoviral 3'-end, preferably an adenoviral 3' inverted terminal repeat; and /or
- (o) an adenoviral E1 region..

These elements can be from the same adenovirus according to SEQ ID NO: 1219, or from a different adenovirus, in particular from one of a different species, e.g. a human adenovirus, to form a chimeric adenovirus.

In some embodiments of the adenovector it may be desirable that it does not comprise one or more genomic regions as outlined above (as in (a) to (m)). In particular it may not comprise an E1, E3 and/or E4 region, and/or comprises an adenoviral gene which comprises a deletion and/or mutation which renders the at least one gene non-functional. In these preferred embodiments, the suitable adenoviral regions is modified to not include the aforementioned region(s)/gene(s) or to render the selected region(s)/gene(s) non-functional. One possibility to render them non-functional is to introduce one or more artificial stop-codons (e.g. TAA) into the open reading frame of these genes. Methods of rendering the virus replication-defective are

well known in the art (see e.g. Brody et al, 1994 Ann NY Acad Sci., 716: 90-101). A deletion can make space to insert transgenes, preferably within an expression cassette, such as a minigene cassette. Furthermore, deletions can be used to generate adenoviral vectors which are incapable to replicate without the use of a packaging cell line or a helper virus as is well known in the art. Such a recombinant adenovirus comprising comprising one or more of the specified gene/region deletions or loss-of-function mutations can provide a safer recombinant adenovirus for e.g. gene therapy or vaccination.

While the adenovector may not comprise at least one genomic region/gene as outlined herein (such as e.g. region E1, E3 and/or E4), specifically E1A, E1B, E2A, E2B, E3 ORF1, E3 ORF2, E3 ORF3, E3 ORF4, E3 ORF5, E3 ORF6, E3 ORF7, E3 ORF8, E3 ORF9, E4 ORF6/7, E4 ORF6, E4 ORF5, E4 ORF4, E4 ORF3, E4 ORF2 and/or E4 ORF1, preferably E1A, E1B, E2A, E2B, E3 and/or E4, and/or comprises an adenoviral gene which comprises a deletion and/or mutation which renders the at least one gene non-functional, it is desirable to retain an intact E1a and/or E1b region. Such an intact E1 region may be located in its native location in the adenoviral genome or placed in the site of a deletion in the native adenoviral genome (e.g., in the E3 region).

In a preferred embodiment, the adenovector further encodes one or more, preferably all of the following adenoviral proteins: protein VI, protein VIII, protein IX, protein IIIa and protein IVa2.

An average person skilled in the art of adenoviruses is well aware of how to determine the open reading frames that encode for the above-specified adenoviral proteins. He is also aware of the structure of adenoviral genomes and can map, without undue burden, the individual adenoviral regions and ORFs outlined herein to any adenoviral genome.

The term "hexon protein" refers to the hexon (II) protein comprised in an adenovirus. A hexon protein or a variant thereof according to the invention has the same function as a hexon protein or a fragment thereof in an infectious adenovirus virion. Thus, an adenovirus comprising said hexon or variant thereof preferably as a capsid protein is capable of entering a host cell. A suitable method for generating variants of a hexon protein is described in US Patent 5,922,315. In this method, at least one loop region of the adenovirus hexon is changed with at least one loop region of another adenovirus serotype. It can be easily determined if a recombinant adenovirus can enter a host cell. For example, after contacting a host cell with the adenovirus, the recombinant host cell can be washed and lysed and it can be determined whether adenoviral RNA and/or DNA is found in the host cell using, e.g. an appropriate hybridization probe specific for adenoviral RNA and/or DNA. Alternatively or additionally, the host cell after

having been brought into contact with the recombinant adenovirus may be washed, lysed and probed with adenovirus specific antibodies, e.g. using a Western blot. In yet another alternative, it is observed, e.g. *in vivo*, whether the host cell expresses a gene product, for example a fluorescent protein upon infection with a recombinant adenovirus that comprises a suitable expression cassette to express the gene product in the host cell.

The term “hypervariable region” (HVR) refers to domains with high sequence variation between strains, located at the solvent-exposed surface of the hexon protein, so exposed on the outside of the viral capsid. They are major determinants of neutralizing antibodies. HVRs can be identified, for example, by sequence alignment with other hexon proteins.

By “adenoviral penton protein” is meant the penton base (III) protein comprised in an adenovirus. An adenoviral penton protein is characterized in that it localizes to the corners of the icosahedral symmetry of the capsid. A penton protein or a variant thereof according to the invention has the same function as a penton protein in an infectious adenovirus virion. Thus, an adenovirus comprising said penton or variant thereof preferably as a capsid protein is capable of entering a host cell, which can be tested as described above. Further, a functional penton has an affinity to an adenoviral fiber protein. The average skilled person is well aware of how to test protein-protein affinities. To determine if a first protein is capable of binding a second protein, he may use, for example, a genetic yeast two-hybrid assay or a biochemical assay such as a pull-down, an enzyme-linked immunosorbent assay (ELISA), a fluorescence-activated cell sorting (FACS)-based assay or a Plasmon resonance assay. When using pull-down or Plasmon resonance assays, it is useful to fuse at least one of the proteins to an affinity tag such as HIS-tag, GST-tag or other, as is well known in the art of biochemistry.

The term “fiber protein” refers to the knobbed fiber (IV) protein comprised in an adenovirus. A fiber protein or a variant thereof according to the invention has the same function as a fiber protein or a fragment thereof in an infectious adenovirus virion. Thus, an adenovirus comprising said fiber or fiber variant preferably as a capsid protein is capable of entering a host cell, which can be tested as described above. Further, a functional fibre protein has an affinity to an adenoviral penton protein. Also, a functional adenoviral fiber protein in its glycosylated form is capable of trimerizing. Thus, it is also preferred that the variant is capable of being glycosylated and/or of forming a trimer. Affinity, including trimerization, can be tested as described above, and glycosylation assays are also well-known in the art.

The “VA (viral associated) RNA” is a type of non-coding found in adenovirus. It plays a role in regulating translation. There are two copies of this RNA called VAI or VA RNA I and VAII or VA RNA II. The two VA RNA genes are distinct genes in the adenovirus genome. VA

RNA I is the major species with VA RN AII expressed at a lower level. Neither transcript is polyadenylated and both are transcribed by PolIII.

The term "identity" or "identical" in the context of polynucleotide, polypeptide or protein sequences refers to the number of residues in the two sequences that are identical when aligned for maximum correspondence. Specifically, the percent sequence identity of two sequences, whether nucleic acid or amino acid sequences, is the number of exact matches between two aligned sequences divided by the length of the shorter sequence and multiplied by 100. Alignment tools that can be used to align two sequences are well known to the person skilled in the art and can, for example, be obtained on the World Wide Web, e.g., Clustal Omega (<http://www.ebi.ac.uk/Tools/msa/clustalo/>) for polypeptide alignments or MUSCLE (<http://www.ebi.ac.uk/Tools/msa/muscle/>) or MAFFT (<http://www.ebi.ac.uk/Tools/msa/mafft/>) for polynucleotide alignments or WATER (http://www.ebi.ac.uk/Tools/psa/emboss_water/) for polynucleotide and polypeptide alignments. The alignments between two sequences may be carried out using default parameters settings, e.g. for MAFFT preferably: Matrix: Blosum62, Gap Open 1.53, Gap Extend 0.123, for WATER polynucleotides preferably: MATRIX: DNAFULL, Gap Open: 10.0, Gap Extend 0.5 and for WATER polypeptides preferably MATRIX: BLOSUM62, Gap Open: 10.0, Gap Extend: 0.5. Those skilled in the art understand that it may be necessary to introduce gaps in either sequence to produce a satisfactory alignment. The "best sequence alignment" is defined as the alignment that produces the largest number of aligned identical residues while having a minimal number of gaps. Preferably, it is a global alignment, which includes every residue in every sequence in the alignment.

The term "variant" refers, with respect to a polypeptide, generally to a modified version of the polypeptide, e.g. a mutation, so one or more amino acids of the polypeptide may be deleted, inserted, modified and/or substituted. Generally, the variant is functional, meaning that an adenovirus comprising the functional variant is capable of infecting a host cell. More specific functions are defined herein and have precedence over the general definition. A "mutation" or "amino acid mutation" can be an amino acid substitution, deletion and/or insertion ("and" may apply if there is more than one mutation). Preferably, it is a substitution (i.e. a conservative or non-conservative amino acid substitution), more preferably a conservative amino acid substitution. In some embodiments, a substitution also includes the exchange of a naturally occurring amino acid with a not naturally occurring amino acid. A conservative substitution comprises the substitution of an amino acid with another amino acid having a chemical property

similar to the amino acid that is substituted. Preferably, the conservative substitution is a substitution selected from the group consisting of:

- (i) a substitution of a basic amino acid with another, different basic amino acid;
- (ii) a substitution of an acidic amino acid with another, different acidic amino acid;
- 5 (iii) a substitution of an aromatic amino acid with another, different aromatic amino acid;
- (iv) a substitution of a non-polar, aliphatic amino acid with another, different non-polar, aliphatic amino acid; and
- (v) a substitution of a polar, uncharged amino acid with another, different polar, uncharged amino acid.

