

MEANS AND METHODS FOR MONITORING PROTEASE
INHIBITOR ANTIRETROVIRAL THERAPY AND GUIDING
THERAPEUTIC DECISIONS IN THE TREATMENT OF HIV/AIDS

This application claims the benefit of U.S. Application No. 09/591,899, filed June 12, 2000 and U.S. Application No. 09/338,323, filed June 22, 1999, the contents of each of which are hereby incorporated by reference in to this application.

Throughout this application, various references are referred to within parenthesis. Disclosures of these publications in their entirety are hereby incorporated by reference into this application to more fully describe the state of the art to which this invention pertains.

Technical Field

This invention relates to antiretroviral drug susceptibility and resistance tests to be used in identifying effective drug regimens for the treatment of human immunodeficiency virus (HIV) infection and acquired immunodeficiency syndrome (AIDS). The invention further relates to the means and methods of monitoring the clinical progression of HIV infection and its response to antiretroviral therapy using phenotypic or genotypic susceptibility assays. The invention also relates to novel vectors, host cells and compositions for carrying out phenotypic susceptibility tests. The invention further relates to the use of various genotypic methodologies to identify patients who do not respond to a particular antiretroviral drug regimen. This invention also relates to the screening of candidate antiretroviral

drugs for their capacity to inhibit viral replication, selected viral sequences and/or viral proteins. More particularly, this invention relates to the determination of protease inhibitor (PRI) susceptibility using phenotypic or genotypic susceptibility tests. This invention also relates to a means and method for accurately and reproducibly measuring viral replication fitness.

Background of the Invention

HIV infection is characterized by high rates of viral turnover throughout the disease process, eventually leading to CD4 depletion and disease progression. Wei X, Ghosh SK, Taylor ME, et al. (1995) Nature 343, 117-122 and Ho DD, Naumann AU, Perelson AS, et al. (1995) Nature 373, 123-126. The aim of antiretroviral therapy is to achieve substantial and prolonged suppression of viral replication. Achieving sustained viral control is likely to involve the use of sequential therapies, generally each therapy comprising combinations of three or more antiretroviral drugs. Choice of initial and subsequent therapy should, therefore, be made on a rational basis, with knowledge of resistance and cross-resistance patterns being vital to guiding those decisions. The primary rationale of combination therapy relates to synergistic or additive activity to achieve greater inhibition of viral replication. The tolerability of drug regimens will remain critical, however, as therapy will need to be maintained over many years.

In an untreated patient, some 10^{10} new viral particles are produced per day. Coupled with the failure of HIV reverse transcriptase (RT) to correct transcription errors by exonucleolytic proofreading, this high level of viral turnover results in 10^4 to 10^5 mutations per day at each position in the HIV genome. The result is the rapid establishment of extensive genotypic variation. While some template positions or base pair substitutions may be more error prone (Mansky LM, Temin HM (1995) J Virol 69, 5087-5094) (Schinazi RF, Lloyd RM, Ramanathan CS, et al. (1994) Antimicrob Agents Chemother 38, 268-274), mathematical modeling suggests that, at every possible single point, mutation may occur up to 10,000 times per day in infected individuals.

For antiretroviral drug resistance to occur, the target enzyme must be modified while preserving its function in the presence of the inhibitor. Point mutations leading to an amino acid substitution may result in changes in shape, size or charge of the active site, substrate binding site or in positions surrounding the active site of the enzyme. Mutants resistant to antiretroviral agents have been detected at low levels before the initiation of therapy. (Mohri H, Singh MK, Ching WTW, et al. (1993) Proc Natl Acad Sci USA 90, 25-29) (Nájera I, Richman DD, Olivares I, et al. (1994) AIDS Res Hum Retroviruses 10, 1479-1488) (Nájera I, Holguin A, Quiñones-Mateu E, et al. (1995) J Virol 69, 23-31). However, these mutant strains represent only a small proportion of the total viral load and may

have a replication or competitive disadvantage compared with wild-type virus. (Coffin JM (1995) Science 267, 483-489). The selective pressure of antiretroviral therapy provides these drug-resistant mutants with a competitive advantage and thus they come to represent the dominant quasi species (Frost SDW, McLean AR (1994) AIDS 8, 323-332) (Kellam P, Boucher CAB, Tijnagal JMGH (1994) J Gen Virol 75, 341-351) ultimately leading to a rebound in viral load in the patient.

Early development of antiretroviral therapy focused on inhibitors of reverse transcriptase. Both nucleoside and non-nucleoside inhibitors of this enzyme showed significant antiviral activity (DeClerq, E. (1992) AIDS Res. Hum. Retrovir. 8:119-134). However, the clinical benefit of these drugs had been limited due to drug resistance, limited potency, and host cellular factors (Richman, D.D. (1993) Ann. Rev. Pharm. Tox. 32:149-164). Thus inhibitors targeted against a second essential enzyme of HIV were urgently needed.

In 1988, the protease enzyme of HIV was crystallized and its three-dimensional structure was determined, (Navia MA, Fitzgerald PMD, McKeever BM, Leu CT, Heimbach JC, Herber WK, Sigal IS, Darke PL, Springer JP (1989) Nature 337:615-620 and Winters MA, Schapiro JM, Lawrence J, Merigan TC (1997) In Abstracts of the International Workshop on HIV Drug Resistance, Treatment Strategies and Eradication, St. Petersburg, Fla.) allowing for the rapid

development of protease inhibitors. Initially, it was hypothesized that HIV protease, unlike reverse transcriptase, would be unable to accommodate mutations leading to drug resistance. This is not the case, and to date over 20 amino acid substitutions in the HIV protease have been observed during treatment with the currently available protease inhibitors. The genetic pattern of mutations conferring resistance to these protease inhibitors is complex, and cross-resistance between structurally different compounds occurs.

PROTEASE INHIBITORS

HIV protease was classified as an aspartic proteinase on the basis of putative active-site homology (Toh H, Ono M, Saigo K, Miyata T (1985) Nature 315:691), its inhibition by peptastin (Richards AD, Roberts R, Dunn BM, Graves MC, Kay J (1989) FEBS Lett 247:113), and its crystal structure (Navia MA, Fitzgerald PMD, McKeever BM, Lau CT, Heimbach JC, Herber WK, Sigal IS, Darke PL, Springer JP (1989) Nature 337:615-620). The enzyme functions as a homodimer composed of two identical 99-amino acid chains (Debouck C, Navia MA, Fitzgerald PMD, McKeever BM, Leu CT, Heimbach JC, Herber WK, Sigal IS, Darke PL, Springer JP (1988) Proc. Natl. Acad. Sci. USA 84:8903-8906), with each chain containing the characteristic Asp-Thr-Gly active-site sequence at positions 25 to 27 (Toh H, Ono M, Saigo K, Miyata T (1985) Nature 315:691).

HIV protease processes gag (p55) and gag-pol (p160) polyprotein products into functional core proteins and viral enzymes (Kohl NE, Diehl RE, Rands E, Davis LJ, Hanobik MG, Wolanski B, Dixon RA (1991) J. Virol. 65:3007-3014 and Kramer RA, Schaber MD, Skalka AM, Ganguly K, Wong-Staal F, Reddy EP (1986) Science 231:1580-1584). During or immediately after budding, the polyproteins are cleaved by the enzyme at nine different cleavage sites to yield the structural proteins (p17, p24, p7, and p6) as well as the viral enzymes reverse transcriptase, integrase, and protease (Pettit SC, Michael SF, Swanstrom R (1993) Drug Discov. Des. 1:69-83).

An asparagine replacement for aspartic acid at active-site residue 25 results in the production of noninfectious viral particles with immature, defective cores (Huff JR (1991) AIDS J. Med. Chem. 34:2305-2314, Kaplan AH, Zack JA, Knigge M, Paul DA, Kempf DJ, Norbeck DW, Swanstrom R (1993) J. Virol. 67:4050-4055, Kohl NE, Emini EA, Schleif WA, Davis LJ, Heimbach JC, Dixon RA, Scolnik EM, Sigal IS (1988) Proc. Natl. Acad. Sci. USA 85:4686-4690, Peng C, Ho BK, Chang TW, Chang NT (1989) J. Virol. 63:2550-2556). Similarly, wild-type virus particles produced by infected cells treated with protease inhibitors contain unprocessed precursors and are noninfectious (Crawford S, Goff SP (1985) J. Virol. 53:899-907, Gottlinger HG, Sodroski JG, Haseltine WA (1989) Proc. Natl. Acad. Sci. USA 86:5781-5785, Katoh IY, Yoshinaka Y, Rein A, Shibuya M, Odaka T, Oroszlan S (1985) Virology 145:280-292, Kohl NE,

Emini EA, Schleif WA, Davis LJ, Heimbach JC, Dixon RA, Scolnik EM, Sigal IS (1988) Proc. Natl. Acad. Sci. USA 85:4686-4690, Peng C, Ho BK, Chang TW, Chang NT (1989) J. Virol. 63:2550-2556, Stewart L, Schatz G, Wogt VM (1990) J. Virol. 64:5076-5092). Unlike reverse transcriptase inhibitors, protease inhibitors block the production of infectious virus from chronically infected cells (Lambert DM, Petteway, Jr. SR, McDaniel CE, Hart TK, Leary JJ, Dreyer GB, Meek TD, Bugelski PJ, Bolognesi DP, Metcalf BW, Matthews TJ (1992) Antibiotic Agents Chemother. 36:982-988). Although the viral protease is a symmetric dimer, it binds its natural substrates or inhibitors asymmetrically (Dreyer, GB, Boehm JC, Chenera B, DesJarlais RL, Hassell AM, Meek TD, Tomaszek TAJ, Lewis M (1993) Biochemistry 32:937-947, Miller MJ, Schneider J, Sathyanarayana BK, Toth MV, Marshall GR, Clawson L, Selk L, Kent SB, Wlodawer A (1989) Science 246:1149-1152). These findings together with the knowledge that amide bonds of proline residues are not susceptible to cleavage by mammalian endopeptidases gave rise to the first class of HIV-1 protease inhibitors based on the transition state mimetic concept, with the phenylalanine-proline cleavage site being the critical nonscissile bond (Roberts NA, Martin JA, Kinchington D, Broadhurst AV, Craig JC, Duncan IB, Galpin SA, Handa BK, Kay J, Krohn A, Lambert RW, Merrett JH, Mills JS, Parkes KEB, Redshaw S, Ritchie AJ, Taylor DL, Thomas GJ, Machin PJ (1990) Science 248:358-361).

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Amino acids implicated in resistance to protease inhibitors.

As new protease inhibitors are developed, the ability of certain amino acid substitutions to confer resistance to the inhibitor is usually determined by several methods, including selection of resistant strains in vitro, site-directed mutagenesis, and determination of amino acid changes that are selected during early phase clinical trials in infected patients. While some amino acid substitutions are specifically correlated with resistance to certain protease inhibitors (see below), there is considerable overlap between sets of mutations implicated in resistance to all approved protease inhibitors. Many investigators have attempted to classify these mutations as either being "primary" or "secondary", with varying definitions. For example, some investigators classify as primary mutations which are predicted, based on X-ray crystallographic data, to be in the enzyme active site with the potential for direct contact with the inhibitor (e.g. D30N, G48V, I50V, V82A/F/S/T, I84V, N88S, L90M). Secondary mutations are usually considered as being compensatory for defects in enzyme activity imposed by primary mutations, or as having enhancing effects on the magnitude of resistance imparted by the primary mutations (e.g. L10I/F/R/V, K20I/M/R/T, L24I, V32I, L33F/V, M36I/L/V, M46I/L/V, I47V, I54L/V, L63X, A71T/V, G73A/S/T, V77I, N88D). Lists of mutations and corresponding inhibitors are maintained by several organizations, for

5 example: Schinazi et al., Mutations in retroviral genes associated with drug resistance, *Intl. Antiviral News* 1999,7:46-69 and Shafer et al., Human Immunodeficiency Virus Reverse Transcriptase and Protease Sequence Database, *Nucleic Acids Research* 1999, 27(1), 348-352 (also accessible via the internet at <http://www.viral-resistance.com/> or <http://hivdb.stanford.edu/hiv/>)

Saquinavir

Saquinavir, developed by Hoffmann-La Roche, was the first protease inhibitor to undergo clinical evaluation, demonstrating that HIV-1 protease was a valid target for the treatment of HIV infection (Jacobsen H, Brun-Vezinet F, Duncan I, Hanggi M, Ott M, Vella S, Weber J, Mous J (1994) J. Virol. 68:2016-2020). Saquinavir is a highly active peptidomimetic protease inhibitor with a 90% inhibitory concentration (IC90) of 6 nM (*id*). In vitro, saquinavir can select for variants with one or both of two amino acid substitutions in the HIV-1 protease gene, a valine-for-glycine substitution at position 48 (G48V), a methionine-for-leucine substitution at residue 90 (L90M), and the double substitution G48V-L90M (Eberle J, Bechowsky B, Rose D, Hauser U, von der Helm K, Guertler L, Nitschko H (1995) AIDS Res. Hum. Retroviruses 11:671-676, Jacobsen H, Yasargil K, Winslow DL, Craig JC, Kroehn A, Duncan IB, Mous J (1995) Virology 206:527-534, Turriziani O, Antonelli G, Jacobsen H, Mous J, Riva E, Pistello M, Dianzani F (1994) Acta Virol. 38:297-298). In most cases, G48V is the first mutation to appear, and continued selection results in highly resistant double-mutant variants. A substitution at either residue results in a 3- to 10-fold decreased susceptibility to the inhibitor, whereas the simultaneous occurrence of both substitutions causes a more severe loss of susceptibility of >100-fold (*id*).

