(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
13 June 2013 (13.06.2013)

WIPO | PCT

(10) International Publication Number
WO 2013/083329 A2

(51) **International Patent Classification:**
C12N 15/867 (2006.01)

(21) **International Application Number:**
PCT/EP2012/071214

(22) **International Filing Date:**
26 October 2012 (26.10.2012)

(25) **Filing Language:** English

(26) **Publication Language:** English

(30) **Priority Data:**

11306385.3	26 October 2011 (26.10.2011)	EP
61/551,629	26 October 2011 (26.10.2011)	US

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(81) **Designated States** *(unless otherwise indicated, for every kind of national protection available):* AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) **Designated States** *(unless otherwise indicated, for every kind of regional protection available):* ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:

— *without international search report and to be republished upon receipt of that report (Rule 48.2(g))*

— *with sequence listing part of description (Rule 5.2(a))*

WO 2013/083329 A2

(54) **Title:** TRANSIENT EXPRESSION LENTIVIRAL VECTORS, PREPARATION AND USES THEREOF

(57) **Abstract:** The present invention describes a recombinant lentiviral vector which cannot by itself achieve complete reverse transcription as well as its uses, in particular for transiently transferring *in vitro, ex vivo* or *in vivo* at least one ribonucleic acid sequence of interest in a cell. Such a transient transgene expression is of interest in the context of research, therapy and more generally in the field of biotechnology.

TRANSIENT EXPRESSION LENTIVIRAL VECTORS, PREPARATION AND USES THEREOF

The present invention describes a recombinant lentiviral vector which cannot by itself achieve complete reverse transcription as well as its uses, in particular for transiently transferring *in vitro, ex vivo* or *in vivo* at least one ribonucleic acid sequence of interest in a cell. Such a transient transgene expression is of interest in the context of research, therapy and more generally in the field of biotechnology.

BACKGROUND

As stated by R Scott Mclvor (Molecular Therapy, 201 1, May; 19(5):822-3, Therapeutic Delivery of mRNA: The Medium Is the Message), it seems as though every advance in gene transfer and expression needs to somehow provide a solution to the problem of genotoxicity. This rely on developing an alternative to gene transfer methods involving a DNA intermediate, which necessarily present a potential risk of insertional mutagenesis, no matter they are intended to be integrative or not.

Messenger RNA (mRNA) has several advantages over DNA for gene transfer and expression, including the lack of any requirement for nuclear localization or transcription and the nearly negligible possibility of genomic integration of the delivered sequence.

However, the development of mRNA as therapeutic faces the same challenge as any nucleic acid: delivery. It is therefore likely that substantial improvements will be required in the efficiency of mRNA delivery and translation into protein product to reach a level that is of more general therapeutic utility.

The present invention now advantageously addresses these drawbacks and provides a new solution for the use of mRNA as a source of gene product usable *in vitro, ex vivo* or *in vivo* for both therapeutic or non-therapeutic (for example research and transgenesis) applications. The present invention more widely answers the long felt need for safe, efficient and transient gene transfer tools as further developed below.

Transiently transferring a nucleic acid or a protein, also herein respectively identified as "recombinant nucleic acid" or "transgene" and "recombinant protein", into a target cell is a major issue in the biotechnological field, in particular in a therapeutic or experimental context.

In the context of therapy, such a transient expression may be mandatory for instance for safety reasons, i.e. in order to avoid deleterious effects of a sustained expression of the recombinant protein in the subject exposed to this therapy or to prevent permanent integration of the recombinant nucleic acid into the host genome by preventing the generation of DNA intermediate forms of the recombinant nucleic acid.

In the context of non-therapeutic uses, the transient expression may be required for example in order to avoid deleterious effects such as positional effects or genomic toxicity. For example, in the context of transgenesis, the transient expression of a DNA modifying enzyme may be advantageous in the zygote or early in the development of the organism to specifically modify a target locus. In this context, avoiding DNA intermediate forms encoding the DNA modifying enzyme in the organism would advantageously prevent potential integration of the genome encoding

the DNA modifying enzyme, consequently preventing constitutive expression of said DNA modifying enzyme in said organism.

One may further wish to limit *in vitro, ex vivo* or *in vivo* the expression of a recombinant peptide, for example when such expression is only transiently required at a particular moment of a biological process.

Among the technical options currently available to allow the transient delivery of a nucleic acid or of a peptide, the skilled person may select either a non-viral or a viral delivery method. The non-viral delivery method may be a direct peptide delivery method or a direct nucleotide delivery method. The viral delivery method may imply the use of replicative RNA viruses, such as RNA (+) viruses and RNA (-) viruses; or transpackaging of fusion proteins in non-replicative retroviral vectors.

Non-viral delivery methods

Direct delivery of protein is chosen in specific contexts, such as for the delivery of a ligand of a cell membrane receptor *in vitro* or ex *vivo.* However, in most cases, if the action of the delivered factor is to be intracellular, the efficiency of direct delivery of protein in the culture media may be limiting and other methods should be considered. In addition, direct protein delivery does not allow for targeting a specific cell type, which is a particular issue for *in vivo* applications.

According to another method used in the art, nucleotide sequences (DNA and/or RNA) can be directly delivered to cells by mean of current transfection protocols based on chemical or physical methods, for *in vitro, ex vivo* or *in vivo* uses.

The cationic polymers (e.g. diethylaminoethyl (DEAE) -dextran, poly(l-lysine), dendrimers, polyethylenimine (PEI)) and the lipid vectors (e.g. liposomes or lipoplexes such as 1,2-dioleoyl-3-trimethylammonium-propane (DOTAP)) are examples of chemical compounds used to transfer nucleic acids.

Physical methods can also be considered for the transient delivery of nucleic acids into a target cell, such as electroporation. For DNA transfer, the strength of the electric shock required is to be high enough to allow the material to reach the cell nucleus. Such a shock may however be responsible for cell damages.

One can also consider delivering nucleic acid molecules by direct micro-injection into the target cells. This method is mainly applied for transgenesis purpose. It can also be used for gene transfer into poorly permissive cells. Micro¬injection is limited to *in vitro* applications and it is a tedious method, highly time consuming (cell by cell) which has not been automated so far for most cells.

These non-viral methods can be of interest under certain circumstances such as transient gene transfer into cell lines *in vitro* or for example in the muscle *in vivo.* Though, they are in most cases of limited efficiency, do not allow targeting a specific cell type and are not easily implemented for they require large amount of highly purified recombinant nucleic acid and some of the recombinant nucleic acid based compositions, complexed with lipid compounds for instance, are particularly unstable and cannot be stored. In addition, in the case of plasmid DNA, bacterial sequences are retained that can have deleterious effects.

Viral delivery methods of RNA

Viruses are nucleoprotein particles transferring their nucleic information into a target cell and hijacking it for their own replication. For years, they have been modified to be used for gene transfer purpose *in vitro, ex vivo* and *in vivo.* "Viral vectors", also herein identified as "virus-derived vectors" or "vector particles", are mostly deprived of virulence factors and non-replicative. They further allow the expression of a sequence of interest: the transgene. They often overcome the lack of efficiency of non-viral gene transfer methods, taking advantage of the strategies viruses have developed over their evolution.

Viruses can be classified in several families, depending on the nature of their nucleic acid content and how it is processed during the viral cycle: RNA viruses contain RNA molecules ((+), (-) or double-stranded), DNA viruses contain DNA molecules (single- or double-stranded) and reverse transcribing viruses have their genome as RNA or DNA depending on the step of the replication cycle.

Among RNA viruses, RNA (+) viruses can be used for transient transfer of RNA because they are never present in the cell as a DNA molecule, i.e. they do not have DNA intermediates, thus precluding in theory any persistence of the viral information and subsequent mutagenic risk. Their genome is processed in the cell cytoplasm like a messenger RNA and is translated by cellular ribosomes for the production of viral proteins. One can thus modify them to carry only the information of interest. Viral vectors have been developed from several RNA (+) viruses including alphavirus (e.g. Sindbis, Semliki forest virus, Venezuelian equine encephalitis), picornavirus (e.g. poliovirus), or flavivirus (e.g. Kunjin virus).

Among those kinds of RNA (+) virus derived vectors, alphaviruses are preferred because of their ability to transduce a large quantity of exogenous proteins into cells of a large range of species. However they exhibit cytopathic effects precluding their use for most therapeutic purposes.

The RNA (-) viruses group comprises most of the main human pathogens, including flu, rabies and measles viruses. The RNA (-) genome is not infectious by its own but has to be associated with a RNA-dependent RNA-polymerase, which will generate the (+) strand.

While several viruses of this family have been used to develop RNA vectors, including measles, the most used one is the Sendai virus (SeV), a paramyxoviridae. The Sendai virus is not genotoxic and can replicate in a large range of mammalian tissues. It is the causative agent of respiratory affections in mice, Guinea pigs, hamsters, rats and in rare cases in pigs, but is not pathogenic for humans. Sendai derived vectors are used in few therapeutic strategies, for instance in cystic fibrosis mouse models.

Nevertheless, one of the major drawbacks of these vectors derived from RNA (+) and RNA (-) viruses is the replication of the RNA genome and the formation of non-transmissible virus like particles (NTVLP) into the host cell, leading to toxicity and cell death in many cases.

Viral delivery methods of protein (trans-packaging of fusion proteins with HIV-1 derived particles)

An approach to transiently bring a protein into a target cell consists in the trans-packaging of a protein of interest in vector particles derived from HIV-1. This trans-packaging can be achieved by a fusion with naturally encapsidated proteins.

Among the viral proteins investigated as trans-packaging partner is VPR (Viral Protein R), which has various functions in the HIV-1 cycle and pathogenicity. The fusion of a heterologous protein of interest to VPR allows one to encapsidate this protein. Such a strategy has for instance been tested for trans-complementation assays to study the functions of integrase and reverse transcriptase during the retroviral cycle. It can also be used to vectorise therapeutic proteins.

The main drawback of this VPR trans-packaging lies in the primary functions of VPR itself regarding cell cycle arrest and its pro-apoptotic and cytotoxic effects, all properties which originally drove the removal of VPR from the improved generation of HIV-1 vectors and which are retained in the fusion proteins. Another disadvantage is the relatively poor efficiency of trans-packaging, depending on the nature of the fusion protein.

Integrase is another viral protein that has been recently used, with mitigated successes, for trans-packaging of heterologous proteins in HIV-derived particles, to visualize cell/particle interactions (fusion with reporter genes), to develop targeted integration vectors (fusions with specific DNA binding domain such as LexA or ZFN), and to vectorise protein of interest (fusion with p53).

Based on fusion with either VPR or integrase (IN) or any other viral protein, the efficiency of trans-packaging strategy is limited by important factors: the low number of proteins that can be delivered and the functionality of the fused protein. Indeed, although the number of encapsidated VPR protein is high in regard to the particle, the packaging efficiency of a fusion protein is expected to be lower, due to the limited size of the particle; this is also true for IN fusion proteins. This low delivery efficiency can, in particular cases, preclude the use of this method. In addition, a protein, which is fused to VPR or IN may lose its function. In consequence, fusion is to be designed with caution in a way not to alter the protein of interest.

The present invention now offers a solution to the problems of the art and provides new tools and vectors for transiently expressing a transgene *in vitro, ex vivo* or *in vivo* with optimal safety.

BRIEF PRESCRIPTION OF THE INVENTION

Inventors now herein provide new types of RNA vector derived from lentiviruses, in particular vectors as defined in the claims. These vectors are unable to achieve reverse transcription of their genome typically through the alteration of the PBS present in the vector genome or through deletion of said PBS from said vector genome.

The present invention describe lentiviral vectors comprising a mutation of the PBS, typically a deletion of the PBS, that indeed prevent the reverse transcription while preserving encapsidation of the lentiviral RNA genome, thus allowing for an efficient gene transfer of the recombinant lentiviral RNA vector genome.

Inventors herein demonstrate that such vectors, preferably vectors containing a complete deletion of the PBS, allow transferring the vector RNA genome into a host target cell to transiently express a recombinant protein of interest for various purposes such as therapeutic applications or biotechnological applications.

The invention is concerned particularly with a recombinant lentiviral (derived-) vector which cannot by its own achieve complete reverse transcription wherein the vector comprises a recombinant ribonucleic vector genome comprising a 5' LTR retroviral sequence and a 3' LTR retroviral sequence flanking: a functional retroviral psi encapsidation sequence and at least one transgene. Preferably, the recombinant retroviral vector genome is devoid of the *gag, pol* and/or *env* gene, for example of the *gag* and *pol* genes, of the *gag* and *env* genes or of the *pol* and *env* genes, even more preferably of the *gag, pol* and *env* genes. At least one of the *gag, pol* and *env* genes, as well as any fragments thereof, can intentionally be reintroduced in the vector genome as a "transgene", for example in the context of vaccination. Typically, the *gag* gene may be reintroduced.

Such lentiviral vectors of the invention, which cannot by their own achieve reverse transcription are also herein identified as reverse transcription deficient or reverse transcription defective vectors.

An example of recombinant lentiviral vector according to the invention is a lentiviral vector, which cannot by its own achieve complete reverse transcription wherein the vector comprises a recombinant ribonucleic vector genome comprising a 5' LTR retroviral sequence and a 3' LTR retroviral sequence preferably flanking: a functional retroviral psi encapsidation sequence, and at least one transgene. The recombinant retroviral vector genome possibly further comprises a RNA nuclear export element such as a Rev responsive element (RRE) from HIV-1, a flap sequence (also herein identified as central polypurine tract - central termination sequence, cPPT-CTS), a splice donor site (SD), a splice acceptor site (SA), and/or a promoter.

Another object of the invention relates to a composition comprising a lentiviral vector according to the invention.
A particular example of such a composition is a pharmaceutical composition (for example a vaccinal composition) comprising a lentiviral vector according to the invention and preferably a pharmaceutically acceptable excipient.

The invention also relates to methods, vectors and compositions for the transient expression of at least one transgene *in vitro, ex vivo* or *in vivo.*

The object of the invention is also any method for producing a lentiviral vector as defined above in a producer cell, consisting in particular in the expression of (i) appropriate transcomplementation cassettes, resulting in the production of lentiviral enveloped capsid, and (ii) of an appropriate vector cassette, resulting in the production of a lentiviral recombinant ribonucleic vector genome that will be encapsidated in the lentiviral enveloped capsid.

A method according to the present invention is a method for preparing a lentiviral vector which cannot by its own achieve complete reverse transcription according to the invention, wherein said method comprises expressing within a cell:

a. a vector cassette encoding for a lentiviral recombinant ribonucleic vector genome comprising a 5' LTR retroviral sequence and a 3' LTR retroviral sequence flanking: a functional retroviral psi encapsidation sequence and at least one transgene, and wherein the recombinant ribonucleic vector genome (i) does not comprise a primer binding site

(PBS) or (ii) comprises a PBS comprising a mutation or a misplaced PBS, thereby preventing the reverse transcription of said recombinant ribonucleic vector genome, and

b. a transcomplementation envelope cassette encoding for an envelope glycoprotein, and

c. a transcomplementation capsid cassette encoding for sequences derived from a lentiviral genome comprising retroviral *gag* and *pol* sequences, said transcomplementation capsid sequences lacking any functional psi encapsidation signal, and said transcomplementation capsid sequences being optionally split into several cassettes, and

recovery of the lentiviral vectors produced.

Another object of the invention is a lentiviral vector obtainable with a method as herein described.

Another object of the invention is a nucleic acid sequence comprising a vector cassette encoding for a lentiviral recombinant ribonucleic vector genome comprising a 5' LTR retroviral sequence and a 3' LTR retroviral sequence flanking: a functional retroviral psi encapsidation sequence and at least one transgene, and wherein the recombinant ribonucleic vector genome (i) does not comprise a primer binding site (PBS) or (ii) comprises a PBS comprising a mutation or a misplaced PBS, thereby preventing the reverse transcription of said recombinant ribonucleic vector genome, and optionally:

- a nucleic acid sequence comprising a transcomplementation envelope cassette encoding for an envelope glycoprotein, and/or
- a nucleic acid sequence comprising a transcomplementation capsid cassette encoding for sequences derived from a lentiviral genome comprising retroviral *gag* and *pol* sequences, said transcomplementation capsid sequences lacking any functional psi encapsidation signal, and said transcomplementation capsid sequences being optionally split into several cassettes

The nucleic acid sequence can be selected for example from a linear nucleic acid sequence, a plasmid, an artificial chromosome, a viral vector genome, and a transposon.

A further object of the invention is a cell or cell line comprising a nucleic acid sequence as herein described, in particular a cell or cell line expressing, in a stable or controlled (for example inducible) manner, a lentiviral ribonucleic vector genome to be encapsidated, which lentiviral vector genome does not comprise a primer binding site (PBS) or comprises a PBS comprising a mutation or a misplaced PBS, thereby preventing the reverse transcription of said recombinant ribonucleic vector genome.

Another object of the invention is a composition, for example a pharmaceutical composition, comprising a vector, a nucleic acid sequence, and/or a cell or a cell line as herein described, and optionally a pharmaceutically acceptable excipient.

Another object of the invention is a kit comprising a vector, a nucleic acid sequence, a cell or a cell line, and/or a composition as herein described, and preferably written instructions for using the kit.