10 A basic amino acid is preferably selected from the group consisting of arginine, histidine, and lysine. An acidic amino acid is preferably aspartate or glutamate. An aromatic amino acid is preferably selected from the group consisting of phenylalanine, tyrosine and tryptophane. A non-polar, aliphatic amino acid is preferably selected from the group consisting of glycine, alanine, valine, leucine, methionine and isoleucine. A polar, uncharged amino acid is preferably
15 selected from the group consisting of serine, threonine, cysteine, proline, asparagine and glutamine. In contrast to a conservative amino acid substitution, a non-conservative amino acid substitution is the exchange of one amino acid with any amino acid that does not fall under the above-outlined conservative substitutions (i) through (v).

Means for determining sequence identity are described above.

20 Amino acids of a protein may also be modified, e.g. chemically modified. For example, the side chain or a free amino or carboxy-terminus of an amino acid of the protein or polypeptide may be modified by e.g. glycosylation, amidation, phosphorylation, ubiquitination, etc. The chemical modification can also take place *in vivo*, e.g. in a host-cell, as is well known in the art. For example, a suitable chemical modification motif, e.g. glycosylation sequence motif present
25 in the amino acid sequence of the protein will cause the protein to be glycosylated. Unless a modification leads to a change in identity of a modified amino acid (e.g. a substitution or deletion), a modified polypeptide is within the scope of polypeptide as mentioned, i.e. it is not a variant as defined herein.

The term “variant” refers, with respect to a polynucleotide, generally to a modified
30 version of the polynucleotide, e.g. a mutation, so one or more nucleotides of the polynucleotide may be deleted, inserted, modified and/or substituted. Generally, the variant is functional, meaning that an adenovirus comprising the functional variant is capable of infecting a host cell. More specific functions are defined herein and have precedence over the general definition. A “mutation” can be a nucleotide substitution, deletion and/or insertion (“and” may apply if there

is more than one mutation). Preferably, it is a substitution, more preferably it causes an amino acid substitution, most preferably a conservative amino acid substitution.

Generally, it is preferred that all expression vectors of the collection of expression vectors, i.e. the collection of expression vectors comprising nucleic acids encoding all FSPs, mFSP and antigenic fragments thereof of the respective CVP are of one type, e.g. a replication competent adenovirus. In the embodiment of the invention in which different layouts of the same CVP or nucleic acids encoding this are used, each layout will be comprised in a separate collection of expression vectors. Thus, each layout may be comprised in the same expression vector or in different expression vectors. The latter is preferred in those instances in which the expression vector itself is antigenic in the patient. Thus, the change of the type of expression vector between two or more repeat administrations of the same CVP, preferably in different layouts increase the chance that the CVP is expressed in the patient.

The present invention also relates to a CVP of the fourth or fifth aspect of the present invention, a collection of nucleic acids of the fourth or sixth aspect of the present invention, or an expression vector collection of the seventh aspect of the present invention, for use in medicine.

The present invention also relates to pharmaceutical composition comprising a CVP of the fourth or fifth aspect of the present invention, a collection of nucleic acids of the fourth or sixth aspect of the present invention, or an expression vector collection of the seventh aspect of the present invention.

In case that different layouts of the same CVP, of nucleic acids encoding such different layouts of the same CVP or expression vectors comprising such nucleic acids with different layouts are used in a homologous or heterologous prime-boost administration regimen (see below) the term “pharmaceutical composition” also covers two physically separated compositions that allow separate administration of the same CVP, of nucleic acids encoding such different layouts of the same CVP or expression vectors comprising such nucleic acids with different layouts.

In preferred embodiments the pharmaceutical composition further comprises a pharmaceutically acceptable carrier and/or excipient and optionally one or more additional active substances. Preferably, the composition of the fifth aspect contains a therapeutically effective amount of the compound, preferably in purified form, together with a suitable amount of carrier and/or excipient so as to provide the form for proper administration to the patient. The formulation should suit the mode of administration.

The pharmaceutical compositions can take the form of solutions, suspensions, emulsion, tablets, pills, capsules, powders, sustained-release formulations and the like. The pharmaceutical composition can be formulated as a suppository, with traditional binders and carriers such as triglycerides.

5 For preparing pharmaceutical compositions of the present invention, pharmaceutically acceptable carriers can be either solid or liquid. Solid form compositions include powders, tablets, pills, capsules, lozenges, cachets, suppositories, and dispersible granules. A solid excipient can be one or more substances, which may also act as diluents, flavouring agents, binders, preservatives, tablet disintegrating agents, or an encapsulating material. In powders, 10 the excipient is preferably a finely divided solid, which is in a mixture with the finely divided inhibitor of the present invention. In tablets, the active ingredient is mixed with the carrier having the necessary binding properties in suitable proportions and compacted in the shape and size desired. Suitable excipients are magnesium carbonate, magnesium stearate, talc, sugar, lactose, pectin, dextrin, starch, gelatin, tragacanth, methylcellulose, sodium 15 carboxymethylcellulose, a low melting wax, cocoa butter, and the like. For preparing suppositories, a low melting wax, such as a mixture of fatty acid glycerides or cocoa butter, is first melted and the active component is dispersed homogeneously therein, as by stirring. The molten homogeneous mixture is then poured into convenient sized moulds, allowed to cool, and thereby to solidify. Tablets, powders, capsules, pills, cachets, and lozenges can be used as 20 solid dosage forms suitable for oral administration.

Liquid form compositions include solutions, suspensions, and emulsions, for example, water, saline solutions, aqueous dextrose, glycerol solutions or water/propylene glycol solutions. For parenteral injections (e.g. intravenous, intraarterial, intraosseous infusion, intramuscular, subcutaneous, intraperitoneal, intradermal, and intrathecal injections), liquid 25 preparations can be formulated in solution in, e.g. aqueous polyethylene glycol solution. A saline solution is a preferred carrier when the pharmaceutical composition is administered intravenously.

Preferably, the pharmaceutical composition is in unit dosage form. In such form the composition may be subdivided into unit doses containing appropriate quantities of the active 30 component. The unit dosage form can be a packaged composition, the package containing discrete quantities of the composition, such as packaged tablets, capsules, and powders in vials or ampoules. Also, the unit dosage form can be a capsule, an injection vial, a tablet, a cachet, or a lozenge itself, or it can be the appropriate number of any of these in packaged form.

The composition, if desired, can also contain minor amounts of wetting or emulsifying agents, or pH buffering agents.

Furthermore, such pharmaceutical composition may also comprise other pharmacologically active substance such as but not limited to adjuvants and/or additional active ingredients. Adjuvants in the context of the present invention include but are not limited to
5 inorganic adjuvants, organic adjuvants, oil-based adjuvants, cytokines, particulate adjuvants, virosomes, bacterial adjuvants, synthetic adjuvants, or synthetic polynucleotides adjuvants.

In an eighth aspect, the present invention relates to a CVP of the fourth or fifth aspect of the present invention, a collection of nucleic acids of the fourth or sixth aspect of the present
10 invention, or an expression vector collection of the seventh aspect of the present invention, for use in prophylaxis or treatment of a patient with a cancer comprising cancer cells with an MSI phenotype or being at risk of developing such cancer, wherein the cancer is preferably selected from the group consisting of colorectal colorectal cancer, gastric cancer, endometrial cancer, small intestine cancer, hepatobiliary tract cancer, liver cancer, neuroendocrine cancers, cervical
15 cancer, ovarian cancer, uterine sarcomas, brain cancer and skin cancer

As outlined above one particular advantage of the universal vaccine of the present invention is the fact that it provides prophylaxis or therapy of more than just one cancer type. Accordingly, it is preferred according to the eighth aspect to provide prophylaxis or therapy for at least two types of MSI cancers, more preferably at least three types of MSI cancers. Preferably,
20 colorectal cancer, gastric cancer, endometrial cancer, small intestine cancer, hepatobiliary tract cancer, liver cancer, neuroendocrine cancers, cervical cancer, ovarian cancer, uterine sarcomas, brain cancer and skin cancer.

Prophylaxis is in the context of the present invention preferably for patients known to be at risk of developing MSI cancers according to clinical guidelines, including patients with
25 germline mutations in genes involved in the mismatch repair system (MMR) such as MLH-1, MSH-2, MSH-6, PMS2 and TACSTD1/EPCAM. Treatment is for patients with cancers at all stages (I-IV), arising in any tissue after diagnosis of MSI status according to most recent clinical guidelines. The use of such vaccine is intended for treatment of cancers with an MSI status that can be either spontaneous or pharmacologically induced.

30 In many cases, a single administration of the CVP is not sufficient to generate the number of long-lasting immune cells which is required for effective protection against tumor diseases or for therapeutically treating a tumor disease. Consequently, repeated challenge with a biological preparation specific for a specific disease is required in order to establish lasting and protective immunity against said disease or to cure a given disease. An administration regimen

comprising the repeated administration of a CVP, the collection of nucleic acids encoding such CVP or a collection of expression vectors comprising such nucleic acid is referred to in the present as “prime-boost vaccination regimen”. Preferably, a prime-boost vaccination regimen involves at least two administrations of a CVP, the collection of nucleic acids encoding such CVP or a collection of expression vectors comprising such nucleic acid. The first administration of the CVP, the collection of nucleic acids encoding such CVP or a collection of expression vectors comprising such nucleic acid is referred to as “priming” and any subsequent administration of the same CVP, the collection of nucleic acids encoding such CVP or a collection of expression vectors comprising such nucleic acid is referred to as “boosting”. It is understood from above explanation that the same CVP may nevertheless be administered in different layouts in each subsequent administrations of the CVP, the collection of nucleic acids encoding such CVP or a collection of expression vectors comprising such nucleic acid.