In vivo, saquinavir therapy appears to select almost exclusively for mutations at codons 90 and 48 (*id*,

Jacobsen H, Hangi M, Ott M, Duncan IB, Owen S, Andreoni M, Vella S, Mous J (1996) *J. Infect. Dis.* 173:1379-1387, Vella S, Galluzzo C, Giannini G, Pirillo MF, Duncan I, Jacobsen H, Andreoni M, Sarmati L, Ercoli L (1996) *Antiviral Res.* 29:91-93). Saquinavir-resistant variants emerge in approximately 45% of patients after 1 year of monotherapy with 1,800 mg daily (Craig IC, Duncan IB, Roberts NA, Whittaker L (1993) In Abstracts of the 9th International Conference on AIDS, Berlin, Germany, Duncan IB, Jacobsen H, Owen S, Roberts NA (1996) In Abstracts of the 3rd Conference of Retroviruses and Opportunistic Infections, Washington, D.D., id, Mous J, Brun-Vezinet F, Duncan IB, Haenggi M, Jacobsen H, Vella S (1994) In Abstracts of the 10th International Conference on AIDS, Yokohama, Japan). The frequency of resistance is lower (22%) in patients receiving combination therapy with zidovudine, zalcitabine, and saquinavir (Collier AC, Coombs R, Schoenfeld DA, Bassett RL, Joseph Timpone MS, Baruch A, Jones M, Facey K, Whitacre C, McAuliffe VJ, Friedman HM, Merigan TC, Reichmann RC, Hooper C, Corey L (1996) *N. Engl. J. Med.* 334:1011-1017). In contrast to in vitro-selected virus, where the G48V mutation is the first step to resistance, the L90M exchange is the predominant mutation selected in vivo while the G48V (2%) or the double-mutant (<2%) is rarely found (id). In another recent study of in vivo resistance during saquinavir monotherapy no patient was found to harbor a G48V mutant virus (Ives KJ, Jacobsen H, Galpin SA, Garaev MM, Dorrell L, Mous J, Bragman K, Weber JN (1997) *J. Antimicrob.*

Chemother. 39:771-779). Interestingly, Winters et al. (id) observed a higher frequency of the G48V mutation in patients receiving higher saquinavir doses as monotherapy. All patients (six of six) who initially developed G48V also acquired a V82A mutation either during saquinavir treatment or after switching to either indinavir or nelfinavir. An identical mutational pattern was found in another study during saquinavir monotherapy (Eastman PS, Duncan IB, Gee C, Race E (1997) In Abstracts of the International Workshop on HIV Drug Resistance, Treatment Strategies and Eradication, St. Petersburg, Fla.). Some residues represent sites of natural polymorphism of the HIV-1 protease (positions 10, 36, 63, and 71) and appear to be correlated to the L90M mutation (id). Another substitution, G73S, has been recently identified and may play a role in saquinavir resistance in vivo. Isolates from five patients with early saquinavir resistance and those from two patients with induced saquinavir resistance after a switch of therapy to indinavir carried the G73S and the L90M substitutions Dulioust A, Paulous S, Guillemot L, Boue F, Galanaud P, Clavel F (1997) In Abstracts of the International Workshop on HIV Drug Resistance, Treatment Strategies and Eradication, St. Petersburg, Fla.).

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Ritonavir

Ritonavir, developed by Abbott Laboratories, was the second HIV protease inhibitor to be licensed in the United States. Ritonavir is a potent and selective inhibitor of HIV protease that is derived from a C2-symmetric, peptidomimetic inhibitor (Ho DD, Toyoshima T, Mo H, Kempf DJ, Norbeck D, Chen CM, Wideburg NE, Burt SK, Erickson JW, Singh MK (1994) J. Virol. 68:2016-2020). In vitro activity has been demonstrated against a variety of laboratory strains and clinical isolates of HIV-1 with IC90s of 70 to 200 nM (Kuroda MJ, El-Farrash MA, Clouthury S, Harada S (1995) Virology 210:212-216).

Resistant virus generated by serial in vitro passages is associated with specific mutations at positions 84, 82, 71, 63, and 46 (Markowitz M, Mo H, Kempf DJ, Norbeck DW, Bhat TN, Erickson JW, Ho DD (1995) J. Virol. 69:701-706). The I84V substitution appeared to be the major determinant of resistance, resulting in a 10-fold reduction in sensitivity to ritonavir. Addition of the V82F mutation confers an even greater level of resistance, up to 20-fold. The substitutions M46I, L63P, and A71V, when introduced into the protease coding region of wild-type NL4-3, did not result in significant changes in drug susceptibility. Based on replication kinetics experiments, these changes are likely to be compensatory for active-site mutations, restoring the impaired replicative capacity of the combined V82F and I84V mutations.

Indinavir

Indinavir, developed by Merck & Co., is the third HIV protease inhibitor licensed in the United States. Indinavir is a potent and selective inhibitor of HIV-1 and HIV-2 proteases with K_i values of 0.34 and 3.3 nM, respectively (Vacca Jp, Dorsey BD, Schleif WA, Levin RB, McDaniel SL, Darke PL, Zugay J, Quintero JC, Blahy OM, Roth E, Sardana VV, Schlabach AJ, Graham PI, Condra JH, Gotlib L, Holloway MK, Lin J, Chen L-w, Vastag K, Ostobich D, Anderson PS, Emini EA, Huff JR (1994) Proc. Natl. Acad. Sci. USA 91:4096-4100). The drug acts as peptidomimetic transition state analogue and belongs to the class of protease inhibitors known as HAPA (hydroxyaminopentane amide) compounds (ibid). Indinavir provides enhanced aqueous solubility and oral bioavailability and in cell culture exhibits an IC_{95} of 50 to 100 nM (Emini EA, Schleif WA, Deutsch P, Condra JH (1996) Antiviral Chemother. 4:327-331).

Despite early reports of a lack of in vitro resistance by selection with indinavir (id), Tisdale et al. (Tisdale M, Myers RE, Maschera B, Parry NR, Oliver NM, Blair ED (1995) Antibicrob. Agents Chemother. 39:1704-1710) were able to obtain resistant variants during selection in MT-4 cells with substitutions at residues 32, 46, 71, and 82. At least four mutations were required to produce a significant loss of susceptibility (6.1-fold compared with the wild type). The mutation at position 71, described as compensatory (Markowitz M, Mo H, Kempf DJ, Norbeck DW,

Bhat TN, Erickson JW, Ho DD (1995) J. Virol. (id), appeared to contribute phenotypic resistance and also to improve virus growth. Emini et al. (id) and Condra et al. (Condra JH, Holder DJ, Schleif WA, Blahy OM, Danovich RM, 5 Gabryelski LJ, Graham DJ, Laird D, Quintero JC, Rhodes A, Robbins HL, Roth E, Shivaprakash M, Yang T, Chodakewitz JA, Deutsch PJ, Leavitt RY, Massari Fe, Mellors JW, Squires KE, Steigbigel RT, Teppler H, Emini EA (1995) Nature 374:569-571) found by constructing mutant HIV-1 10 clones that at least three mutations at residues 46, 63, and 82 were required for the phenotypic manifestation of resistance with a fourfold loss of susceptibility.

Nelfinavir

Nelfinavir, developed by Agouron Pharmaceuticals, is a selective, nonpeptidic HIV-1 protease inhibitor that was designed by protein structure-based techniques using iterative protein crystallographic analysis (Appelt KR, Bacquet J, Bartlett C, Booth CLJ, Freer ST, Fuhry MM, Gehring MR, Herrmann SM, Howland EF, Janson CA, Jones TR, Kan CC, Kathardekar V, Lewis KK, Marzoni GP, Mathews DA, Mohr C, Moomaw EW, Morse CA, Oatley SJ, Ogden RC, Reddy MR, Reich SH, Schoettlin WS, Smith WW, Varney MD, Villafranca JE, Ward RW, Webber S, Webber SE, Welsh KM, White J (1991) J. Med. Chem. 34:1925-1928). In vitro, nelfinavir was found to be a potent inhibitor of HIV-1 protease with a K_i of 2.0 nM (Kaldor SW, Kalish VJ, Davies JF, Shetty BV, Fritz JE, Appelt K, Burgess JA, Campanale KM, Chirgadze NY, Clawson DK, Dressman BA, Hatch SD, Khalil DA, Kosa MB, Lubbehusen PP, Muesing MA, Patrick AK, Reich SH, Su KS, Tatlock JH (1997) J. Med. Chem. 40:3979-3985). The drug demonstrated antiviral activity against several laboratory and clinical HIV-1 and HIV-2 strains with 50% effective concentrations ranging from 9 to 60 nM (Patick AK, Boritzki TJ, Bloom LA (1997) Antimicrob. Agents Chemother. 41:2159-2164). Nelfinavir exhibits additive-to-synergistic effects when combined with other antiretroviral drugs (Partaledis JA, Yamaguchi AK, Tisdale M, Blair EE, Falcione C, Maschera B, Myers RE, Pazhanisamy S, Futer O, Bullinan AB, Stuver CM, Byrn RA, Livingston DJ (1995) J. Virol. 69:5228-5235). Preclinical data showed high levels of the drug in mesenteric lymph

nodes and the spleen and good oral bioavailability (Shetty BV, Kosa MB, Khalil DA, Webber S (1996) Antimicrob. Agents Chemother. 40:110-114).

5 *In vitro*, following 22 serial passages of HIV-1_{NL4-3} in the
presence of nelfinavir, a variant (P22) with a sevenfold
reduced susceptibility was isolated. After an additional
six passages a variant (P28) with a 30-fold-decreased
10 susceptibility to nelfinavir was identified (Patick AK, Ho
H, Markowitz M, Appelt K, Wu B, Musick L, Kaldor S, Reich
S, Ho D, Webber S (1996) Antimicrob. Agents Chemother.
40:292-297). Sequence analysis of the protease gene from
these variants identified in decreasing frequency the
substitutions D30N, A71V, and I84V for the P22 variant and
15 mutations M46I, I84V/A, L63P, and A71V for the P28
variant. Antiviral susceptibility testing of recombinant
mutant HIV-1_{NL4-3} containing various mutations resulted in a
fivefold-increased 90% effective concentration for the
I84V and D30N single mutants and the M46I/I84V double
20 mutant, whereas no change in susceptibility was observed
with M46I, L63P, or A71V alone (*ibid*).

