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(54) **Titre : COMPOSITIONS ET PROCEDES POUR L'EXCISION IN VIVO D'ADN PROVIRAL DE VIH-1**
(54) **Title: COMPOSITIONS AND METHODS FOR IN VIVO EXCISION OF HIV-1 PROVIRAL DNA**

(57) **Abrégé/Abstract:**

Methods and kits for excising HIV-1 DNA in vivo are provided, which employ Clustered Regularly Interspaced Short Palindromic Repeats (CRISPR) and CRISPR-Associated (cas) proteins. Vectors harboring nucleic acids encoding one or more guide RNA, wherein said guide RNA hybridizes with a target HIV-1 DNA are also provided.



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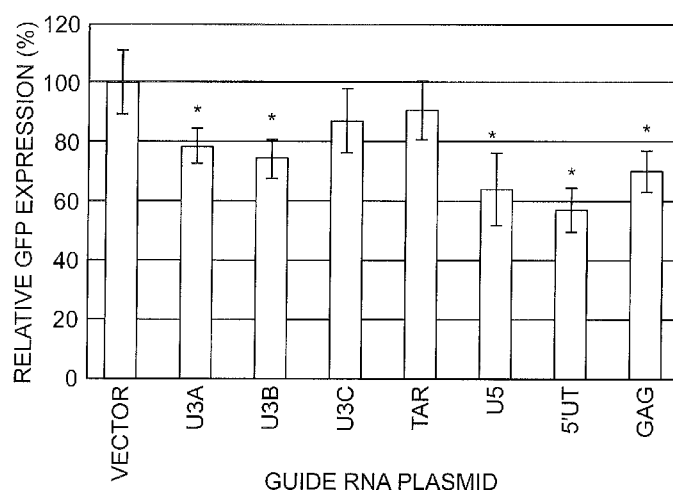


FIG. 4A

(57) Abstract: Methods and kits for ex-
cising HIV-1 DNA in vivo are provided,
which employ Clustered Regularly Inter-
spaced Short Palindromic Repeats (CRIS-
PR) and CRISPR-Associated (cas) pro-
teins. Vectors harboring nucleic acids en-
coding one or more guide RNA, wherein
said guide RNA hybridizes with a target
HIV-1 DNA are also provided.

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**Compositions and Methods for *In Vivo* Excision of HIV-1
Proviral DNA**

Introduction

[0001]

[0002] This invention was made with government support under Grant No. 001 awarded by the Veteran's Administration. The government has certain rights in the invention.

Background

[0003] The CRISPR (Clustered Regularly Interspaced Short Palindromic Repeat); SPIDR (Spacers Interspersed Direct Repeats), VNTR (Variable Number of Tandem Repeats), SRVR (Short Regularly Variable Repeats), or SRSR (Short Regularly Spaced Repeats) loci, described by Jansen et al. ((2002) *OMICS J. Integr. Biol.* 6:23-33), constitute a novel family of repeat sequences that is present in Bacteria and Archaea but not in Eukaryotes. The repeat loci are typically composed of repetitive stretches of nucleotides with a length of 25 to 37 base pairs alternated by nonrepetitive DNA spacers of approximately equal length.

[0004] The primary products of the CRISPR loci appear to be short RNAs that contain the invader targeting sequences, and are termed prokaryotic silencing RNAs (psiRNAs) based on their role in the pathway (Makarova, et al. (2006) *Biol. Direct* 1:7; Hale, et al. (2008) *RNA* 14:2572-2579). RNA analysis indicates that CRISPR locus transcripts are cleaved within the repeat sequences to release ~60-nt to 70-nt RNA intermediates that contain individual invader

targeting sequences and flanking repeat fragments (Tang, et al. (2002) *Proc. Natl. Acad. Sci. USA* 99:7536-7541; Tang, et al. (2005) *Mol. Microbiol.* 55:469-481; Lillestol, et al. (2006) *Archaea* 2:59-72; Brouns, et al. (2008) *Science* 321:960-964; Hale, et al. (2008) *RNA* 14:2572-2579). In the archaeon *Pyrococcus furiosus*, these intermediate RNAs are further processed to abundant, stable ~35-nt to 45-nt mature psiRNAs (Hale, et al. (2008) *supra*). The use of the CRISPR/CRISPR-associated (Cas) system for synthetic biology, direct and multiplexed perturbation of gene networks and targeted *ex vivo* and *in vivo* gene therapy has been suggested (Mali, et al. (2013) *Science* 339:823-6). However, particular molecules for targeting exogenous DNA integrated into the human genome have not been described.

Summary of the Invention

[0005] This invention is a method for inhibiting the function or presence of a target human immunodeficiency virus 1 (HIV-1) DNA sequence in a eukaryotic cell by contacting a eukaryotic cell harboring a target HIV-1 DNA sequence with (a) one or more guide RNA, or nucleic acids encoding said one or more guide RNA, and (b) a Clustered Regularly Interspaced Short Palindromic Repeats-Associated (cas) protein, or nucleic acids encoding said cas protein, wherein said guide RNA hybridizes with said target HIV-1 DNA sequence thereby inhibiting the function or presence of said target HIV-1 DNA sequence. In one embodiment, the target HIV-1 DNA sequence is selected from the group consisting of SEQ ID NO:2-10. In other embodiments, the cas protein is cas9, codon-optimized for expression in human cells and/or includes a nuclear localization sequence.

[0006] A kit containing (a) one or more guide RNA, or nucleic acids encoding said one or more guide RNA, wherein

said guide RNA hybridizes with a target HIV-1 DNA sequence; and (b) a cas protein; or a nucleic acid encoding said protein is also provided. In one embodiment, the target HIV-1 DNA sequence is selected from the group consisting of SEQ ID NO:2-10. In other embodiments, the cas protein is cas9, codon-optimized for expression in human cells and/or includes a nuclear localization sequence.

[0007] A vector harboring nucleic acids encoding one or more guide RNA, wherein said guide RNA hybridizes with a target human immunodeficiency virus 1 DNA sequence selected from the group consisting of SEQ ID NO:2-10 is further provided.

Brief Description of the Drawings

[0008] Figure 1 depicts the secondary structure of a guide RNA transcript with the spacer sequence from HIV-1 LTR.

[0009] Figure 2 shows the delivery of the guide RNA (gRNA) and cas protein with subsequent transcription, translation and cleavage of the HIV-1 target sequence.

[00010] Figure 3A shows the effect of HIV-specific guide RNA and hCas9 expression on the expression of endogenous LTR promoter-driven GFP expression. Transfection of an empty vector modestly activates expression of GFP (15% GFP+ cells versus 6% GFP+ cells in untreated controls). Co-transfection of hCas expression plasmid and the indicated guide RNA expression plasmids (U3A, U3B, U3C, TAR, U5, 5'UT, and GAG) in some cases (most notably U3B and U5) reduced the expression to below 10%, whereas other guide RNAs had no effect (e.g., U3A, U3C and TAR). All transfections were performed in triplicate. ANOVA statistics indicate significant differences between the empty vector and some guide RNAs with *p=<0.05; **p=<0.005; ***p=<0.0005.

[00011] Figure 3B shows the effect of HIV-specific guide RNA and hCas9 expression on the expression of endogenous LTR promoter-driven GFP expression in the presence of TNF- α . This analysis indicated that moderate activation of J-Lat cells with exposure to 5 ng/ml TNF- α for only six hours did not alter the results presented in Figure 3A, indicating durable alterations in the integrity of the LTR resulting from specific guide RNA-guided cleavage. All transfections were performed in triplicate. ANOVA statistics indicate significant differences between the empty vector and some guide RNAs with *p=<0.05; **p=<0.005; ***p=<0.0005.

[00012] Figure 4A shows that specific guide RNA reduce GFP expression from a LTR reporter plasmid. Jurkat cells were transfected with three plasmids: guide RNA, hCas and HIV-1 reporter plasmid in which an intact LTR and 5' sequence promote the expression of GFP. The results show a reduction in the percent of cells expressing GFP with several guide RNA plasmids, but not with guide RNA to U3C and TAR. The graph represents the compilation of two separate experiments each with triplicate wells, *p=<0.05.