Thus, in a preferred embodiment of the present invention the prime-boosting vaccination regimen involves one administration of the CVP, the collection of nucleic acids encoding such CVP or a collection of expression vectors comprising such nucleic acid for priming the immune response and at least one subsequent administration for boosting the immune response. It is to be understood that 2, 3, 4 or even 5 administrations for boosting the immune response are also contemplated by the present invention.

The period of time between prime and boost is, preferably, 1 week, 2 weeks, 4 weeks, 6 weeks or 8 weeks. More preferably, it is 4 weeks or 8 weeks. If more than one boost is performed, the subsequent boost is, preferably, administered 1 week, 2 weeks, 4 weeks, 6 weeks or 8 weeks after the preceding boost. More preferably, the interval between any two boosts is 4 weeks or 8 weeks.

The prime-boost vaccination regimens of the present invention may be homologous or heterologous. In homologous prime-boost regimens both the priming and the at least one boosting is performed using the same means of administration of the CVP, the collection of nucleic acids encoding such CVP or a collection of expression vectors comprising such nucleic acid. In heterologous prime-boosting regimens a different means for priming and for boosting the immune response are used. In the context of the present invention, a heterologous prime-boosting regimen could, e.g. comprise a poxviral vector for the priming of an immune response and a different expression vector or the CPV for the boosting of the immune response.

In one preferred embodiment of the present invention the prime-boosting vaccination regimen is homologous and in another preferred embodiment of the present invention the prime-boosting vaccination regimen is heterologous.

Accordingly, in one aspect the present invention relates to a collection of nucleic acids of the fourth or sixth aspect of the present invention and/or a expression vector collection of the seventh aspect of the present invention for use in prophylaxis or treatment of a patient with a cancer comprising cancer cells with an MSI phenotype or being at risk of developing such cancer, wherein the collection of nucleic acids and/or the expression vector collection is
5 administered in a heterologous prime-boost vaccination scheme, preferably the prime is with an adenovirus vector and the one or more boosts with a poxviral vector, preferably an MVA vector.

10

EXAMPLES

EXAMPLE 1: SELECTION OF MONONUCLEOTIDE REPEAT (MNR) MUTATIONS IN PROTEIN-CODING GENES OF MSI TUMOR SAMPLES

Mutation Annotation Format (MAF) files based on whole exome sequence data (release date 4.0-October 31 2016) and available from the TCGA data portal (<https://gdc-portal.nci.nih.gov/>) were analyzed for the presence of frameshift mutations (FSM) in MNRs
15 equal or longer than 6 nucleotides located within protein-coding segments of exomes of protein-coding genes. Only tumors with a MSI phenotype as defined in the TCGA sample annotation data were considered in the analysis. This group comprised a total 320 tumor and matched normal control samples, corresponding to 69 MSI-high (MSI-H) colorectal (CRC), 85 MSI
20 gastric and 166 MSI endometrial (EC) cancers. In a second filtering step, only FSMs derived from a 1 nucleotide deletion were accepted, as this type of FSM is the most frequently observed in CRC and EC tumors (1). The resulting list was further refined by accepting only those FSMs fulfilling the following criteria: (i) the number of reads harboring the mutation was significantly higher in the tumor compared to the matched normal sample (FDR-corrected Fisher-test *p-value*
25 ≤ 0.05); (ii) the allele frequency of the FSM in the matched normal sample was $\leq 25\%$. The remaining FSMs were filtered further by retaining only those FSMs that were present in at least 5% of tumor samples in one of the three analyzed tumor types (CRC, gastric, EC). In a final selection step, FSMs that fell in the following categories were excluded because deemed inappropriate for a vaccine: (i) presence of the FSM in $\geq 2\%$ of samples from a collection of
30 normal samples (EXAC database <http://exac.broadinstitute.org/>) and/or (ii) the mRNA expression (RSEM $\log_2$ expression value) of the FSM-carrying gene was within the lower 20 percentile value of all expressed protein-coding genes (TCGA gene-level mRNA expression data) considering all three tumor types (CRC, EC and gastric). The list thus obtained comprised 1283 FSMs and represents the CFSM for these tumors.

EXAMPLE 2: SELECTION OF A LIST OF FRAMESHIFT PEPTIDES WITH ACCEPTABLE PROPERTIES

Each of the FSMs of the CFSM selected in Example 1 was then mapped onto the corresponding mRNA sequence (or sequences) from the NCBI REFSEQ database using ANNOVAR (Wang K, et al. (2010) NAR, 38:e164) and both the wild-type (wt) and the resulting mutated mRNA were translated into proteins. Comparison of the wt and mutated protein sequences allowed determining the amino acid (*aa*) sequence of the corresponding frame shift peptide (FSP). When an FSM generated multiple FSPs with different length and/or *aa* sequence due to the presence of multiple mRNA isoforms, all resulting FSPs were retained. The resulting list was filtered to exclude all FSPs shorter than 4 *aa* in that unable to yield potential CD8 T neo-epitopes.

Furthermore, the amino acid sequence of FSPs to be included in the CVP was modified by the addition or deletion of amino acids (or a FSP that did not fulfill certain criteria was excluded from after modification), if they fulfilled certain criteria: (i) if the FSP is shorter than 10 *aa*, 4 wt *aa* naturally occurring immediately N-terminally of the amino acid encoded by the FC is added to the N-terminus of the FSP to ensure the peptide (which is referred to as mFSP since it differs from the FSP as defined in the context of the present invention to be the complete translation product of the protein-encoding segment of a nucleic acid comprising a FSM starting from the codon encoding the first amino acid that is different relative to the translation product of the corresponding wild type (wt) nucleic acid without the FSM) that reached the minimum length of a putative CD8 T cell neo-epitope (8-10mer). Amino acid stretches shared between multiple FSPs deriving from the same FSM were only retained in the longest FSP, i.e. in the shorter FSPs these amino acid stretches were deleted. In a final step, any segment of 8 or more continuous amino acids also present in the wt human proteome (NCBI REFSEQ database) was removed from the FSPs to minimize the risk of inducing autoimmunity. If, after exclusion of the wt segment, the resulting FSP was shorter than 4 *aa*, it was removed from the list. The final group of FSPs thus obtained comprises of 1087 amino acid sequences (SEQ ID NO: 1 to 1087) encoded by 1059 FSMs (Table 1) and is referred to as CVP.

Table 1

For each of the 1087 FSPs, the SEQ ID NO is reported together with the genomic coordinates (hg19 assembly) of the FSM generating the FSP.