Amprenavir

Amprenavir is a novel protease inhibitor developed by Vertex Laboratories and designed from knowledge of the HIV-1 protease crystal structure (Kim EE, Baker CT, Dyer MD, Murcko MA, Rao BG, Tung RD, Navia MA (1995) J. Am. Chem. Soc. 117:1181-1182). The drug belongs to the class of sulfonamide protease inhibitors and has been shown to be a potent inhibitor of HIV-1 and HIV-2, with IC50s of 80 and 340 nM, respectively. The mean IC50 for amprenavir against clinical viral isolates was 12 nM (St. Clair MH, Millard J, Rooney J, Tisdale M, Parry N, Sadler BM, Blum MR, Painter G (1996) Antiviral Res. 29:53-56). HIV-1 variants 100-fold resistant to amprenavir have been selected by in vitro passage experiments (id). DNA sequence analysis of the protease of these variants revealed a sequential accumulation of point mutations resulting in amino acid substitutions L10F, M46I, I47V, and I50V. The key resistance mutation in the HIV-1 protease substrate binding site is I50V. As a single mutation it confers a two- to threefold decrease in susceptibility (ibid). The other substitutions did not result in reduced susceptibility when introduced as single mutations into an HIV-1 infectious clone (HXB2). However, a triple protease mutant clone containing the mutations M46I, I47V, and I50V was 20-fold less susceptible to amprenavir than wild-type virus. The I50V mutation has not been frequently reported in resistance studies with other HIV protease inhibitors. Kinetic characterization of these substitutions demonstrated an 80-fold reduction

in the inhibition constant (K_i) for the I50V single-mutant protease and a 270-fold-reduced K_i for the triple mutant M46I/I47V/I50V, compared to the wild-type enzyme (Pazhanisamy S, St6uvr CM, Cullinan AB, Margolin N, Rao BG (1996) J. Biol. Chem. 271:17979-17985). The single mutants L10F, M46I, and I47V did not display reduced affinity for amprenavir. The catalytic efficiency (k_{cat}/K_m) of the I50V mutant was decreased up to 25-fold, while the triple mutant M46I/I47V/I50V had a 2-fold-higher processing efficiency than the I50V single mutant, confirming the compensatory role of the M46I-and-I47V mutation. The reduced catalytic efficiency (k_{cat}/K_m) for these mutants in processing peptides appeared to be due to both increased K_m and decreased k_{cat} values.

VIRAL FITNESS

The relative ability of a given virus or virus mutant to replicate is termed viral fitness. Fitness is dependent on both viral and host factors, including the genetic composition of the virus, the host immune response, and selective pressures such as the presence of anti-viral compounds. Many drug-resistant variants of HIV-1 are less fit than the wild-type, i.e. they grow more slowly in the absence of drug selection. However, since the replication of the wild-type virus is inhibited in the presence of drug, the resistant mutant can outgrow it. The reduction in fitness may be a result of several factors including: decreased ability of the mutated enzyme (i.e. PR or RT) to recognize its natural substrates, decreased stability of

the mutant protein, or decreased kinetics of enzymatic catalysis. See Back et al., EMBO J. 15: 4040-4049, 1996; Goudsmit et al., J. Virol. 70: 5662-5664, 1996; Maschera et al., J. Biol. Chem. 271: 33231-33235, 1996; Croteau et al., J. Virol. 71: 1089-1096, 1997; Zennou et al., J. Virol. 72: 300-3306, 1998; Harrigan et al., J. Virol. 72: 3773-3778, 1998; Kosalaraksa et al., J. Virol. 73: 5356-5363, 1999; Gerondelis et al., J. Virol. 73: 5803-5813, 1999. Drug resistant viruses that are less fit than wild type may be less virulent i.e. they may cause damage to the host immune system more slowly than a wild type virus. Immunological decline may be delayed after the emergence of drug resistant mutants, compared to the rate of immunological decline in an untreated patient. The defect causing reductions in fitness may be partially or completely compensated for by the selection of viruses with additional amino acid substitutions in the same protein that bears the drug resistance mutations (for example, see Martinez-Picado et al., J. Virol. 73:3744-3752, 1999), or in other proteins which interact with the mutated enzyme. Thus, amino acids surrounding the protease cleavage site in the gag protein may be altered so that the site is better recognized by a drug-resistant protease enzyme (Doyon et al., J. Virol. 70: 3763-3769, 1996; Zhang et al., J. Virol. 71: 6662-6670, 1997; Mammano et al., J. Virol. 72: 7632-7637, 1998).

It is an object of this invention to provide a drug susceptibility and resistance test capable of showing

whether a viral population in a patient is either more or less susceptible to a given prescribed drug. Another object of this invention is to provide a test that will enable the physician to substitute one or more drugs in a therapeutic regimen for viruses that show altered susceptibility to a given drug or drugs after a course of therapy. Yet another object of this invention is to provide a test that will enable selection of an effective drug regimen for the treatment of HIV infections and/or AIDS. Yet another object of this invention is to provide the means for identifying alterations in the drug susceptibility profile of a patient's virus, in particular identifying changes in susceptibility to protease inhibitors. Still another object of this invention is to provide a test and methods for evaluating the biological effectiveness of candidate drug compounds which act on specific viruses, viral genes and/or viral proteins particularly with respect to alterations in viral drug susceptibility associated with protease inhibitors. It is also an object of this invention to provide the means and compositions for evaluating HIV antiretroviral drug resistance and susceptibility.

It is an object of this invention to provide a method for measuring replication fitness which can be adapted to viruses, including, but not limited to human immunodeficiency virus (HIV), hepadnaviruses (human hepatitis B virus), flaviviruses (human hepatitis C virus) and herpesviruses (human cytomegalovirus). This and other

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objects of this invention will be apparent from the specification as a whole.

Summary of the Invention

The present invention relates to methods of monitoring, via phenotypic and genotypic methods the clinical progression of human immunodeficiency virus infection and its response to antiviral therapy. The invention is also based, in part, on the discovery that genetic changes in HIV protease (PR) which confer changes in susceptibility to antiretroviral therapy may be rapidly determined directly from patient plasma HIV RNA using phenotypic or genotypic methods. The methods utilize nucleic acid amplification based assays, such as polymerase chain reaction (PCR). Herein—after, such nucleic acid amplification based assays will be referred to as PCR based assays. This invention is based in part on the discovery of mutations at codons 10, 20, 36, 46, 63, 77 and 88 of HIV protease in PRI treated patients in which the presence of certain combinations of these mutations correlate with changes in certain PRI susceptibilities. This invention is also based on the discovery that susceptibility to HIV protease antivirals may not be altered even if primary mutations are present. Additional mutations at secondary positions in HIV protease are required for a reduction in virus susceptibility. This invention established for the first time that a mutation at position 82 of protease (V82A, F, S, or T) in the absence of another primary mutation was not correlated with a reduction in drug susceptibility. Decreased susceptibility to protease inhibitors, such as indinavir and saquinavir, in viruses containing V82A, F, S or T was

observed in viruses with additional mutations at secondary positions, such as, 24, 71, 54, 46, 10 and/or 63 as described herein. Decreased susceptibility to protease inhibitors, such as indinavir and saquinavir, in viruses containing V82A, F, S or T was also observed in viruses with at least 3 or more additional mutations at secondary positions. This inventions also established for the first time that a mutation at position 90 of protease (L90M) in the absence of another primary mutation was not correlated with a reduction in drug susceptibility. Decreased susceptibility to protease inhibitors, such as indinavir and saquinavir, in viruses containing L90M was observed in viruses with additional mutations at secondary positions, such as, 73, 71, 77, and/or 10 as described herein. Decreased susceptibility to protease inhibitors, such as indinavir and saquinavir, in viruses containing L90M was also observed in viruses with at least 3 or more additional mutations at secondary positions. The mutations were found in plasma HIV nucleic acid after a period of time following the initiation of therapy. The development of these mutations, or combinations of these mutations, in HIV PR was found to be an indicator of the development of alterations in phenotypic susceptibility/resistance, which can be associated with virologic failure and subsequent immunological response.

In one embodiment of the invention, a method of assessing the effectiveness of protease antiretroviral therapy of an HIV-infected patient is provided comprising:(a)collecting

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a plasma sample from the HIV-infected patient; (b) evaluating whether the plasma sample contains nucleic acid encoding HIV protease having a mutation at primary and secondary positions; and (c) determining changes in susceptibility to a protease inhibitor.

In a further embodiment of the invention, PCR based assays, including phenotypic and genotypic assays, may be used to detect a substitution at codon 88 from asparagine to a serine residue either alone or in combination with one or more mutations at other codons selected from the group consisting of 10, 20, 36, 46, 63 and/or 77 or a combination thereof of HIV PR. A mutation at codon 88 from an asparagine residue to a serine residue (N88S) alone correlates with an increase in susceptibility to amprenavir and a mutation at codon 88 from an asparagine residue to a serine residue in combination with mutations at codons 63 and/or 77 or a combination thereof correlates with an increase in susceptibility to amprenavir and a decrease in nelfinavir and indinavir susceptibility.

In a further embodiment of the invention, PCR based assays, including phenotypic and genotypic assays, may be used to detect mutations at codons 10, 20, 36, 46, 63, 77, and 88 of HIV PR which correlate with changes in susceptibility to antiretroviral therapy and immunologic response. Once mutations at these loci have been detected in a patient undergoing PRI antiretroviral therapy, an alteration in the therapeutic regimen should be

considered. The timing at which a modification of the therapeutic regimen should be made, following the assessment of antiretroviral therapy using PCR based assays, may depend on several factors including the patient's viral load, CD4 count, and prior treatment history.

In a further embodiment of the invention, PCR based assays, including phenotypic and genotypic assays, may be used to detect a substitution at codon 82 from valine to an alanine (V82A), phenylalanine (V82F), serine (V82S), or threonine (V82T) residue either alone or in combination with one or more mutations at other codons, referred to herein as secondary mutations, selected from the group consisting of 20, 24, 36, 71, 54, 46, 63 and/or 10 or a combination thereof of HIV PR. A mutation at codon 82 from a valine residue to a alanine, phenylalanine, serine or threonine alone correlates with susceptibility to certain protease inhibitors including indinavir and saquinavir. A mutation at codon 82 from a valine residue to a alanine, phenylalanine, serine or threonine in combination with secondary mutations at codons 24 and/or 71 or 20 and/or 36 correlates with a reduction in susceptibility to indinavir and saquinavir, respectively. A mutation at codon 82 from a valine residue to a alanine, phenylalanine, serine or threonine in combination with at least 3 secondary mutations correlates with a reduction in susceptibility to indinavir and saquinavir.

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In a further embodiment of the invention, PCR based assays, including phenotypic and genotypic assays, may be used to detect a substitution at codon 90 from leucine to a methionine (L90M) residue either alone or in combination with one or more mutations at other codons, referred to herein as secondary mutations, selected from the group consisting of 73, 71, 46 and/or 10 or a combination thereof of HIV PR. A mutation at codon 90 from a leucine residue to a methionine alone correlates with susceptibility to certain protease inhibitors including indinavir and saquinavir. A mutation at codon 90 from a leucine residue to a methionine in combination with secondary mutations at codons 73 and/or 71 or 73, 71 and/or 77 correlates with a reduction in susceptibility to indinavir and saquinavir, respectively. A mutation at codon 90 from a leucine residue to a methionine in combination with at least 3 secondary mutations correlates with a reduction in susceptibility to indinavir and saquinavir.

In another aspect of the invention there is provided a method for assessing the effectiveness of a protease inhibitor antiretroviral drug comprising: (a) introducing a resistance test vector comprising a patient-derived segment and an indicator gene into a host cell; (b) culturing the host cell from step (a); (c) measuring expression of the indicator gene in a target host cell wherein expression of the indicator gene is dependent upon the patient derived segment; and (d) comparing the expression of the indicator gene from step (c) with the

expression of the indicator gene measured when steps (a) -
(c) are carried out in the absence of the PRI anti-HIV
drug, wherein a test concentration of the PRI, anti-HIV
drug is presented at steps (a) - (c); at steps (b) - (c);
5 or at step (c).