A further object of the invention relates to uses of any product as herein described (vector, nucleic acid sequence, cell, cell line, composition and kit of the invention) for transiently expressing at least one transgene *in vitro, ex vivo* or *in vivo.*

DETAILED DESCRIPTION OF THE INVENTION

Unless defined otherwise, all technical and scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art (e.g. in cell biology, in molecular biology, nucleic acid chemistry and biochemistry). In order to assist with the understanding of the invention several terms are defined herein.

Unless otherwise indicated, the practice of the present invention employs conventional techniques of chemistry, molecular biology, microbiology, recombinant DNA technology, chemical methods, pharmaceutical formulations and delivery and treatment of patients, which are within the capabilities of a person of ordinary skill in the art. Such techniques are also explained in the literature, for example, J. Sambrook, E. F. Fritsch, and T. Maniatis, 1989, Molecular Cloning: A Laboratory Manual, Second Edition, Books 1-3, Cold Spring Harbor Laboratory Press; Ausubel, F. M. et al. (1995 and periodic supplements; Current Protocols in Molecular Biology, ch. 9, 13, and 16, John Wiley & Sons, New York, N. Y.); B. Roe, J. Crabtree, and A. Kahn, 1996, DNA Isolation and Sequencing: Essential Techniques, John Wiley & Sons; J. M. Polak and James O'D. McGee, 1990, In Situ Hybridisation: Principles and Practice, Oxford University Press; M. J. Gait (Editor), 1984, Oligonucleotide Synthesis: A Practical Approach, IRL Press; and D. M. J. Lilley and J. E. Dahlberg, 1992, Methods of Enzymology: DNA Structure Part A: Synthesis and Physical Analysis of DNA Methods in Enzymology, Academic Press. Each of these general texts is herein incorporated by reference.

The term "amino acid" in the context of the present invention is used in its broadest sense and is meant to include naturally occurring L a-amino acids or residues. The commonly used one and three letter abbreviations for naturally occurring amino acids are used herein: A=Ala; C=Cys; D=Asp; E=Glu; F=Phe; G=Gly; H=His; l=lle; K=Lys; L=Leu; M=Met; N=Asn; P=Pro; Q=Gln; R=Arg; S=Ser; T=Thr; V=Val; W=Trp; and Y=Tyr (Lehninger, A. L , (1975) Biochemistry, 2d ed., pp. 71-92, Worth Publishers, New York). The general term 'amino acid' may further include D-amino acids, retro-inverso amino acids as well as chemically modified amino acids such as amino acid analogues, naturally occurring amino acids that are not usually incorporated into proteins such as norleucine, and chemically synthesised compounds having properties known in the art to be characteristic of an amino acid, such as β-amino acids. For example, analogues or mimetics of phenylalanine or proline, which allow the same conformational restriction of the peptide compounds as do natural Phe or Pro, are included within the broad definition of amino acid. Such analogues and mimetics are referred to herein as 'functional equivalents' of the respective amino acid. Other

examples of amino acids are listed by Roberts and Vellaccio, The Peptides: Analysis, Synthesis, Biology, Gross and Meiehofer, eds., Vol. 5 p. 341 , Academic Press, Inc., N.Y. 1983, which is incorporated herein by reference.

The term **"peptide"** as used herein refers to a plurality of amino acids joined together in a linear or circular chain. The term oligopeptide is typically used to describe peptides having between 2 and about 50 or more amino acids. Peptides larger than about 50 amino acids are often referred to as polypeptides or proteins. For purposes of the present invention, however, the term 'peptide' is not limited to any particular number of amino acids, and is used interchangeably with the terms 'polypeptide' and 'protein'.

The terms **"nucleic acid", "polynucleotide",** and **"oligonucleotide"** are used interchangeably and refer to a deoxyribonucleotide (DNA), ribonucleotide (RNA) polymer, in linear or circular conformation, in either single- or double-stranded form and in any combination thereof (for example a hybrid DNA/RNA molecule). For the purposes of the present invention such DNA or RNA polymers may include natural nucleotides, non-natural or synthetic nucleotides, and mixtures thereof. Non-natural nucleotides may include analogues of natural nucleotides, as well as nucleotides that are modified in the base, sugar and/or phosphate moieties (e.g. phosphorothioate backbones). Examples of modified nucleic acids are PNAs and morpholino nucleic acids. Generally an analogue of a particular nucleotide has the same base-pairing specificity, i.e. an analogue of G will base pair with C. For the purposes of the invention, these terms are not to be considered limiting with respect to the length of a polymer.

A **"gene",** as used herein, is the segment of nucleic acid (typically DNA) that is involved in producing a peptide or ribonucleic acid gene product. It includes regions preceding and following the coding region (leader and trailer) as well as intervening sequences (introns) between individual coding segments (exons). Conveniently, this term also includes the necessary control sequences for gene expression (e.g. enhancers, silencers, promoters, terminators etc.), which may be adjacent to or distant to the relevant coding sequence, as well as the coding and/or transcribed regions encoding the gene product.

The phrase **"genomic sequence"** includes genes and fragments or partial gene sequences. It may refer to non-coding and/or coding gene sequences. Such genomic sequences may be within a gene, or it may be isolated or extracted from its corresponding gene, such as an isolated nucleic acid molecule, vector or plasmid. Genomic sequences include those present in chromosomes whether natural or artificial, and whether in the nucleus or other organelles (e.g., mitochondria and chloroplasts). The genomic sequences may be animal (e.g. mammals, such as humans), or may be viral, parasitic, bacterial or fungal (e.g. yeast).

The expressions *"in vitro"* and *"in vivo"* each defines the other, more precisely *"in vivo"* is understood as "in the naturally occurring conditions", while *"in vitro"* is understood as "in artificial conditions", said conditions being defined by the subject it refers to. For instance, the "naturally occurring conditions" for a cell is "within an organism"; the term *"in vivo",* when referring to a cell will thus be understood as "within an organism", while the term *"in vitro"* will be understood as "out of an organism", for instance in a Petri dish. As another example, the "naturally occurring

conditions" for a retroviral integrase is "in the context of a retroviral particle" or "in the context of a retroviral vector particle" (i.e. respectively within said retroviral particle or a cell being infected by said retroviral particle or within said retroviral vector particle or a cell being transduced by said retroviral vector particle); the term *"in vivo",* when referring to a retroviral integrase will then be understood as for example "in the context of a retroviral (vector) particle" or "in the context of a cell being infected (or transduced) by said retroviral (vector) particle", while the expression *"in vitro"* will be understood as "out of a retroviral (vector) particle or a cell", for example "in a solution".

The expression **"ex** *vivo"* refers to *"in vitro",* as previously defined, and usually implies that the subject is transiently taken out of its natural condition before being reintroduced *in vivo,* i.e. in its naturally occurring conditions. A typical example of use of the term "ex *vivo"* is in the context of stem cells manipulation: stem cells are collected from an organism, treated "ex *vivo",* for instance submitted to transduction by retroviral vectors, and then reinfused to the organism, i.e. *"in vivo".*

More specifically in the context of the present invention, when referring to the use of retroviral vector, the term *"in vivo"* will refer to the naturally occurring conditions of the target cells, i.e. within an organism, while *"in vitro"* and "ex *vivo"* will refer to artificial conditions of the target cells, i.e. out of an organism, for instance in a Petri dish.

The term **"PBS"** refers to the **"primer binding site"** in a retroviral genome. The process of reverse transcription is initiated at a particular sequence of the RNA genome: the primer binding site (PBS). The first DNA strand (-) synthesis is initiated by the binding of a specific tRNA on the primer binding site, a sequence of 18 nucleotides, located in 3' from the 5' LTR. For example, the PBS in HIV-1 is recognised by a tRNA Lys3, as another example, the PBS in BIV is recognised by a tRNA Lys1 ,2. The U5 and R regions of the 5' LTR are synthesised by elongation of the tRNA thanks to the DNA polymerase activity of the reverse transcriptase while the corresponding RNA matrix fragments, with the exception of the PBS region, are degraded thanks to the RNAseH activity of the reverse transcriptase.

As explained previously, there is a need in the art for improved tools and methods allowing the transient expression of a transgene in therapeutic as well as non-therapeutic uses. The present invention provides such improved tools and methods.

In the sense of the invention, the term **"transgene"** generally refers to any nucleic acid sequence of interest. This is typically a sequence encoding a peptide, for example an enzyme, a transcription factor, a growth factor, a trophic factor, an hormone, a cytokine, an antibody, a receptor, a differentiation factor, a colony stimulating factor, a suicide protein, a cell-cycle modifying protein, an anti-proliferative protein, a nuclease, a recombinase, a transposase, a neurotransmitter or a precursor thereof. It can be part of an RNA or of a DNA molecule. Preferably, it is a sequence deriving from a cDNA, a gDNA, a RNA, a synthetic nucleic acid, or a combination thereof. The context will indicate whether the term "transgene" refers to a DNA or a RNA sequence. Typically, the transgene includes a sequence encoding a product of interest. Furthermore, the transgene can include one or more transcription termination regions, typically a polyadenylation signal.

The "transgene" may also typically refer to a non-coding sequence. The transgene can be for example selected from a catalytic nucleic acid (for example a ribozyme), an interfering nucleic acid, an antisense nucleic acid, an aptamer, a miRNA or a decoy RNA.

In the context of the present invention, transient expression vectors relate to retrovirus-derived vectors unable to achieve complete reverse transcription of their genome but able to deliver a RNA and optionally (i.e. when said RNA is a coding RNA) produce a recombinant peptide from the messenger RNA molecules delivered by the vector particles. These lentiviral vectors are advantageously able to transiently transfer the transgene to host target cells or organisms.

"Lentiviral vectors", in the context of the invention, are defined as engineered vector particles derived from retroviruses such as oncoretroviruses, lentiviruses or spumaviruses. They consist, as the viruses they are derived from, in (i) an envelope made of cell membrane including an envelope glycoprotein, for example derived from an enveloped virus, possibly from a retrovirus or from any other enveloped virus, for example originating from a rhabdovirus, or a cellular glycoprotein or a synthetic glycoprotein - in this case the retroviral vector is designated as "pseudotyped retroviral vector" ; and (ii) a capsid consisting in gag -derived proteins (gag-polyprotein, matrix, capsid, nucleocapsid) containing a nucleic acid genome, namely the **"retroviral vector genome",** possibly retroviral enzymes derived from the *pol* gene: protease, integrase and reverse transcriptase, and possibly other retroviral proteins such as regulatory and accessory proteins (for instance *tat, nef, rev,* etc.). They possibly contain any other peptide of interest brought within the vector particle by means of fusion with one of the naturally encapsidated viral peptides. Retroviral vectors of the invention are defined in that the ribonucleic acid vector genome they enclose has been engineered (i) to be deprived of transcomplementation sequences required for replication, namely gag, *pol* and *env* (although fragments thereof may remain, e.g. partial or complete sequence of the gag gene), and (ii) to contain an expression cassette allowing the expression of at least one transgene of interest when applied to target cell, said transgene possibly corresponding to gag, *pol, env* and/or fragments thereof, for instance in a vaccination purpose.

"Reverse transcription" is a step of the viral cycle typical of the retroviruses by which their single stranded RNA genome is processed into a double stranded DNA molecule, namely the **"provirus".** This reaction is mediated by the reverse transcriptase, a retroviral enzyme and involves two different catalytic activities: a DNA polymerase activity and an RNaseH activity, both of which require divalent cations, typically Mg2+. In addition, DNA polymerase activity requires deoxynucleotides.

The present invention more particularly relates to lentiviral vectors wherein the recombinant ribonucleic vector genome (i) does not comprise a primer binding site (PBS) or (ii) comprises a PBS comprising a mutation or a misplaced PBS, thereby preventing the reverse transcription of said recombinant ribonucleic vector genome. These new vectors have been successfully tested by inventors in therapeutic and non-therapeutic fields as herein illustrated.

A recombinant lentiviral vector, which cannot by its own achieve complete reverse transcription is thus herein described. Such a lentiviral vector of the invention which cannot by itself achieve reverse transcription is also herein identified as reverse transcription deficient or reverse transcription defective vector. This vector comprises a recombinant ribonucleic vector genome, namely the **"retroviral vector genome",** comprising a 5' LTR retroviral sequence and a 3' LTR retroviral sequence flanking: a functional retroviral psi encapsidation sequence and at least one transgene, for example two, three or four transgenes.

The vector of the invention is a lentiviral vector derived from a lentivirus selected for example from HIV-1, HIV-2, SIV, FIV, EIAV, BIV, VISNA, CAEV and any combination thereof.

In the present invention, the PBS of a lentiviral vector genome is altered so that the reverse transcription process cannot be completed and does not lead to the generation of a full double stranded DNA molecule, namely the lentiviral provirus.

Said alteration consist in mutations of the RNA vector genome in a way modifying its 3D structure or not, and preventing the correct binding of the reverse transcriptase, the correct binding of the tRNA, the initiation of the reverse transcription, the elongation of the primer, the strand jumps, and/or the termination of elongation.

In a preferred embodiment of the invention, the alteration of the PBS in a lentiviral recombinant vector genome derived from HIV-1, HIV-2, SIV, FIV and EIAV affects the PBS sequence 5'-TGGCGCCCGAACAGGGAC-3' (DNA sequence SEQ ID NO: 15) or corresponding 5'-UGGCGCCCGAACAGGGAC-3' (RNA sequence SEQ ID NO: 17), complementary to tRNA Lys3.

In another preferred embodiment of the invention, the alteration of the PBS in a lentiviral recombinant vector genome derived from CAEV, VISNA and BIV affects the PBS sequence 5'-TGGCGCCCAACGTGGGGC-3' (DNA sequence SEQ ID NO: 16) or 5'-UGGCGCCCAACGUGGGGC-3' (RNA sequence SEQ ID NO: 18), complementary to tRNA Lys1,2.

In yet another preferred embodiment, the alteration of the PBS in a lentiviral recombinant vector genome is a deletion of 18 bp of sequence 5'-TGGCGCCCGAACAGGGAC-3' (DNA sequence SEQ ID NO:15) or 5'-UGGCGCCCGAACAGGGAC-3' (RNA sequence SEQ ID NO:17) for vector genomes derived from HIV-1, HIV-2, SIV, FIV and EIAV and a deletion of 18 bp of sequence 5'-TGGCGCCCAACGTGGGGC-3' (DNA sequence SEQ ID NO: 16) or 5'-UGGCGCCCAACGUGGGGC-3' (RNA sequence SEQ ID NO:18) for vector genomes derived from CAEV, VISNA and BIV.

Lentiviruses, from which vectors of the invention are derived, have *gag, pol* and *env* genes flanked by two LTR (Long Terminal Repeat) sequences. Each of these genes encodes for numerous peptides, which are initially expressed in the form of a single precursor polypeptide. The *gag* gene encodes for the internal structure proteins (matrix, capsid and nucleocapsid). The *pol* gene encodes for lentiviral enzymes reverse transcriptase, integrase and protease. The

env gene encodes for viral envelope glycoprotein. Furthermore, the lentivirus genome can contain c/s-acting elements, for example elements responsible for exporting out of the nucleus the unspliced viral genomic RNA, which will further be packaged, such as the RRE (Rev Responsive Element) from HIV. The LTR 5' and 3' sequences serve to promote the transcription and also serve as a polyadenylation sequence of the viral RNAs. Sequences necessary for the initiation of reverse transcription of the genome (binding site of the tRNA primer) and for the encapsidation of viral RNA in particles (psi sequence) are adjacent to the LTR 5'. If the sequences necessary for encapsidation are absent from the viral genome, genomic RNA is not actively packaged. Furthermore, the genome of lentiviruses comprises genes encoding for accessory and/or regulatory proteins (distinct from *gag, pol* and *env* proteins) such as, but not limited to (depending on the nature of the virus): *src, sag, Tax, vif, vpr, vpx, vpu, nef, TAT, REV, tmx, Tas* or *Bet* (see Figure 1). For example, the HIV-1 genome contains 7 accessory genes: *vif, vpr, vpx, vpu, nef, TAT and REV.*

The lentiviral vector is derived typically from HIV-1, HIV-2, SIV, FIV, EIAV, BIV, VISNA, CAEV. The lentiviral vector may further be derived from a combination of any of the previously mentioned lentiviruses.

Reverse transcription is a typical step of retroviral cycle (see Figure 2) and is normally shared by lentiviruses and lentiviral vectors (see Figure 3). This reaction is mostly cytoplasmic, although it can be initiated within the particle (before the uncoating step) and be completed after nuclear import within the preintegration complex (PIC). It is a multistep process involving three key molecules: the RNA template (with particular nucleic acid sequences and three-dimensional structures), a specific tRNA that serves as a primer for the initiation of the reverse transcription, and the reverse transcriptase (RT) viral enzyme which functions as a RNA- and DNA-dependent DNA polymerase (Pol) and a RNA- and DNA-dependent ribonuclease H (RNAseH) (see Figure 4 and Figure 5). The reverse transcriptase polymerase activity is primer dependent and can transcribe both RNA (RNA-dependent polymerase activity, responsible for the (+) strand synthesis) and DNA (DNA-dependent polymerase activity, responsible for the (-) strand synthesis) templates in a 5'-3' direction. The RNAseH acts on the RNA strand of RNA/DNA duplexes and can catalyse both endo- and exonucleolytic cleavage of such an RNA strand. The RNaseH domain has two particular activities: (a) a polymerase dependent activity, involved in the degradation of the viral RNA simultaneously to the DNA synthesis, and (b) a polymerase independent activity, specifically responsible for the degradation of the polypurine tract (PPT).