SEQ ID NO	Genomic Coordinate FSM	SEQ ID NO	Genomic Coordinate FSM	SEQ ID NO	Genomic Coordinate FSM	SEQ ID NO	Genomic Coordinate FSM
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1	chr18:34205516	273	chr1:85331665	545	chr8:144621235	817	chr12:117615412
2	chr18:34205516	274	chr2:170665008	546	chr7:42005573	818	chr17:73814802
3	chr1:6257785	275	chr6:33178990	547	chr16:72991758	819	chr1:12052736
4	chr2:148683686	276	chr12:51392999	548	chr12:54645832	820	chr11:65653077
5	chr17:56435161	277	chr4:56765965	549	chr6:4031881	821	chrX:131762582
6	chr3:51417604	278	chr16:58589340	550	chr1:1961598	822	chr12:57921002
7	chr5:79970915	279	chr11:6662142	551	chr13:114523858	823	chr20:36627613
8	chr18:57013194	280	chr15:28200305	552	chr10:52005194	824	chr11:970195
9	chr5:145647320	281	chrX:10188763	553	chr11:45948373	825	chr6:30157254
10	chr11:77784147	282	chr4:118005517	554	chr19:58084579	826	chr1:230798959
11	chr13:115057211	283	chr2:24086326	555	chr1:52305912	827	chr12:12814274
12	chr11:126137087	284	chr19:19906351	556	chr1:52305912	828	chr10:129913974
13	chr2:165551296	285	chr2:152112048	557	chr2:204305619	829	chr9:124536637
14	chr6:80751897	286	chr5:131944382	558	chr7:107395909	830	chr11:104874011
15	chr7:151874148	287	chr11:119213688	559	chr13:46543661	831	chr5:1074698
16	chr12:122242658	288	chr19:38028415	560	chr1:110300580	832	chr15:72190580
17	chr6:108214755	289	chr5:57753012	561	chr12:8281937	833	chr17:38552642
18	chr19:49850473	290	chr12:49443667	562	chr16:4944500	834	chr1:35370731
19	chr7:77423460	291	chr16:15131990	563	chr15:86287017	835	chr9:135277388
20	chr8:103289349	292	chr8:22472975	564	chr4:142143532	836	chr15:75499804
21	chr3:100039736	293	chrX:56591874	565	chr12:56559113	837	chr3:54596940
22	chr1:27621108	294	chr20:18287008	566	chr12:110344435	838	chr9:125861042
23	chr3:136573486	295	chr20:18287008	567	chr5:127610311	839	chr8:92352747
24	chr1:14108749	296	chr20:18287008	568	chr10:127697969	840	chr11:111896977
25	chr14:24040436	297	chr1:1116223	569	chr12:88512305	841	chr2:160604680
26	chr16:10867203	298	chr22:46931227	570	chr3:142030643	842	chr11:111904183
27	chr12:64812755	299	chr12:95650969	571	chr7:94174999	843	chr18:265348
28	chr17:48433967	300	chr2:240002823	572	chr19:33167776	844	chr18:45566519
29	chr1:231131567	301	chr2:175213713	573	chr9:33385690	845	chr2:225738848
30	chr6:71508370	302	chr3:195595229	574	chr14:94088050	846	chr4:129869675
31	chr19:49458971	303	chr12:57572242	575	chr2:211018375	847	chr9:139945517
32	chr10:78729786	304	chr4:3432431	576	chr14:27066542	848	chr3:121573659
33	chr11:62649529	305	chr12:27950769	577	chr10:89717770	849	chr9:35091693
34	chr1:160589601	306	chr6:107391602	578	chr2:203168133	850	chr4:122723894
35	chr3:114058003	307	chr1:16462199	579	chr12:123351892	851	chr15:57489984
36	chr3:20216050	308	chr3:169700664	580	chr1:36636626	852	chr19:50333113
37	chr10:70182521	309	chr14:93761193	581	chr4:140291445	853	chr11:6292451
38	chr9:96422612	310	chr19:6477251	582	chr13:100925452	854	chr15:49309051
39	chr5:140049102	311	chr14:52481919	583	chr13:79918807	855	chr7:140482927
40	chr3:183665257	312	chr6:109850222	584	chr16:28909714	856	chr7:126173278
41	chr5:145886723	313	chr9:138379043	585	chr4:113570754	857	chr3:182987674
42	chr15:79750586	314	chr6:13206135	586	chr5:98206409	858	chr2:190626331
43	chr1:45407182	315	chr2:196866535	587	chr12:63541343	859	chr8:145150876
44	chr4:3430399	316	chr1:27876869	588	chr2:113060881	860	chr2:16082314
45	chr1:28785730	317	chr1:247319909	589	chr1:200822549	861	chr8:113241029
46	chr11:118220583	318	chr3:50099450	590	chr12:970297	862	chr12:7310658
47	chr2:203922058	319	chr18:29453418	591	chr20:23065992	863	chr9:98209617
48	chrX:37312611	320	chr22:43213780	592	chr3:142142409	864	chr17:46135788
49	chr10:111893350	321	chr11:58962827	593	chr11:134048586	865	chr14:74967607
50	chr10:93601946	322	chr4:153864507	594	chr3:126735391	866	chr17:7496122

51	chr1:155308000	323	chr2:86831015	595	chr6:161469776	867	chr16:1270496
52	chr6:131481276	324	chr12:57883053	596	chr1:52991780	868	chr3:169802469
53	chr1:23240246	325	chr17:73498973	597	chr20:56735727	869	chr7:47955186
54	chr6:139097330	326	chr4:164428219	598	chr2:220504282	870	chr6:34839369
55	chr2:207174428	327	chr2:197649614	599	chr2:58373509	871	chr12:72038781
56	chr15:56736723	328	chr19:38899416	600	chr2:242179467	872	chr7:86978480
57	chr21:38524243	329	chr2:1652960	601	chr9:35547974	873	chr7:86978480
58	chr2:203420130	330	chr17:16285785	602	chr14:35331423	874	chr13:60582734
59	chr10:890939	331	chr16:77356311	603	chr2:219529514	875	chr6:90415853
60	chr5:131931452	332	chr14:102718303	604	chr3:176769342	876	chr6:111498763
61	chr14:45693722	333	chr4:170428203	605	chr4:156273869	877	chr5:125939712
62	chr20:49508204	334	chr12:58025103	606	chr2:20200211	878	chr22:32794006
63	chr1:65306997	335	chr14:31074772	607	chr4:76891521	879	chr19:38102620
64	chr2:165365288	336	chr21:33949091	608	chr4:68530907	880	chr20:47989891
65	chr11:77920856	337	chr16:66599895	609	chr20:5924808	881	chr7:100028068
66	chr17:57247171	338	chr4:170613460	610	chr2:103334978	882	chr1:53543377
67	chr6:158508009	339	chr4:170613460	611	chr13:95735432	883	chr3:150289746
68	chr3:142274740	340	chr1:36935323	612	chr19:5590343	884	chr17:54921519
69	chr1:91967357	341	chr3:15084406	613	chr1:155448996	885	chr5:137803132
70	chr16:19725706	342	chr7:158704353	614	chr6:36181729	886	chr11:69063724
71	chr1:74575213	343	chr17:28505167	615	chr2:88327536	887	chr2:42488302
72	chr2:178988920	344	chr7:115594657	616	chr5:37226878	888	chr12:122018740
73	chr8:124384893	345	chr18:10741064	617	chr8:27364393	889	chr14:104642560
74	chr1:27105931	346	chr2:99778781	618	chr16:50825519	890	chr15:23890894
75	chr12:57422573	347	chr13:114542718	619	chr4:83827648	891	chr17:56448298
76	chr3:157081227	348	chr12:31448178	620	chr10:18834895	892	chr16:15131931
77	chr17:49077041	349	chr7:91603085	621	chrX:41089035	893	chr2:43452512
78	chr17:49077041	350	chr5:35874637	622	chr3:113380090	894	chr12:7173239
79	chr17:42756253	351	chr6:80720630	623	chr1:207642044	895	chr2:149447829
80	chr21:16338330	352	chr17:7751137	624	chr17:17119709	896	chr12:80201042
81	chr17:20108263	353	chr20:45875072	625	chr6:84896233	897	chr12:80201042
82	chr9:35059647	354	chr8:67488453	626	chr18:67697249	898	chr12:104476535
83	chr1:93667516	355	chr15:62244050	627	chr7:100285170	899	chr17:4837373
84	chr15:64967247	356	chr3:48465485	628	chr18:21745097	900	chr7:107763584
85	chr1:204228411	357	chr4:2242634	629	chr6:30572795	901	chr7:139833448
86	chr17:7798765	358	chr4:107156505	630	chr9:109689491	902	chr12:77449827
87	chr6:163899920	359	chr11:61539013	631	chr4:95173910	903	chr6:112389434
88	chr13:50235209	360	chr2:152320541	632	chr19:13882968	904	chr8:90967512
89	chrX:129190011	361	chr2:201683505	633	chr10:124758127	905	chr10:27322259
90	chr5:64023941	362	chr2:201683505	634	chr13:103381996	906	chr2:55138130
91	chr2:74687410	363	chr1:65339111	635	chr16:709106	907	chr16:74976691
92	chr7:100802405	364	chr7:92760738	636	chr22:41257115	908	chr15:49036443
93	chr7:8198251	365	chr13:95696016	637	chr12:40713870	909	chr21:34799292
94	chr15:42742957	366	chr10:13151192	638	chr13:23914687	910	chrX:63412648
95	chr10:98336475	367	chr11:125505378	639	chr15:44843099	911	chr12:19514518
96	chr9:115806416	368	chr10:115662308	640	chr7:29070262	912	chr3:160143940
97	chr1:89473442	369	chr1:68171151	641	chr8:124707762	913	chr12:131283100
98	chr17:55028016	370	chr1:155152179	642	chr13:114514859	914	chr12:131283100
99	chr1:240072444	371	chr16:88504203	643	chr1:35365852	915	chr2:220502413
100	chr7:108205526	372	chr1:19467923	644	chr9:35043650	916	chr15:55759242