This invention also provides a method for assessing the
effectiveness of protease inhibitor antiretroviral therapy
in a patient comprising: (a) developing a standard curve
10 of drug susceptibility for an PRI anti-HIV drug; (b)
determining PRI anti-HIV drug susceptibility in the
patient using the susceptibility test described above; and
(c) comparing the PRI anti-HIV drug susceptibility in step
(b) with the standard curve determined in step (a),
15 wherein a decrease in PRI anti-HIV susceptibility
indicates development of anti-HIV drug resistance in the
patient's virus and an increase in PRI anti-HIV
susceptibility indicates drug hypersensitivity in the
patient's virus.

20 This invention also provides a method for evaluating the
biological effectiveness of a candidate PRI HIV
antiretroviral drug compound comprising: (a) introducing a
resistance test vector comprising a patient-derived
25 segment and an indicator gene into a host cell; (b)
culturing the host cell from step (a); (c) measuring
expression of the indicator gene in a target host cell
wherein expression of the indicator gene is dependent upon
the patient derived segment; and (d) comparing the

expression of the indicator gene from step (c) with the expression of the indicator gene measured when steps (a) - (c) are carried out in the absence of the candidate PRI anti-viral drug compound, wherein a test concentration of the candidate PRI anti-viral drug compound is present at steps (a) - (c); at steps (b) - (c); or at step (c).

The expression of the indicator gene in the resistance test vector in the target cell is ultimately dependent upon the action of the HIV enzymes (PR and RT) encoded by the patient-derived segment DNA sequences. The indicator gene may be functional or non-functional.

In another aspect this invention is directed to antiretroviral drug susceptibility and resistance tests for HIV/AIDS. Particular resistance test vectors of the invention for use in the HIV/AIDS antiretroviral drug susceptibility and resistance test are identified.

Yet another aspect of this invention provides for the identification and assessment of the biological effectiveness of potential therapeutic antiretroviral compounds for the treatment of HIV and/or AIDS. In another aspect, the invention is directed to a novel resistance test vector comprising a patient-derived segment further comprising one or more mutations on the PR gene and an indicator gene.

Still another aspect of this invention provides for the

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identification and assessment of the fitness of a virus
infecting a patient. In another aspect, the invention is
directed to a novel resistance test vector comprising a
patient-derived segment further comprising one or more
5 mutations on the PR gene and an indicator gene, enabling
the measurement of viral fitness.

Brief Description of the Drawings

Fig. 1

Resistance Test Vector. A diagrammatic representation of the resistance test vector comprising a patient derived segment and an indicator gene.

Fig. 2

Two Cell Assay. Schematic Representation of the Assay. A resistance test vector is generated by cloning the patient-derived segment into an indicator gene viral vector. The resistance test vector is then co-transfected with an expression vector that produces amphotropic murine leukemia virus (MLV) envelope protein or other viral or cellular proteins which enable infection. Pseudotyped viral particles are produced containing the protease (PR) and the reverse transcriptase (RT) gene products encoded by the patient-derived DNA sequences. The particles are then harvested and used to infect fresh cells. Using defective PR and RT sequences it was shown that luciferase activity is dependent on functional PR and RT. PR inhibitors are added to the cells following transfection and are thus present during particle maturation. RT inhibitors, on the other hand, are added to the cells at the time of or prior to viral particle infection. The assay is performed in the absence of drug and in the presence of drug over a wide range of concentrations. Luciferase activity is determined and the percentage (%) inhibition is calculated at the different drug

concentrations tested.

Fig. 3

Examples of phenotypic drug susceptibility profiles. Data are analyzed by plotting the percent inhibition of luciferase activity vs. log10 concentration. This plot is used to calculate the drug concentration that is required to inhibit virus replication by 50% (IC50) or by 95% (IC95). Shifts in the inhibition curves towards higher drug concentrations are interpreted as evidence of drug resistance. Three typical curves for a nucleoside reverse transcriptase inhibitor (AZT), a non-nucleoside reverse transcriptase inhibitor (efavirenz), and a protease inhibitor (indinavir) are shown. A reduction in drug susceptibility (resistance) is reflected in a shift in the drug susceptibility curve toward higher drug concentrations (to the right) as compared to a baseline (pre-treatment) sample or a drug susceptible virus reference control, such as pNL4-3 or HXB-2, when a baseline sample is not available.

Fig. 4

Phenotypic PRI susceptibility profile: patient 0732. A PCR-based phenotypic susceptibility assay was carried out giving the phenotypic drug susceptibility profile showing decreased susceptibility to nelfinavir and indinavir, and increased susceptibility to amprenavir.

Fig. 5

Phenotypic PRI susceptibility profile of a protease mutant generated by site-specific oligonucleotide-directed mutagenesis. A PCR-based phenotypic susceptibility assay was carried out giving the phenotypic drug susceptibility profile of a virus having substitutions at codons 63, 77 and 88 (L63P, V77I and N88S). The profile demonstrates resistance to both nelfinavir and indinavir, and increased susceptibility to amprenavir.

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Fig. A

Two Cell Fitness Assay. Schematic Representation of the Fitness Assay. A fitness test vector is generated by cloning the patient-derived segment into an indicator gene viral vector. The fitness test vector is then co-transfected with an expression vector that produces amphotropic murine leukemia virus (MLV) envelope protein or other viral or cellular proteins which enable infection. Pseudotyped viral particles are produced containing the protease (PR) and the reverse transcriptase (RT) gene products encoded by the patient-derived DNA sequences. The particles are then harvested and used to infect fresh cells. Using defective PR and RT sequences it was shown that luciferase activity is dependent on functional PR and RT. The fitness assay is typically performed in the absence of drug. If desired, the assay can also be performed at defined drug concentrations. Luciferase activity produced by patient derived viruses is compared to the luciferase activity produced by well-characterized reference viruses. Replication fitness is expressed as a percent of the reference.

Figure B.

Determining the replication fitness of patient viruses. Virus stocks produced from fitness test vectors derived from patient samples were used to infect cells. Luciferase activity was measured at various times after infection. Patient derived viruses may produce more, approximately the same, or less luciferase activity

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5 than the reference virus (Ref) and are said to have greater, equivalent, or reduced replication fitness, respectively. The drug susceptibility profiles of three representative patient derived viruses are shown (P1, P2, P3).

Figure C.

10 Identifying alterations in protease or reverse transcriptase function associated with differences in replication fitness of patient viruses. Replication fitness is expressed as a percent of the reference virus (top). Fitness measurements are compared to protease processing of the p55 gag polyprotein (middle) and reverse transcriptase activity (bottom). Protease processing is
15 measured by Western blot analysis using an antibody that reacts with the mature capsid protein (p24). The detection of unprocessed p55 or incompletely processed p41 polyproteins are indicators of reduced cleavage. Reverse transcriptase activity is measured using a quantitative
20 RT-PCR assay and is expressed as a percent of the reference virus.

Figure D.

25 Correlating reduced replication fitness with reduced reverse transcriptase activity. Viruses containing various amino acid substitutions at position 190 (A, S, C, Q, E, T, V) of reverse transcriptase were constructed using site directed mutagenesis. The reference virus contains G at this position. Replication fitness and

reverse transcriptase activities were compared.

Figure E.

Correlating reduced replication fitness with reduced
5 protease processing of p55 gag. Viruses containing
various amino acid substitutions in protease (D30N, L90M,
etc) were constructed using site directed mutagenesis.
Replication fitness and p55 gag processing were compared.

10 Figure F.

Correlating reduced replication fitness with reduced drug
susceptibility. A large collection (n=134) of patient
samples were evaluated for phenotypic drug susceptibility
and replication fitness. Replication fitness and drug
15 susceptibility were compared.

Figure G.

Relationship between protease inhibitor susceptibility and
replication fitness. Patient samples were sorted based on
20 their replication fitness (<25% of reference, 26-75% of
reference, and >75% of reference). Mean values for
protease inhibitor susceptibility were determined for each
fitness group and plotted for each drug and all drugs
combined.

25 Figure H.

Relationship between reverse transcriptase inhibitor
susceptibility and replication fitness. Patient samples
were sorted based on their replication fitness (<25% of

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reference, 26-75% of reference, and >75% of reference). Mean values for reverse transcriptase susceptibility were determined for each fitness group and plotted for each drug and all drugs combined.

5

Figure I.

Reduced replication fitness is associated with high numbers of protease mutations, and the L90M mutation. Patient viruses were sorted based on the number of protease mutations. Viruses with large numbers of protease mutations or the L90M protease mutation generally exhibit reduced replication fitness.

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Figure J.

Low replication capacity is associated with specific protease mutations. Patient viruses were sorted based on replication capacity. Specific protease mutations either alone (D30N) or in combination (L90M plus others) were observed with high frequency in viruses with reduced replication fitness.

15

20

Figure K.

Relationship between nelfinavir susceptibility, protease processing and replication fitness. Patient viruses were sorted based on nelfinavir susceptibility (<10 or >10 of reference). Protease processing and replication fitness were plotted for all patient viruses. Viruses with reduced nelfinavir susceptibility generally exhibited reduced protease processing and reduced replication

25

fitness.

5 Figure L. Protease mutations associated with reduced
protease processing. Patient viruses were sorted based on
protease processing. Specific protease mutations were
observed at high frequency in viruses with reduced
protease processing.

10 Figure M.

15 Representative patient sample exhibiting reversion to drug
susceptibility during a period of drug treatment
interruption. Virus samples were collected weekly during
a period of treatment interruption and evaluated for
phenotypic drug susceptibility. Values shown represent
fold change in susceptibility compared to the reference
virus.

Figure N.

20 Representative patient sample exhibiting increased
replication fitness during a period of drug treatment
interruption. Virus samples were collected weekly during
a period of treatment interruption and evaluated for
phenotypic drug susceptibility. Fitness values shown
25 represent percent of the reference virus. The increase in
fitness between week 9 and week 10 corresponds to improved
protease processing (bottom) and reversion of the drug
resistant phenotype to a drug sensitive phenotype (Figure
M).

Figure O.

Increased replication fitness during treatment interruption. Replication fitness was measured at the time of treatment interruption and various times during the period of treatment interruption. Generally, replication fitness was significantly higher in samples that corresponded to timepoints after the virus had reverted from a drug resistant phenotype to a drug sensitive phenotype.

Detailed Description of the Invention

The present invention relates to methods of monitoring the clinical progression of HIV infection in patients receiving antiretroviral therapy, particularly protease inhibitor antiretroviral therapy.

In one embodiment, the present invention provides for a method of evaluating the effectiveness of antiretroviral therapy of a patient comprising (i) collecting a biological sample from an HIV-infected patient; and (ii) determining whether the biological sample comprises nucleic acid encoding HIV PR having a mutation at one or more positions in the PR. The mutation(s) correlate positively with alterations in phenotypic susceptibility.

In a specific embodiment, the invention provides for a method of evaluating the effectiveness of PZI antiretroviral therapy of a patient comprising (i)

collecting a biological sample from an HIV-infected patient; and (ii) determining whether the biological sample comprises nucleic acid encoding HIV PR having a mutation at codon 88 from an asparagine residue to a serine residue (N88S). This invention established, using a phenotypic susceptibility assay, that a mutation at codon 88 to a serine residue of HIV protease is correlated with an increase in amprenavir susceptibility.

In a specific embodiment, the invention provides for a method of evaluating the effectiveness of PRI antiretroviral therapy of a patient comprising (i) collecting a biological sample from an HIV-infected patient; and (ii) determining whether the biological sample comprises nucleic acid encoding HIV PR having a mutation at codon 88 from an asparagine residue to a serine residue (N88S) either alone or in combination with mutations at codons 63 and/or 77 or a combination thereof. This invention established, using a phenotypic susceptibility assay, that a mutation at codon 88 to a serine residue of HIV protease is correlated with an increase in amprenavir susceptibility and a mutation at codon 88 to a serine residue in combination with mutations at codons 63 and/or 77 or a combination thereof of HIV protease are correlated with an increase in amprenavir susceptibility and a decrease in nelfinavir and indinavir susceptibility.