[00013] Figure 4B shows the relative integrity of reporter plasmid LTR. Jurkat cells were transfected with three plasmids: guide RNA, hCas and HIV-1 reporter plasmid in which an intact LTR and 5' sequence promote the expression of GFP. Total DNA was isolated and assayed for integrity of the recovered reporter plasmid by real-time PCR using primers flanking the binding sites of U3B through GAG guide RNAs.

Detailed Description of the Invention

[00014] This invention provides methods and kits for using the CRISPR system to interfere with the function and/or presence of segments of human immunodeficiency virus type-1

(HIV-1) DNA, which are integrated into the host cell genome (e.g., located *in vitro* or in a subject) and are the source of new viral particles. Without this integrated segment of viral DNA, the infected cell cannot produce new viral particles, thus reducing viral burden in an infected person.

[00015] Accordingly, this invention is a method for inhibiting the function and/or presence of a target HIV-1 DNA sequence in a eukaryotic cell by administering one or more guide RNA and a cas protein, or nucleic acids encoding said guide RNA or cas protein, to a eukaryotic cell harboring a target HIV-1 DNA sequence, wherein said guide RNA hybridizes with said target HIV-1 DNA sequence thereby interfering with the function and/or presence of said target HIV-1 DNA sequence. The function of an HIV-1 DNA target sequence is inhibited when, e.g., the target sequence is no longer transcribed and/or translated. In this respect, the HIV-1 DNA target can be mutated or excised. The presence of an HIV-1 DNA target sequence is inhibited when the target sequence is, e.g., excised from the host genome.

[00016] In bacteria and archaea, the clustered regularly interspaced short palindromic repeats (CRISPR)/CRISPR-associated (Cas) system uses short RNA to direct degradation of foreign nucleic acids (DNA/RNA). CRISPR defense involves acquisition and integration of new targeting "spacers" from invading virus or plasmid DNA into the CRISPR locus, expression and processing of short guiding CRISPR RNAs (crRNAs) composed of spacer-repeat units, and cleavage of nucleic acids (most commonly DNA) complementary to the spacer.

[00017] Three classes of CRISPR systems have been described (Type I, II and III). In certain embodiments of this

invention, the Type II CRISPR system is employed as it uses a single effector enzyme, Cas9, to cleave dsDNA, whereas Type I and Type III systems require multiple distinct effectors acting as a complex (Makarova, et al. (2011) *Nat. Rev. Microbiol.* 9:467). The Type II effector system is composed of a long pre-crRNA transcribed from the spacer-containing CRISPR locus, the multifunctional Cas9 protein, and a tracrRNA for gRNA processing. The tracrRNAs hybridize to the repeat regions separating the spacers of the pre-crRNA, initiating dsRNA cleavage by endogenous RNase III, which is followed by a second cleavage event within each spacer by Cas9, producing mature crRNAs that remain associated with the tracrRNA and Cas9. However, it has been demonstrated that a tracrRNA:crRNA fusion, termed a guide RNA (gRNA) can function *in vitro*, obviating the need for RNase III and the crRNA processing in general (Jinek, et al. (2012) *Science* 337:816). Accordingly, in a particular embodiment of this invention, a guide RNA molecule is used to target a HIV-1 DNA sequence. Guide RNA molecules of this invention can range in size from 80 to 130 nucleotides, 90 to 120 nucleotides or 100 to 110 nucleotides in length and be composed of a combination of RNA and DNA. In particular embodiments, the guide RNA has the sequence R-GU UUU AGA GCU AGA AAU AGC AAG UUA AAA UAA GGC UAG UCC GUU AUC AAC UUG AAA AAG UGG CAC CGA GUC GGU GCT TTT TT (SEQ ID NO:1), wherein R is a spacer sequence that specifically hybridizes to an HIV-1 DNA target sequence.

[00018] Type II CRISPR interference is a result of Cas9 unwinding the DNA duplex and searching for sequences matching the crRNA to cleave. Target recognition occurs upon detection of complementarity between a "protospacer" sequence in the target DNA and the remaining spacer sequence in the crRNA. Cas9 cuts the DNA only if a correct

protospacer-adjacent motif (PAM) is also present at the 3' end. Different Type II systems have differing PAM requirements. The *S. pyogenes* system requires an NGG sequence, where N can be any nucleotide (Mali, et al. (2013) *Science* 339:823-6). *S. thermophilus* Type II systems require NGGNG (Horvath & Barrangou (2010) *Science* 327:167) and NNAGAAW (Deveau, et al. (2008) *J. Bacteriol.* 190:1390), respectively, while different *S. mutans* systems tolerate NGG or NAAR (van der Ploeg, et al. (2009) *Microbiology* 155:1966).

[00019] In some embodiments, the guide RNA targets one site in the HIV-1 DNA sequence. In other embodiments, more than one guide RNA is used to target multiple sites within the HIV-1 DNA sequence. In certain embodiments, the spacer of the guide RNA has a target sequence selected from those presented in Table 1. However, bioinformatic analyses have generated extensive databases of CRISPR loci in a variety of bacteria and are of use in determining PAMs and identifying addition CRISPR-targetable HIV-1 sequences (Rho, et al. (2012) *PLoS Genet.* 8:e1002441; Pride, et al. (2011) *Genome Res.* 21:126).

TABLE 1

Corresponding Region in HIV-1	Location in Corresponding Region	Guide RNA Target Sequence	SEQ ID NO:
LTR	U3	TCTACTTGCTCTGGTTCAACTGG	2
LTR	U3	GGGCCATGTGACGAAATGCTAGG	3
LTR	U3	CAGCAGTCTTTGTAGTACTCCGG	4
LTR	TAR	ACTCAAGGCAAGCTTTATTGAGG	5
LTR	U5	TACCAGAGTCACACAACAGACGG	6
GAG	5' UT	GCTGAAGCGCGCACGGCAAGAGG	7
GAG	N-term	GCGAGAGCGTCGGTATTAAGCGG	8
GAG	N-term	GAGAGCGTCGGTATTAAGCGGGG	9
GAG	Coding	GAACGATTTCGCAGTTAATCCTGG	10

LTR, long terminal repeat; u3, a control element; TAR, Tat activating region; U5, a control element; UT, untranslated sequence of Gag; N-term, N-terminal portion of Gag; coding,

within protein coding sequence of Gag. Underlined nucleotides indicate a protospacer-adjacent motif (PAM).

[00020] In particular embodiments of this invention, the guide RNA targets the LTR portion of the HIV-1 DNA. The LTR functions to promote and regulate the transcription of the genes that are essential for assembling new virions, as well as transcribing the entire HIV-1 genome, which is packaged into infectious particles. There are two copies of the LTR in the integrated provirus, thereby doubling the size of the instant target. The above identified LTR target sequences have the required PAM sequence and are unique to HIV-1, having no cross-reacting homologies in the human genome. This is of particular importance because the human genome contains many other retroviruses with LTR-like sequences. Thus, very low or no cytotoxicity is expected in uninfected cells.

[00021] The Type II CRISPR systems include the 'HNH'-type system (*Streptococcus*-like; also known as the Nmeni subtype, for *Neisseria meningitidis* serogroup A str. Z2491, or CASS4), in which Cas9 is sufficient for generating crRNA and cleaving the target DNA. Cas9 contains at least two nuclease domains, a RuvC-like nuclease domain near the amino terminus and the HNH (or McrA-like) nuclease domain in the middle of the protein. Given that the HNH nuclease domain is abundant in restriction enzymes and possesses endonuclease activity (Kleanthous, et al. (1999) *Nat. Struct. Biol.* 6:243-52; Jakubauskas, et al. (2007) *J. Mol. Biol.* 370:157-169), it has been suggested that this domain is responsible for target cleavage. Furthermore, for the *S. thermophilus* type II CRISPR-Cas system, targeting of plasmid and phage DNA has been demonstrated *in vivo* (Garneau, et al. (2010) *Nature* 468:67-71) and inactivation

of Cas9 has been shown to abolish interference (Barrangou, et al. (2007) *Science* 315:1709-12). In some embodiments of this invention, the cas protein used in the cleavage of the HIV-1 target sequence is a Type II cas protein. In other embodiments, the cas protein is a Type II cas protein isolated from *Streptococcus thermophilus*, *Listeria innocua*, *Neisseria meningitidis* or *S. pyogenes*. In other embodiments, the cas protein is a cas9 protein isolated from *Streptococcus thermophilus* (See GENBANK Accession No. YP_820832), *Listeria innocua* (See GENBANK Accession No. NP_472073), *Neisseria meningitidis* (See GENBANK Accession No. YP_002342100) or *S. pyogenes* (See GENBANK Accession Nos. AAK33936 and NP_269215). In certain embodiments, the cas9 protein has been codon-optimized for expression in human (SEQ ID NO:11). Plasmids harboring nucleic acids encoding cas9 proteins are available from repository sources such as Addgene (Cambridge, MA). Examples of such plasmids include pMJ806 (*S. pyogenes* cas9), pMJ823 (*L. innocua* cas9), pMJ824 (*S. thermophilus* cas9), pMJ839 (*N. meningitidis* cas9), and pMJ920 (human codon-optimized cas9).