101	chr5:35705894	373	chr9:37357250	645	chr17:46629737	917	chr10:91359120
102	chr1:109560141	374	chr16:88691141	646	chr2:227661664	918	chr2:236649677
103	chr17:4875738	375	chr11:32637520	647	chr14:89878534	919	chr16:31151942
104	chr1:35846960	376	chr17:63532585	648	chr3:168833257	920	chr10:135111566
105	chr19:1430254	377	chr2:210887680	649	chr8:6289099	921	chr10:96352051
106	chr19:48197891	378	chr3:57276921	650	chr8:105509429	922	chr4:87769943
107	chr1:237969494	379	chr13:32954023	651	chr7:120971879	923	chr1:215793922
108	chr3:122433232	380	chr16:9857380	652	chr7:2641075	924	chr15:53908071
109	chr10:90682146	381	chr16:30007665	653	chr5:140857742	925	chr15:34444996
110	chr1:24078404	382	chr5:72264329	654	chr11:34910341	926	chr7:104746985
111	chr16:4862229	383	chr9:131019390	655	chr12:4719362	927	chr16:11141159
112	chr21:34882122	384	chr5:43173517	656	chr2:132021078	928	chr19:5667115
113	chr10:64159513	385	chr12:102108338	657	chr8:70514026	929	chrX:53112052
114	chrX:13764946	386	chr17:67218780	658	chr17:25975972	930	chr17:28296061
115	chr5:147499875	387	chr2:201437004	659	chr12:124848228	931	chr1:35578941
116	chr5:147499875	388	chr16:3817721	660	chr12:124848228	932	chr9:114695180
117	chr5:147499875	389	chr4:40144449	661	chr1:228559450	933	chr1:214830653
118	chr11:71948748	390	chr15:59186310	662	chr12:110019240	934	chr7:25200833
119	chr2:172549339	391	chr7:150656679	663	chr9:90321802	935	chr8:86114461
120	chr2:37454908	392	chr6:74351590	664	chr19:42838298	936	chr1:231487256
121	chr5:36985083	393	chr19:18887993	665	chr10:64952699	937	chr12:99071207
122	chrX:154157686	394	chr12:56347514	666	chr15:59376343	938	chrX:99854070
123	chr10:29760116	395	chr5:60822215	667	chr8:144941378	939	chr14:54896992
124	chr3:41860985	396	chr5:140502487	668	chr4:38774956	940	chr11:65314283
125	chr12:416953	397	chr8:133150233	669	chr7:22197474	941	chr11:75905667
126	chr1:156642804	398	chr5:137627690	670	chr2:71650549	942	chrX:21675046
127	chr4:15067858	399	chr1:10177642	671	chr1:91406040	943	chr19:16314384
128	chr15:52901069	400	chr2:71337212	672	chr17:44248731	944	chr19:16314384
129	chr6:90432675	401	chr9:17135271	673	chr7:44120414	945	chr15:101438350
130	chr4:114823494	402	chr11:17352468	674	chr3:141326548	946	chr11:400077
131	chr1:204924033	403	chr16:53263000	675	chr6:116967058	947	chr19:42383610
132	chr2:196788374	404	chr20:37146233	676	chr2:220081103	948	chr19:39663913
133	chr6:36867371	405	chrX:153042691	677	chr20:17581680	949	chr1:149895562
134	chr16:19722724	406	chr3:142775212	678	chr2:128238676	950	chr5:108290522
135	chr7:2968323	407	chr9:115941002	679	chr16:28913640	951	chrX:19560215
136	chr4:15995680	408	chr5:96315249	680	chr19:17039884	952	chr18:31319986
137	chr2:27248517	409	chr14:92472698	681	chr1:153751860	953	chr16:30041821
138	chr11:32635951	410	chr5:109940905	682	chr19:50158042	954	chr5:140953309
139	chr9:5968044	411	chr1:158058203	683	chr6:99849343	955	chr2:169997025
140	chr12:6924043	412	chr19:58264857	684	chr3:42679036	956	chr22:41195058
141	chr5:162917426	413	chr8:124140521	685	chr4:39462464	957	chr22:41195058
142	chr2:71191573	414	chr3:133670083	686	chr18:54358513	958	chr19:36357214
143	chr19:55815036	415	chr9:69421905	687	chr5:61847115	959	chr12:130184705
144	chr13:35733663	416	chr17:7193637	688	chr5:76358967	960	chr8:37728933
145	chr15:81271633	417	chr1:62253580	689	chr9:35108148	961	chr2:26534413
146	chr15:55631503	418	chr17:33749493	690	chr12:20522723	962	chr1:156884483
147	chr1:147091501	419	chr8:70488249	691	chr16:71668442	963	chr11:64032517
148	chr17:26653807	420	chr14:65035126	692	chr11:88068108	964	chr19:52888438
149	chr18:45567076	421	chr1:113471890	693	chr11:88068108	965	chr14:75230947
150	chr11:107325228	422	chr15:91019925	694	chr9:84208132	966	chr2:203848308

151	chr9:136918529	423	chr19:7987519	695	chr1:100588802	967	chr8:32453511
152	chr2:97749725	424	chr6:52334208	696	chr5:38923329	968	chr7:97933623
153	chr1:151318741	425	chr6:90576391	697	chr4:38690460	969	chr2:169948389
154	chr19:50434211	426	chr10:131666125	698	chr5:131007941	970	chr1:206821441
155	chr9:131591120	427	chr3:167507159	699	chr14:75265533	971	chr16:84213651
156	chr12:88524079	428	chr20:40739003	700	chr10:62149221	972	chr7:154782740
157	chr18:46474795	429	chr5:137505021	701	chr3:169557805	973	chr4:153244156
158	chr18:46474795	430	chr16:29818054	702	chr11:35513670	974	chr3:126142183
159	chr3:180666228	431	chr10:116730192	703	chr12:113442830	975	chrX:54497148
160	chr11:16822525	432	chr4:160253755	704	chr14:95662949	976	chr11:118770652
161	chr16:89951020	433	chrX:70327614	705	chr2:219508084	977	chr18:30349862
162	chr20:50400983	434	chr10:116887435	706	chr12:117624320	978	chr12:42706971
163	chr2:103149137	435	chr8:67716612	707	chr8:72958792	979	chr2:196801374
164	chr1:150530506	436	chr15:76958036	708	chr17:38546381	980	chr8:124368685
165	chr11:118969143	437	chr1:226352491	709	chr12:75893593	981	chr13:31480852
166	chr6:160485488	438	chr13:77581683	710	chr1:170004605	982	chr6:18122226
167	chr1:25775375	439	chr14:23745310	711	chr12:122748169	983	chr3:71821968
168	chr11:4703475	440	chr22:38895455	712	chr16:88694459	984	chr4:71844995
169	chr11:75694431	441	chr6:71546674	713	chr6:4052975	985	chr2:159077217
170	chr12:123794283	442	chr11:63313709	714	chr4:128564917	986	chr19:47969003
171	chr6:15496722	443	chr19:5587282	715	chr15:69331226	987	chr22:50277679
172	chr18:21750331	444	chr13:20638677	716	chr4:76539580	988	chr12:88566417
173	chr11:31812317	445	chr15:55912892	717	chr5:13701426	989	chr8:53062482
174	chr3:57509313	446	chr9:138715800	718	chr3:89499363	990	chr10:93247481
175	chr1:40756543	447	chr12:50025258	719	chr2:170493804	991	chr5:13766239
176	chr5:179149920	448	chr10:13696452	720	chr4:170359358	992	chr9:32633025
177	chr13:33344580	449	chr6:87969484	721	chr19:12155504	993	chr11:73021527
178	chr9:18680350	450	chr12:88449444	722	chr22:31485922	994	chr1:178412041
179	chr2:54093345	451	chr10:100186987	723	chr9:140356679	995	chr16:27509009
180	chr13:34398063	452	chr19:4816465	724	chr11:380921	996	chr15:85634360
181	chr5:176675269	453	chr13:103524612	725	chr17:61781804	997	chr16:31373986
182	chr13:27255387	454	chr4:38691476	726	chr17:61781804	998	chr19:35435665
183	chr1:49201967	455	chr2:173368931	727	chr17:61781804	999	chr6:126176317
184	chr11:111953289	456	chr11:124845049	728	chr18:45567085	1000	chr10:32311826
185	chr2:234394237	457	chr16:14346300	729	chr15:28525215	1001	chr6:71235776
186	chr1:100534122	458	chr11:6629392	730	chr19:7976149	1002	chr4:37447379
187	chr2:44145165	459	chr12:57921401	731	chr19:7976149	1003	chr6:45390355
188	chr8:74507471	460	chr15:41029894	732	chr3:33602361	1004	chr2:157185029
189	chr11:71948209	461	chr16:77775744	733	chr11:45955607	1005	chr14:50930796
190	chr20:23066469	462	chr20:31041556	734	chr4:186515044	1006	chr7:91732039
191	chr17:40939870	463	chr14:88940113	735	chr2:176995417	1007	chr4:47939172
192	chr17:76046980	464	chr4:25849258	736	chr7:128852004	1008	chr10:27329038
193	chr9:34257623	465	chr8:95531563	737	chr16:30409310	1009	chr1:229422305
194	chr3:182602674	466	chr20:39990829	738	chr14:75514604	1010	chr6:76423416
195	chr13:53049034	467	chr2:74763924	739	chr10:17363321	1011	chr1:154932028
196	chr5:143853531	468	chr8:24257686	740	chr9:21007046	1012	chr13:108518338
197	chr1:203786225	469	chr19:49218106	741	chr5:154173390	1013	chr9:20912931
198	chr7:91936914	470	chr7:100479332	742	chr8:24167473	1014	chr8:125080031
199	chr13:109661386	471	chr17:80615786	743	chr11:64572093	1015	chr5:14487781
200	chr1:169366580	472	chr17:17046886	744	chr3:194147850	1016	chr1:154942911