In a preferred embodiment, the lentiviral vector of the invention comprise a recombinant ribonucleic vector genome comprising a 5' LTR retroviral sequence and a 3' LTR retroviral sequence flanking: a functional retroviral psi encapsidation sequence and at least one transgene and wherein said recombinant ribonucleic vector genome does not comprise a primer binding site (PBS).

In yet another preferred embodiment, the lentiviral vector of the invention comprises a PBS comprising a mutation or a misplaced PBS, thereby preventing the reverse transcription of said recombinant ribonucleic vector genome.

In the present invention, the PBS can be mutated, displaced or deleted so that the reverse transcription process is altered and cannot be completed, i.e. cannot give rise to full length retroviral double-stranded DNA intermediate molecules in the target cell, and consequently cannot generate a proviral vector genome. This inability to give rise to a full length double stranded DNA molecule is the consequence of alteration(s) of the reverse transcription reaction occurring at the initiation step, the elongation, and/or the termination, the first jump and/or the second jump, and/or during the first strand synthesis and/or the second strand. This inability, in the context of the invention, results from either (i) an absence of a primer binding site (PBS) in the lentiviral vector genome or (ii) a PBS comprising a mutation or a misplaced PBS, thereby preventing the reverse transcription of said recombinant ribonucleic vector genome.

In another embodiment, the recombinant vector genome herein described can further comprises at least one sequence favouring or enhancing the transgene expression, in particular a post-transcriptional regulatory sequence and/or a sequence modifying the stability of mRNAs, for example selected from an intron (natural or synthetic), WPRE, APP 5'UTR, TAU 3'UTR, at least one copy of a miRNA target sequence and any combinations thereof, preferably chosen from WPRE, APP 5'UTR, TAU 3'UTR, and at least one copy of a miRNA target sequence (for example miRNA target sequence of mir 142-3p), even more preferably from two to twelve copies of a miRNA target sequences, typically at least four copies.

In another embodiment, the recombinant vector genome herein described can further comprises other regulatory sequences or elements for example selected from an insulator (MAR, SAR, scs, scs', LCR, etc.), an IRES, a KOZAK or Shine-Dalgarno sequence, and a lentiviral central sequence (cPPT-CTS).

When the vector of the invention is to contain more than one transgene, said transgenes can be linked directly through a fusion construct preferentially including a 2A protease cleavage site, for example originating from the foot-and-mouth disease virus, or alternatively through an IRES sequence.

Transgenes advantageously usable in the context of the present invention can be selected from a catalytic nucleic acid, an aptamer, a miRNA, a decoy RNA, a nucleic acid encoding a biologically active peptide, for example an enzyme, a transcription factor, a growth factor, a trophic factor, a hormone, a cytokine, an antibody, a receptor, a differentiation factor, a colony stimulation factor, a suicide protein, a cell-cycle modifying protein, an anti-proliferative protein, a nuclease, a recombinase, a transposase, and a neurotransmitter or a precursor thereof.

The present invention further includes any composition comprising a vector as herein described, typically a pharmaceutical composition comprising such a vector together with a pharmaceutically acceptable excipient.
Pharmaceutically acceptable excipient or carriers are well known in the art and include but are not limited to saline, buffered saline, dextrose, water, glycerol, sterile isotonic aqueous buffer, and combinations thereof. One example of such an acceptable carrier is a physiologically balanced culture medium containing one or more stabilizing agents such as stabilized, hydrolyzed proteins, lactose, etc. The carrier is preferably sterile. The formulation will be easily

selected by the skilled person depending on the chosen mode of administration. Examples of administration methods are further described below.

The lentiviral vectors of the present invention may be administered by injection, for example intravenous injection or subcutaneous injection. The pharmaceutical forms suitable for injectable use include sterile aqueous solutions or dispersions and sterile powders for the extemporaneous preparation of sterile injectable solutions or dispersions. In all cases, the form must be sterile and must be fluid to the extent that easy syringability exists. It must be stable under the conditions of manufacture and storage and must be preserved against the contaminating action of microorganisms, such as bacteria and fungi. The carrier can be a solvent or dispersion medium containing, for example, water, ethanol, polyol (e.g., glycerol, propylene glycol, and liquid polyethylene glycol), suitable mixtures thereof, and vegetable oils.

The lentiviral vectors of the present invention may also be administered directly to the airways in the form of an aerosol. For use as aerosols, the agents of the present invention in solution or suspension may be packaged in a pressurized aerosol container together with suitable propellants, for example, hydrocarbon propellants like propane, butane, or isobutane with conventional adjuvants. The materials of the present invention also may be administered in a non-pressurized form such as in a nebulizer or atomizer.

Suitable subjects to be treated with a lentiviral vector of the present invention are those requiring the transient delivery of a particular RNA, said RNA being incorporated in the retroviral vector genome as a transgene. Such subjects include human and non-human animals, preferably mammals or avian species. Exemplary mammalian subjects include, without limitation, humans, non-human primates, dogs, cats, rodents, cattle, horses, sheep, and pigs. Exemplary avian subjects include, without limitation chicken, quail, turkey, duck or goose.

The present invention further provides methods for preparing, *in vitro* or ex *vivo,* typically *in vitro,* a lentiviral vector of the invention, which cannot by its own achieve complete reverse transcription.

An example of such a method typically comprises expressing within a cell:

a. a vector cassette encoding for a lentiviral recombinant ribonucleic vector genome comprising a 5' LTR retroviral sequence and a 3' LTR retroviral sequence flanking: a functional retroviral psi encapsidation sequence and at least one transgene, and wherein the recombinant ribonucleic vector genome does not comprise a primer binding site (PBS), and

b. a transcomplementation envelope cassette encoding for an envelope glycoprotein, and

c. a transcomplementation capsid cassette encoding for sequences derived from a lentiviral genome comprising retroviral *gag* and *pol* sequences, said transcomplementation capsid sequences lacking any functional psi encapsidation signal, and said transcomplementation capsid sequences being optionally split into several cassettes, and

recovery of the lentiviral vectors produced.

The term "cassette" or "expression cassette" in the context of the present invention is to be understood as a nucleic acid sequence possibly involved in the production of one or several RNAs and/or of one or several peptides or polypeptides. The cassette or expression cassette consists in possibly transcribed sequences, for instance but not limited to a gene or a combination of genes, which are possibly associated with functional transcription element(s), namely "promoter(s)", it possibly contains additional sequences such as leader and trailer sequences, introns and sequences involved in the regulation or modulation of transcription such as inhibitor, enhancer, stabilizer, internal ribosomal entry site (IRES). The cassette or expression cassette can typically be transferred into target cells for example as part of a plasmid, an artificial chromosome, a viral vector genome (for example a baculoviral or adenoviral vector genome), or of a transposon. This cassette is then possibly expressed in the target cells.

When the cassette or expression cassette is a DNA molecule or part of a DNA molecule, "expression" is understood as transcription, i.e. production of a polyadenylated messenger RNA and in case of a coding mRNA, its potential subsequent translation and production of a peptide.

When the cassette is a RNA molecule or part of a RNA molecule, "expression" refers to the mRNA translation into a peptide.

Alternatively, when the cassette contains a non-coding RNA (for example a decoy RNA, miRNA, a ribozyme, etc.), "expression" refers to delivery of the RNA into the target cell and its subsequent processing as a catalytic, decoy or interfering RNA.

"Transcomplementation proteins" or "Transcomplementation peptides", in the context of the invention, are defined as proteins or peptides that are intended to be part of a retroviral vector particle as a protein but not as nucleic information (coding sequence) and that are expressed in *trans* within a "producer cell". Transcomplementation proteins or peptides for example typically include retroviral structural proteins (capsid, nucleocapsid, matrix) encoded by the *gag* gene, retroviral enzymes encoded by the *pol* gene (protease, reverse transcriptase, integrase), accessory or regulatory peptides (such as *tat, rev* and *net)* and an envelope glycoprotein encoded by the *env* gene. The glycoprotein can be of retroviral origin or can be derived from a non-retroviral enveloped virus or from a cellular glycoprotein or can be a synthetic glycoprotein (such as a chimeric glycoprotein). Genes encoding the transcomplementation proteins or peptides, namely the "transcomplementation cassettes" (for example the "transcomplementation envelope cassette" or the "transcomplementation capsid cassette"), are to be present transiently or constitutively (i.e. a transformed cell containing an integrated transcomplementation cassette) and expressed in a constitutive or regulated (for example inducible) manner, in the "producer cells" to produce retroviral vectors typically using a plasmid, an artificial chromosome, a viral vector genome (for example a baculoviral or adenoviral vector genome), a transposon, or any combinations thereof. As an example, plasmids used in the invention to bring the transcomplementation cassettes are also herein identified as "transcomplementation plasmids", for example the "transcomplementation envelope plasmid" or the "transcomplementation capsid plasmid". Retroviral transcomplementation proteins are derived from a single retrovirus or from a combination of different retroviruses, either oncoretroviruses, lentiviruses, or spumaviruses. Expression of the transcomplementation cassettes in producer cells along with the retroviral vector genome cassette leads to the production of the retroviral vector particles.

The "Retroviral genome", in the context of the invention, refers to a nucleic acid sequence, which is possibly encapsidated into a retroviral particle, for example (i) when present as a ribonucleic molecule in a "retroviral particle", or (ii) when present as a ribonucleic molecule in a cell infected by a "retrovirus" and undergoing retroviral replication.

The "Retroviral vector genome", also herein identified as "vector genome" in the context of the invention refers to a nucleic acid sequence, which is possibly encapsidated into a retroviral vector particle, for example (i) when present in producer cells as a ribonucleic molecule, or when present in the "retroviral vector particle" or (ii) when present as a ribonucleic molecule in a cell transduced by a "retroviral vector". In the context of the invention, the "retroviral vector genome" contains all the c/s- and frans-active elements necessary for its proper production and encapsidation, including but not limited to the long terminal repeats (LTR) and the psi encapsidation signal. It also contains one or several cassette(s) encoding the gene of interest or transgene, said cassette possibly containing, as understood in the present invention, any element involved in the transcriptional or post-transcriptional regulation of the coding sequence.

Preferably, the recombinant retroviral vector genome is devoid of the *gag, pol* and/or *env gene,* even more preferably of the *gag, pol* and *env* genes. At least one of the *gag, pol* and *env* genes, as well as any fragments thereof, can intentionally be reintroduced as a "transgene" in the vector genome, for example in the context of vaccination. Typically, the *gag* gene may be reintroduced.

The "vector cassette" in the context of the invention allows the expression of a "vector genome" that will be encapsidated in the vector particles in "producer cells". The "vector cassette", in the context of the invention, is to be present transiently or constitutively (i.e. a transformed cell containing an integrated transcomplementation cassette) and expressed in a constitutive or regulated (for example inducible) manner, in the "producer cells" to produce retroviral vector genomes typically using a plasmid, an artificial chromosome, a viral vector genome (for example a baculoviral or adenoviral vector genome), a transposon, or any combinations thereof. As an example, plasmid used in the invention to bring the vector cassette is also herein identified as "vector plasmid" or "transcomplementation vector plasmid".

"Producer cells", in the context of the invention are cells (transiently or constitutively) containing transcomplementation cassettes, which when expressed lead to the production of transcomplementation peptides. Expression of said transcomplementation peptides along with a retroviral vector genome in producer cells allows the production of retroviral vector particles, containing generally two copies of the retroviral vector genome RNA, said retroviral vector particles can be collected in the cell culture medium and further used for *in vitro, ex vivo* and/or *in vivo* purposes. Transcomplementation cassettes and vector cassette can be brought into the producer cells by any method known by skilled persons, including but not limited to, plasmid transfection, artificial chromosome transfection, viral vector transduction, for example using adenovirus-derived vectors, baculovirus-derived vectors, herpes simplex virus-derived vectors, or transposon. Transcomplementation cassettes and vector cassette are stably or transiently introduced in the producer cells and are constitutively transcriptionally active or their transcription is dependent on activation of the promoter, for example by a doxycycline-dependent regulation system.

Another example of a method according to the invention comprises expressing within a cell:

a. a vector cassette encoding for a lentiviral recombinant ribonucleic vector genome comprising a 5' LTR retroviral sequence and a 3' LTR retroviral sequence flanking: a functional retroviral psi encapsidation sequence and at least one transgene, and wherein the recombinant ribonucleic vector genome comprises a PBS comprising a mutation or a misplaced PBS, thereby preventing the reverse transcription of said recombinant ribonucleic vector genome, and

b. a transcomplementation envelope cassette encoding for an envelope glycoprotein, and

c. a transcomplementation capsid cassette encoding for sequences derived from a lentiviral genome comprising retroviral *gag* and *pol* sequences, said transcomplementation capsid sequences lacking any functional psi encapsidation signal, and said transcomplementation capsid sequences being optionally split into several cassettes, and

recovery of the lentiviral vectors produced.

In a particular embodiment, a method of the invention for preparing, *in vitro* or ex *vivo,* typically *in vitro,* a lentiviral vector of the invention consists in transient transfection of cells, for example HEK 293T cells, with at least two transcomplementation plasmids as defined previously and one retroviral vector plasmid expressing the ribonucleic retroviral vector genome to be encapsidated (Nat Biotechnol. 1997 Sep; 15(9):871-5. Multiply attenuated lentiviral vector achieves efficient gene delivery in vivo. Zufferey R, Nagy D, Mandel RJ, Naldini L, Trono D. Cell. 2000 Apr 14;101(2): 173-85. HIV-1 genome nuclear import is mediated by a central DNA flap. Zennou V, Petit C, Guetard D, Nerhbass U, Montagnier L, Charneau P.).

In another particular embodiment, a method of the invention for preparing, *in vitro* or ex *vivo,* typically *in vitro,* a lentiviral vector of the invention consists in stably expressing all or part of the required transcomplementation peptides in a producer cell and further transiently or stably expressing the ribonucleic lentiviral vector genome to be encapsidated, optionally with the other required transcomplementation proteins (J Virol. 1998 Nov;72(11):8463-71. A third-generation lentivirus vector with a conditional packaging system. Dull T, Zufferey R, Kelly M, Mandel RJ, Nguyen M, Trono D, Naldini L; Mol Ther. 2000 Aug;2(2):170-6. A stable system for the high-titer production of multiply attenuated lentiviral vectors. Klages N, Zufferey R, Trono D.).

Another object of the invention is a nucleic acid sequence comprising a vector cassette encoding for a lentiviral recombinant ribonucleic vector genome comprising a 5' LTR retroviral sequence and a 3' LTR retroviral sequence flanking: a functional retroviral psi encapsidation sequence and at least one transgene, and wherein the recombinant ribonucleic vector genome (i) does not comprise a primer binding site (PBS) or (ii) comprises a PBS comprising a mutation or a misplaced PBS, thereby preventing the reverse transcription of said recombinant ribonucleic vector genome, and optionally:

- a nucleic acid sequence comprising a transcomplementation envelope cassette encoding for an envelope glycoprotein, and/or

- a nucleic acid sequence comprising a transcomplementation capsid cassette encoding for sequences derived from a lentiviral genome comprising retroviral *gag* and *pol* sequences, said transcomplementation capsid sequences lacking any functional psi encapsidation signal, and said transcomplementation capsid sequences being optionally split into several cassettes

The nucleic acid sequence can be selected for example from a linear nucleic acid sequence, a plasmid, an artificial chromosome, a viral vector genome (such as a genome derived from a baculovirus, an adenovirus or an herpes virus), and a transposon.

A further object of the invention is a cell or cell line comprising a nucleic acid sequence as herein described, in particular a cell or cell line expressing, in a stable or an inducible manner, a lentiviral ribonucleic vector genome to be encapsidated, which lentiviral vector genome does not comprise a primer binding site (PBS) or comprises a PBS comprising a mutation or a misplaced PBS, thereby preventing the reverse transcription of said recombinant ribonucleic vector genome.

Another object of the invention is a composition, for example a pharmaceutical composition, comprising a vector, a nucleic acid sequence, and/or a cell or a cell line as herein described, and optionally a pharmaceutically acceptable excipient.

Another object of the invention is a kit comprising a vector, a nucleic acid sequence, a cell or a cell line, and/or a composition as herein described, and preferably written instructions for using the kit.

Applications

Also encompassed by the present invention are any possible uses of a product as herein described (vector, nucleic acid sequence, cell, cell line, composition and kit of the invention) for transiently expressing at least one transgene *in vitro, ex vivo* or *in vivo,* in particular of a vector according to the present invention or of a composition comprising such a vector.

There are multiple applications for the transient transfer of nucleic acids, in particular in experimental (e.g. research) and therapeutic fields. Examples of such applications relate to the transfer of functional nucleic acids into target cells and to the transient expression of a protein of interest or transient delivery of a non-coding RNA.

Such a protein of interest may be selected from any protein usable in the context of genetic engineering, of differentiation, of dedifferentiation, of therapy and of research.

In a particular embodiment, the vectors of the invention can be used to transiently express a genetic engineering tool, typically a DNA modifying enzyme. A **"DNA modifying enzyme"** is a natural or synthetic peptide, generally an

enzyme, capable of (i) a particular affinity for a DNA molecule or chromatin, possibly a sequence dependent affinity, and (ii) introducing modification in said DNA or chromatin by for example generating a double stranded break in target DNA molecule, removing a sequence from the target DNA molecule, introducing a sequence into a target DNA molecule, modifying the epigenetic imprinting of the target DNA or chromatin, modifying the tridimensional structure and/or ligating ends of one or several DNA molecules.