[00022] To facilitate entry into the nucleus, the cas protein of the invention can include a nuclear localization sequence (NLS). The term "nuclear localization sequence" means an amino acid sequence that induces transport of molecules having such sequences or linked to such sequences into the nucleus of eukaryotic cells. In this context, the term "having" preferably means that the nuclear localization sequence forms part of the molecule, i.e. that it is linked to the remaining parts of the molecule by covalent bonds, e.g., an in-frame protein fusion. The term "linked" in this context means any possible linkage between the nuclear localization sequence and another molecule to

be introduced into the nucleus of a eukaryotic cell, e.g., by covalent bonds, hydrogen bonds or ionic interactions. The term "transport into the nucleus" in this context means that the molecule is translocated into the nucleus.

[00023] Nuclear translocation can be detected by direct and indirect means. For example, direct observation can be achieved by fluorescence or confocal laser scanning microscopy when the nuclear localization sequence or the translocated molecule (e.g., the cas protein or guide RNA) are labeled with a fluorescent dye (labeling kits are commercially available, e.g., from Pierce or Molecular Probes). Translocation can also be assessed by electron microscopy if the nuclear localization sequence or the translocated molecule (e.g., the cas protein or guide RNA) are labeled with an electron-dense material such as colloidal gold (Oliver (1999) *Methods Mol. Biol.* 115:341-345). Translocation can be assessed in indirect ways, e.g., by measuring cleavage of a target HIV-1 DNAs sequence.

[00024] A number of nuclear localization sequences have been described in the art. These include the nuclear localization sequence of the SV40 virus large T-antigen, the minimal functional unit of which is the seven amino acid sequence PKKKRKV (SEQ ID NO:12). Other examples of nuclear localization sequences include the nucleoplasmin bipartite NLS with the sequence NLSKRPAAIKKAGQAKKKK (SEQ ID NO:13) (Michaud & Goldfarb (1991) *J. Cell Biol.* 112:215-223), the c-myc nuclear localization sequence having the amino acid sequence PAAKRVKLD (SEQ ID NO:14) or RQRRNELKRSF (SEQ ID NO:15) (Chesky, et al. (1989) *Mol. Cell Biol.* 9:2487-2492) and the hRNPAI M9 NLS having the sequence NQSSNFGPMKGGNFGGRSSGPYGGGGQYFAKPRNQGGY (SEQ ID NO:16) (Siomi & Dreyfuss (1995) *J. Cell Biol.* 129:551-560). Further examples of NLSs include the sequences

RMRKFKNKGKDTAELRRRRVEVSVELRKAKKDEQILKRRNV (SEQ ID NO:17) of the IBB domain from importin-alpha (Gorlich, et al. (1995) *Nature* 377:246-248); VSRKRPRP (SEQ ID NO:18) and PPKKARED (SEQ ID NO:19) of the myoma T protein; PQPKKKPL (SEQ ID NO:20) from human p53; SALIKKKKKMAP (SEQ ID NO:21) from mouse c-abl IV (Van Etten, et al. (1989) *Cell* 58:669-678); DRLRR (SEQ ID NO:22) and PKQKKRK (SEQ ID NO:23) from influenza virus NS1 (Greenspan, et al. (1988) *J. Virol.* 62:3020-3026), RKLKKIKKL (SEQ ID NO:24) from the Hepatitis virus delta antigen (Chang, et al. (1992) *J. Virol.* 66:6019-6027); and REKKKFLKRR (SEQ ID NO:25) from the mouse Mx1 protein (Zurcher, et al. (1992) *J. Virol.* 66:5059-5066). It is also possible to use bipartite nuclear localization sequences such as the sequence KRKGDEV DGVDEVAKKSKK (SEQ ID NO:26) of the human poly(ADP-ribose) polymerase (Schreiber, et al. (1992) *EMBO J.* 11:3263-3269) or the sequence RKCLQAGMNLEARKTKK (SEQ ID NO:27) of the steroid hormone receptors (human) glucocorticoid (Cadepond, et al. (1992) *Exp. Cell Res.* 201:99-108). In some embodiments, the NLS is located at the N-terminus of the cas protein. In other embodiments, the NLS is located the C-terminus of the cas protein.

[00025] The one or more guide RNA and cas protein can be used in accordance with the methods of this invention as isolated RNA and protein, respectively. As used herein, an isolated molecule (e.g., an isolated nucleic acid such as DNA, RNA or an isolated polypeptide) means a molecule separated or substantially free from at least some of the other components of the naturally occurring organism, such as for example, the cell structural components or other polypeptides or nucleic acids commonly found associated with the molecule. In general, an isolated molecule is at

least about 25%, 50%, 60%, 70%, 75%, 80%, 85%, 90%, 95%, 97%, 98%, 99% or more pure (w/w).

[00026] Alternatively, the one or more guide RNA and cas protein can be provided to a cell or subject via isolated nucleic acids that encode the guide RNA and cas protein, respectively. In one embodiment, the isolated nucleic acids encoding the guide RNA and cas protein are provided as naked DNA. In another, embodiment, the isolated nucleic acids encoding the guide RNA and cas protein are incorporated into a gene delivery vector. In particular embodiments, the vector is an expression vector. Exemplary vectors include plasmids, lipid vectors and viral vectors. By the term express, expresses or expression of a nucleic acid it is meant that the sequence is transcribed, and in the case of the cas protein, translated thereby resulting in the production of the cas protein.

[00027] The methods of the present invention provide a means for delivering, and expressing, nucleic acids encoding a guide RNA and cas protein in human cells. In some embodiments, the nucleic acids are expressed transiently in the target cell. In other embodiments, the nucleic acids are stably incorporated into the target cell, for example, by integration into the genome of the cell or by persistent expression from stably maintained episomes (e.g., derived from Epstein Barr Virus).

[00028] As one aspect, the isolated nucleic acids, vectors, methods and kits of the invention find use in a method of administering a guide RNA and cas protein to a subject. In this manner, the guide RNA and cas protein can thus be produced *in vivo* in the subject. The subject can have, or be at risk of having an HIV-1 infection such that the guide RNA and cas protein impart a therapeutic effect, e.g., reducing viral burden or spread.

[00029] It will be apparent to those skilled in the art that any suitable vector can be used to deliver the isolated nucleic acids of this invention to the target cell(s) or subject of interest. The choice of delivery vector can be made based on a number of factors known in the art, including age and species of the target host, level and persistence of expression desired, the target cell or organ, route of delivery, size of the isolated nucleic acid, safety concerns, and the like.

[00030] Suitable vectors include virus vectors (e.g., retrovirus, alphavirus; vaccinia virus; adenovirus, adeno-associated virus, or herpes simplex virus), lipid vectors, poly-lysine vectors, synthetic polyamino polymer vectors, plasmids, and the like.

[00031] As used herein, the term viral vector or viral delivery vector can refer to a virus particle that functions as a nucleic acid delivery vehicle, and which contains the vector genome packaged within a virion. Alternatively, these terms can be used to refer to the vector genome when used as a nucleic acid delivery vehicle in the absence of the virion.

[00032] Protocols for producing recombinant viral vectors and for using viral vectors for nucleic acid delivery can be found in *Current Protocols in Molecular Biology*, Ausubel, F. M. et al. (eds.) Greene Publishing Associates, (1989) and other standard laboratory manuals (e.g., *Vectors for Gene Therapy*. In: *Current Protocols in Human Genetics*. John Wiley and Sons, Inc.: 1997). Particular examples of viral vectors include, for example, retrovirus, adenovirus, AAV, herpes virus, and poxvirus vectors.