201	chr6:101296336	473	chr3:42679486	745	chr4:1980559	1017	chr3:63981832
202	chr7:102584993	474	chr11:94230059	746	chr8:6302639	1018	chr17:4575894
203	chr1:1290110	475	chr19:49982166	747	chr13:73337684	1019	chr12:39734129
204	chr3:77657038	476	chr4:169317264	748	chr14:100594927	1020	chr12:29450110
205	chr7:1037311	477	chr1:149884981	749	chr18:40857246	1021	chr11:66055105
206	chr21:33073336	478	chr17:55028118	750	chr10:103826900	1022	chr11:66055105
207	chr18:12699829	479	chr1:169790867	751	chr14:20846338	1023	chr11:108044069
208	chr19:12430217	480	chr4:39515753	752	chr5:72199545	1024	chr12:6657974
209	chrX:48887952	481	chr17:26449740	753	chr12:49374348	1025	chr5:41181560
210	chr5:130815369	482	chr2:219449364	754	chr16:24942180	1026	chr19:11577605
211	chr11:47196853	483	chr1:237024474	755	chr14:105174185	1027	chr7:44684936
212	chr11:47196853	484	chr19:36223002	756	chr2:203831759	1028	chr1:8716109
213	chr2:148657041	485	chr1:156694023	757	chr1:7998254	1029	chr13:50065970
214	chrX:302052	486	chr11:64004663	758	chr12:57860075	1030	chr5:180432665
215	chr6:80751910	487	chr19:20228702	759	chr19:12384448	1031	chr14:100728644
216	chr8:31001132	488	chr8:68992721	760	chr11:9735070	1032	chr8:145727027
217	chr9:88937823	489	chr18:13746253	761	chr2:10059788	1033	chr7:105655642
218	chr9:88937823	490	chr1:151774033	762	chr17:73491063	1034	chr4:8616156
219	chr1:108700183	491	chr9:103111633	763	chr9:33464082	1035	chr2:110926098
220	chr16:67645339	492	chr9:106885501	764	chr16:71483562	1036	chr11:82877219
221	chr10:70156583	493	chr2:39074185	765	chr17:61497894	1037	chr8:145065718
222	chr11:62381084	494	chr7:99817848	766	chr18:13681751	1038	chr1:55081757
223	chr6:96999786	495	chr12:6711546	767	chr4:2698177	1039	chr19:14593640
224	chr6:31323363	496	chr12:6711546	768	chr12:53452903	1040	chr17:2579802
225	chr3:108229398	497	chr1:156715104	769	chr3:25647591	1041	chr2:230661315
226	chr17:79803764	498	chr19:39330959	770	chr8:39068767	1042	chr3:40529660
227	chr22:42564716	499	chr10:81072446	771	chr22:33255324	1043	chr9:123954450
228	chr20:31022442	500	chr7:6196443	772	chr7:151845524	1044	chr9:125141077
229	chr2:207174869	501	chr7:100855927	773	chr9:135277541	1045	chr10:115481532
230	chr3:154032978	502	chr12:107937778	774	chr7:33014804	1046	chr10:91514406
231	chr1:67390426	503	chr2:172546762	775	chr2:99976805	1047	chr8:92406218
232	chr20:25422397	504	chr11:121475905	776	chr12:54971060	1048	chr21:37605286
233	chr16:29825016	505	chr12:117977605	777	chr4:26417146	1049	chr20:44050026
234	chr21:33074655	506	chr17:44109601	778	chr19:36210764	1050	chr8:68128856
235	chr6:76599858	507	chr7:21939669	779	chr10:91203598	1051	chr5:132534817
236	chr6:31504446	508	chr8:133826909	780	chr7:102760123	1052	chr15:65994675
237	chr7:94185017	509	chrX:70472854	781	chr5:68492902	1053	chr22:42610948
238	chr2:206166298	510	chr1:26671971	782	chr14:55818555	1054	chr19:17836781
239	chr2:95815035	511	chr11:33117910	783	chr1:46494559	1055	chr8:55538813
240	chr17:67125767	512	chr7:92146721	784	chr14:96761299	1056	chr1:233388513
241	chr10:61823946	513	chr13:45008838	785	chr3:26751758	1057	chr1:38274674
242	chr2:169699563	514	chr3:53889347	786	chr9:6012690	1058	chr4:678571
243	chr7:50531075	515	chr2:163134716	787	chr8:100990178	1059	chr4:678571
244	chr1:27106804	516	chr13:23912864	788	chr11:27362973	1060	chr7:23775341
245	chr20:56227349	517	chr20:30789952	789	chr6:17788023	1061	chr20:62193251
246	chr20:58452519	518	chr6:114292040	790	chr3:37367468	1062	chr11:1902786
247	chr12:122720397	519	chr1:168054869	791	chr17:18181545	1063	chr1:179337955
248	chr7:150698398	520	chr2:55176077	792	chr6:42832627	1064	chr1:192779369
249	chr16:28883208	521	chr15:49776644	793	chr2:99977965	1065	chr4:74313372
250	chr11:65836146	522	chr18:19154750	794	chr11:102713563	1066	chr4:110756541

251	chr15:91304139	523	chr7:19738024	795	chr4:3133117	1067	chr8:27634577
252	chr3:58089788	524	chr1:93599280	796	chr1:153362605	1068	chr14:24032654
253	chr9:134007993	525	chr5:131676327	797	chrX:133378875	1069	chr6:144086414
254	chr20:57769140	526	chr2:109086477	798	chr14:105614481	1070	chr19:50098808
255	chr10:94243045	527	chr8:99168468	799	chr17:19641649	1071	chr10:105363391
256	chr13:51530587	528	chr3:185212518	800	chr17:40134398	1072	chr16:88504852
257	chr10:75560464	529	chr6:102503432	801	chr9:19063047	1073	chr2:97637864
258	chr11:108216477	530	chr6:102503432	802	chr19:45996513	1074	chr15:63986203
259	chr22:50898756	531	chr6:102503432	803	chr2:231931680	1075	chr11:118402960
260	chr17:25910016	532	chr16:50745399	804	chr8:30703516	1076	chr2:241808308
261	chr11:95555113	533	chr16:30736371	805	chr10:91163033	1077	chr6:29641359
262	chr11:95555113	534	chr10:63958149	806	chr1:89732166	1078	chr8:145773375
263	chr18:43459143	535	chr1:100889837	807	chr20:2816204	1079	chr11:17794004
264	chr11:74336609	536	chr1:46752129	808	chr1:89206848	1080	chr12:57704152
265	chr12:57921732	537	chr22:18300932	809	chr16:53348351	1081	chr5:56219767
266	chr2:201436992	538	chr19:10433828	810	chr9:90582463	1082	chr19:33703794
267	chr9:39073899	539	chr6:33263965	811	chr3:38949441	1083	chr8:26221272
268	chr19:21992087	540	chr19:45556129	812	chr19:48789818	1084	chr16:25232875
269	chr6:84634231	541	chr18:12370885	813	chr7:89929188	1085	chr7:4830445
270	chr20:36361416	542	chr1:28920547	814	chr3:195487898	1086	chr6:86275080
271	chr12:98921672	543	chr1:197145703	815	chr15:42738788	1087	chr19:46025663
272	chr14:35585935	544	chr12:121432118	816	chr9:95221949		

EXAMPLE 3: SELECTION OF AN OPTIMAL SUBSET OF FSPs FOR AN MSI VACCINE WITH HIGH “IMMUNOGENIC COVERAGE”

SEQ ID NOs: 1 to 1087 indicate the amino acid sequence of FSPs and mFSPs that may be included in a CVP of the present invention. This exemplary CFSP comprises 1087 FSPs and mFSPs. If the criteria outlined in Example 1 and 2 are altered the CFSP will include additional or fewer FSPs and, accordingly the CVP will include additional or fewer FSPs and mFSPs. Depending on the way of administering the CVP, e.g. viral vector, naked DNA/RNA, it may not be practical or economical to generate CVPs of such a large number of FSPs and mFSPs. Thus, the present inventors have developed further selection criteria to select from a CFSP generated as outlined in Examples 1 and 2 a suitable number of FSPs or of mFSPs derived from FSPs of the CFSP to be included in the CVP to attain an optimal immunization of the majority of patients afflicted with a particular MSI cancer or optimal prophylaxis in patients likely to develop a MSI cancer. In the following such additional selection criteria which the present inventors used to determine subsets of FSPs and mFSPs to be included in preferred CVPs are described.

In previous studies in human subjects vaccinated with different viral antigens have shown that an antigenic sequence of about 400 aa contains on average 3 immunogenic epitopes (min 1, max 12) (Figure 1) (Borthwick, N., *et al.* (2017) PLoS One 12(4), Swadling, L., *et al.* (2014)

Sci Transl Med 6(261)). Therefore, to obtain a good “immunogenic coverage”, that is here intended as an expected average of 3 immunogenic epitopes, it would be desirable that the FSPs selected for the vaccine were represented in each patient’s tumor for a total length of at least 400 *aa*. Thus, the present inventors have developed an algorithm to select FSPs from the CFSP
5 in a way that the empirically established minimal immunogenic coverage threshold of 400 *aa* was reached for the maximum number of MSI tumors examined. Whenever feasible, the present inventors aimed at reaching a target immunogenic coverage of 800 *aa* to compensate for the possibility that a proportion of the FSPs were not translated or presented on tumor cells. These criteria should ensure: (i) a high probability to induce effective immune responses in a large
10 cohort of patients; and (ii) that a large number of cancer cells within a given patient will be targeted by vaccine-induced immunity.

An additional constrain was imposed in the algorithm to achieve a maximal total length of 6000 *aa* for all FSPs in the final vaccine set. This length cutoff reflected a preferred total number of vaccine vectors ($n = 4$) given the maximal insert size of about 4.500 nucleotides per
15 vector encoding about ~1500 *aa* of continuous joined FSPs and/or mFSPs.

For each of the 1059 FSMs generating the FSPs in the CVSP collection, a value of 1 or zero was attributed based on the presence or absence of the FSM, respectively, in each of the 320 TCGA MSI tumors (69 MSI-H colorectal cancer, 85 MSI gastric cancer and 166 MSI endometrial cancer). For each tumor type, FSMs with a frequency $< 5\%$ were assigned a value
20 of zero to favor the inclusion in the vaccine list of those FSMs that are more shared within each tumor group.