In a specific embodiment, the invention provides for a

method of evaluating the effectiveness of PRI antiretroviral therapy of a patient comprising (i) collecting a biological sample from an HIV-infected patient; and (ii) determining whether the biological sample comprises nucleic acid encoding HIV PR having a mutation at codon 88 from an asparagine residue to a serine residue (N88S) either alone or in combination with mutations at codons 46, 63 and/or 77 or a combination thereof. This invention established, using a phenotypic susceptibility assay, that a mutation at codon 88 to a serine residue of HIV protease is correlated with an increase in amprenavir susceptibility and a mutation at codon 88 to a serine residue in combination with mutations at codons 46, 63 and/or 77 or a combination thereof of HIV protease are correlated with an increase in amprenavir susceptibility and a decrease in nelfinavir and indinavir susceptibility.

In a specific embodiment, the invention provides for a method of evaluating the effectiveness of PRI antiretroviral therapy of a patient comprising (i) collecting a biological sample from an HIV-infected patient; and (ii) determining whether the biological sample comprises nucleic acid encoding HIV PR having a mutation at codon 88 from an asparagine residue to a serine residue (N88S) either alone or in combination with mutations at codons 10, 20, 36, 46, 63 and/or 77 or a combination thereof. This invention established, using a phenotypic susceptibility assay, that a mutation at codon

88 to a serine residue of HIV protease is correlated with an increase in amprenavir susceptibility and a mutation at codon 88 to a serine residue in combination with mutations at codons 10, 20, 36, 46, 63 and/or 77 or a combination thereof of HIV protease are correlated with an increase in amprenavir susceptibility and a decrease in nelfinavir and indinavir susceptibility.

Under the foregoing circumstances, the phenotypic susceptibility profile and genotypic profile of the HIV virus infecting the patient has been altered reflecting a change in response to the antiretroviral agent. In the case of PRI antiretroviral therapy, the HIV virus infecting the patient may be resistant to one or more PRIs but hypersensitive to another of the PRIs as described herein. It therefore may be desirable after detecting the mutation(s), to either increase the dosage of the antiretroviral agent, change to another antiretroviral agent, or add one or more additional antiretroviral agents to the patient's therapeutic regimen. For example, if the patient was being treated with nelfinavir when the N88S mutation arose, the patient's therapeutic regimen may desirably be altered by either (i) changing to a different PRI antiretroviral agent, such as saquinavir, ritonavir or amprenavir and stopping nelfinavir treatment; or (ii) increasing the dosage of nelfinavir; or (iii) adding another antiretroviral agent to the patient's therapeutic regimen. The effectiveness of the modification in therapy may be further evaluated by monitoring viral burden such

as by HIV RNA copy number. A decrease in HIV RNA copy number correlates positively with the effectiveness of a treatment regimen.

5 The phrase "correlates positively," as used herein, indicates that a particular result renders a particular conclusion more likely than other conclusions.

10 When reference is made to a particular codon number, it is understood that the codon number refers to the position of the amino acid that the codon codes for. Therefore a codon referencing a particular number is equivalent to a "postion" referencing a particular number, such as for example, "codon 88" or "position 88".

15 Another preferred, non-limiting, specific embodiment of the invention is as follows: A method of evaluating the effectiveness of PRI therapy of a patient comprising (i) collecting a biological sample from an HIV-infected patient; (ii) purifying and converting the viral RNA to cDNA and amplifying HIV sequences using HIV primers that
20 result in a PCR product that comprises the PR gene; (iii) performing PCR using primers that result in PCR products comprising wild type or serine at codon 88; and (iv)
25 determining, via the products of PCR, the presence or absence of a serine residue at codon 88.

Another preferred, non-limiting, specific embodiment of the invention is as follows: A method of evaluating the

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effectiveness of PRI therapy of a patient comprising (i) collecting a biological sample from an HIV-infected patient; (ii) purifying and converting the viral RNA to cDNA and amplifying HIV sequences using HIV primers that result in a PCR product that comprises the PR gene; (iii) performing PCR using primers that result in PCR products comprising wild type or serine at codon 88 and mutations at codons 63 and/or 77; and (iv) determining, via the products of PCR, the presence or absence of a serine residue at codon 88 and the presence or absence of mutations at codons 63 and/or 77.

Another preferred, non-limiting, specific embodiment of the invention is as follows: A method of evaluating the effectiveness of PRI therapy of a patient comprising (i) collecting a biological sample from an HIV-infected patient; (ii) purifying and converting the viral RNA to cDNA and amplifying HIV sequences using HIV primers that result in a PCR product that comprises the PR gene; (iii) performing PCR using primers that result in PCR products comprising wild type or serine at codon 88 and mutations at codons 63, 77 and/or 46 or a combination thereof; and (iv) determining, via the products of PCR, the presence or absence of a serine residue at codon 88 and the presence or absence of mutations at codons 63, 77 and/or 46 or a combination thereof.

Another preferred, non-limiting, specific embodiment of the invention is as follows: A method of evaluating the

effectiveness of PRI therapy of a patient comprising (i) collecting a biological sample from an HIV-infected patient; (ii) purifying and converting the viral RNA to cDNA and amplifying HIV sequences using HIV primers that result in a PCR product that comprises the PR gene; (iii) performing PCR using primers that result in PCR products comprising wild type or serine at codon 88 and mutations at codons 63, 77, 46, 10, 20, and/or 36 or a combination thereof; and (iv) determining, via the products of PCR, the presence or absence of a serine residue at codon 88 and the presence or absence of mutations at codons 63, 77, 46, 10, 20, and/or 36 or a combination thereof.

The presence of the mutation at codon 88 to a serine of HIV PR indicates that the effectiveness of the current or prospective PRI therapy may require alteration, since as shown by this invention mutation at codon 88 to a serine residue increases the susceptibility to amprenavir. Using the methods of this invention, changes in the PRI therapy would be indicated.

The presence of the mutation at codon 88 to a serine of alone or in combination with mutations at condons 63, 77, 46, 10, 20, and/or 36 or a combination thereof of HIV PR indicates that the effectiveness of the current or prospective PRI therapy may require alteration, since as shown by this invention a mutation at codon 88 to a serine residue alone increases the susceptibility to amprenavir and a mutation at codon 88 to a serine residue in

combination with mutations at condons 63, 77, 46, 10, 20, and/or 36 or a combination increases the susceptibility to amprenavir but also reduces the susceptibility to nelfinavir and indinavir. Using the methods of this invention, changes in the PRI therapy would be indicated.

Another preferred, non-limiting, specific embodiment of the invention is as follows: a method of evaluating the effectiveness of antiretroviral therapy of an HIV-infected patient comprising: (a) collecting a biological sample from an HIV-infected patient; and (b) determining whether the biological sample comprises nucleic acid encoding HIV protease having a mutation at codon 88 to serine. Using the phenotypic susceptibility assay, it was observed that the presence of the mutation at codon 88 to serine of HIV PR causes a an increase in amprenavir susceptibility.

Another preferred, non-limiting, specific embodiment of the invention is as follows: a method of evaluating the effectiveness of antiretroviral therapy of an HIV-infected patient comprising: (a) collecting a biological sample from an HIV-infected patient; and (b) determining whether the biological sample comprises nucleic acid encoding HIV protease having a mutation at codon 88 to serine and additional mutation(s) at codons 63 and/or 77 or a combination thereof. Using the phenotypic susceptibility assay, it was observed that the presence of the mutation at codon 88 to serine of HIV PR causes an increase in amprenavir susceptibility and the presence of the

mutations at codon 88 to serine in combination with a mutation at codon(s) 63 and/or 77 or a combination thereof of HIV PR causes a decrease in nelfinavir and indinavir susceptibility while increasing amprenavir susceptibility.

5

Another preferred, non-limiting, specific embodiment of the invention is as follows: a method of evaluating the effectiveness of antiretroviral therapy of an HIV-infected patient comprising: (a) collecting a biological sample
10 from an HIV-infected patient; and (b) determining whether the biological sample comprises nucleic acid encoding HIV protease having a mutation at codon 88 to serine and additional mutation(s) at codons 63, 77 and/or 46 or a combination thereof. Using the phenotypic susceptibility
15 assay, it was observed that the presence of the mutation at codon 88 to serine of HIV PR causes an increase in amprenavir susceptibility and the presence of the mutations at codon 88 to serine in combination with a mutation at codon(s) 46, 63 and/or 77 or a combination
20 thereof of HIV PR causes a decrease in nelfinavir and indinavir susceptibility while increasing amprenavir susceptibility.

25

Another preferred, non-limiting, specific embodiment of the invention is as follows: a method of evaluating the effectiveness of antiretroviral therapy of an HIV-infected patient comprising: (a) collecting a biological sample
from an HIV-infected patient; and (b) determining whether the biological sample comprises nucleic acid encoding HIV

protease having a mutation at codon 88 to serine and additional mutation(s) at codons 63, 77, 46, 10, 20 and/or 36 or a combination thereof. Using the phenotypic susceptibility assay, it was observed that the presence of the mutation at codon 88 to serine of HIV PR causes an increase in amprenavir susceptibility and the presence of the mutations at codon 88 to serine in combination with a mutation at codon(s) 63, 77, 46, 10, 20 and/or 36 or a combination thereof of HIV PR causes a decrease in nelfinavir and indinavir susceptibility while increasing amprenavir susceptibility.

This invention also provides the means and methods to use the resistance test vector comprising an HIV gene and further comprising a PR mutation for drug screening. More particularly, the invention describes the resistance test vector comprising the HIV protease having a mutation at codon 88 to a serine alone or in combination with mutations at codons 10, 20, 36, 46, 63 and/or 77 or a combination thereof for drug screening. The invention further relates to novel vectors, host cells and compositions for isolation and identification of the HIV-1 protease inhibitor resistant mutant and using such vectors, host cells and compositions to carry out anti-viral drug screening. This invention also relates to the screening of candidate drugs for their capacity to inhibit said mutant.

This invention provides a method for identifying a

compound which is capable of affecting the function of the protease of HIV-1 comprising contacting the compound with the polypeptide(s) comprising all or part of the HIV-1 protease, wherein codon 88 is changed to a serine residue, wherein a positive binding indicates that the compound is capable of affecting the function of said protease.

This invention also provides a method for assessing the viral fitness of patient's virus comprising: (a) determining the luciferase activity in the absence of drug for the reference control using the susceptibility test described above; (b) determining the luciferase activity in the absence of drug for the patient virus sample using the susceptibility test described above; and (c) comparing the luciferase activity determined in step (b) with the luciferase activity determined in step (a), wherein a decrease in luciferase activity indicates a reduction in viral fitness of the patient's virus.

If a resistance test vector is constructed using a patient derived segment from a patient virus which is unfit, and the fitness defect is due to genetic alterations in the patient derived segment, then the virus produced from cells transfected with the resistance test vector will produce luciferase more slowly. This defect will be manifested as reduced luciferase activity (in the absence of drug) compared to the drug sensitive reference control, and may be expressed as a percentage of the control.

In a further embodiment of the invention, PCR based assays, including phenotypic and genotypic assays, may be used to detect mutations at positions 20 and 88 of HIV PR, which correlate with a reduction in viral fitness and immunological response.

It is a further embodiment of this invention to provide a means and method for measuring replication fitness for viruses, including, but not limited to human immunodeficiency virus (HIV), hepadnaviruses (human hepatitis B virus), flaviviruses (human hepatitis C virus) and herpesviruses (human cytomegalovirus).

This invention further relates to a means and method for measuring the replication fitness of HIV-1 that exhibits reduced drug susceptibility to reverse transcriptase inhibitors and protease inhibitors.

In a further embodiment of the invention, a means and methods are provided for measuring replication fitness for other classes of inhibitors of HIV-1 replication, including, but not limited to integration, virus assembly, and virus attachment and entry.

This invention relates to a means and method for identifying mutations in protease or reverse transcriptase that alter replication fitness.

In a further embodiment of the invention , a means and methods are provided for identifying mutations that alter replication fitness for other components of HIV-1 replication, including, but not limited to integration, virus assembly, and virus attachment and entry.

This invention also relates to a means and method for quantifying the affect that specific mutations in protease or reverse transcriptase have on replication fitness.

In a further embodiment of the invention , a means and method are provided for quantifying the affect that specific protease and reverse transcriptase mutations have on replication fitness in other viral genes involved in HIV-1 replication, including, but not limited to the gag, pol, and envelope genes.