[00033] In certain embodiments of this invention, the delivery vector is an adenovirus vector. The term adenovirus, as used herein, is intended to encompass all

adenoviruses, including the *Mastadenovirus* and *Aviadenovirus* genera. To date, at least forty-seven human serotypes of adenoviruses have been identified (see, e.g., Fields, et al., *Virology*, volume 2, chapter 67 (3d ed., Lippincott-Raven Publishers). In one embodiment, the adenovirus is a human serogroup C adenovirus, in another embodiment, the adenovirus is serotype 2 (Ad2) or serotype 5 (Ad5) or simian adenovirus such as AdC68.

[00034] Those skilled in the art will appreciate that vectors can be modified or targeted as described in Douglas, et al. (1996) *Nature Biotechnology* 14:1574 and US 5,922,315; US 5,770,442 and/or US 5,712,136.

[00035] An adenovirus genome can be manipulated such that it encodes and expresses a nucleic acid of interest but is inactivated in terms of its ability to replicate in a normal lytic viral life cycle. See, for example, Berkner, et al. (1988) *BioTechniques* 6:616; Rosenfeld, et al. (1991) *Science* 252:431-434; and Rosenfeld et al. (1992) *Cell* 68:143-155.

[00036] Recombinant adenoviruses can be advantageous in certain circumstances in that they are not capable of infecting nondividing cells and can be used to infect a wide variety of cell types. Furthermore, the virus particle is relatively stable and amenable to purification and concentration, and can be modified so as to affect the spectrum of infectivity. Additionally, introduced adenoviral DNA (and foreign DNA contained therein) is not integrated into the genome of a host cell but remains episomal, thereby avoiding potential problems that can occur as a result of insertional mutagenesis in situations where introduced DNA becomes integrated into the host genome (e.g., as occurs with retroviral DNA). Moreover, the carrying capacity of the adenoviral genome for foreign DNA

is large relative to other delivery vectors (Haj-Ahmand and Graham (1986) *J. Virol.* 57:267).

[00037] In particular embodiments, the adenovirus genome contains a deletion therein, so that at least one of the adenovirus genomic regions does not encode a functional protein. For example, an adenovirus vectors can have E1 genes and packaged using a cell that expresses the E1 proteins (e.g., 293 cells). The E3 region is also frequently deleted as well, as there is no need for complementation of this deletion. In addition, deletions in the E4, E2a, protein IX, and fiber protein regions have been described, e.g., by Armentano, et al. (1997) *J. Virology* 71:2408; Gao, et al. (1996) *J. Virology* 70:8934; Dedieu, et al. (1997) *J. Virology* 71:4626; Wang, et al. (1997) *Gene Therapy* 4:393; US 5,882,877. In general, the deletions are selected to avoid toxicity to the packaging cell. Combinations of deletions that avoid toxicity or other deleterious effects on the host cell can be routinely selected by those skilled in the art.

[00038] Those skilled in the art will appreciate that typically, with the exception of the E3 genes, any deletions will need to be complemented in order to propagate (replicate and package) additional virus, e.g., by transcomplementation with a packaging cell.

[00039] The present invention can also be practiced with gutted adenovirus vectors (as that term is understood in the art, see e.g., Lieber, et al. (1996) *J. Virol.* 70:8944-60) in which essentially all of the adenovirus genomic sequences are deleted.

[00040] Adeno-associated viruses (AAV) have also been employed as nucleic acid delivery vectors. For a review, see Muzyczka, et al. (1992) *Curr. Topics Micro. Immunol.* 158:97-129). AAV are among the few viruses that can

integrate their DNA into non-dividing cells, and exhibit a high frequency of stable integration into human chromosome 19 (see, for example, Flotte, et al. (1992) *Am. J. Respir. Cell. Mol. Biol.* 7:349-356; Samulski, et al., (1989) *J. Virol.* 63:3822-3828; McLaughlin, et al. (1989) *J. Virol.* 62:1963-1973). A variety of nucleic acids have been introduced into different cell types using AAV vectors (see, for example, Hermonat, et al. (1984) *Proc. Natl. Acad. Sci. USA* 81:6466-6470; Tratschin, et al. (1985) *Mol. Cell. Biol.* 4:2072-2081; Wondisford, et al. (1988) *Mol. Endocrinol.* 2:32-39; Tratschin, et al. (1984) *J. Virol.* 51:611-619; and Flotte, et al. (1993) *J. Biol. Chem.* 268:3781-3790).

[00041] Any suitable method known in the art can be used to produce AAV vectors expressing the nucleic acids of this invention (see, e.g., US 5,139,941; US 5,858,775; US 6,146,874 for illustrative methods). In one particular method, AAV stocks can be produced by co-transfection of a rep/cap vector encoding AAV packaging functions and the template encoding the AAV vDNA into human cells infected with the helper adenovirus (Samulski, et al. (1989) *J. Virology* 63:3822). The AAV rep and/or cap genes can alternatively be provided by a packaging cell that stably expresses the genes (see, e.g., Gao, et al. (1998) *Human Gene Therapy* 9:2353; Inoue, et al. (1998) *J. Virol.* 72:7024; US 5,837,484; WO 98/27207; US 5,658,785; WO 96/17947).

[00042] Another vector for use in the present invention is Herpes Simplex Virus (HSV). HSV can be modified for the delivery of nucleic acids to cells by producing a vector that exhibits only the latent function for long-term gene maintenance. HSV vectors are useful for nucleic acid delivery because they allow for a large DNA insert of up to

or greater than 20 kilobases; they can be produced with extremely high titers; and they have been shown to express nucleic acids for a long period of time in the central nervous system as long as the lytic cycle does not occur.

[00043] In other embodiments of the invention, the delivery vector of interest is a retrovirus. The development of specialized cell lines (termed packaging cells) which produce only replication-defective retroviruses has increased the utility of retroviruses for gene therapy, and defective retroviruses are characterized for use in gene transfer for gene therapy purposes (for a review, see Miller (1990) *Blood* 76:271). A replication-defective retrovirus can be packaged into virions which can be used to infect a target cell through the use of a helper virus by standard techniques.

[00044] In addition to viral transfer methods, such as those illustrated above, non-viral methods can also be employed. Many non-viral methods of nucleic acid transfer rely on normal mechanisms used by mammalian cells for the uptake and intracellular transport of macromolecules. In particular embodiments, non-viral nucleic acid delivery systems rely on endocytic pathways for the uptake of the nucleic acid molecule by the targeted cell. Exemplary nucleic acid delivery systems of this type include liposomal-derived systems, poly-lysine conjugates, and artificial viral envelopes.

[00045] In particular embodiments, plasmid vectors are used in the practice of this invention. Naked plasmids can be introduced into cells by injection into the tissue. Expression can extend over many months, although the number of positive cells is typically low (Wolff, et al. (1989) *Science* 247:247). Cationic lipids have been demonstrated to aid in introduction of nucleic acids into some cells in

culture (Felgner and Ringold (1989) *Nature* 337:387). Injection of cationic lipid plasmid DNA complexes into the circulation of mice has been shown to result in expression of the DNA in lung (Brigham, et al. (1989) *Am. J. Med. Sci.* 298:278). One advantage of plasmid DNA is that it can be introduced into non-replicating cells.

[00046] In a representative embodiment, a nucleic acid molecule (e.g., a plasmid) can be entrapped in a lipid particle bearing positive charges on its surface and, optionally, tagged with antibodies against cell-surface antigens of the target tissue (Mizuno, et al. (1992) *No Shinkei Geka* 20:547; WO 91/06309; JP 1047381).

[00047] Liposomes that are composed of amphiphilic cationic molecules are useful non-viral vectors for nucleic acid delivery *in vitro* and *in vivo* (reviewed in Crystal (1995) *Science* 270:404-410; Blaese, et al. (1995) *Cancer Gene Ther.* 2:291-297; Behr, et al. (1994) *Bioconjugate Chem.* 5:382-389; Remy, et al. (1994) *Bioconjugate Chem.* 5:647-654; and Gao, et al. (1995) *Gene Therapy* 2:710-722). The positively charged liposomes are believed to complex with negatively charged nucleic acids via electrostatic interactions to form lipid:nucleic acid complexes. The lipid:nucleic acid complexes have several advantages as nucleic acid transfer vectors. Unlike viral vectors, the lipid:nucleic acid complexes can be used to transfer expression cassettes of essentially unlimited size. Since the complexes lack proteins, they can evoke fewer immunogenic and inflammatory responses. Moreover, they cannot replicate or recombine to form an infectious agent and have low integration frequency. A number of publications have demonstrated that amphiphilic cationic lipids can mediate nucleic acid delivery *in vivo* and *in vitro* (Felgner, et al. (1987) *Proc. Natl. Acad. Sci. USA*

84:7413-17; Loeffler, et al. (1993) *Methods in Enzymology* 217:599-618; Felgner, et al. (1994) *J. Biol. Chem.* 269:2550-2561).