As a first step, the algorithm ranked the 1059 FSMs according to a score that is the product between the total length of all FSPs generated by each FSM and the FSM’s observed frequency across the 320 MSI tumors (*aa* length $\times$ number of samples containing the FSM/total samples).
25

The first FSM included in the vaccine list was the one with the highest score. Subsequently, the algorithm proceeded in a cyclic manner, by selecting at each round the FSM that enabled the maximal number of tumors to increase their immunogenic coverage. If more than one FSM fulfilled this condition, the FSM with the highest score was chosen. When an FSM was selected, all FSPs encoded by that FSM were added to the vaccine list and the
30 immunogenic coverage of the samples carrying the selected FSM was updated accordingly by adding the total *aa* length of the corresponding FSPs. Once a sample reached the target immunogenic coverage threshold (in the present case selected to be 800 *aa* for colorectal and gastric cancer, 400 *aa* for endometrial cancer), the algorithm discounted it for the selection of

subsequent FSMs, while only taking into account those samples that had yet to reach the target coverage.

The algorithm continued to add FSPs or mFSPs to the vaccine list, i.e. the amino acid sequences forming the CVP, until one of the three following conditions was fulfilled: (i) the total *aa* length of all selected FSPs encoded by the selected FSMs superseded 6000*aa*; (ii) all cancer samples had an immunogenic coverage $\geq$ the target threshold or (iii) there were no more FSMs that increased the immunogenic coverage of the samples below the threshold.

The final subset of FSPs selected with the described algorithm comprises 209 FSPs arising from 204 FSMs for a total length of 6021*aa* and is referred to as Nous-209 (SEQ ID NO: 1 to 209). This subset of FSPs provides immunogenic coverage ≥ 400 *aa* for 98% of TCGA colorectal cancer samples with a median number of 50 FSPs per sample and a median immunogenic coverage of 1322 *aa*. Similarly, FSPs in Nous-209 confer an immunogenic coverage ≥ 400 *aa* in 95% of the gastric cancer samples with a median number of 46 FSPs per sample and a median coverage of 1178 *aa*. Finally, immunogenic coverage ≥ 400 *aa* is reached by 70% of TCGA endometrial cancer, with a median number of 21 FSPs per sample and median coverage of 512 *aa*. The immunogenic coverage remains very high for colorectal cancer and gastric cancer (93% and 83%, respectively) when calculated for the target value of 800 *aa*.

Example 4: Validation of Nous-209 as a candidate MSI cancer vaccine with high immunogenic coverage

As a first validation step for the list of FSPs and mFSPs included in Nous-209, the inventors performed next-generation sequencing (NGS) on a panel of MSI cell lines (7 CRC and 1 EC). At the genomic level (exome-sequencing), the number of FSMs detected in each cell line that were also included in Nous-209 was such that all cell lines overcame significantly the minimal immunogenic coverage threshold of 400 *aa*, with an average coverage (FSPs cumulative length) of 2037 *aa* (Figure 2A).

Secondly, the inventors analyzed the same cell lines by RNA-seq to determine how many FSMs in Nous-209 that were detected by exome sequencing were also expressed at the transcriptional level. Notably, an immunogenic coverage above 400*aa* was maintained for all cell lines at the RNA-seq level as well (Figure 2B).

Similar results to those obtained for the MSI cell lines were obtained by exome sequencing of six fresh frozen MSI colorectal cancer matched biopsies (tumor and normal tissue). For all patients analyzed, the immunogenic coverage was higher than the minimal

threshold of 400 *aa*, with an average coverage of 926 *aa*. Four out of six samples exceeded the target threshold of 800 *aa* (Figure 3).

Moreover, to estimate the immunogenicity potential of Nous-209, the inventors calculated how many of the vaccine-encoded FSPs in MSI CRC biopsies were predicted to generate epitopes with a good binding profile ($IC_{50} \leq 500$ nM) to MHC-I molecules. To this aim, the inventors first derived the HLA haplotype of the 6 patients from the sequencing data of their biopsies. Subsequently, the inventors performed HLA-I-matched patient-specific binding predictions on the subset of vaccine-encoded FSPs present in each patient using the IEDB software (<http://www.iedb.org/>). Each MSI patient had on average 67 epitopes (min 29, max 141) predicted to bind their own HLA-I haplotype (Figure 4).

Taken together, these results demonstrate that high immunogenic coverage can be achieved through a subset of FSPs, like the subset included in Nous-209 both in MSI cell lines and primary tumor biopsies.

The inventors then verified whether immunogenic responses against FSPs in Nous-209 could be measured *in vivo*. To this aim, the inventors immunized HLA-A02⁺ transgenic mice with a subset of Nous-209 FSPs. Vaccine-induced immune responses were evaluated by cytofluorimetry (FACS) using nonamers selected from those FSPs based on binding prediction to HLA-A02. Figure 5 shows representative CD8 T cell responses to an HLA-A02 nonamer derived from the FSP corresponding to SEQ ID NO: 123 in 5 animals, as measured by intracellular staining (ICS) for interferon γ (IFN- γ) (panel A). FACS plot of gating strategy for IFN- γ ⁺ CD8 T cells from one of those mice are depicted in panel B, showing a significant percentage (5.6%) of FSP-reactive T cells.

Example 5: Construction of nucleic acid cassettes for Nous-209

The FSPs in Nous-209 were split into 4 subsets to generate artificial genes of a length of about 4500 nucleotides, each encoding about 1500 *aa* suitable for cloning into the following viral backbones: Great Apes Adenovirus (GAd) and Modified Vaccinia Ankara (MVA). Each gene was assembled by joining the FSP sequences one after the other without any linker. The 209 FSPs were distributed across the 4 genes in a way to ensure that each gene would contain approximately the same number of FSPs with similar rank levels according to the algorithm described in Example 3 and would contain FSPs where the corresponding FSMs have a similar overall distribution of observed frequencies across the three cancer types. This procedure resulted in:

Gene 1 = 1507*aa* (46 FSPs)

Gene 2 = 1501aa (54 FSPs)

Gene 3 = 1506aa (59 FSPs)

Gene 4 = 1507aa (51 FSPs).

Each artificial gene was assembled in four different layouts (A, B, C and D) corresponding to a different order of the FSPs (Table 2). Genes in layout A and C were used to construct GAd vectors, while genes in layout B and D were cloned in MVA backbones, based on a heterologous prime-boost vaccination strategy. The scrambling of FSPs between layouts A and B and between layouts C and D was designed to avoid having both GAd and MVA encoding the same junctional aa sequences between adjacent FSPs, which could boost immune responses against junctional epitopes. To choose the order of FSPs for each gene in the two layouts, the inventors used a procedure that generates 50,000 different polypeptides where FSPs are joined in random order. Out of these, the inventors selected two with different junctions and with a disordered sequence in the first 50 aa (mean disorder tendency >0.50, as estimated by the IUPRED software (Dosztányi Z., *et al.* (2005) *Bioinformatics* 21, 3433) (Figure 6). The latter choice was based on the notion that a disordered N-terminus favours processing by the proteasome and, therefore, should increase the chances of presentation of FSP-derived epitopes on MHC-I molecules. Subsequently, the artificial polypeptides were screened *in silico* for similarity to human reference proteins to avoid generation of regions cross-reactive with the human proteome. The aa sequences of the four poly-FSP strings in layouts A, B, C and D are listed as SEQ ID NO: 1088 to 1091 (layout A), SEQ ID NO: 1092 to 1095 (layout B), SEQ ID NO: 1155 to 1158 (layout C) and SEQ ID NO: 1159 to 1162 (layout D) corresponding to a different order of the FSPs (Table 2). Genes in layout A and C were used to construct GAd vectors, while genes in layout B and D were cloned in MVA backbones, based on a heterologous prime-boost vaccination strategy. The scrambling of FSPs between layouts A and B and between layouts C and D was designed respectively. Their corresponding nt sequences are SEQ ID NO: 1096 to 1099 (layout A), SEQ ID NO: 1100 to 1103 (layout B), SEQ ID NO: 1163 to 1166 (layout C) and SEQ ID NO: 1167 to 1170 (layout D).

In order to construct an expression cassette, a sorting signal (either the human tissue plasminogen activator signal peptide (hTPA; SEQ ID NO: 1104) or the human invariant chain (hINV; SEQ ID NO: 1105) was added at the N-terminus and an influenza HA-tag sequence (SEQ ID NO: 1106) at the C-terminus of each polypeptide sequence (Figure 7). The extended sequence of the so constructed polypeptides is provided as SEQ ID NO: 1107 to 1110 (layout A), SEQ ID NO: 1111 to 1114 (layout B), SEQ ID NO: 1171 to 1174 (layout C) and SEQ ID NO: 1179 to 1182 (layout D) for hTPA and by SEQ ID NO: 1115 to 1118 (layout A), SEQ ID

NO: 1119 to 1122 (layout B), SEQ ID NO: 1175 to 1178 (layout C) and SEQ ID NO: 1183 to 1186 (layout D) for hINV. The corresponding nt sequences to generate the indicated poly-FSPs strings were codon-optimized based on human codon usage (SEQ ID NO: 1123 to 1126 for layout A, SEQ ID NO: 1127 to 1130 for layout B, SEQ ID NO: 1187 to 1190 for layout C and 5 SEQ ID NO: 1191 to 1194 for layout D with hTPA; SEQ ID NO: 1131 to 1134 for layout A, SEQ ID NO: 1135 to 1138 for layout B, SEQ ID NO: 1195 to 1198 for layout C and SEQ ID NO: 1199 to 1202 for layout D with hINV). In addition, a Kozak sequence (CGCGACTTCGCCGCC) was placed immediately upstream of the start codon to allow for efficient initiation of translation and a TAA stop codon was placed downstream of the HA tag.