Such a DNA modifying enzyme can be for example a unidirectional site-specific recombinase, a bidirectional site-specific recombinase, a nuclease (for example Zinc-finger nuclease, meganuclase, TAL effectors), a transposase, a resolvase, a gyrase, a methyl transferase, as well as histone-deacetylase, histone-deacetylase inhibitor, etc.

The use of the vectors of the invention for transiently expressing a DNA modifying enzyme is particularly advantageous, as compared to other typical methods used in the art. For instance, the potential insertion of a recombinant vector genome encoding said DNA modifying enzyme is of potential harm to the cell or the organism. Indeed, DNA modifying enzymes may for example display off-target activities, i.e. non-specific modification of the target DNA or chromatin, leading potentially to genotoxicity, chromosomal aberrations or cell death. The vectors of the invention allow to transiently express the DNA modifying enzyme, thereby preventing the risk of permanent integration of the genome encoding the DNA modifying enzyme, and consequently reducing the risk of off-target activities.

In another particular embodiment, the vectors of the invention can be used to transiently express a differentiation factor in a pluripotent or totipotent cell such as a primary stem cell (embryonic, foetal, juvenile or adult stem cells), an embryonic stem cell line (i.e. ES cells), a progenitor cell, an induced pluripotent stem cell (iPS). Such a differentiation factor can be selected for example from a transcription factor, an epigenetic regulatory factor, a cell cycle modifier, etc., either natural or synthetic.

The use of the vectors of the invention for transiently expressing a differentiation factor is particularly advantageous, as compared to other typical methods used in the art. For instance, the potential insertion of a recombinant vector genome encoding said differentiation factor is of potential harm to the cell or the organism. Indeed, random integration of the recombinant vector genome into the genome of the host cell may induce insertional mutagenesis. Moreover, the vectors of the invention allow to transiently express the differentiation factor, thereby preventing the risk of long-term or constitutive expression of a differentiation factor reducing potential harmful effects of the differentiation factor, and thus allowing to tightly control the duration of the expression of the differentiation factor to the needed time.

In another particular embodiment, the vectors of the invention can be used to transiently express at least one dedifferentiation factor, typically between two and four dedifferentiation factors. According to methods previously described (e.g.: patent application WO2009/061442 A1), one can induce the dedifferentiation of a differentiated cell into a stem cell-like cell and for example generate so-called "iPS" typically from animal, preferentially mammal, for example human, non-human primates, swine (porcine), bovine, caprine, canine, or feline.

This dedifferentiation can be achieved by transient delivery of one or several factors such as for example oct-4, sox-2, kfl-4, myc and any combinations thereof, using the vectors of the invention.

The use of the vectors of the invention for transiently expressing a dedifferentiation factor is particularly advantageous, as compared to other typical methods used in the art. For instance, the potential insertion of a recombinant vector genome encoding said dedifferentiation factor is of potential harm to the cell or the organism. Indeed, random integration of the recombinant vector genome into the genome of the host cell may induce insertional mutagenesis. Moreover, the vectors of the invention allow to transiently express the dedifferentiation factor, thereby preventing the risk of long-term or permanent expression of a dedifferentiation factor reducing potential harmful effects of the dedifferentiation factor, and thus allowing to tightly control the duration of the expression of the dedifferentiation factor to the needed time. Indeed, dedifferentiation factors are often oncogenic and their permanent expression may thus induce the generation of cancer cells.

Another field wherein the present invention can be used relates to vaccination. Retroviral vectors of the invention are particularly suitable for use in the field of medicinal treatment where especially an immune response, including a cellular immune response, elicited by endogenously expressed antigen is beneficial or necessary; accordingly, the invention provides tools for the design of vaccination protocols for use in hosts in need of preventive or curative treatment against intracellular pathogenic organisms, including viruses, or more generally against a pathogenic state, including to perform gene therapy *in vivo.* In particular, the invention is appropriate to elicit a cellular immune response, which may be protective when administered to a host, especially when prevention or treatment of viral infection is desired, and possibly to prevent development of pathogenesis associated with the infection.

In the context of eliciting an immune response, preferably a cellular immune response, either for a prophylactic or a therapeutic purpose, retroviral vectors of the invention are intended to transduce antigen presenting cells, and especially dendritic cells. They are thus pseudotyped with a glycoprotein enabling the fusion of said retroviral vector particle of the invention with the target dendritic cells, preferably the VSV glycoprotein, as herein described.

Prophylactic and/or therapeutic vaccination using the vector of the invention can be used to treat human as well as non-human animals, preferably mammals or avian species. Examples of mammalian subjects include, without limitation, humans, non-human primates, dogs, cats, rodents, cattle, horses, sheep, and pigs. Examples of avian subjects include, without limitation chicken, quail, turkey, duck or goose.

The use of retroviral vectors of the invention allows the transient expression of an antigen for inducing an immune reaction along with optimized conditions regarding safety since the uniquely RNA state of the retroviral vector genome prevents any persistence of the genetic information in the target cell. As a consequence, such transient retroviral vectors can be advantageously used for vaccination of a subject against any retrovirus, for example for the vaccination of human subjects against HIV infection, without any risk of recombination of the vector genome with the wild type viral genome, thus precluding any risk of dissemination of the vector genome.

Other advantages and applications of the invention are illustrated in greater detail in the following examples, which must be considered as illustrative and non-restrictive.

KEYS TO THE FIGURES

Figure 1: Relationship of retrovirus groups.

The relationships are based on amino acid sequence similarities in the Reverse transcriptase protein of the groups shown. The insertion of sequence from another source is indicated (arrows), typically the accessory and/or regulatory genes, such as *bel 1, bel 2, tat, rev, sag, tax, rex.* Lentiviruses, oncoretroviruses (MLV-related, D-type retroviruses, B-type retroviruses, ALV-related retroviruses, BLV-HTLV group) and Spumaviruses (also herein identified as foamy viruses) are represented. Note that the scale is approximate and not necessarily linear. (HERV-C, an ancient endogenous provirus of humans; SMRV, squirrel monkey retrovirus; HSRV, human spumavirus (also herein identified as human foamy virus); MLV, murine leukemia virus; HIV, human immunodeficiency virus, MMTV, mouse mammary tumor virus; IAP, intracisternal type A particle, a murine endogenous retrovirus; RSV, Rous sarcoma virus; BLV, bovine leukemia virus; HTLV, human T cell leukemia virus.)

Figure 2: Retroviral cycle.

Retroviral cycle first requires the binding of the particle to the cell membrane, followed by cell entry and uncoating of the particle. The uncoating step leads to the introduction into the cytoplasm of the nucleoproteic core, consisting of gag- and pol-derived proteins, full length genomic RNA (2 molecules) and RT (reverse transcriptase) protein. While this core is progressing toward the cell nucleus the reverse transcription occurs, leading to the generation of a double stranded DNA molecule from the RNA vector genome, namely the provirus. After nuclear import, the nucleoproteic complex is named preintegration complex (PIC). The DNA genome is then processed by the integrase (IN) protein, which mediates the recombination within the host cell chromatin, leading to the stable integration of the genome into a host cell chromosome. Another possible fate of the vector genome is the circularization, this process involves different cellular and viral factors; the genome thus remains in the cell nucleus as an extrachromosomal DNA circle. Both DNA forms, integrated as well as circular extrachromosomal forms, can be transcribed by the host cell machinery, leading to the production of RNA, which can be exported to the cell cytoplasm. These newly formed RNA can subsequently be translated, leading to expression of viral proteins necessary for generating new particles, which encapsidates unspliced RNA genomic molecules and are released from the cell by budding. The maturation of the particle then occurs outside from the cell.

Figure 3: Mechanism of reverse transcription in retroviruses.

During the reverse transcription, first strand synthesis is similar for all retroviruses. (1) The first strand (-) synthesis is initiated by the binding of a specific tRNA on the Primer Binding Site, a sequence of 18 nucleotides, located in 3' from the 5' LTR. The U5 and R regions of the 5' LTR are synthesised by elongation of the tRNA thanks to the DNA polymerase activity of the reverse transcriptase while the corresponding RNA matrix fragments, with the exception of the PBS region, are degraded thanks to the RNAseH activity of the reverse transcriptase. (2) This first synthetized fragment, called the minus-strand strong stop DNA, jumps on the 3' LTR and the R regions of the DNA and RNA fragments hybridize. (3) The elongation of the DNA fragment is pursued on the U3 region and toward the 5' end of the RNA molecule until the PBS region. The RNAseH activity degrades the RNA matrix after the DNA synthesis. If

the RNA matrix is not fully degraded, the second strand synthesis is prevented. A region is however protected from this degradation: the polypurine tract. The RNA fragment spared will be further use a primer for the second strand synthesis. The second strand synthesis (+) occurs in a different manner for oncoretroviruses and other retroviruses.

In oncoretroviruses, (4-7) the synthesis of the second strand is initiated on the polypurine tract (PPT) sequence located in 5' of the 3' LTR. The elongation progresses toward the U5 region at the 3' end of the genome, using the (-) strand DNA as a template. Meanwhile, minus-strand synthesis continues through the genome, using the (+) strand RNA as a template and removing the RNA template in its wake via RNAseH activity. PPT initiated (+) strand stops after copying the annealed portion of the RNA to generate the (+) strand DNA form of the PBS, forming the (+) strand strong stop product. The tRNA is then removed by the RNAseH activity of the reverse transcriptase. This may facilitate annealing to the PBS complement on the (-) strand DNA, providing the complementarity for the second jump (intramolecular). DNA synthesis then continues. Strand displacement synthesis by reverse transcriptase to the PBS and PPT ends, and/or repair and ligation of a circular intermediate, produces a linear duplex with long terminal repeats (U3 - R - U5) at both ends.

In lentiviruses and foamy viruses, (4-7) the mechanism is quite similar except that initiation occurs on 2 sites: the PPT located in 3' of the first strand and an additional PPT located in the centre of the first strand: the central polypurine tract (cPPT). A central termination sequence is located in 3' of the cPPT and stops the (+) strand synthesis initiated from the 3' PPT. As a consequence, the reverse transcription induces a transient 3 strand-structure overlapping the cPPT and the CTS, named "triplex" (6). Although this sequence is dispensable in lentiviral vectors, its presence significantly increases the transduction efficiency of the particles.

Figure 4: Retroviral reverse transcriptase structure.

Retroviral reverse transcriptases are organized in two domains, each corresponding to the two enzymatic activities of the protein: the DNA polymerase domain (POL) and the RNAseH domain. As an example, detailed organization is shown for HIV-1 and MLV reverse transcriptase. Positions of the two functional domains, as well as sub-domains are figured for HIV-1 p66 and p51 (HIV-1 p51 being generated by protease cleavage of HIV-1 p66) and MLV p75. (F: Finger domain ; P: Palm domain ; T: Thumb domain ; C: Connection domain.)

Figure 5: Crystal structure of human immunodeficiency virus type 1 reverse transcriptase heterodimer and MLV p75 reverse transcriptase.

TOP: This schema figures the p66 (560 residues) and the p51 (440 residues) subunits of HIV-1 reverse transcriptase (top) and the different structural domains: the polymerase domain, which is divided in 4 subdomains: the finger, the palm, the thumb and the connection ; and the RNAseH domain C: C terminus, N: N terminus.

BOTTOM: This schema figures the different structural domains of the MLV reverse transcriptase: the polymerase domain, which is divided in 4 subdomains: the finger, the palm, the thumb and the connection ; and the RNAseH domain (from Retroviral reverse transcriptases. Herschhorn A, Hizi A. Cell Mol Life Sci. 2010 Aug;67(16):2717-47. Epub 2010 Apr 1).

Figure 6: Schematic representation of a 3 plasmid-system used for production of HIV-1 lentiviral vectors by transient transfection.

A: the transcomplementation capsid plasmid contains the backbone bacterial sequences, including the Ampicilin resistance gene (Amp), the bacterial promoter (SV40), the glutamic-pyruvate transaminase coding sequence (gpt), the bacterial origin of replication (ORI), and eukaryote elements: sequences encoding for the structural and enzymatic proteins required for the formation of a particle under the control of a promoter, for example the CMV promoter (hCMV). It particularly contains the *gag* gene (encoding for the capsid (CA), the matrix (MA), the nucleocapsid (NC)) and the *pol* gene (encoding for the integrase (IN), the reverse transcriptase (RT) and the protease (PR)), it further comprises the *tat* and *rev* genes. The plasmid also includes a polyadenylation signal (insulin polyA) ;

B: the transcomplementation envelope plasmid contains the backbone bacterial sequences, including the Ampicilin resistance gene AmpR, the bacterial origin of replication (ORI), and sequences active in eukaryote cells: the sequence encoding for a particular envelope glycoprotein envelope under the control of a promoter, for example a CMV promoter, and possibly regulatory elements, such as the beta globin intron (Intron B Glob) ;

C: the vector plasmid contains the backbone bacterial sequences, including the Ampicilin resistance gene (AmpR), the bacterial promoter (SV40), the glutamic-pyruvate transaminase coding sequence (gpt), a polyadenylation signal (polyA), and the retroviral vector elements, including the 5' and the 3' Long Terminal Repeats (LTR5', and Self Inactivating, LTR3' SIN), the Rev Responsive Element (RRE), the triplex or cPPT-CTS (central polypurine tract - central termination sequence), the expression cassette, possibly including a promoter, for example a CMV promoter, and at least one transgene coding sequence and regulatory elements such as WPRE, and an encapsidation signal (Psi), the vector plasmid is further deprived of a functional primer binding site, thus preventing the binding of the tRNA Lys3 and subsequent initiation of reverse transcription.

Figure 7: Encapsidation of RNA viral genome and transgene expression.

A: Detection of encapsidated RNA genome by RT-PCR.

Vector particle preparations are assayed for encapsidation of RNA genome. RNA is extracted and reverse transcribed, generated cDNA are submitted to PCR amplification using primers located in 5' and 3' of the GFP sequence. The PCR product is 979 base pairs. (1: DNA ladder, 2: vector production capsid(2) : vector(2) : envelope(1) ; 3: vector production capsid(2) : vector(4) : envelope(1), 4: PCR positive control).

B and C: Detection of GFP and PhiC31 expression by Western blot.

Vector particle preparations are used to transduce 293T cells (B: 400 000 cells plated 24 hours before transduction with 750 ng p24; C 2 to 7 and 10 and 11: 400 000 cells plated 24 hours before transduction with below mentioned doses; C 8 and 9: 800 000 cells incubated with below mentioned doses). Cells are collected at different time points after transduction and proteins are extracted and submitted to western blot analysis for the transgene expression (B and C 1 to 9: primary antibody: Abeam ab290 ; C 10 to 12: primary antibody: PhiC31 specific antibody (gift from M-C Serre) ; revelation ECL+ GE Healthcare) (B: DPBS GFP vector, 1: 4 hours, 2: 8 hours, 3: 24 hours, 4: 32 hours, 5: 48 hours, 6: 56 hours, 7: 5 days, 8: 9 days, 9: 12 days, 10: 16 days, 11: 19 days, 12: 23 days, 13: 26 days, 14: GFP control ; C 1 to 9: DPBS GFP integrase D64V vector, 1: GFP control, 2-5: 100ng p24; 3-6: 500 ng p24, 4- 7-9: 1000

ng p24, 8: 200 ng p24, 2-3-4: 4 hours, 5-6-7: 8 hours, 8-9: 18 hours ; C 10 to 12: DPBS PHIC31 integrase D64V vector, 1000 ng p24, 10: 24 hours, 11: 48 hours, 12: PHIC31 control).

Figure 8: Genuine transduction mechanism mediated by reverse transcription deficient vector.

293T cells are transduced with different HIV-1 vectors in normal medium or in presence of 10 µM azido thymidine (AZT), an inhibitor of retroviral reverse transcriptase or 0.1 mM chloroquine, an inhibitor of lentiviral uncoating. Cells are grown for 24 hours after transduction. Cells are then collected and proteins are extracted and submitted to western blot analysis to detect GFP expression (primary antibody: Abeam ab290, revelation ECL+ GE Healthcare). (1: GFP control, 2-3: reverse transcription and integration proficient vector, 4-5-6: reverse transcription proficient integrase deficient vector, 7-8-9: reverse transcription integrase deficient vector, 2-4: AZT, 3-6-9: control medium, 5-8: chloroquine).

Figure 9: Detection of Luciferase activity mediated by reverse transcription deficient HIV-1 vectors.

HeLa cells are transduced with increasing doses of vectors deleted for the primer binding site and containing a Luciferase coding sequence. Cells are grown for 24 hours after transduction and then collected and processed with Bright Glow Luciferase kit (Promega), according to manufacturer's protocol (10 µL lysate per well). Luciferase activity is measured by a Luminometer. Results are expressed as Relative Light Unit per 10 µL of lysate and figured as mean of 3 samples per condition +/- standard deviation (SD). (1: 1 µL, 2: 3 µL, 3: 5 µL, 4: control non-transduced cells).

Figure 10: The CV-1 5B reporter cell line and LacZ expression in CV1-5B cells after transient expression of Cre recombinase mediated by reverse transcription deficient HIV-1 vectors.