[00048] As indicated, the isolated nucleic acids (*i.e.*, encoding guide RNA and a cas protein) can be incorporated into an expression vector (viral or nonviral as described herein). Expression vectors compatible with various host cells are well-known in the art and contain suitable elements for transcription and translation of nucleic acids. Typically, an expression vector contains an expression cassette, which includes, in the 5' to 3' direction, a promoter, a coding sequence encoding one or more guide RNA and/or one or more cas protein operatively associated with the promoter, and, optionally, a termination sequence including a stop signal for RNA polymerase and a polyadenylation signal for polyadenylase. Nucleic acids encoding one or more guide RNA and one or more cas protein can be transcribed as independent molecules (*e.g.*, via independent promoters in independent vectors or the same vector) or on the same molecule, *e.g.*, as bi- or pluri-cistronic mRNA separated by internal ribosomal entry sites (IRESs).

[00049] Isolated cas proteins and/or guide RNA, or nucleic acids or vectors encoding said proteins and/or RNA of the invention can be conveniently used or administered in a composition containing the active agents in combination with a carrier. Such compositions can be prepared by methods and contain carriers which are well-known in the art. A generally recognized compendium of such methods and ingredients is Remington: The Science and Practice of Pharmacy, Alfonso R. Gennaro, editor, 20th ed. Lippincott Williams & Wilkins: Philadelphia, PA, 2000. A carrier, pharmaceutically acceptable carrier, or vehicle, such as a

liquid or solid filler, diluent, excipient, or solvent encapsulating material, is involved in carrying or transporting the subject compound from one organ, or portion of the body, to another organ, or portion of the body. Each carrier must be acceptable in the sense of being compatible with the other ingredients of the formulation and not injurious to the patient.

[00050] The protein, RNA, nucleic acids or vectors of the invention can be administered via any route including, but not limited to, oral, rectal, topical, buccal (e.g., sublingual), vaginal, parenteral (e.g., subcutaneous, intramuscular including skeletal muscle, diaphragm muscle and smooth muscle, intradermal, intravenous, intraperitoneal), topical (i.e., both skin and mucosal surfaces, including airway surfaces), intranasal, transdermal, intraarticular, intrathecal and inhalation administration, administration to the liver by intraportal delivery, as well as direct organ injection. The most suitable route in any given case will depend on the subject being treated and on the nature of the particular molecule which is being used.

[00051] Upon administration of one or more guide RNA and cas protein, either isolated or encoded by one or more nucleic acid molecules, to a eukaryotic cell harboring a target HIV-1 DNA sequence, the target HIV-1 DNA sequence is damaged or excised from the genome of the cell and the function of said target HIV-1 DNA sequence is reduced or inhibited. This RNA-directed DNA-targeting via CRISPR interference acts at the DNA level, and therefore differs fundamentally from the RNAi phenomenon observed in eukaryotes and to which CRISPR activity was originally compared (Makarova, et al. (2006) *Biol. Direct.* 1:7).

[00052] Eukaryotic cells of interest in the methods of this invention are preferably mammalian cells, especially HIV-1-positive human immune cells such as helper T cells (specifically CD4⁺ T cells), macrophages, and dendritic cells. For example, it is contemplated that introduction of the one or more guide RNA and cas protein into the bloodstream of an HIV-1 infected subject will result in transfection of cells in the bloodstream. If a cell is not HIV-1-infected, there will be no damage to the cell as the guiding RNA will not bind. In contrast, if a cell is infected with HIV-1, the guide RNA will hybridize with the target HIV-1 DNA via the spacer sequence, and the cas protein will cleave the target HIV-1 DNA thereby inhibiting the function (e.g., production of new virions/infectious particles) the HIV-1 DNA. In this respect, inhibition of HIV-1 function, using the guide RNA molecules and cas proteins of this invention, is of use in treating or preventing the spread of an HIV-1 infection.

[00053] Accordingly, this invention also provides a method for treating or preventing the spread of an HIV-1 infection by administering, to a subject infected by HIV-1, one or more guide RNA and cas protein, or nucleic acid sequences encoding said one or more guide RNA or cas protein, thereby inhibiting the function and/or presence of the HIV-1. The one or more guide RNA and cas protein, or nucleic acids encoding said one or more guide RNA or cas protein, can be administered simultaneously or sequentially. In this respect, the guide RNA or cas proteins (or nucleic acids encoding the same) can be administered in a single formulation or separate formulations. Further, it is contemplated that various combinations of guide RNA and cas proteins can be used. For example, one or more isolated guide RNA molecules can be administered in combination with

nucleic acids encoding a cas protein (e.g., in a vector). Alternatively, one or more guide RNA molecules can be administered in a vector in combination with an isolated cas protein. Further, isolated guide RNA molecules can be administered in combination with an isolated cas protein and/or one or more vectors harboring nucleic acids encoding guide RNA molecules can be administered in combination with a vector harboring nucleic acids encoding a cas protein.

[00054] Subjects benefiting from such treatment include those identified as being HIV-1-positive as well as subjects at risk of being infected with HIV-1 (e.g., health care workers that may have been exposed to a HIV virus through a needle stick or other patient contact, or patients involved in high-risk activities such as intravenous drug use). Use of the compositions and methods of this invention can decrease viral load and/or prevent the spread of HIV-1 within a subject or from subject to subject.

[00055] To facilitate use of the compositions described herein, this invention also provides a kit. The kit contains one or more guide RNA according to the invention, a cas protein as described herein, or nucleic acids encoding the guide RNA or cas protein, e.g., in one or more vectors. In some embodiments, the guide RNA has the sequence as set forth in SEQ ID NO:1. In particular embodiments, the spacer of the guide RNA targets HIV-1 DNA selected from the group of SEQ ID NO:2-10. In another embodiment, the cas protein is a cas9 protein, in particular a human codon-optimized cas9 protein, e.g., as set forth in SEQ ID NO:11. The kit can also include a pharmaceutically acceptable carrier as well as, optionally, technical instructions with information on the administration and dosage of the guide RNA and cas protein

invention can be used alone or in combination or concurrently with other conventional HIV treatments including, but not limited to highly active anti-retroviral treatments (HAART), e.g., non-nucleoside reverse transcriptase inhibitors (NNRTIs) such as efavirenz, etravirine and nevirapine; nucleoside reverse transcriptase inhibitors (NRTIs) such as Abacavir, and the combination drugs emtricitabine and tenofovir, and lamivudine and zidovudine; protease inhibitors (PIs) such as atazanavir, darunavir, fosamprenavir and ritonavir; entry or fusion inhibitors such as enfuvirtide and maraviroc; and integrase inhibitors such as raltegravir.

[00056] The invention will be further described in the following example, which does not limit the scope of the invention described in the claims.

Example 1: Targeting HIV-1 LTR *In Vivo*

[00057] Plasmid DNA encoding the guiding RNA molecule that uniquely binds to one of five specific regions located within the HIV-1 long terminal repeat region of the HIV-1 proviral DNA is generated (Figure 1). Likewise, a plasmid encoding a cas9 nuclease is generated. Both plasmids are delivered to human cells, where the cas9 and guiding RNA loci are transcribed and the cas9 transcript is translated. Subsequently, the guiding RNA segment binds the cas9 nuclease to form a hybrid complex. Because of the addition of a nuclear localization sequence, this hybrid complex enters the nucleus where the guiding RNA segment binds to its complementary sequence in the HIV-1 proviral DNA. The nuclease cuts the proviral DNA, effecting a double-stranded DNA cut that is generally not repairable. See Figure 2.

Using this method, HIV-1 proviral DNA can be excised from the genome of an infected cell.