10 Finally, two flanking segments comprising unique restriction sites to facilitate the sub-cloning of the cassettes were added at the 5'- and 3'-end of the nucleotide sequence, respectively (Figure 7). The nt sequences representing the artificial genes (SEQ ID NO: 1139 to 1142 for layout A, SEQ ID NO: 1143 to 1146 for layout B, SEQ ID NO: 1203 to 1206 for layout C and SEQ ID NO: 1207 to 1210 for layout D with hTPA; SEQ ID NO: 1147 to 1150 for layout A, SEQ ID

15 NO: 1151 to 1154 for layout B, SEQ ID NO: 1211 to 1214 for layout C and SEQ ID NO: 1215 to 1218 for layout D with hINV) were generated by standard oligonucleotide synthesis methods and sub-cloned between the TetO-CMV promoter (hCMV promoter with binding site for the Tet Repressor) and the BGH (Bovine growth hormone) polyA.

20

Table 2

FSP composition of the assembled polypeptides for Gene1, Gene2, Gene3 and Gene4 in layout A, B, C and D. In each case the SEQ ID NOs of the FSPs are listed based on their position in the assembled polypeptide (from the N-terminus to the C terminus).

1A	2A	3A	4A	1B	2B	3B	4B	1C	2C	3C	4C	1D	2D	3D	4D
58	183	135	57	58	183	135	57	70	11	126	128	55	183	139	161
93	103	172	113	18	92	49	177	58	39	49	161	42	100	184	73
178	92	40	9	51	100	172	113	42	150	184	177	149	11	125	54
18	106	139	25	174	71	8	78	118	100	8	148	87	199	206	67
180	100	168	54	127	79	147	148	110	90	135	83	74	150	209	177
129	3	8	155	141	194	44	33	1	35	125	50	1	187	208	33
63	199	126	121	55	187	197	21	102	162	152	169	14	47	176	5
102	86	192	128	14	52	107	161	145	59	36	54	170	159	160	89
87	195	91	82	118	23	156	17	149	43	197	13	63	117	107	140
42	47	143	189	102	3	204	165	182	203	160	57	101	167	16	157
166	154	49	193	1	19	139	181	101	31	32	37	70	116	99	108
101	7	131	140	10	195	137	45	166	71	95	140	102	35	32	181
22	15	95	205	62	117	176	193	186	75	68	113	22	124	147	155
30	123	202	61	22	94	28	54	2	7	53	205	26	109	156	169
2	194	60	5	170	154	208	157	18	195	192	17	18	75	188	121
51	115	80	153	74	179	80	136	55	123	12	108	182	142	91	50
151	138	107	148	166	7	202	37	190	207	107	77	118	207	4	77
145	117	99	97	145	106	188	155	141	167	209	89	30	115	168	144
127	159	24	161	66	199	184	89	93	199	28	136	114	162	48	104
62	116	197	33	93	146	88	29	34	116	84	132	133	203	172	82
186	150	20	13	186	86	76	25	10	47	98	165	66	195	68	148
74	167	81	21	114	15	200	50	129	94	139	29	38	71	36	132

70	79	28	29	110	159	32	173	66	86	176	67	145	130	40	113
14	179	152	177	42	167	40	205	127	142	196	155	51	7	49	153
133	109	160	37	46	35	60	69	30	194	44	5	129	31	76	65
46	27	164	41	87	116	4	67	85	52	131	158	166	59	95	165
38	43	206	67	34	142	131	153	105	79	201	73	34	123	200	189
174	35	204	50	178	124	20	120	14	154	204	185	190	92	204	61
141	52	188	69	30	198	201	108	151	163	206	153	174	79	53	9
66	142	53	108	38	123	119	158	180	117	156	61	85	86	60	120
149	162	208	73	2	43	160	97	114	106	16	189	110	163	131	41
190	163	209	77	129	130	24	128	87	138	168	82	105	90	119	45
1	94	12	78	105	150	168	41	174	130	164	25	58	52	175	17
110	203	44	83	133	162	125	73	63	179	64	181	127	103	112	193
55	75	137	89	182	191	196	144	38	146	208	121	46	179	143	69
10	11	36	96	85	115	91	82	46	187	72	69	2	198	192	37
118	59	196	104	180	39	95	83	51	27	99	78	178	111	24	25
85	23	48	45	70	207	81	132	170	124	188	157	10	43	126	83
114	124	64	120	26	56	12	189	22	15	20	144	151	27	20	57
170	56	72	65	149	109	164	104	62	92	147	9	62	194	28	185
182	198	156	132	63	111	175	13	133	103	112	96	93	19	98	96
26	191	98	136	151	103	98	77	178	3	60	41	6	146	202	205
105	19	76	144	101	75	206	9	6	111	137	65	180	15	152	29
6	130	119	157	190	47	143	185	26	171	4	45	141	134	197	21
34	187	147	158	6	138	209	121	74	23	48	33	186	23	88	128
146	125	165			90	99	169		115	80	193		154	201	78
	71	176	17		27	72	65		109	172	21		39	72	173
	90	84	169		134	16	96		183	202	120		56	12	158
	207	200	173		203	36	5		191	76	104		106	81	136
	171	88	181		171	122	61		56	122	173		171	137	97
	111	112	185		163	126	140		134	40	97		138	164	13
	134	184			59	112			19	200			191	135	
	39	4			11	192			198	175			94	84	
	31	68			31	84			159	88			3	122	
		122				152				91				8	
		32				53				119				44	
		201				64				143				196	
		16				68				24				64	
		175				48				81				80	

Example 6: Confirmation of immunogenicity

The immunogenicity of the 4 GAd vectors (GAd20-209-FSPs) containing the 4 genes in layout A (polypeptide sequence SEQ ID NO: 1107 to 1110, nucleotide sequence SEQ ID NO: 1139 to 1142) and the 4 MVA vectors (MVA-209-FSPs) containing the 4 genes in layout B (polypeptide sequence SEQ ID NO: 1111 to 1114, nucleotide sequence SEQ ID NO: 1143 to 1146) has been evaluated in mice (CB6F1 mouse strain). GAd20-209-FSPs were constructed from GAd20 (SEQ ID NO: 1219) deleted for region E3 and with region E1 substituted by the genes. Mice were immunized by a single intramuscular immunization of GAd20-209-FSPs at doses of 10^8 viral particles (vp) for each vector and two weeks later were boosted by MVA-209-FSPs at doses of 10^7 plaque forming units (pfu). Induction of T-cell responses against vaccine-encoded FSPs was measured by ELISpot assay using synthetic peptides covering the 209 FSPs sequences. Synthetic peptides were diluted in DMSO and mixed to form 16 pools. Immune responses (number of T cells producing Interferon-gamma (IFN- γ) per million

splenocytes) were analyzed 2 weeks post prime and one-week post boost. Data show induction of a T-cell mediated immune response after priming with GAd20-209-FSPs and a powerful boost of the immune response obtained after administration of MVA-209-FSPs (Figure 8). Responses were directed to multiple FSPs distributed over the vaccine constructs as they were detected against each of the 16 peptides pools (Figure 9). Importantly, vector co-administration did not affect the immune responses against FSP encoded by a single vector, thus excluding immune interference in presence of the vaccine mixture of FSPs (Figure 10). Finally, quality of T cell responses was assessed by intracellular staining (ICS) by using two peptide pools (pool1 and pool3) and showing the induction of FSP-specific CD4 and CD8 IFN gamma+ T cells (Figure 11).

As explained in Example 4, it was verified whether immunogenic responses against FSPs in Nous-209 could also be measured *in vivo*. HLA-A02+ transgenic mice were immunized with a subset (30 FSPs) of Nous-209 FSPs or with a DMSO negative control. Vaccine-induced immune responses were evaluated by cytofluorimetry (FACS) using nonamers selected from the 30 FSPs based on binding prediction to HLA-A02. Figure 11 shows a representative CD8 T cell response in 5 animals to a HLA-A02 nonamer present in FSP SEQ ID NO: 123, as measured by intracellular staining (ICS) for interferon γ (IFN- γ) (panel A). FACS plot of gating strategy for IFN- γ + CD8 T cells from one of those mice are depicted in panel B, showing a significant percentage (5.6%) of FSP-reactive T cells.

Taken together, these results demonstrate that

- i) The constructs are highly immunogenic and induce a CD4 and CD8 immune response. ii) The immune response is directed against 16 different peptides pools and therefore recognizes at least 16 different epitopes (one for each pool). It is shown that, even in inbred mice (mice practically genetically identical), the rule of at least one epitope in 400 aa is confirmed, because having 16 epitopes over 6000 aa of vaccine corresponds, on average, to at least one immunogenic epitope in 375 aa.
- iii) There is no apparent interference effect, in particular no suppression between the individual vectors since comparable immune responses against vector 1 encoded antigens were measured, whether vector 1 was used alone or combined with the other three vectors. Similarly, comparable immune responses against vector 2 encoded antigens were measured, whether vector 2 was used alone or combined with the other three.