A: The CV1-5B reporter cell line created by Kellendonk et al.(Kellendonk C , Tronche F., Monaghan A.P., Angrand P.O., Stewart F., Schutz G. Nucleic Acids Res. 1996;24: 1404-141 1) harbours a stable integration of the pHSVtk/loxNeolox/NLS-lacZ reporter construct. Expression of the *NLS-lacZ* gene is only detected in cells that have undergone Cre-mediated deletion of the loxP flanked neomycin phosphotransferase gene.

B-C: CV1-5B cells are transduced with increasing doses of reverse transcription deficient vectors encoding for the Cre recombinase. Cells are grown for 72 hours after transduction and then fixed and processed for LacZ activity by a X Gal staining. Positive cells are those having undergone a recombination mediated by Cre. (B1: control non transduced cells, B2: 1 µL, B3: 3 µL, B4: 5 µL, B5: 7 µL, B6: 9 µĩ , B7: higher magnification of B6; C1: VSV + DNase, C2: VSV wo DNase, C3: wo VSV + DNAse, C4: wo VSV wo DNase).

Figure 11: The ROSA26 reporter mouse strain and Cre mediated recombination in the ROSA26 reporter mouse strain.

A: The Rosa26 reporter mouse strain

The Rosa26 reporter mouse strain created by Soriano et al 1999 (Soriano, P. (1999). Generalized lacZ expression with the ROSA26 Cre reporter strain. Nat Genet 21, 70-71.) harbours a stable integration of the pRosa26/loxNeolox/NLS-lacZ reporter construct. Expression of the *lacZ* gene is only detected in cells that have

undergone Cre-mediated deletion of the loxP flanked neomycin phosphotransferase gene. Black arrowheads indicate the position of the primers that are used for the genotyping assay.

B to D: Transgenesis in Rosa26 mice and Transient expression of Cre mediated by reverse transcription deficient vector particles.

Rosa26 reporter embryos are submitted to lentiviral transgenesis: eggs are treated with reverse transcription deficient HIV-1 vectors carrying a Cre recombinase encoding sequence. Embryos are reimplanted in pseudopregnant females and allowed to develop for 13 days. Embryos are then collected and assayed for LacZ activity (B and C) and genotyping (D). The size of the PCR product for recombined DNA (5, marked with a cross) is expected to be lower compared to non-recombined DNA (2, 3, 4, 6, 7, 8, marked with a star). (1: DNA ladder).

EXPERIMENTAL PART

Example 1: Production of a reverse transcription deficient retroviral vector derived from HIV-1 by transient transfection.

According to the present invention, HIV-1 derived vectors deficient for reverse transcription can be produced, for instance by transient transfection of 3 particular plasmids in producer cells (see Figure 6). These three plasmids are (i) the transcomplementation encapsidation plasmid, (ii) the transcomplementation envelope plasmid and (iii) the vector plasmid, which accordingly to the present description contains a modified Primer Binding Site preventing the binding of the tRNA Lys3 and the subsequent initiation of reverse transcription. In the present embodiment, said modification consists in a deletion of the 18 nucleotides of the PBS, ie nucleotides 5577 located 5594 on SEQ ID NO:1, thus generating the plasmid SEQ ID NO:2.

Briefly, the 3 plasmids are transfected by calcium phosphate precipitation method into 293T cells. The transfected cells then produce HIV-1 vector particles including a RNA molecule. These particles can be recovered from the cell culture medium and subsequently used for different purposes, in vitro or in vivo.

In a particular embodiment of the invention, plasmid SEQ ID NO:3, plasmid SEQ ID NO:4 and plasmid SEQ ID NO:2 can be used. The produced vector particles are then characterized in that (1) they are enveloped with VSV glycoprotein, (2) they contain a RNA molecule allowing the expression of GFP and deprived of recognition site for the tRNA Lys3.

In another particular embodiment of the invention, plasmid SEQ ID NO:3, plasmid SEQ ID NO:5 and plasmid SEQ ID NO:6 can be used. The produced vector particles are then characterized in that (1) they are enveloped with Mokola glycoprotein, (2) they contain a RNA molecule allowing the expression of Luciferase and deprived of recognition site for the tRNALys3.

Different combinations of any envelope/capsid/transgene can be used.

Example 2: Production of a reverse transcription deficient retroviral vectors derived from HIV-1 by using stable producer cell lines.

According to the present invention, HIV-1 derived vectors deficient for reverse transcription can be produced, for instance by using stable producer cell lines. Such cell lines are generated by introducing in a single cell the required transcomplementation elements: envelope and capsid, along with a HIV-1 vector genome, expression of which leading to the formation of ribonucleic vector genome that can be encapsidated but containing a modified PBS preventing the initiation of reverse transcription.

These elements (envelop, capsid and ribonucleic vector genome) are stably introduced into a cell as one or more expression cassettes under the control of promoter (s) which are constitutively or inducible promoters. When the elements are expressed altogether in the cell (constitutively or when the inducible promoters are activated), they form vector particles, which are released by the cells in the surrounding culture medium, similarly as after the transient transfection method described in the previous example. These produced HIV-1 vector particles include a RNA molecule. These particles are collected from the cell culture medium and subsequently used for different purposes, in vitro or in vivo.

In a particular embodiment of the invention, the stable producing cell lines contain the following sequences SEQ ID N0:7, SEQ ID N0:8 and SEQ ID N0:9, and will allow the production of vector particles characterized in that (1) they are enveloped with Mokola glycoprotein, (2) they contain a RNA molecule allowing the expression of Neomycine phosphotransferase. This cell line is generated by transient transfection of 293T cells with 3 plasmids containing the above-mentioned sequences. These cells are then treated with G418, Puromycine and Hygromycine, which allow selecting the cells that have stably incorporated the 3 plasmids: Neo expression cassette brought by the vector plasmid, the Puromycine resistance gene brought by the envelope transcomplementation plasmid and the Hygromycine resistance gene brought by the capsid transcomplementation plasmid. Selected cells are seeded at a very low density to generate homogenous clonal populations. Clonal population are then screened to verify cells that express efficiently all the required elements and allow the highest vector particle titre production.

In another particular embodiment of the invention, the stable producing cell lines contain the following sequences SEQ ID NO: 10, SEQ ID N0:9 and SEQ ID N0: 11. The produced vector particles are then characterized in that (1) they are enveloped with VSV glycoprotein, (2) they contain a RNA molecule allowing the expression of Neomycine phosphotransferase, and deprived of a functional PBS. To avoid the toxicity of the constitutive expression of VSV glycoprotein for the cells, the VSV gene is under control of a doxycycline inducible promoter activated by a transactivator RtTa2M2 in the presence of doxycycline. The VSV glycoprotein is then expressed when the cells are treated by sufficient dose of doxycycline. In this particular embodiment, the treatment of cells by Hygromycine, G418 and Puromycine allows to select for cells respectively containing the inducible envelope transcomplementation cassette along with the constitutive capsid transcomplementation cassette, the vector cassette and the transactivator cassette. The selection of the most efficient clones is then performed in a doxycycline-containing medium.

In another particular embodiment of the invention, the stable cell line allowing the production of HIV-1 vector particles pseudotyped with VSV and expressing the Neo gene and deficient for reverse transcription, does not contain the VSV expressing cassette. Cells constitutively express the genome and the encapsidation elements, leading to incomplete and non-functional particles. The production of complete and functional reverse transcription deficient particles is induced when the VSV is expressed in the cells. The VSV expressing cassette is brought by transient transfection by calcium phosphate. 48 hours after the transfection, HIV-1 vector particles are released from the cells in the cell culture medium and are collected for further use, *in vitro* and/or *in vivo.*

Different combinations of any envelope/capsid/transgene can be used.

Example 3: GFP expression mediated by HIV-1 reverse transcription deficient vector particles *in vitro.*

HIV-1 derived vector particles are produced by transient transfection of 293T cells with the envelope transcomplementation plasmid encoding VSV (SEQ ID NO:4), the capsid transcomplementation (SEQ ID NO:3) and the vector plasmid encoding the GFP (SEQ ID NO:2).

In this example, different conditions were tested for the production: the ratio capsid : vector : envelope was 2 : 2 : 1 or 2 : 4 : 1.

Vector particles preparations are first assayed for encapsidation of RNA genome. RNA is extracted and submitted to in vitro reverse transcription using SuperScriptll (Invitrogen) and primers located in 5' and 3' of the GFP expression cassette. Results are presented Figure 7A.

The vector particle preparations are used to treat 293T cells (750 ng p24 per 400,000 plated cells). Cells are harvested at different time point after transduction to evaluate the kinetic of transgene expression, analysed by Western blot using GFP specific antibody. Results are shown on Figure 7B.

In another experience, cells are transduced with a single dose of vector (10uL for 80,000 cells) and GFP expression is measured by FACS 36 hours after transduction. The percentage of GFP positive cells is 7.5.

In another embodiment of the invention, HIV-1 derived vector particles deficient for the reverse transcription are produced by transient transfection of 293T cells with the envelope transcomplementation plasmid encoding VSV (SEQ ID NO:4), the capsid transcomplementation encoding for an integrase which has been mutated in the catalytic site (D64V substitution) and is thus impaired for catalysing the integration reaction (SEQ ID NO: 12) and the vector plasmid encoding the GFP deleted for the primer binding site (SEQ ID NO:2).

Increasing doses of the vector particle preparations are used to treat 293T cells. Cells are harvested at different time point after transduction to evaluate the kinetic of transgene expression, analysed by Western blot using GFP specific antibody. Results are shown on Figure 7C.

These results show that the reverse transcription deficient particles comprising the sequence encoding the GFP, genuinely encapsidate the recombinant lentiviral ribonucleic vector genome and allow the transient expression of GFP after contact with target cells. Said GFP expression is dose dependent and starts 4 hours after contact with the cell, the maximum level is reached between 56 hours and 5 days after transduction and is no longer detected from 9 days after transduction.

Example 4: Transient expression of a GFP mediated by HIV-1 reverse transcription deficient vector particles *in vitro* results from genuine transduction mechanism.

In order to demonstrate that the transgene expression observed after transduction with reverse transcription deficient vectors results from of genuine transduction mechanism (expression from the recombinant RNA vector genome brought by the vector particle) and does not result from contamination of the vector preparation by plasmid used during the production, experience described in Example 3, Figure 7B is reproduced with or without treatment of the cells with chloroquine, an inhibitor of endosome acidification (VSV pseudotyped retroviral vector particle uncoating pathway).

Results presented on Figure 8 show that GFP expression is inhibited in cells treated with Chloroquine.

In addition, to verify that the GFP expression is the result of translation of encapsidated RNA genomes and not of transcription of reverse transcribed DNA genomes, cells transduced with GFP expressing DPBS vectors are treated with Azido-thymidine (AZT), an inhibitor of retroviral reverse transcriptases. Cells are collected 24 hours after transduction and protein extracts are submitted to Western blot analysis. As shown on Figure 8, GFP expression mediated by reverse transcription deficient HIV-1 vectors is independent of reverse transcription.

These results show that the reverse transcription deficient particles comprising the sequence encoding the GFP allow the expression of GFP after contact with target cells and said expression is dependent on uncoating of the particle but not on reverse transcriptase activity. Measured GFP expression is thus genuinely resulting from (i) a transduction mechanism and not from pseudo transduction or contamination of the vector production and (ii) direct

translation of the recombinant RNA vector genome and it does not involve the reverse transcription of the recombinant RNA vector genome into a DNA proviral genome.

Example 5: PhiC31 expression mediated by HIV-1 reverse transcription deficient vector particles *in vitro.*

HIV-1 derived vector particles are produced by transient transfection of 293T cells with the envelope transcomplementation plasmid encoding VSV (SEQ ID NO:4), the capsid transcomplementation (SEQ ID NO:3) and the vector plasmid encoding the PhiC31 phage recombinase (SEQ ID NO: 13).

The vector particle preparations are used to treat 293T cells. Cells are harvested at different time point after transduction to evaluate the kinetic of transgene expression, analysed by Western blot using PhiC31 specific antibody. Results are shown on Figure 7C.

These results show that the reverse transcription deficient particles comprising the sequence encoding the PhiC31 recombinase allow the expression of PhiC31 recombinase 48 hours after contact with target cells.

Example 6: Luciferase expression mediated by HIV-1 reverse transcription deficient vector particles *in vitro.*

HIV-1 derived vector particles are produced by transient transfection of 293T cells with the envelope transcomplementation plasmid encoding VSV (SEQ ID NO:4), the capsid transcomplementation (SEQ ID NO:3) and the vector plasmid encoding the Luciferase (SEQ ID NO:6).

The vector particle preparations are used to treat 293T cells (0, 1, 3 or 5 µL per 35 000 cells). Cells are harvested 48 hours after transduction and proteins are extracted. Luciferase activity in the protein extracts is measured using Bright Glow Luciferase kit (Promega). Results are shown on Figure 9.

These results show that the reverse transcription deficient particles comprising the sequence encoding the Luciferase allow the expression of Luciferase 48 hours after contact with target cells and said expression is dose dependent.

Example 7: Transient expression of a DNA modifying enzyme mediated by HIV-1 reverse transcription deficient vector particles *in vitro.*

In order to demonstrate the potential of reverse transcriptase deficient HIV-1 vectors to transiently express a DNA modifying enzyme such as recombinase in a way that it can induce recombination in cell, Cre expressing vectors are produced by transient transfection of 293T cells with the envelope transcomplementation plasmid encoding VSV (SEQ ID NO:4), the capsid transcomplementation (SEQ ID NO:3) and the vector plasmid encoding the Cre recombinase (SEQ ID NO:14). The produced vectors are used to transduce CV-1 5B reporter cells.

The CV-1 5B reporter cell line created by Kellendonk et al.(Kellendonk C , Tranche F., Monaghan A.P., Angrand P.O., Stewart F., Schutz G. Nucleic Acids Res. 1996;24:1404-1411) harbours a stable integration of the pHSVtk/loxNeolox/NLS-lacZ reporter construct. Expression of the *NLS-lacZgene* is only detected in cells that have undergone Cre-mediated deletion of the loxP flanked neomycin phosphotransferase gene, as shown Figure 10A.

CV-1 5B cells are transduced with increasing doses of reverse transcription deficient HIV-1 vectors (0 µL, 1 µL, 3 µL, 5 µL, 7 µL, 9 µL per 100,000 cells) and grown for 72 hours in 6 well-plates. Cells are then fixed and LacZ expression is revealed by X-Gal assay. Results are shown Figure 10B.

These results show that the reverse transcription deficient particles comprising the sequence coding for a DNA modifying enzyme, for instance the Cre recombinase, allow the expression of said DNA modifying enzyme. For instance, the Cre recombinase was expressed in a way that it can induce the recombination of the LacZ locus in CV-1 5B target cells and further induce LacZ expression.

Example 8: Transient expression of a DNA modifying enzyme mediated by HIV-1 reverse transcription deficient vector particles *in vitro* results from genuine transduction mechanism.

In order to demonstrate that the transgene expression observed after transduction with reverse transcription deficient vectors results from of genuine transduction mechanism (expression from the RNA vector genome brought by the vector particle) and does not result from contamination of the vector preparation by plasmid used during the production, experience described in Example 7 is reproduced with or without initial treatment of the vector preparation with 1 µg/mL DNase and with or without including the VSV plasmid during the production.

Results presented on Figure 10C show that Cre recombination is not dependent on DNAse treatment but dependent on the presence of VSV glycoprotein on the particle envelope.

These results show that the reverse transcription deficient particles comprising the sequence coding for the Cre recombinase allow the expression of Cre recombinase 72 hours after contact with target cells and said expression does not result from pseudo-transduction or contamination with DNA plasmid but results from a genuine transduction mechanism since (i) it is dependent on fusion of the particle with the cell membrane through interaction with VSV glycoprotein and (ii) it is not altered by the treatment of the vector preparation with DNase.

Example 9: Transient expression of a DNA modifying enzyme mediated by HIV-1 reverse transcription deficient vector particles for genetic engineering of an animal.

Cre expressing vectors as described in Example 7 are also used in genetic engineering application. In this assay, Cre ROSA 26 (R26R) mice are used. This mouse strain contains a construction similar to the one harboured by the CV1-5B cells and presented on Figure 11A. The LacZ expression requires a recombination induced by the Cre recombinase.

Eggs from R2R6 mice are fertilized and collected. They are microinjected with Cre expressing reverse transcription deficient HIV-1 vectors and transferred into pseudo-pregnant females. Embryos are allowed to develop for 13 days and then collected and LacZ expression is assayed. As showed on the Figure 11B and 11C, one embryo out of 24 that developed in the females after transgenesis, undergone a recombination mediated by Cre (positive for LacZ assay). This result is confirmed by PCR analysis performed on the DNA on the embryos: using primers located both upstream and downstream of the LoxP sequences, as shown on Figure 11A, the recombination is evidenced on the genomic DNA level (see Figure 11D).

These results show that the reverse transcription deficient particles comprising the sequence coding for the Cre recombinase allow the expression of Cre recombinase in a way that it can induce the recombination of the LacZ locus during a transgenesis procedure in ROSA26 mice, thus generating genetically modified animals.