This invention also relates to the high incidence of patient samples with reduced replication fitness.

This invention relates to the correlation between reduced drug susceptibility and reduced replication fitness.

This invention further relates to the occurrence of viruses with reduced fitness in patients receiving protease inhibitor and/or reverse transcriptase inhibitor treatment.

This invention further relates to the incidence of patient samples with reduced replication fitness in which the reduction in fitness is due to altered protease processing of the gag polyprotein (p55).

5

This invention further relates to the incidence of protease mutations in patient samples that exhibit low, moderate or normal (wildtype) replication fitness.

10 This invention further relates to protease mutations that are frequently observed, either alone or in combination, in viruses that exhibit reduced replication capacity.

15 This invention also relates to the incidence of patient samples with reduced replication fitness in which the reduction in fitness is due to altered reverse transcriptase activity. This invention relates to the occurrence of viruses with reduced replication fitness in patients failing antiretroviral drug treatment. This
20 invention further relates to a means and method for using replication fitness measurements to guide the treatment of HIV-1. This invention further relates to a means and method for using replication fitness measurements to guide the treatment of patients failing antiretroviral drug
25 treatment. This invention further relates to the means and methods for using replication fitness measurements to guide the treatment of patients newly infected with HIV-1.

This invention, provides the means and methods for using replication fitness measurements to guide the treatment of viral diseases, including, but not limited to HIV-1, hepadnaviruses (human hepatitis B virus), flaviviruses (human hepatitis C virus) and herpesviruses (human cytomegalovirus).

In a further embodiment, the invention provides a method for determining replication capacity for a patient's virus comprising:

- (a) introducing a resistance test vector comprising a patient derived segment and an indicator gene into a host cell;
- (b) culturing the host cell from (a);
- (c) harvesting viral particles from step (b) and infecting target host cells;
- (d) measuring expression of the indicator gene in the target host cell, wherein the expression of the indicator gene is dependent upon the patient-derived segment;
- (e) comparing the expression of the indicator gene from (d) with the expression of the indicator gene measured when steps (a) through (d) are carried out in a control resistance test vector; and
- (f) normalizing the expression of the indicator gene by measuring an amount of virus in step (c).

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As used herein, "patient-derived segment" encompasses segments derived from human and various animal species. Such species include, but are not limited to chimpanzees, horses, cattles, cats and dogs.

Patient-derived segments can also be incorporated into resistance test vectors using any of several alternative cloning techniques as set forth in detail in US Patent Number 5,837,464 (International Publication Number WO 97/27319) which is hereby incorporated by reference. For example, cloning via the introduction of class II restriction sites into both the plasmid backbone and the patient-derived segments or by uracil DNA glycosylase primer cloning.

The patient-derived segment may be obtained by any method of molecular cloning or gene amplification, or modifications thereof, by introducing patient sequence acceptor sites, as described below, at the ends of the patient-derived segment to be introduced into the resistance test vector. For example, in a gene amplification method such as PCR, restriction sites corresponding to the patient-sequence acceptor sites can be incorporated at the ends of the primers used in the PCR reaction. Similarly, in a molecular cloning method such as cDNA cloning, said restriction sites can be incorporated at the ends of the primers used for first or

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second strand cDNA synthesis, or in a method such as primer-repair of DNA, whether cloned or uncloned DNA, said restriction sites can be incorporated into the primers used for the repair reaction. The patient sequence acceptor sites and primers are designed to improve the representation of patient-derived segments. Sets of resistance test vectors having designed patient sequence acceptor sites provide representation of patient-derived segments that may be underrepresented in one resistance test vector alone.

"Resistance test vector" means one or more vectors which taken together contain DNA comprising a patient-derived segment and an indicator gene. Resistance test vectors are prepared as described in US Patent Number 5,837,464 (International Publication Number WO 97/27319), which is hereby incorporated by reference, by introducing patient sequence acceptor sites, amplifying or cloning patient-derived segments and inserting the amplified or cloned sequences precisely into indicator gene viral vectors at the patient sequence acceptor sites. Alternatively, a resistance test vector (also referred to as a resistance test vector system) is prepared by introducing patient sequence acceptor sites into a packaging vector, amplifying or cloning patient-derived segments and inserting the amplified or cloned sequences precisely into the packaging vector at the patient sequence acceptor sites and co-transfecting this packaging vector with an indicator gene viral vector.

"Indicator or indicator gene," as described in US Patent Number 5,837,464 (International Publication Number WO 97/27319) refers to a nucleic acid encoding a protein, DNA or RNA structure that either directly or through a reaction gives rise to a measurable or noticeable aspect, e.g. a color or light of a measurable wavelength or in the case of DNA or RNA used as an indicator a change or generation of a specific DNA or RNA structure. Preferred examples of an indicator gene is the E. coli lacZ gene which encodes beta-galactosidase, the luc gene which encodes luciferase either from, for example, Photinus pyralis (the firefly) or Renilla reniformis (the sea pansy), the E. coli phoA gene which encodes alkaline phosphatase, green fluorescent protein and the bacterial CAT gene which encodes chloramphenicol acetyltransferase. The indicator or indicator gene may be functional or non-functional as described in US Patent Number 5,837,464 (International Publication Number WO 97/27319).

The phenotypic drug susceptibility and resistance tests of this invention may be carried out in one or more host cells as described in US Patent Number 5,837,464 (International Publication Number WO 97/27319) which is incorporated herein by reference. Viral drug susceptibility is determined as the concentration of the anti-viral agent at which a given percentage of indicator gene expression is inhibited (e.g. the IC50 for an anti-viral agent is the concentration at which 50% of

indicator gene expression is inhibited). A standard curve for drug susceptibility of a given anti-viral drug can be developed for a viral segment that is either a standard laboratory viral segment or from a drug-naive patient (i.e. a patient who has not received any anti-viral drug) using the method described in the aforementioned patent. Correspondingly, viral drug resistance is a decrease in viral drug susceptibility for a given patient compared to such a given standard or when making one or more sequential measurements in the same patient over time, as determined by decreased susceptibility in virus from later time points compared to that from earlier time points.

The antiviral drugs being added to the test system are added at selected times depending upon the target of the antiviral drug. For example, in the case of HIV protease inhibitors, including saquinavir, ritonavir, indinavir, nelfinavir and amprenavir, they are added to packaging host cells at the time of or shortly after their transfection with a resistance test vector, at an appropriate range of concentrations. HIV reverse transcriptase inhibitors, including AZT, ddI, ddC, d4T, 3TC, abacavir, nevirapine, delavirdine and efavirenz are added to target host cells at the time of or prior to infection by the resistance test vector viral particles, at an appropriate range of concentration. Alternatively, the antiviral drugs may be present throughout the assay. The test concentration is selected from a range of concentrations which is typically between about 8×10^{-6}

μM and about 2mM and more specifically for each of the following drugs: saquinavir, indinavir, nelfinavir and amprenavir, from about $2.3 \times 10^{-5} \mu\text{M}$ to about 1.5 μM and ritonavir, from about $4.5 \times 10^{-5} \mu\text{M}$ to about 3 μM .

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In another embodiment of this invention, a candidate PRI antiretroviral compound is tested in the phenotypic drug susceptibility and resistance test using the resistance test vector comprising PR having a mutation at codon 88 to a serine. The candidate antiviral compound is added to the test system at an appropriate range of concentrations and at the transfection step. Alternatively, more than one candidate antiviral compound may be tested or a candidate antiviral compound may be tested in combination with an approved antiviral drug such as AZT, ddI, ddC, d4T, 3TC, abacavir, delavirdine, nevirapine, efavirenz, saquinavir, ritonavir, indinavir, nelfinavir, amprenavir, or a compound which is undergoing clinical trials such as adefovir and ABT-378. The effectiveness of the candidate antiviral will be evaluated by measuring the expression or inhibition of the indicator gene. In another aspect of this embodiment, the drug susceptibility and resistance test may be used to screen for viral mutants. Following the identification of mutants resistant to either known antiretrovirals or candidate antiretrovirals the resistant mutants are isolated and the DNA is analyzed. A library of viral resistant mutants can thus be assembled enabling the screening of candidate PRI antiretrovirals, alone or in combination. This will enable one of ordinary skill to

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identify effective PRI antiretrovirals and design effective therapeutic regimens.

5 The structure, life cycle and genetic elements of the
viruses which could be tested in the drug susceptibility
and resistance test of this invention would be known to
one of ordinary skill in the art. It is useful to the
10 practice of this invention, for example, to understand the
life cycle of a retrovirus, as well as the viral genes
required for retrovirus rescue and infectivity.
Retrovirally infected cells shed a membrane virus
containing a diploid RNA genome. The virus, studded with
an envelope glycoprotein (which serves to determine the
15 host range of infectivity), attaches to a cellular
receptor in the plasma membrane of the cell to be
infected. After receptor binding, the virus is
internalized and uncoated as it passes through the
cytoplasm of the host cell. Either on its way to the
20 nucleus or in the nucleus, the reverse transcriptase
molecules resident in the viral core drive the synthesis
of the double-stranded DNA provirus, a synthesis that is
primed by the binding of a tRNA molecule to the genomic
viral RNA. The double-stranded DNA provirus is
25 subsequently integrated in the genome of the host cell,
where it can serve as a transcriptional template for both
mRNAs encoding viral proteins and virion genomic RNA,
which will be packaged into viral core particles. On
their way out of the infected cell, core particles move
30 through the cytoplasm, attach to the inside of the plasma
membrane of the newly infected cell, and bud, taking with
them tracts of membrane containing the virally encoded

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5 envelope glycoprotein gene product. This cycle of
infection - reverse transcription, transcription,
translation, virion assembly, and budding - repeats itself
over and over again as infection spreads.

10 The viral RNA and, as a result, the proviral DNA encode
several cis-acting elements that are vital to the
successful completion of the viral lifecycle. The virion
RNA carries the viral promoter at its 3' end. Replicative
acrobatics place the viral promoter at the 5' end of the
15 proviral genome as the genome is reverse transcribed.
Just 3' to the 5' retroviral LTR lies the viral packaging
site. The retroviral lifecycle requires the presence of
virally encoded transacting factors. The
viral-RNA-dependent DNA polymerase (*pol*)-reverse
20 transcriptase is also contained within the viral core and
is vital to the viral life cycle in that it is responsible
for the conversion of the genomic RNA to the integrative
intermediate proviral DNA. The viral envelope
glycoprotein, *env*, is required for viral attachment to the
25 uninfected cell and for viral spread. There are also
transcriptional *trans*-activating factors, so called
transactivators, that can serve to modulate the level of
transcription of the integrated parental provirus.
Typically, replication-competent (non-defective) viruses
30 are self-contained in that they encode all of these
trans-acting factors. Their defective counterparts are
not self-contained.

5 In the case of a DNA virus, such as a hepadnavirus,
understanding the life cycle and viral genes required for
infection is useful to the practice of this invention.
The process of HBV entry has not been well defined.
Replication of HBV uses an RNA intermediate template. In
10 the infected cell the first step in replication is the
conversion of the asymmetric relaxed circle DNA (rc-DNA)
to covalently closed circle DNA (cccDNA). This process,
which occurs within the nucleus of infected liver cells,
involves completion of the DNA positive-strand synthesis
15 and ligation of the DNA ends. In the second step, the
cccDNA is transcribed by the host RNA polymerase to
generate a 3.5 kB RNA template (the pregenome). This
pregenome is complexed with protein in the viral core.
The third step involves the synthesis of the first
20 negative-sense DNA strand by copying the pregenomic RNA
using the virally encoded P protein reverse transcriptase.
The P protein also serves as the minus strand DNA primer.
Finally, the synthesis of the second positive-sense DNA
strand occurs by copying the first DNA strand, using the P
25 protein DNA polymerase activity and an oligomer of viral
RNA as primer. The pregenome also transcribes mRNA for
the major structural core proteins.

5 The following flow chart illustrates certain of the various vectors and host cells which may be used in this invention. It is not intended to be all inclusive.