Example 2: Use of CRISPR/Cas to Target Integrated HIV-1 LTR in J-Lat Cells

[00058] Using a J-Lat cell line (a human T cell cancer line), it was determined whether cleavage of the HIV-1 Long Terminal Repeat (LTR) region by the guide RNA:hCas9 complex alters the transcriptional activity of these cells. Flow cytometry was used to quantify cells that produce green fluorescent protein (GFP) from the LTR promoter 22 hours after transfection. Flow cytometry analysis provides both a percentage of cells that express GFP and allows the quantification of the intensity of expression within the cell population by quantifying the mean fluorescence intensity (MFI) of the GFP+ cells. Flow cytometry can distinguish between mutations in the LTR region that reduce transcription from those that completely abolish it.

[00059] For this analysis, J-Lat cells were co-transfected with HIV-specific guide RNAs recognizing several different regions within the integrated provirus as described herein, along with the plasmid encoding hCas9. As shown in Figures 3A and 3B, guide RNAs to the U3B and U5 regions of the LTR were the most effective in reducing GFP expression (indicating a disruption in the HIV-1 LTR), whereas those to the U3A, U3C and TAR regions were relatively ineffective. In addition to demonstrating the ability of the CRISPR/Cas to target the HIV-1 LTR in a human cell line, these data also underscore the utility of this cell line in providing a rapid readout of guide RNA efficacy.

Example 3: CRISPR/Cas Method for Cleave HIV-1 DNA Expressed by Plasmid DNA

[00060] To determine the efficacy of the CRISPR/Cas method to cleave within the HIV-1 LTR and alter transcription, Jurkat cells were transfected with three different plasmids. These plasmids included various guide RNAs, the humanized Cas9 plasmid, and a third (reporter) plasmid in which an intact HIV-1 LTR and 5' sequences promote the expression of GFP.

[00061] As shown in Figure 4A, the use of guide RNAs to the U3A, U3B and U5 regions in the LTR significantly reduced expression of GFP from the reporter plasmid in transfected Jurkat cells. This confirmed the results observed in J-Lat cells (Figure 3A and 3B). Interestingly, guide RNAs to the 5' untranslated region immediately downstream from the LTR (5'Untranslated region (UT) and to the gag (group antigen) region (GAG)), also reduced GFP expression from the reporter plasmid. The cells were subsequently lysed to recover the DNA and polymerase chain reaction was performed using primers to the reporter plasmid that would amplify a region from U3B through GAG (and hence not amplify the U3A region). The preliminary data (Figure 4B) indicated that the integrity of the reporter plasmid was compromised (cleaved) in transfections that included guide RNAs to U3B, U3C, GAG, and likely also to the U5 and 5'UT region, but not to TAR (a regulatory region in the HIV-1 provirus). Thus, this reporter plasmid is also of use in quickly screening guide RNAs.

What is claimed is:

1. Use of a therapeutically effective amount of a composition to inhibit function or presence of a target human immunodeficiency virus 1 (HIV-1) DNA sequence in a eukaryotic cell comprising a cellular genome and harboring a target HIV-1 DNA sequence integrated into the cellular genome, comprising:
 - the therapeutically effective amount of the composition comprising
 - (a) one or more guide RNAs, or nucleic acids encoding said one or more guide RNAs, and
 - (b) a Clustered Regularly Interspaced Short Palindromic Repeats-Associated 9 (cas9) protein, or nucleic acids encoding said cas9 protein;
 - wherein said one or more guide RNAs uniquely hybridizes with said target HIV-1 DNA sequence upon contact with the eukaryotic cell, thereby inhibiting the function or the presence of said target HIV-1 DNA sequence, wherein said target HIV-1 DNA sequence is selected from the group consisting of SEQ ID NO:3, SEQ ID NO:6, and SEQ ID NO:4.
2. The use according to claim 1, wherein the cas protein is cas9.
3. The use according to claim 1, wherein the cas protein has been codon-optimized for expression in human cells.
4. The use according to claim 1, wherein the cas protein further comprises a nuclear localization sequence.
5. A kit comprising
 - (a) one or more guide RNAs, or nucleic acids encoding said one or more guide RNAs, wherein said guide RNAs uniquely hybridizes with a target HIV-1 DNA sequence, wherein said target HIV-1 DNA sequence

is selected from the group consisting of SEQ ID NO:3, SEQ ID NO:6, and SEQ ID NO:4; and

(b) a Clustered Regularly Interspaced Short Palindromic Repeats-Associated 9 (cas9) protein, or nucleic acids encoding said cas9 protein.

6. The kit according to claim 5, wherein the cas protein is cas9.

7. The kit according to claim 5, wherein the cas protein has been codon-optimized for expression in human cells.

8. The kit according to claim 5, wherein the cas protein further comprises a nuclear localization sequence.

9. A vector comprising nucleic acids encoding one or more guide RNAs, wherein said guide RNA uniquely hybridizes with a target HIV-1 DNA sequence selected from the group consisting of SEQ ID NO:3, SEQ ID NO:4, and SEQ ID NO:6.

10. Use of a therapeutically effective amount of a composition for cleaving a LTR of a target human immunodeficiency virus 1 (HIV-1) DNA sequence in a eukaryotic cell harboring a target HIV-1 DNA sequence comprising

the therapeutically effective amount of the composition comprising

(a) one or more guide RNA, or nucleic acids encoding said one or more guide RNA, and

(b) a Clustered Regularly Interspaced Short Palindromic Repeats-Associated (cas) protein, or nucleic acids encoding said cas protein,

wherein said one or more guide RNA hybridizes with said target HIV-1 DNA sequence, wherein the LTR of the target HIV-1 DNA sequence is selected from the group consisting of base sequences designated by SEQ ID NO: 3, SEQ ID NO:4, and SEQ ID NO:6,

wherein the cas protein is Cas9,

wherein the guide RNA and Cas9 contribute to the cleaving of the LTR of the target HIV-1 DNA sequence.

11. The use of claim 10, wherein the cas protein has been codon-optimized for expression in human cells.

12. The use of claim 10, wherein the cas protein further comprises a nuclear localization sequence.

13. The use of claim 10, wherein said target HIV-1 LTR sequence is SEQ ID NO:3, and wherein said one or more guide RNA, or nucleic acids encoding said one or more guide RNA comprise the sequence of SEQ ID NO:3, or the complement thereof.

14. The use of claim 10, wherein said target HIV-1 LTR sequence is SEQ ID NO:4, and wherein said one or more guide RNA, or nucleic acids encoding said one or more guide RNA comprise the sequence of SEQ ID NO:4, or the complement thereof.

15. The use of claim 10, wherein said target HIV-1 LTR sequence is SEQ ID NO:6, and wherein said one or more guide RNA, or

nucleic acids encoding said one or more guide RNA comprise the sequence of SEQ ID NO:6, or the complement thereof.

16. The use of claim 10, wherein said nucleic acids encoding said one or more guide RNA, and said nucleic acids encoding said cas protein are contained in a viral vector.

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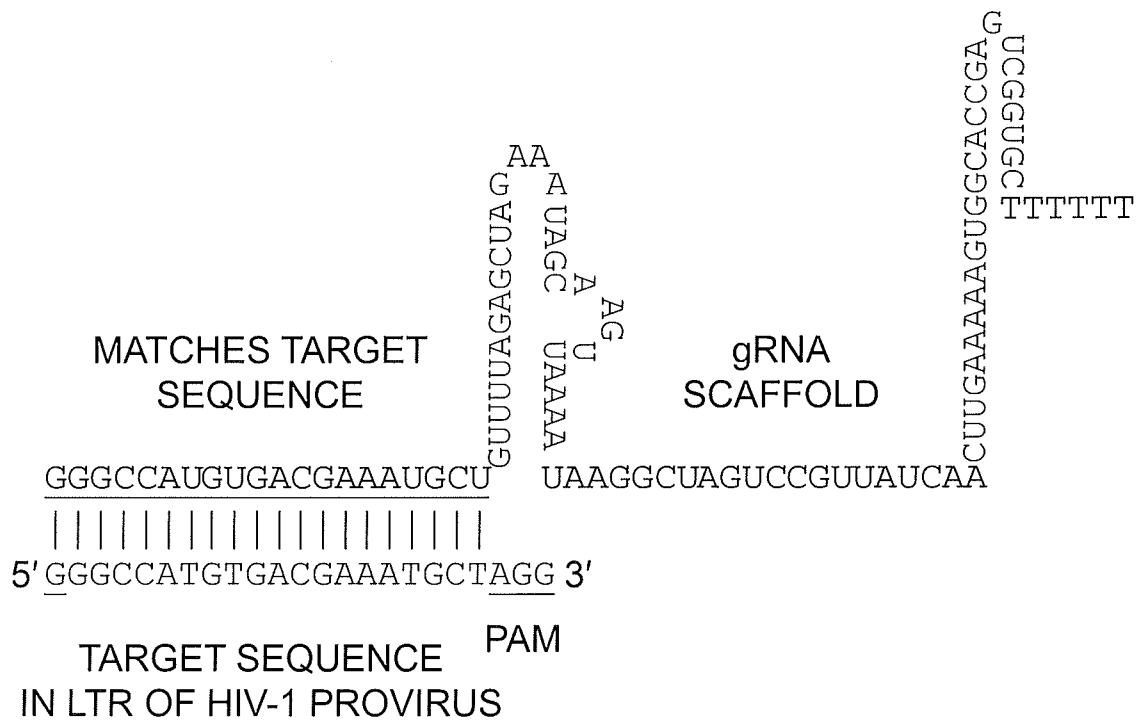