CLAIMS

1. A recombinant lentiviral vector which cannot by its own achieve complete reverse transcription wherein the vector comprises a recombinant ribonucleic vector genome comprising a 5' LTR retroviral sequence and a 3' LTR retroviral sequence flanking: a functional retroviral psi encapsidation sequence and at least one transgene, and wherein the recombinant ribonucleic vector genome (i) does not comprise a primer binding site (PBS) or (ii) comprises a PBS comprising a mutation or a misplaced PBS, thereby preventing the reverse transcription of said recombinant ribonucleic vector genome.

2. The vector according to claim 1, wherein said lentiviral vector is derived from HIV-1, HIV-2, SIV, FIV, EIAV, BIV, VISNA, CAEV and any combination thereof.

3. The vector according to anyone of claims 1 or 2, wherein the mutation in the primer binding site (PBS) preventing reverse transcription of the recombinant ribonucleic vector genome is selected from a deletion, an addition and a substitution of at least one nucleotide, preferably at least 3 nucleotides.

4. The vector according to claim 3, wherein the vector is a HIV-1 derived vector and the mutation is a deletion of the HIV-1 PBS sequence corresponding to SEQ ID NO:15 (DNA) and SEQ ID NO:17 (RNA).

5. The vector according to anyone of claims 1 to 4, wherein the recombinant lentiviral vector genome further comprises a posttranscriptional regulatory sequence chosen from WPRE, APP 5'UTR, TAU 3'UTR, and a miRNA target sequence.

6. The vector according to anyone of the preceding claims, wherein the transgene is selected from a catalytic nucleic acid, an aptamer, a miRNA, a decoy RNA, a nucleic acid encoding a biologically active peptide, for example an enzyme, a transcription factor, a growth factor, a trophic factor, an hormone, a cytokine, an antibody, a receptor, a differentiation factor, a colony stimulation factor, a suicide protein, a cell-cycle modifying protein, an anti-proliferative protein, a nuclease, a recombinase, a transposase, a neurotransmitter or a precursor thereof.

7. A method for preparing a lentiviral vector which cannot by its own achieve complete reverse transcription according to anyone of claims 1 to 6, wherein said method comprises expressing within a cell:

a. a vector cassette encoding for a lentiviral recombinant ribonucleic vector genome comprising a 5' LTR retroviral sequence and a 3' LTR retroviral sequence flanking: a functional retroviral psi encapsidation sequence and at least one transgene, and wherein the recombinant ribonucleic vector genome (i) does not comprise a primer binding site (PBS) or (ii) comprises a PBS comprising a mutation or a misplaced PBS, thereby preventing the reverse transcription of said recombinant ribonucleic vector genome, and

b. a transcomplementation envelope cassette encoding for an envelope glycoprotein, and

c. a transcomplementation capsid cassette encoding for sequences derived from a lentiviral genome comprising retroviral *gag* and *pol* sequences, said transcomplementation capsid sequences lacking any functional psi encapsidation signal, and said transcomplementation capsid sequences being optionally split into several cassettes, and

recovery of the retroviral vector produced.

8. A lentiviral vector obtainable with a method according to claim 7.

9. A nucleic acid sequence comprising a vector cassette encoding for a lentiviral recombinant ribonucleic vector genome comprising a 5' LTR retroviral sequence and a 3' LTR retroviral sequence flanking: a functional retroviral psi encapsidation sequence and at least one transgene, and wherein the recombinant ribonucleic vector genome (i) does not comprise a primer binding site (PBS) or (ii) comprises a PBS comprising a mutation or a misplaced PBS, thereby preventing the reverse transcription of said recombinant ribonucleic vector genome, and optionally:

- a nucleic acid sequence comprising a transcomplementation envelope cassette encoding for an envelope glycoprotein, and/or
- a nucleic acid sequence comprising a transcomplementation capsid cassette encoding for sequences derived from a lentiviral genome comprising retroviral *gag* and *pol* sequences, said transcomplementation capsid sequences lacking any functional psi encapsidation signal, and said transcomplementation capsid sequences being optionally split into several cassettes

10. The nucleic acid sequence according to claim 9, wherein the sequence is selected from a linear nucleic acid sequence, a plasmid, an artificial chromosome, a viral vector genome, and a transposon.

11. A cell or cell line comprising a nucleic acid sequence according to claim 9 or 10.

12. A composition comprising a vector according to anyone of claims 1 to 6 or 8, a nucleic acid sequence according to claim 9 or 10, and/or a cell or a cell line according to claim 11.

13. A composition according to claim 12, wherein the composition is a pharmaceutical composition comprising a vector according to anyone of claims 1 to 6 or 8, a nucleic acid sequence according to claim 9 or 10, and/or a cell or a cell line according to claim 11, and a pharmaceutically acceptable excipient.

14. A kit comprising a vector according to anyone of claims 1 to 6 or 8, a nucleic acid sequence according to claim 9 or 10, a cell or a cell line according to claim 11 and/or a composition according to claim 12 or 13, and preferably written instructions for using the kit.

15. A vector according to anyone of claims 1 to 6 or 8, a nucleic acid sequence according to claim 9 or 10, a cell or a cell line according to claim 11, a composition according to claim 12 or 13 and/or of a kit according to claim 14, for transiently expressing at least one transgene *in vitro, ex vivo* or for use *in vivo.*

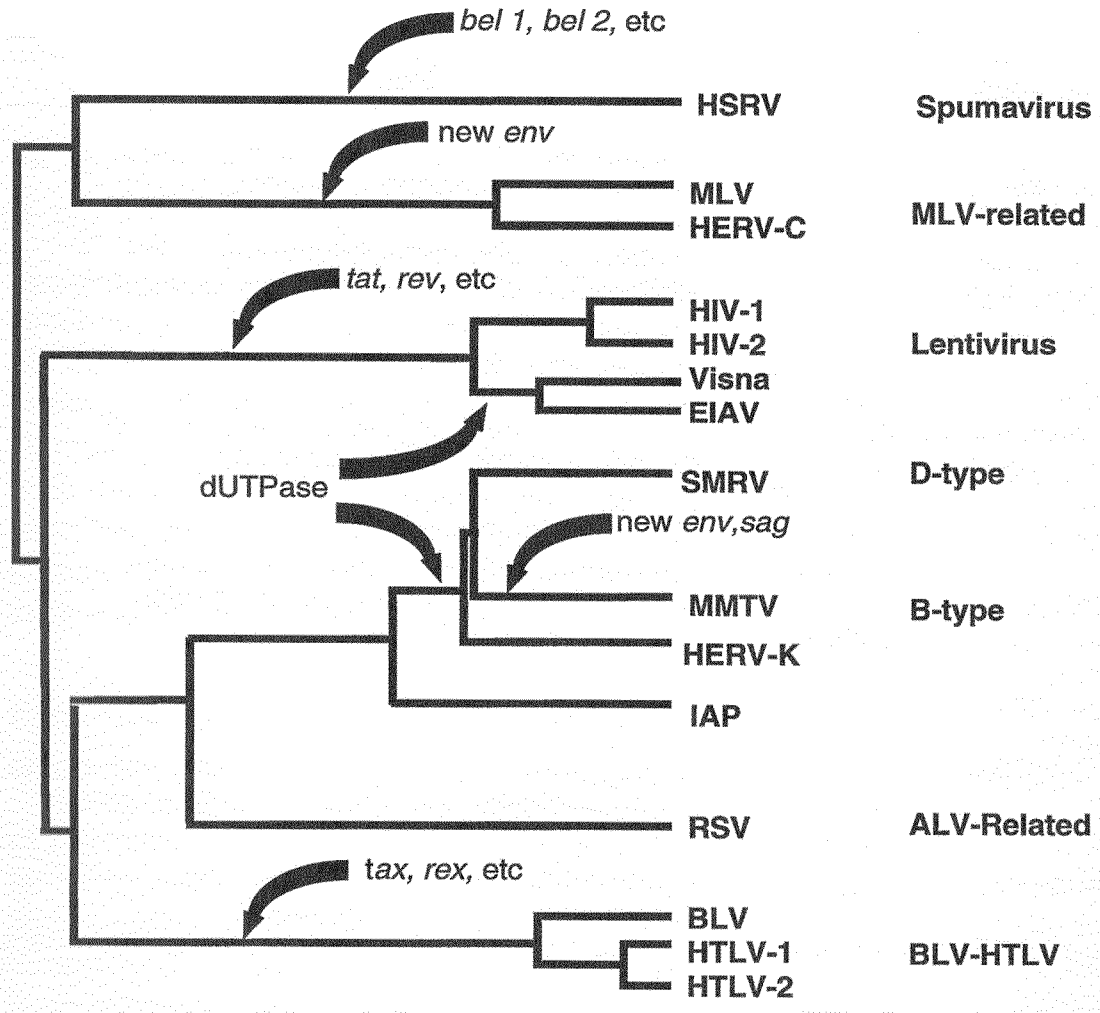

bel 1, bel 2, etc
HSRV
Spumavirus
new env
MLV
HERV-C
MLV-related
tat, rev, etc
HIV-1
HIV-2
Visna
EIAV
Lentivirus
dUTPase
SMRV
D-type
new env,sag
MMTV
HERV-K
B-type
IAP
RSV
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tax, rex, etc
BLV
HTLV-1
HTLV-2
BLV-HTLV

Figure 1

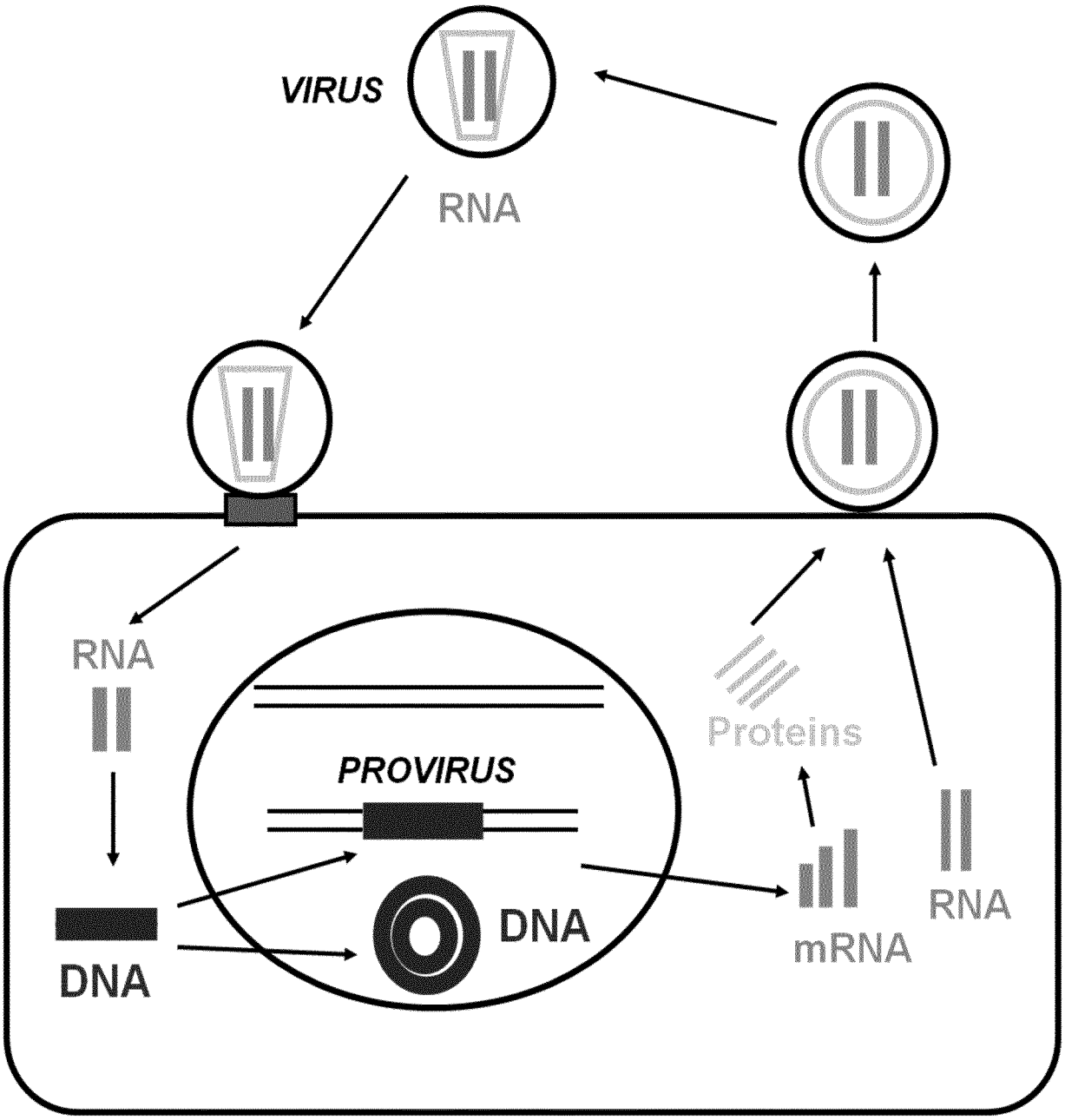


Figure 2

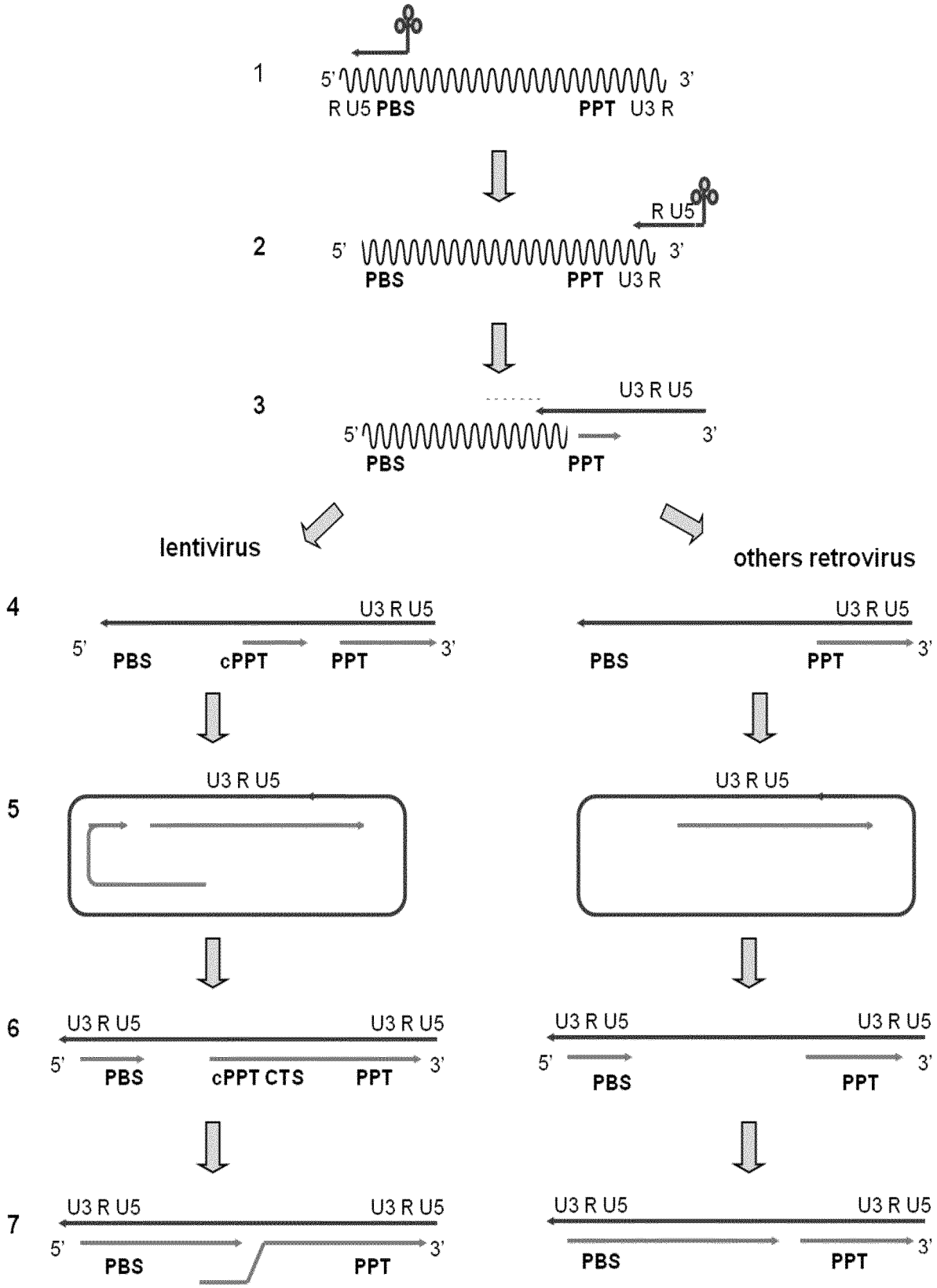

1
5'
3'
R U5 PBS
PPT U3 R
2
R U5
5'
3'
PBS
PPT U3 R
3
U3 R U5
5'
3'
PBS
PPT
lentivirus
others retrovirus
4
U3 R U5
5'
PBS
cPPT
PPT
3'
U3 R U5
PBS
PPT
3'
5
U3 R U5
U3 R U5
6
U3 R U5
U3 R U5
5'
PBS
cPPT CTS
PPT
3'
U3 R U5
U3 R U5
5'
PBS
PPT
3'
7
U3 R U5
U3 R U5
5'
PBS
PPT
3'
U3 R U5
U3 R U5
PBS
PPT
3'