Vectors

10 Indicator gene cassette + Viral vector
(functional/nonfunctional (genomic or subgenomic)
indicator gene)



15 Indicator Gene Viral Vector
(functional/nonfunctional indicator gene)



20 + Patient sequence
acceptor sites

+ Patient-derived
segments

25 Resistance Test Vector
(patient-derived segments + indicator gene)

30

Host Cells

Packaging Host Cell - transfected with packaging

5 expression vectors

Resistance Test Vector Host Cell - a packaging host cell transfected with a resistance test vector

10 Target Host Cell - a host cell to be infected by a resistance test vector viral particle produced by the resistance test vector host cell

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Resistance Test Vector

"Resistance test vector" means one or more vectors which taken together contain DNA or RNA comprising a patient-derived segment and an indicator gene. In the case where the resistance test vector comprises more than one vector the patient-derived segment may be contained in one vector and the indicator gene in a different vector. Such a resistance test vector comprising more than one vector is referred to herein as a resistance test vector system for purposes of clarity but is nevertheless understood to be a resistance test vector. The DNA or RNA of a resistance test vector may thus be contained in one or more DNA or RNA molecules. In one embodiment, the resistance test vector is made by insertion of a patient-derived segment into an indicator gene viral vector. In another embodiment, the resistance test vector is made by insertion of a patient-derived segment into a packaging vector while the indicator gene is contained in

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5 a second vector, for example an indicator gene viral
vector. As used herein, "patient-derived segment" refers
to one or more viral segments obtained directly from a
patient using various means, for example, molecular
cloning or polymerase chain reaction (PCR) amplification
10 of a population of patient-derived segments using viral
DNA or complementary DNA (cDNA) prepared from viral RNA,
present in the cells (e.g. peripheral blood mononuclear
cells, PBMC), serum or other bodily fluids of infected
patients. When a viral segment is "obtained directly"
15 from a patient it is obtained without passage of the virus
through culture, or if the virus is cultured, then by a
minimum number of passages to essentially eliminate the
selection of mutations in culture. The term "viral
segment" refers to any functional viral sequence or viral
20 gene encoding a gene product (e.g., a protein) that is the
target of an anti-viral drug. The term "functional viral
sequence" as used herein refers to any nucleic acid
sequence (DNA or RNA) with functional activity such as
enhancers, promoters, polyadenylation sites, sites of
25 action of trans-acting factors, such as tar and RRE,
packaging sequences, integration sequences, or splicing
sequences. If a drug were to target more than one
functional viral sequence or viral gene product then
patient-derived segments corresponding to each said viral
30 gene would be inserted in the resistance test vector. In
the case of combination therapy where two or more
anti-virals targeting two different functional viral
sequences or viral gene products are being evaluated,

5 patient-derived segments corresponding to each functional
viral sequence or viral gene product would be inserted in
the resistance test vector. The patient-derived segments
are inserted into unique restriction sites or specified
10 locations, called patient sequence acceptor sites, in the
indicator gene viral vector or for example, a packaging
vector depending on the particular construction being used
as described herein.

15 As used herein, "patient-derived segment" encompasses
segments derived from human and various animal species.
Such species include, but are not limited to chimpanzees,
horses, cattles, cats and dogs.

20 Patient-derived segments can also be incorporated into
resistance test vectors using any of several alternative
cloning techniques. For example, cloning via the
introduction of class II restriction sites into both the
plasmid backbone and the patient-derived segments or by
uracil DNA glycosylase primer cloning (refs).

25 The patient-derived segment may be obtained by any method
of molecular cloning or gene amplification, or
modifications thereof, by introducing patient sequence
acceptor sites, as described below, at the ends of the
30 patient-derived segment to be introduced into the
resistance test vector. For example, in a gene
amplification method such as PCR, restriction sites
corresponding to the patient-sequence acceptor sites can

5 be incorporated at the ends of the primers used in the PCR
reaction. Similarly, in a molecular cloning method such
as cDNA cloning, said restriction sites can be
incorporated at the ends of the primers used for first or
10 second strand cDNA synthesis, or in a method such as
primer-repair of DNA, whether cloned or uncloned DNA, said
restriction sites' can be incorporated into the primers
used for the repair reaction. The patient sequence
acceptor sites and primers are designed to improve the
representation of patient-derived segments. Sets of
15 resistance test vectors having designed patient sequence
acceptor sites provide representation of patient-derived
segments that would be underrepresented in one resistance
test vector alone.

20 Resistance test vectors are prepared by modifying an
indicator gene viral vector (described below) by
introducing patient sequence acceptor sites, amplifying or
cloning patient-derived segments and inserting the
amplified or cloned sequences precisely into indicator
25 gene viral vectors at the patient sequence acceptor sites.

The resistance test vectors are constructed from
indicator gene viral vectors which are in turn derived
from genomic viral vectors or subgenomic viral vectors and
an indicator gene cassette, each of which is described
30 below. Resistance test vectors are then introduced into a
host cell. Alternatively, a resistance test vector (also
referred to as a resistance test vector system) is
prepared by introducing patient sequence acceptor sites

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5 into a packaging vector, amplifying or cloning
patient-derived segments and inserting the amplified or
cloned sequences precisely into the packaging vector at
the patient sequence acceptor sites and co-transfecting
this packaging vector with an indicator gene viral vector.

10 In one preferred embodiment, the resistance test vector
may be introduced into packaging host cells together with
packaging expression vectors, as defined below, to produce
resistance test vector viral particles that are used in
15 drug resistance and susceptibility tests that are referred
to herein as a "particle-based test." In an alternative
preferred embodiment, the resistance test vector may be
introduced into a host cell in the absence of packaging
expression vectors to carry out a drug resistance and
20 susceptibility test that is referred to herein as a
"non-particle-based test." As used herein a "packaging
expression vector" provides the factors, such as packaging
proteins (e.g. structural proteins such as core and
envelope polypeptides), transacting factors, or genes
25 required by replication-defective retrovirus or
hepadnavirus. In such a situation, a
replication-competent viral genome is enfeebled in a
manner such that it cannot replicate on its own. This
means that, although the packaging expression vector can
30 produce the trans-acting or missing genes required to
rescue a defective viral genome present in a cell
containing the enfeebled genome, the enfeebled genome
cannot rescue itself.

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5 **Indicator or Indicator Gene**

10 "Indicator or indicator gene" refers to a nucleic acid
encoding a protein, DNA or RNA structure that either
directly or through a reaction gives rise to a measurable
or noticeable aspect, e.g. a color or light of a
measurable wavelength or in the case of DNA or RNA used as
an indicator a change or generation of a specific DNA or
RNA structure. Preferred examples of an indicator gene is
the *E. coli lacZ* gene which encodes beta-galactosidase,
the *luc* gene which encodes luciferase either from, for
15 example, *Photinus pyralis* (the firefly) or *Renilla*
reniformis (the sea pansy), the *E. coli phoA* gene which
encodes alkaline phosphatase, green fluorescent protein
and the bacterial CAT gene which encodes chloramphenicol
acetyltransferase. Additional preferred examples of an
20 indicator gene are secreted proteins or cell surface
proteins that are readily measured by assay, such as
radioimmunoassay (RIA), or fluorescent activated cell
sorting (FACS), including, for example, growth factors,
cytokines and cell surface antigens (e.g. growth hormone,
25 Il-2 or CD4, respectively). "Indicator gene" is
understood to also include a selection gene, also referred
to as a selectable marker. Examples of suitable
selectable markers for mammalian cells are dihydrofolate
reductase (DHFR), thymidine kinase, hygromycin, neomycin,
30 zeocin or *E. coli gpt*. In the case of the foregoing
examples of indicator genes, the indicator gene and the
patient-derived segment are discrete, i.e. distinct and
separate genes. In some cases a patient-derived segment

5 may also be used as an indicator gene. In one such
embodiment in which the patient-derived segment
corresponds to more than one viral gene which is the
target of an anti-viral, one of said viral genes may also
serve as the indicator gene. For example, a viral
10 protease gene may serve as an indicator gene by virtue of
its ability to cleave a chromogenic substrate or its
ability to activate an inactive zymogen which in turn
cleaves a chromogenic substrate, giving rise in each case
to a color reaction. In all of the above examples of
15 indicator genes, the indicator gene may be either
"functional" or "non-functional" but in each case the
expression of the indicator gene in the target cell is
ultimately dependent upon the action of the
patient-derived segment.

20 Functional Indicator Gene

In the case of a "functional indicator gene" the indicator
gene may be capable of being expressed in a "packaging
host cell/resistance test vector host cell" as defined
25 below, independent of the patient-derived segment,
however the functional indicator gene could not be
expressed in the target host cell, as defined below,
without the production of functional resistance test
vector particles and their effective infection of the
30 target host cell. In one embodiment of a functional
indicator gene, the indicator gene cassette, comprising
control elements and a gene encoding an indicator protein,
is inserted into the indicator gene viral vector with the

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5 same or opposite transcriptional orientation as the native
or foreign enhancer/promoter of the viral vector. One
example of a functional indicator gene in the case of HIV
or HBV, places the indicator gene and its promoter (a CMV
10 IE enhancer/promoter) in the same or opposite
transcriptional orientation as the HIV-LTR or HBV
enhancer-promoter, respectively, or the CMV IE
enhancer/promoter associated with the viral vector.

Non-Functional Indicator Gene

15 Alternatively the indicator gene, may be "non-functional"
in that the indicator gene is not efficiently expressed in
a packaging host cell transfected with the resistance test
vector, which is then referred to a resistance test vector
host cell, until it is converted into a functional
20 indicator gene through the action of one or more of the
patient-derived segment products. An indicator gene is
rendered non-functional through genetic manipulation
according to this invention.

25 1. Permuted Promoter In one embodiment an indicator gene
is rendered non-functional due to the location of the
promoter, in that, although the promoter is in the same
transcriptional orientation as the indicator gene, it
follows rather than precedes the indicator gene coding
30 sequence. This misplaced promoter is referred to as a
"permuted promoter." In addition to the permuted promoter
the orientation of the non-functional indicator gene is
opposite to that of the native or foreign

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5 promoter/enhancer of the viral vector. Thus the coding
sequence of the non-functional indicator gene can neither
be transcribed by the permuted promoter nor by the viral
promoters. The non-functional indicator gene and its
permuted promoter is rendered functional by the action of
10 one or more of the viral proteins. One example of a
non-functional indicator gene with a permuted promoter in
the case of HIV, places a T7 phage RNA polymerase promoter
(herein referred to as T7 promoter) promoter in the 5' LTR
in the same transcriptional orientation as the indicator
15 gene. The indicator gene cannot be transcribed by the T7
promoter as the indicator gene cassette is positioned
upstream of the T7 promoter. The non-functional indicator
gene in the resistance test vector is converted into a
functional indicator gene by reverse transcriptase upon
20 infection of the target cells, resulting from the
repositioning of the T7 promoter, by copying from the 5'
LTR to the 3' LTR, relative to the indicator gene coding
region. Following the integration of the repaired
indicator gene into the target cell chromosome by HIV
25 integrase, a nuclear T7 RNA polymerase expressed by the
target cell transcribes the indicator gene. One example
of a non-functional indicator gene with a permuted
promoter in the case of HBV, places an enhancer-promoter
region downstream or 3' of the indicator gene both having
30 the same transcriptional orientation. The indicator gene
cannot be transcribed by the enhancer-promoter as the
indicator gene cassette is positioned upstream. The
non-functional indicator gene in the resistance test

5 vector is converted into a functional indicator gene by reverse transcription and circularization of the HBV indicator gene viral vector by the repositioning of the enhancer-promoter upstream relative to the indicator gene coding region.