FIG. 1

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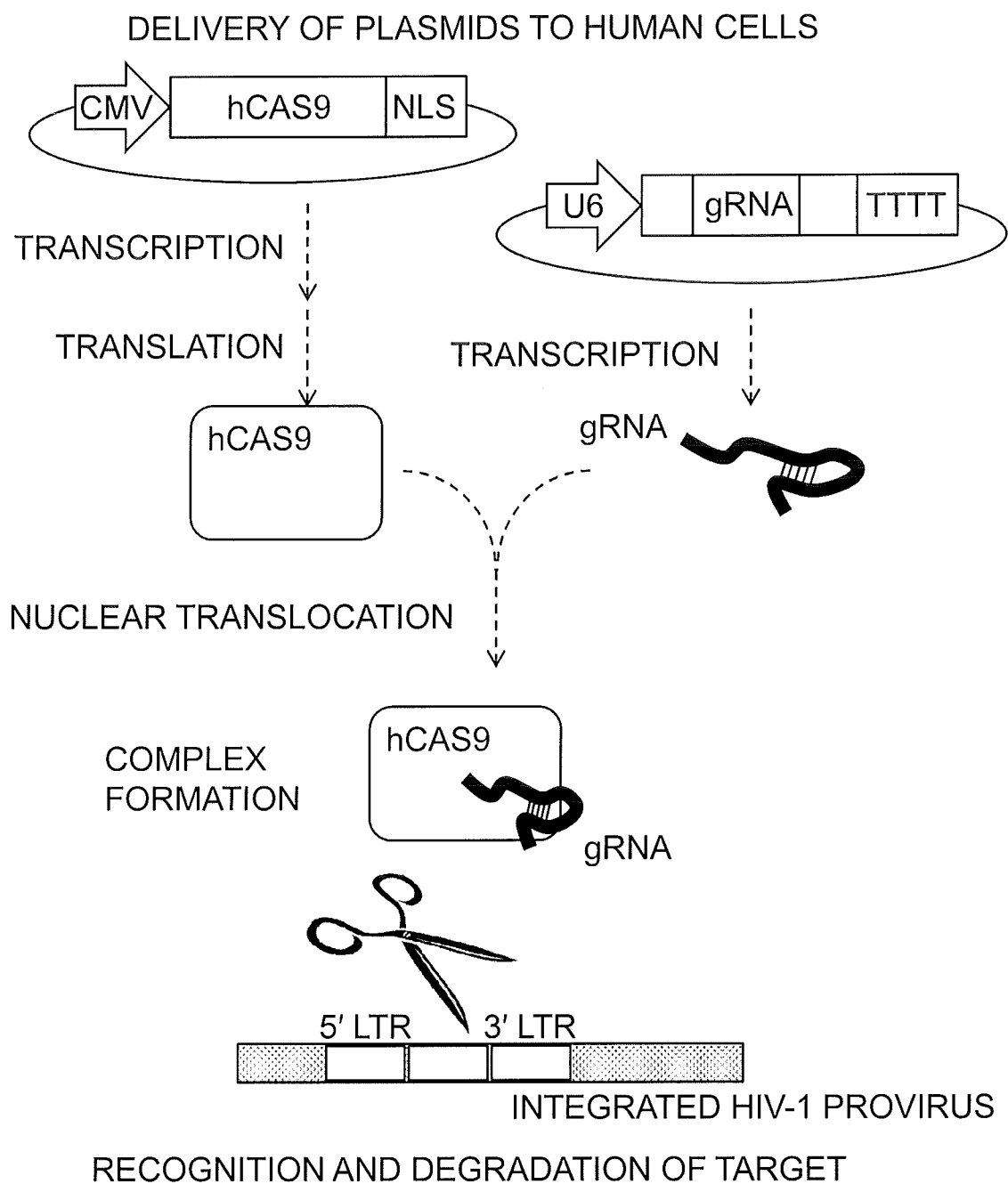
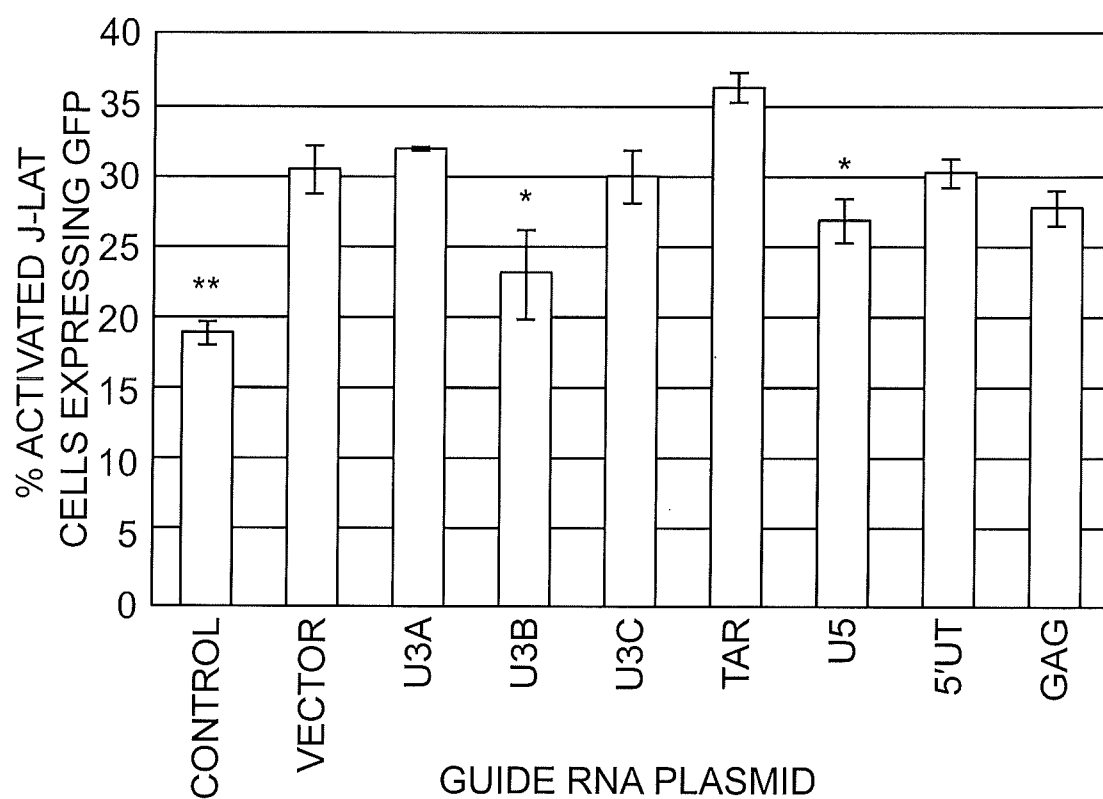