Figure 3

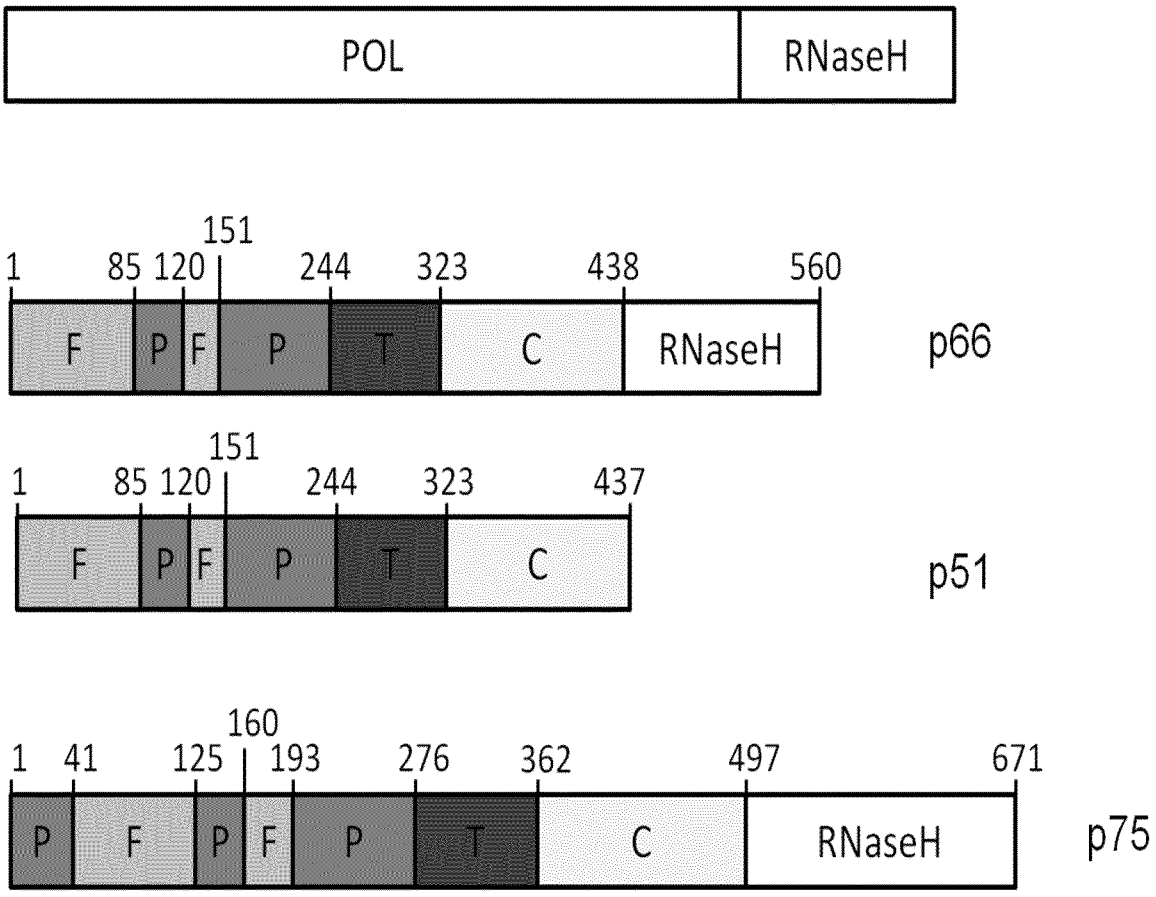
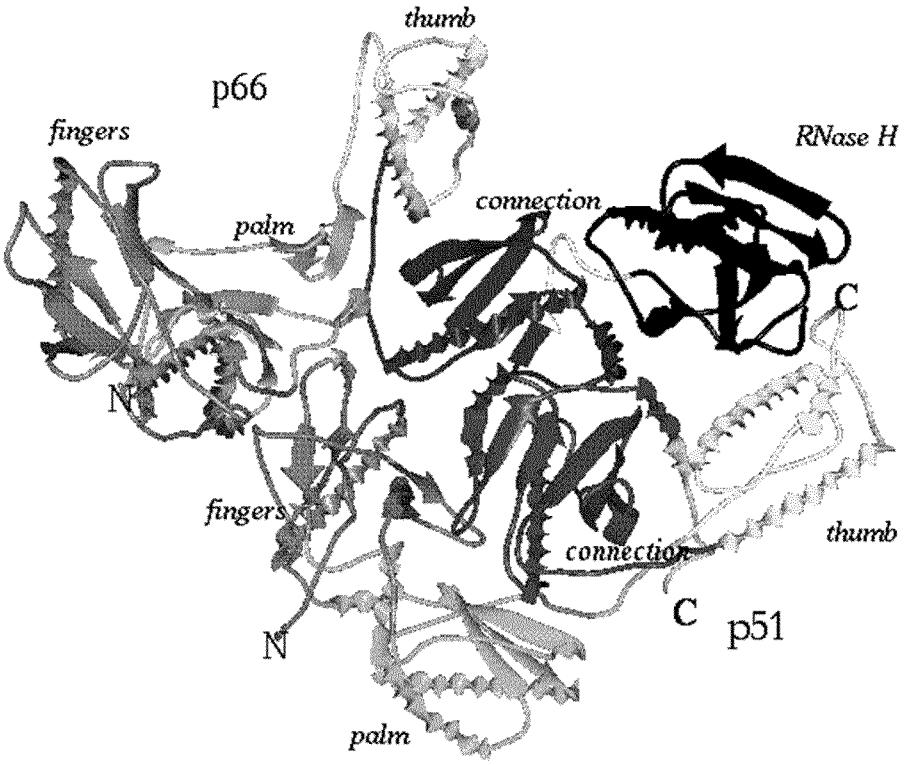

POL
RNaseH
1
85
120
151
244
323
438
560
F
P
F
P
T
C
RNaseH
p66
1
85
120
151
244
323
437
F
P
F
P
T
C
p51
1
41
125
160
193
276
362
497
671
P
F
P
F
P
T
C
RNaseH
p75

Figure 4


thumb
p66
fingers
RNase H
palm
connection
C
N
fingers
thumb
connection
C
p51
N
palm

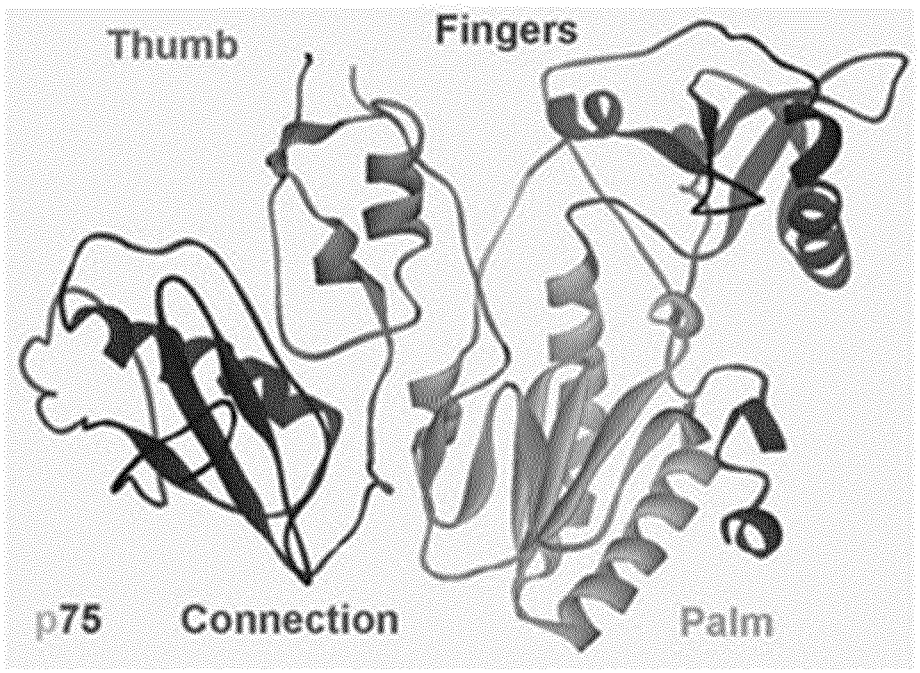

Thumb
Fingers
p75
Connection
Palm

Figure 5

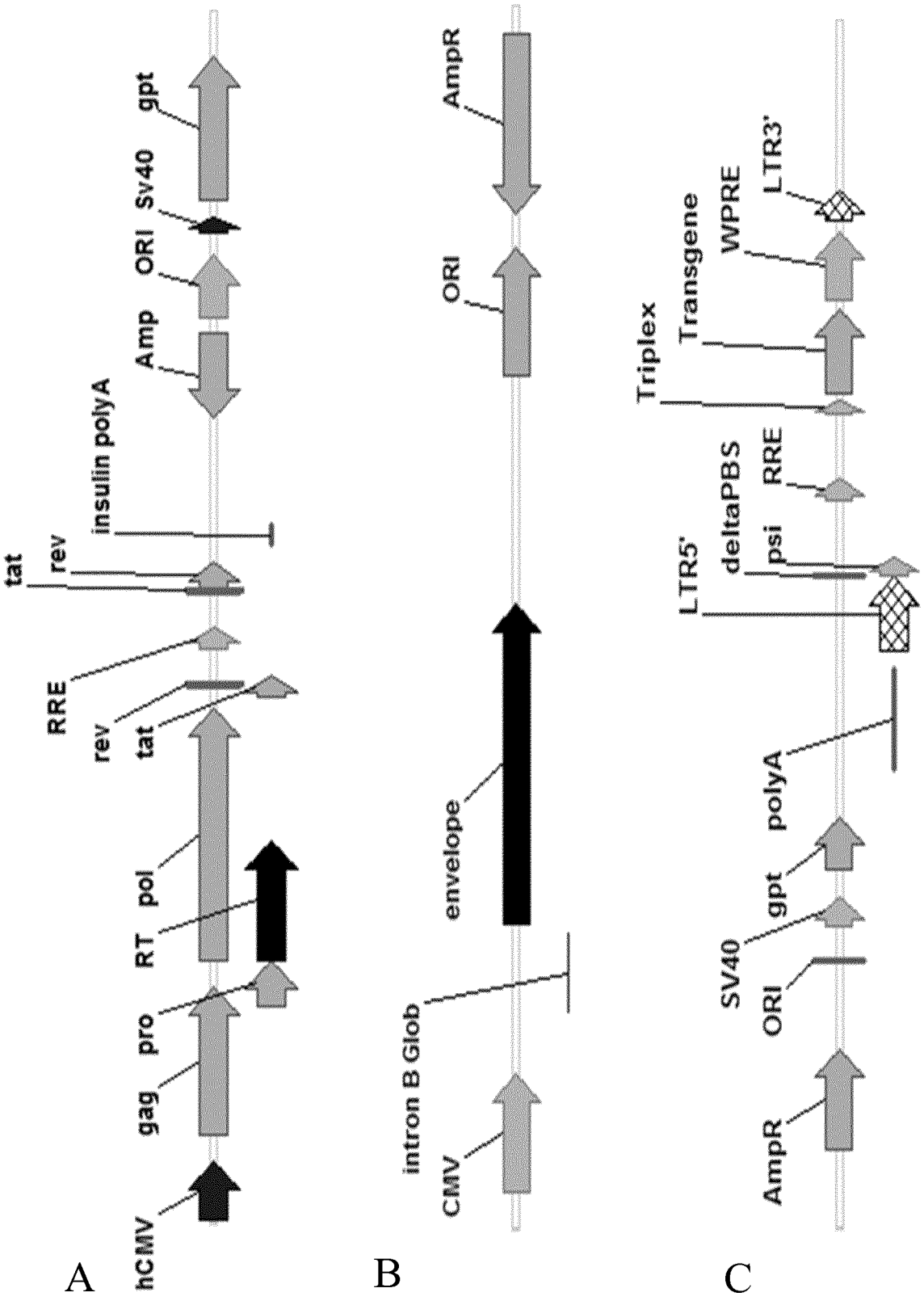
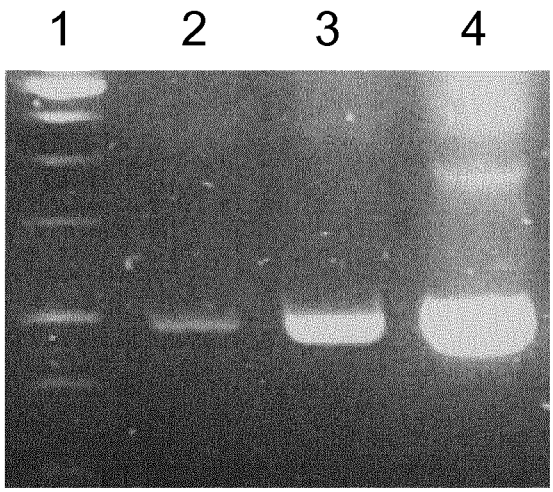
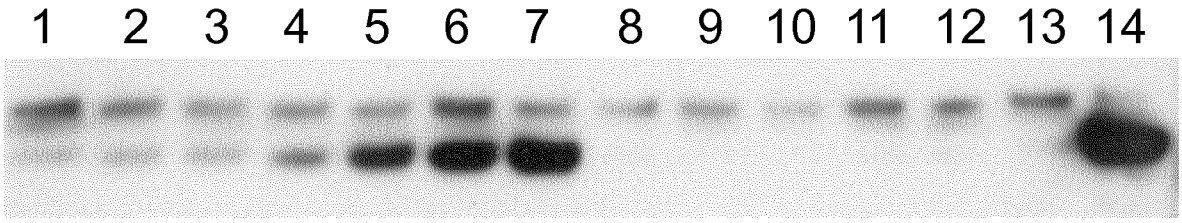

hCMV
gag
pro
RT
pol
RRE
rev
tat
tat
rev
insulin polyA
Amp
ORI
Sv40
gpt
A
CMV
intron B Glob
envelope
ORI
AmpR
B
AmpR
ORI
SV40
gpt
polyA
LTR5'
deltaPBS
psi
RRE
Triplex
Transgene
WPRE
LTR3'
C

Figure 6

A



B



C

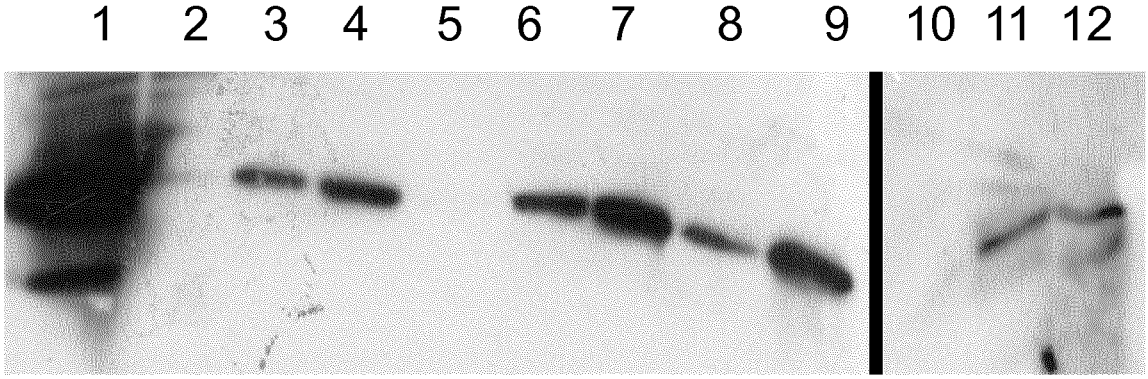


Figure 7

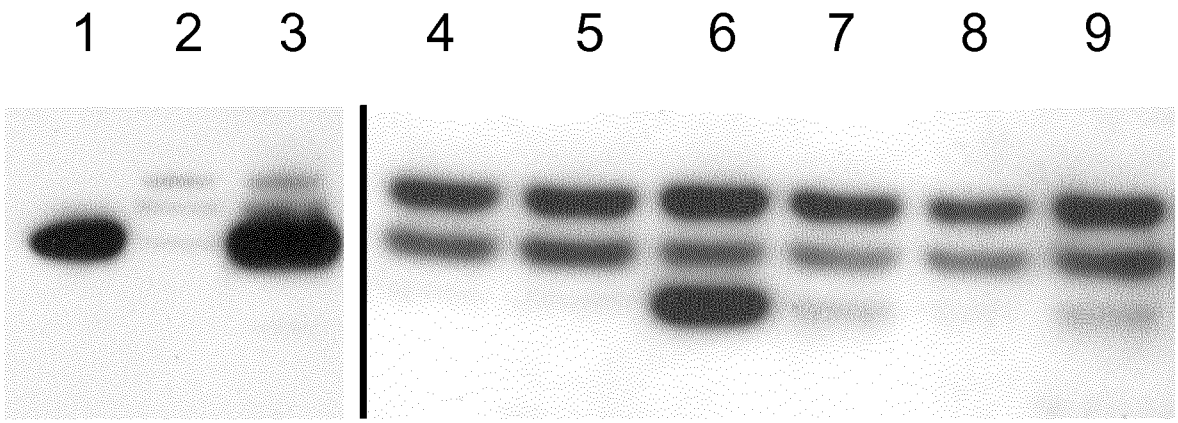


Figure 8

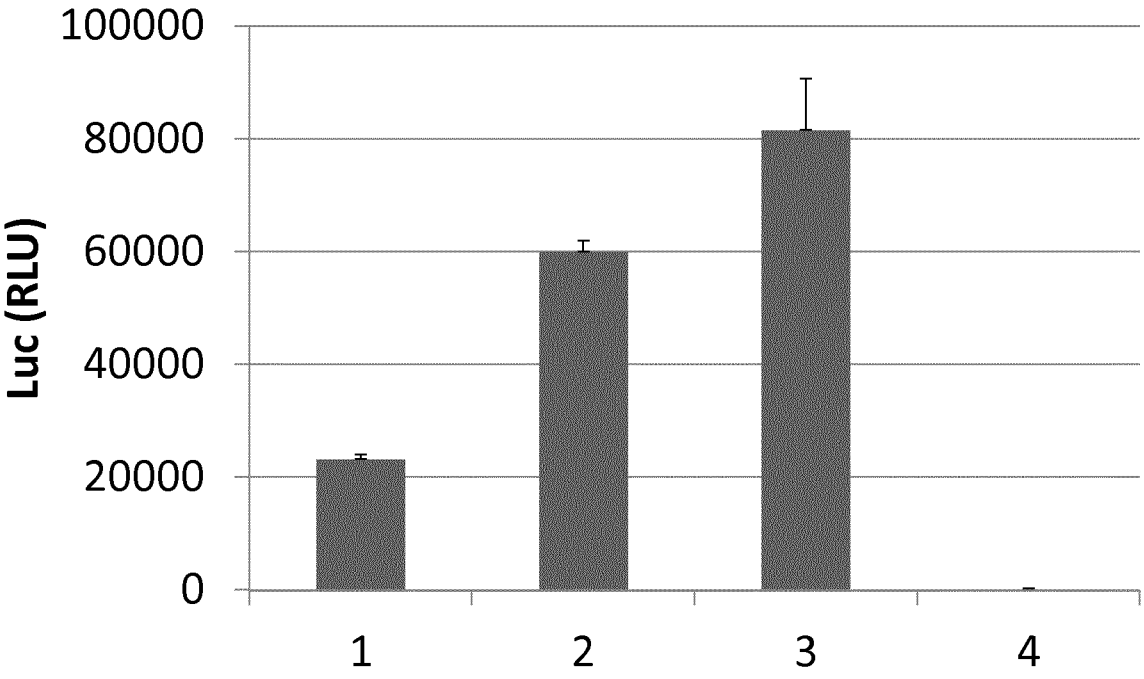


Figure 9

A

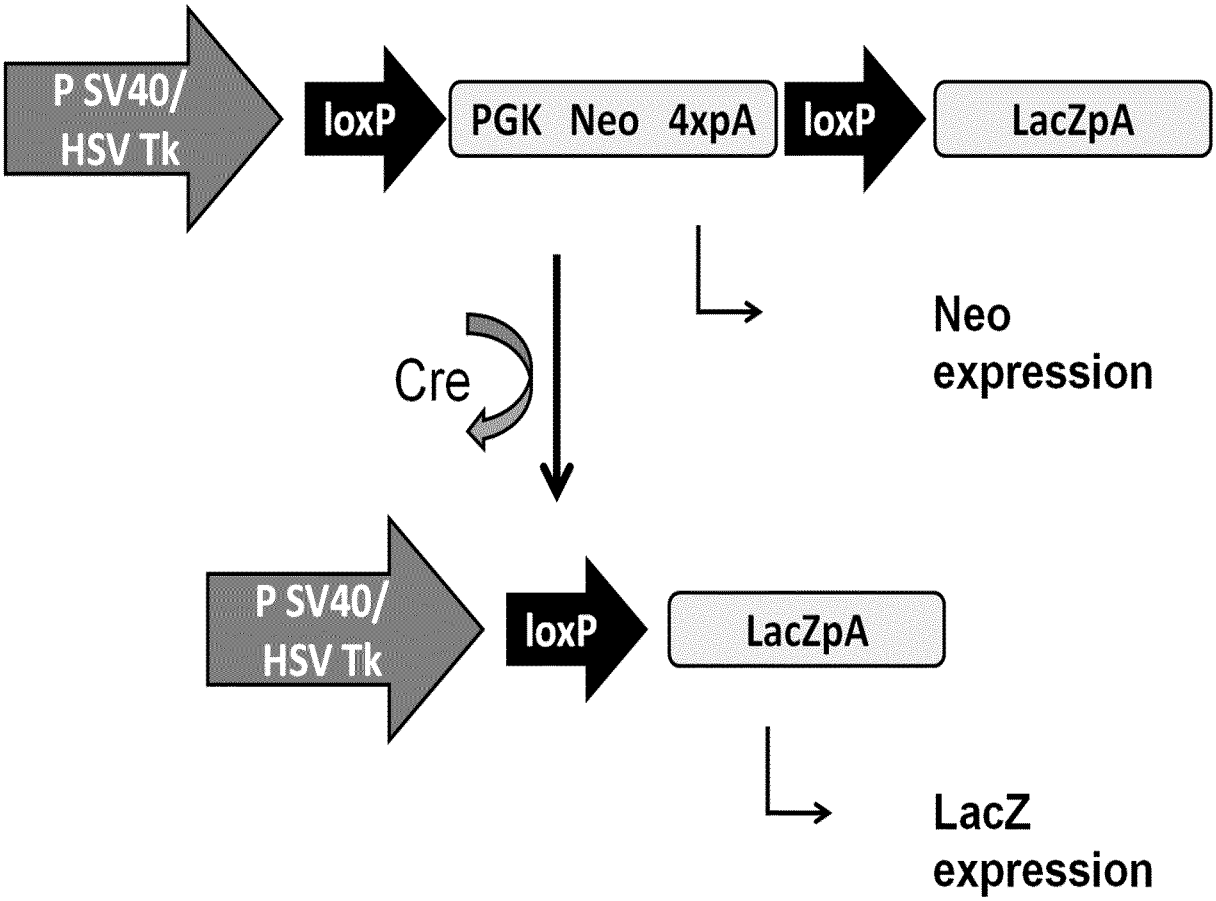
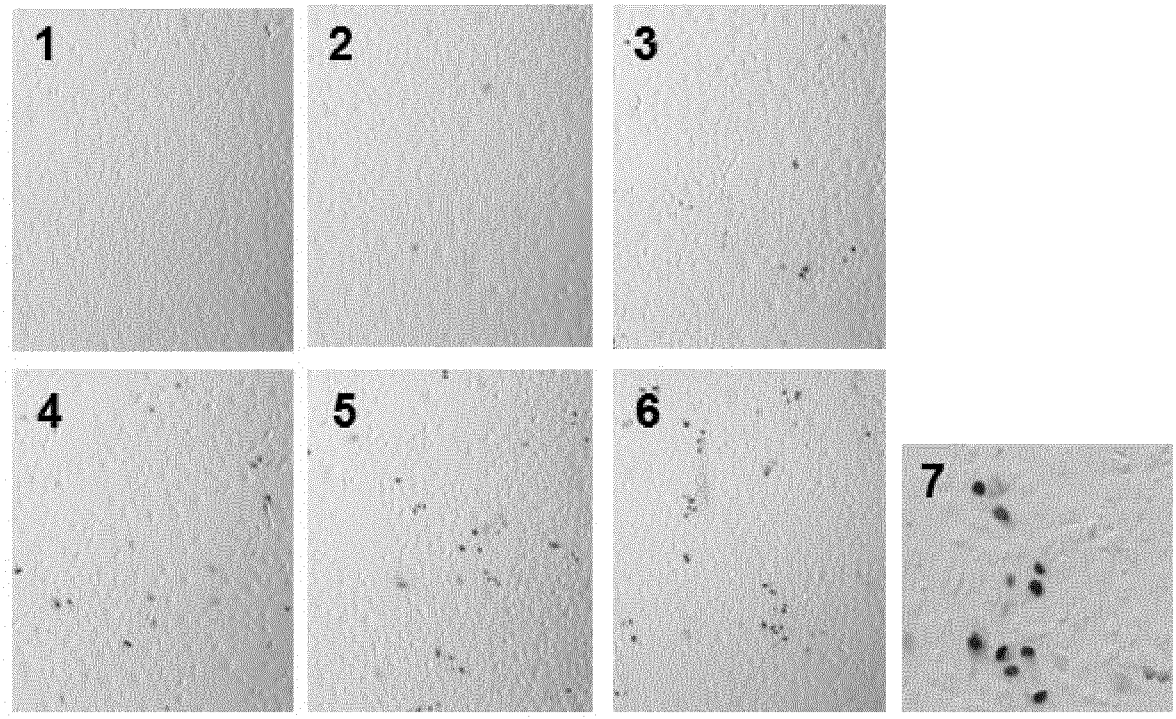

P SV40/
HSV Tk
loxP
PGK Neo 4xpA
loxP
LacZpA
Neo
expression
Cre
P SV40/
HSV Tk
loxP
LacZpA
LacZ
expression

Figure 10

B



C

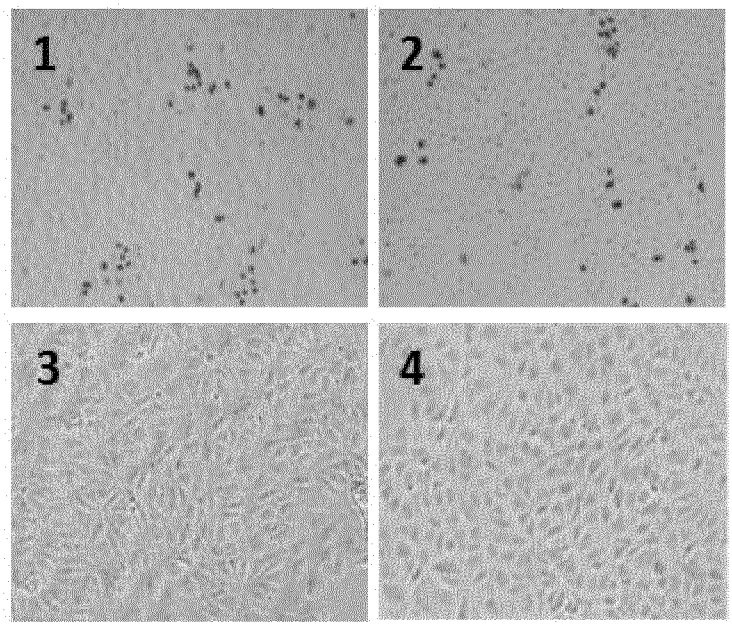


Figure 10 (continued)

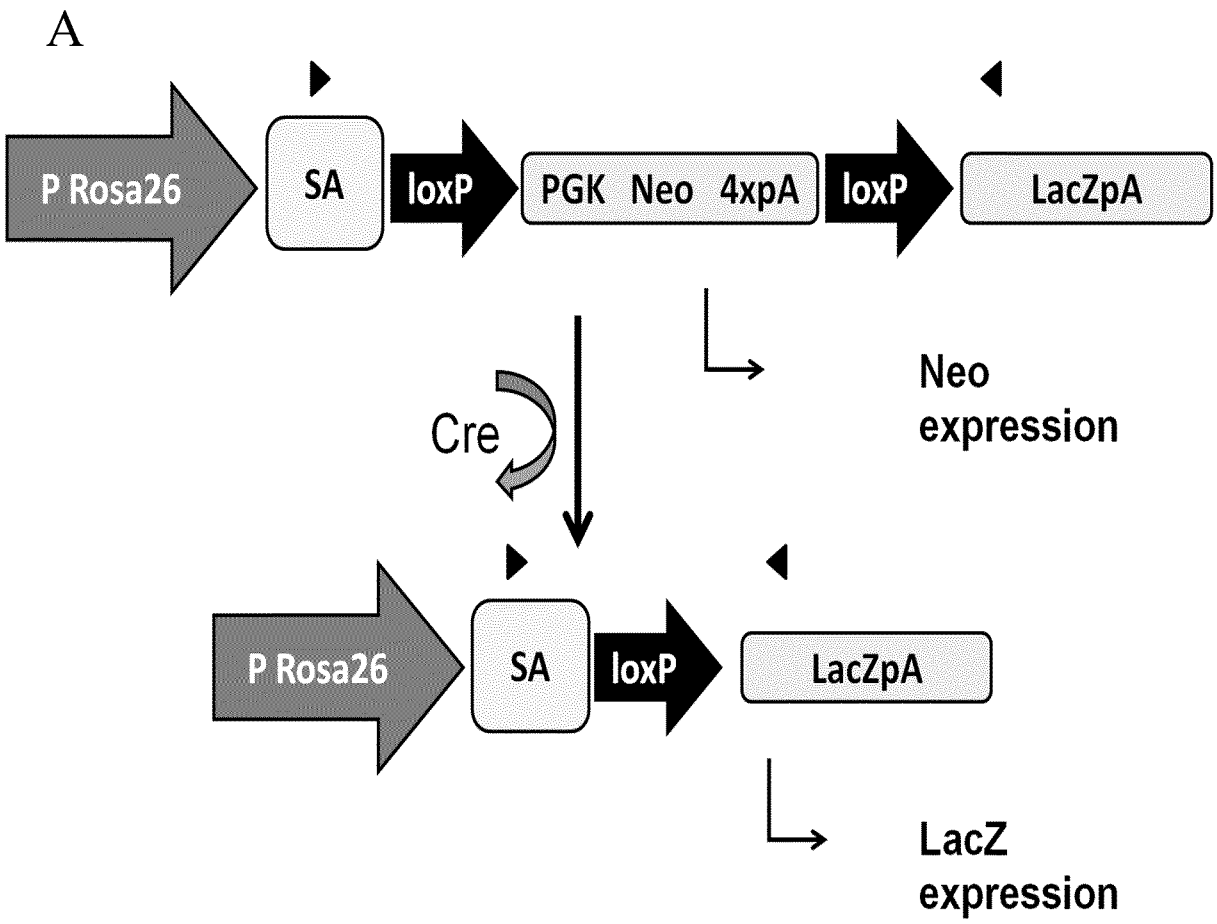
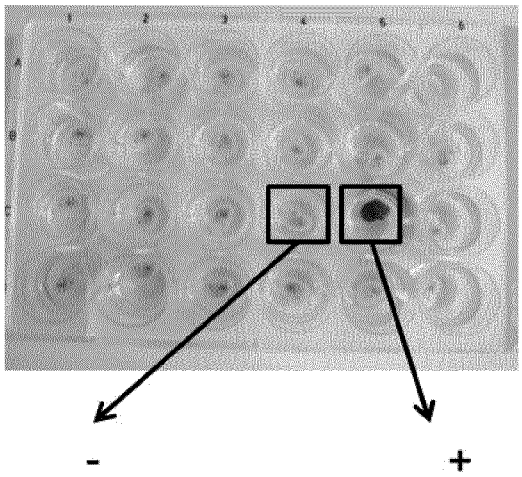
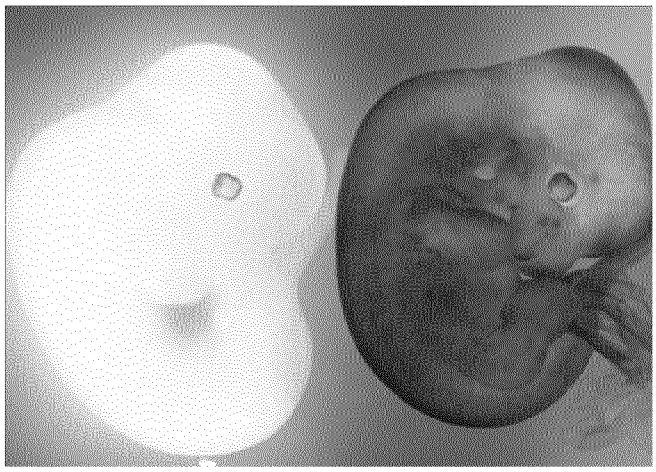

A
P Rosa26
SA
loxP
PGK Neo 4xpA
loxP
LacZpA
Neo expression
Cre
P Rosa26
SA
loxP
LacZpA
LacZ expression

Figure 11

B



C



D

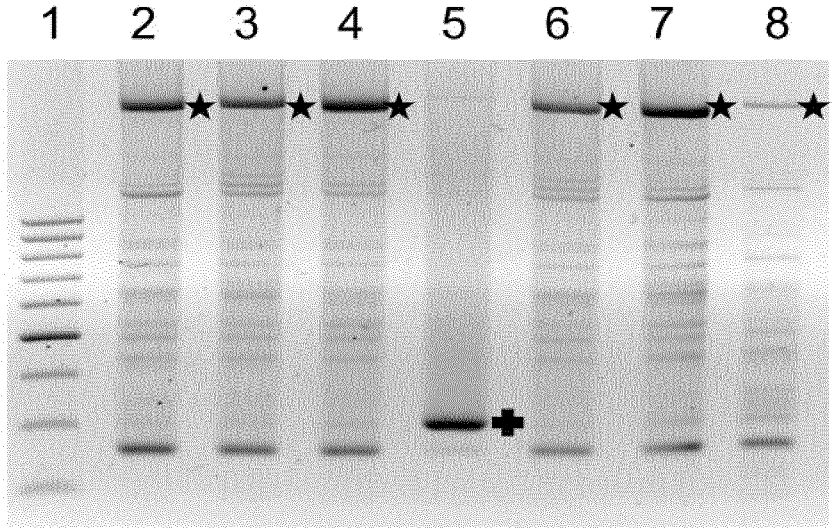


Figure 11 (continued)