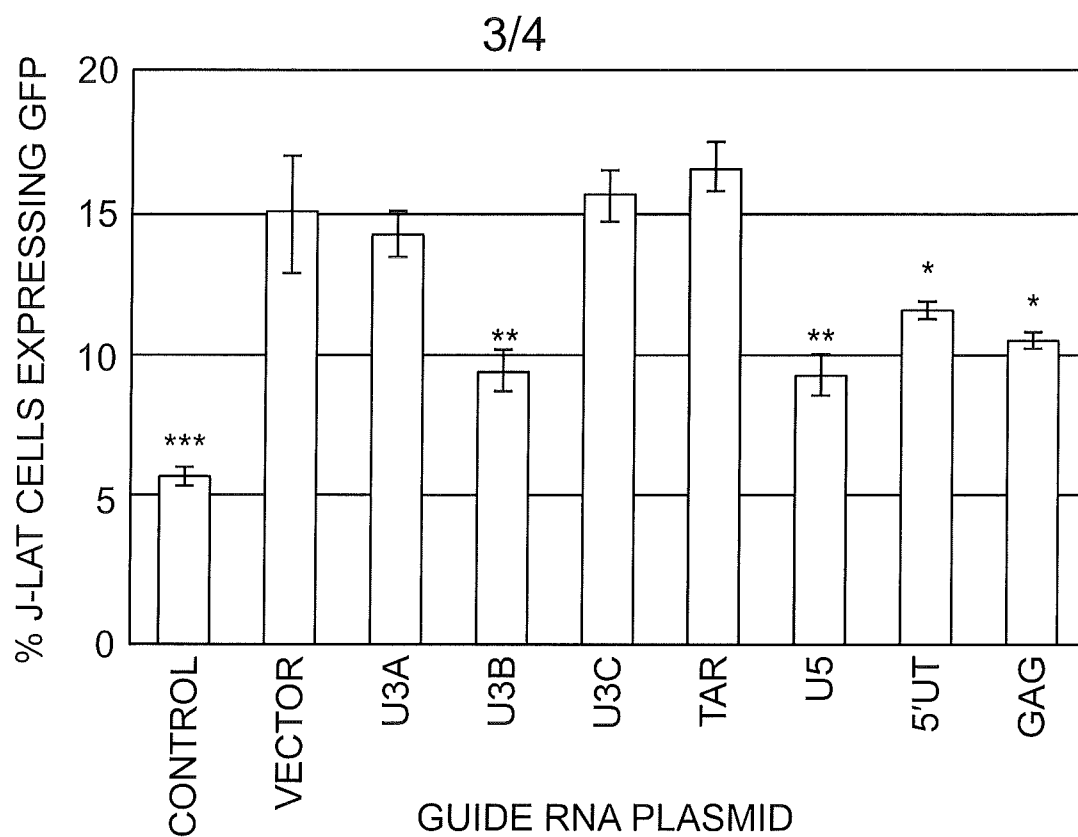
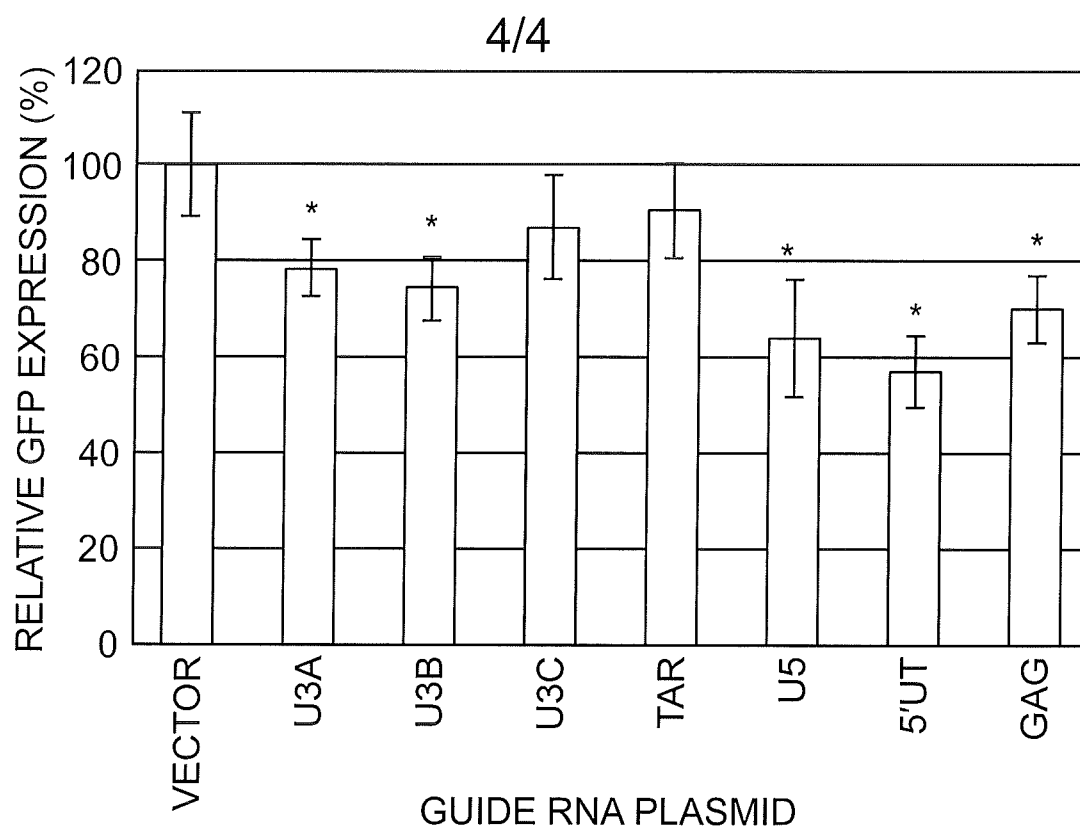
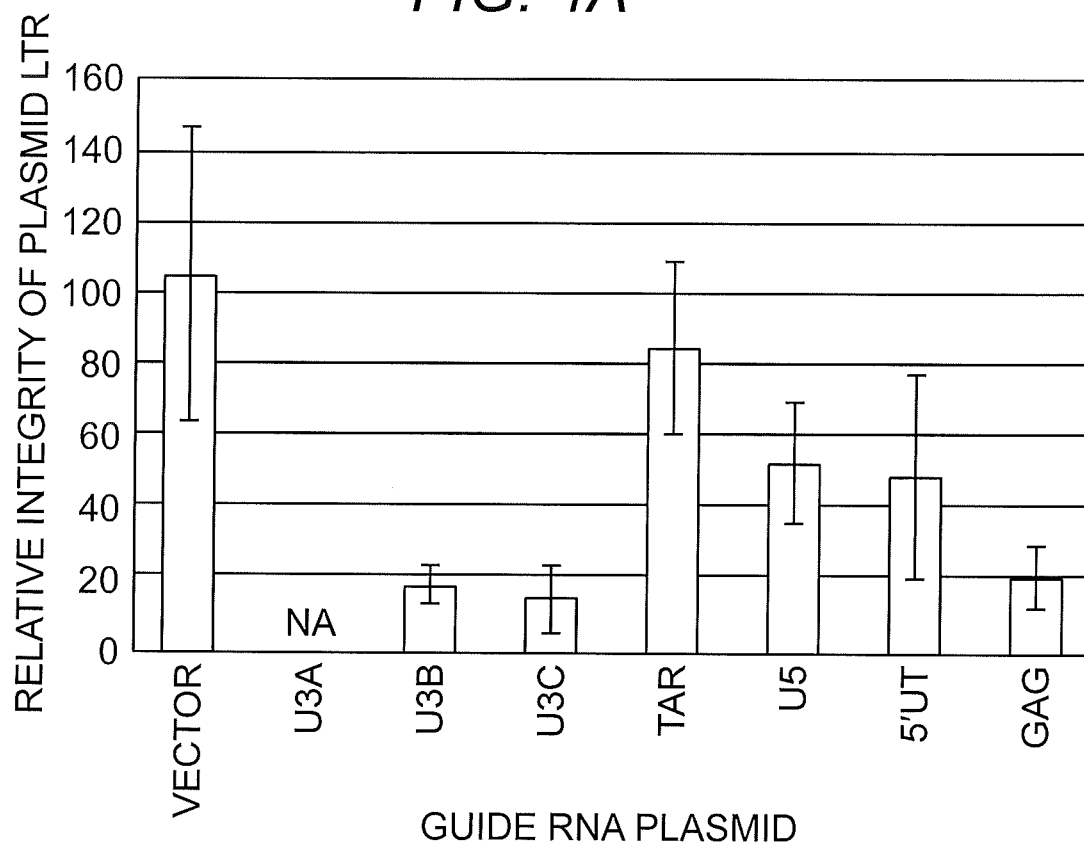


FIG. 2

**FIG. 3B**

**FIG. 4A****FIG. 4B**