10 A permuted promoter may be any eukaryotic or prokaryotic promoter which can be transcribed in the target host cell. Preferably the promoter will be small in size to enable insertion in the viral genome without disturbing viral replication. More preferably, a promoter that is small in
15 size and is capable of transcription by a single subunit RNA polymerase introduced into the target host cell, such as a bacteriophage promoter, will be used. Examples of such bacteriophage promoters and their cognate RNA
20 polymerases include those of phages T7, T3 and Sp6. A nuclear localization sequence (NLS) may be attached to the RNA polymerase to localize expression of the RNA polymerase to the nucleus where they may be needed to transcribed the repaired indicator gene. Such an NLS may
25 be obtained from any nuclear-transported protein such as the SV40 T antigen. If a phage RNA polymerase is employed, an internal ribosome entry site (IRES) such as the EMC virus 5' untranslated region (UTR) may be added in front of the indicator gene, for translation of the
30 transcripts which are generally uncapped. In the case of HIV, the permuted promoter itself can be introduced at any position within the 5' LTR that is copied to the 3' LTR during reverse transcription so long as LTR function is

5 not disrupted, preferably within the U5 and R portions of
the LTR, and most preferably outside of functionally
important and highly conserved regions of U5 and R. In
the case of HBV, the permuted promoter can be placed at
any position that does not disrupt the cis acting elements
10 that are necessary for HBV DNA replication. Blocking
sequences may be added at the ends of the resistance test
vector should there be inappropriate expression of the
non-functional indicator gene due to transfection
artifacts (DNA concatenation). In the HIV example of the
15 permuted T7 promoter given above, such a blocking sequence
may consist of a T7 transcriptional terminator, positioned
to block readthrough transcription resulting from DNA
concatenation, but not transcription resulting from
repositioning of the permuted T7 promoter from the 5' LTR
20 to the 3' LTR during reverse transcription.

2. Permuted Coding Region In a second embodiment, an
indicator gene is rendered non-functional due to the
relative location of the 5' and 3' coding regions of the
25 indicator gene, in that, the 3' coding region precedes
rather than follows the 5' coding region. This misplaced
coding region is referred to as a "permuted coding
region." The orientation of the non-functional indicator
gene may be the same or opposite to that of the native or
foreign promoter/enhancer of the viral vector, as mRNA
30 coding for a functional indicator gene will be produced in
the event of either orientation. The non-functional
indicator gene and its permuted coding region is rendered

5 functional by the action of one or more of the
patient-derived segment products. A second example of a
non-functional indicator gene with a permuted coding
region in the case of HIV, places a 5' indicator gene
coding region with an associated promoter in the 3' LTR U3
10 region and a 3' indicator gene coding region in an
upstream location of the HIV genome, with each coding
region having the same transcriptional orientation as the
viral LTRs. In both examples, the 5' and 3' coding
regions may also have associated splice donor and acceptor
15 sequences, respectively, which may be heterologous or
artificial splicing signals. The indicator gene cannot be
functionally transcribed either by the associated promoter
or viral promoters, as the permuted coding region prevents
the formation of functionally spliced transcripts. The
20 non-functional indicator gene in the resistance test
vector is converted into a functional indicator gene by
reverse transcriptase upon infection of the target cells,
resulting from the repositioning of the 5' and 3'
indicator gene coding regions relative to one another, by
25 copying of the 3' LTR to the 5' LTR. Following
transcription by the promoter associated with the 5'
coding region, RNA splicing can join the 5' and 3' coding
regions to produce a functional indicator gene product.
One example of a non-functional indicator gene with a
30 permuted coding region in the case of HBV, places a 3'
indicator gene coding region upstream or 5' of the
enhancer-promoter and the 5' coding region of the
indicator gene. The transcriptional orientation of the

5 indicator gene 5' and 3' coding regions are identical to
one another, and the same as that of the indicator gene
viral vector. However, as the indicator gene 5' and 3'
coding regions are permuted in the resistance test vectors
10 (i.e., the 5' coding region is downstream of the 3' coding
region), no mRNA is transcribed which can be spliced to
generate a functional indicator gene coding region.
Following reverse transcription and circularization of the
indicator gene viral vector, the indicator gene 3' coding
region is positioned downstream or 3' to the
15 enhancer-promoter and 5' coding regions thus permitting
the transcription of mRNA which can be spliced to generate
a functional indicator gene coding region.

20 3. Inverted Intron In a third embodiment, the indicator
gene is rendered non-functional through use of an
"inverted intron," i.e. an intron inserted into the coding
sequence of the indicator gene with a transcriptional
orientation opposite to that of the indicator gene. The
overall transcriptional orientation of the indicator gene
25 cassette including its own, linked promoter, is opposite
to that of the viral control elements, while the
orientation of the artificial intron is the same as the
viral control elements. Transcription of the indicator
gene by its own linked promoter does not lead to the
30 production of functional transcripts as the inverted
intron cannot be spliced in this orientation.
Transcription of the indicator gene by the viral control
elements does, however, lead to the removal of the

5 inverted intron by RNA splicing, although the indicator
gene is still not functionally expressed as the resulting
transcript has an antisense orientation. Following the
reverse transcription of this transcript and integration
10 of the resultant retroviral DNA, or the circularization of
hepadnavirus DNA, the indicator gene can be functionally
transcribed using its own linked promoter as the inverted
intron has been previously removed. In this case, the
indicator gene itself may contain its own functional
15 promoter with the entire transcriptional unit oriented
opposite to the viral control elements. Thus the
non-functional indicator gene is in the wrong orientation
to be transcribed by the viral control elements and it
cannot be functionally transcribed by its own promoter, as
20 the inverted intron cannot be properly excised by
splicing. However, in the case of a retrovirus and HIV
specifically and hepadnaviruses, and HBV specifically,
transcription by the viral promoters (HIV LTR or HBV
enhancer-promoter) results in the removal of the inverted
25 intron by splicing. As a consequence of reverse
transcription of the resulting spliced transcript and the
integration of the resulting provirus into the host cell
chromosome or circularization of the HBV vector, the
indicator gene can now be functionally transcribed by its
own promoter. The inverted intron, consisting of a splice
30 donor and acceptor site to remove the intron, is
preferably located in the coding region of the indicator
gene in order to disrupt translation of the indicator
gene. The splice donor and acceptor may be any splice

5 donor and acceptor. A preferred splice donor-receptor is the CMV IE splice donor and the splice acceptor of the second exon of the human alpha globin gene ("intron A").

Indicator Gene Viral Vector - Construction

10 As used herein, "indicator gene viral vector" refers to a vector(s) comprising an indicator gene and its control elements and one or more viral genes. The indicator gene viral vector is assembled from an indicator gene cassette and a "viral vector," defined below. The indicator gene
15 viral vector may additionally include an enhancer, splicing signals, polyadenylation sequences, transcriptional terminators, or other regulatory sequences. Additionally the indicator gene viral vector may be functional or nonfunctional. In the event that the
20 viral segments which are the target of the anti-viral drug are not included in the indicator gene viral vector they are provided in a second vector. An "indicator gene cassette" comprises an indicator gene and control elements. "Viral vector" refers to a vector comprising
25 some or all of the following: viral genes encoding a gene product, control sequences, viral packaging sequences, and in the case of a retrovirus, integration sequences. The viral vector may additionally include one or more viral segments one or more of which may be the target of an
30 anti-viral drug. Two examples of a viral vector which contain viral genes are referred to herein as an "genomic viral vector" and a "subgenomic viral vector." A "genomic viral vector" is a vector which may comprise a deletion of

5 a one or more viral genes to render the virus replication
incompetent, but which otherwise preserves the mRNA
expression and processing characteristics of the complete
virus. In one embodiment for an HIV drug susceptibility
and resistance test, the genomic viral vector comprises
10 the HIV *gag-pol*, *vif*, *vpr*, *tat*, *rev*, *vpu*, and *nef* genes
(some, most or all of *env* may be deleted). A "subgenomic
viral vector" refers to a vector comprising the coding
region of one or more viral genes which may encode the
proteins that are the target(s) of the anti-viral drug.
15 In the case of HIV, a preferred embodiment is a subgenomic
viral vector comprising the HIV *gag-pol* gene. In the case
of HBV a preferred embodiment is a subgenomic viral vector
comprising the HBV P gene. In the case of HIV, two
examples of proviral clones used for viral vector
20 construction are: HXB2 (Fisher et al., (1986) *Nature*, 320,
367-371) and NL4-3, (Adachi et al., (1986) *J. Virol.*, 59,
284-291). In the case of HBV, a large number of full
length genomic sequences have been characterized and could
be used for construction of HBV viral vectors: GenBank
25 Nos. M54923, M38636, J02203 and X59795. The viral coding
genes may be under the control of a native
enhancer/promoter or a foreign viral or cellular
enhancer/promoter. A preferred embodiment for an HIV drug
susceptibility and resistance test, is to place the
30 genomic or subgenomic viral coding regions under the
control of the native enhancer/promoter of the HIV-LTR U3
region or the CMV immediate-early (IE) enhancer/promoter.
A preferred embodiment for an HBV drug susceptibility and

5 resistance test, is to place the genomic or subgenomic
viral coding regions under the control of the CMV
immediate-early (IE) enhancer/promoter. In the case of an
indicator gene viral vector that contains one or more
10 viral genes which are the targets or encode proteins which
are the targets of an anti-viral drug(s) then said vector
contains the patient sequence acceptor sites. The
patient-derived segments are inserted in the patient
sequence acceptor site in the indicator gene viral vector
which is then referred to as the resistance test vector,
15 as described above.

"Patient sequence acceptor sites" are sites in a vector
for insertion of patient-derived segments and said sites
may be: 1) unique restriction sites introduced by
20 site-directed mutagenesis into a vector; 2) naturally
occurring unique restriction sites in the vector; or 3)
selected sites into which a patient-derived segment may be
inserted using alternative cloning methods (e.g. UDG
cloning). In one embodiment the patient sequence acceptor
25 site is introduced into the indicator gene viral vector.
The patient sequence acceptor sites are preferably located
within or near the coding region of the viral protein
which is the target of the anti-viral drug. The viral
sequences used for the introduction of patient sequence
30 acceptor sites are preferably chosen so that no change, or
a conservative change, is made in the amino acid coding
sequence found at that position. Preferably the patient
sequence acceptor sites are located within a relatively

5 conserved region of the viral genome to facilitate
introduction of the patient-derived segments.
Alternatively, the patient sequence acceptor sites are
located between functionally important genes or regulatory
10 sequences. Patient-sequence acceptor sites may be located
at or near regions in the viral genome that are relatively
conserved to permit priming by the primer used to
introduce the corresponding restriction site into the
patient-derived segment. To improve the representation of
patient-derived segments further, such primers may be
15 designed as degenerate pools to accommodate viral sequence
heterogeneity, or may incorporate residues such as
deoxyinosine (I) which have multiple base-pairing
capabilities. Sets of resistance test vectors having
patient sequence acceptor sites that define the same or
20 overlapping restriction site intervals may be used
together in the drug resistance and susceptibility tests
to provide representation of patient-derived segments that
contain internal restriction sites identical to a given
patient sequence acceptor site, and would thus be
25 underrepresented in either resistance test vector alone.

Host Cells

The resistance test vector is introduced into a host cell.
Suitable host cells are mammalian cells. Preferred host
30 cells are derived from human tissues and cells which are
the principle targets of viral infection. In the case of
HIV these include human cells such as human T cells,
monocytes, macrophage, dendritic cells, Langerhans cells,

5 hematopoietic stem cells or precursor cells, and other
cells. In the case of HBV, suitable host cells include
hepatoma cell lines (HepG2, Huh 7), primary human
hepatocytes, mammalian cells which can be infected by
pseudotyped HBV, and other cells. Human derived host
10 cells will assure that the anti-viral drug will enter the
cell efficiently and be converted by the cellular
enzymatic machinery into the metabolically relevant form
of the anti-viral inhibitor. Host cells are referred to
herein as a "packaging host cells," "resistance test
15 vector host cells," or "target host cells." A "packaging
host cell" refers to a host cell that provides the
trans-acting factors and viral packaging proteins required
by the replication defective viral vectors used herein,
such as the resistance test vectors, to produce resistance
20 test vector viral particles. The packaging proteins may
be provided for by the expression of viral genes contained
within the resistance test vector itself, a packaging
expression vector(s), or both. A packaging host cell is a
host cell which is transfected with one or more packaging
25 expression vectors and when transfected with a resistance
test vector is then referred to herein as a "resistance
test vector host cell" and is sometimes referred to as a
packaging host cell/resistance test vector host cell.
Preferred host cells for use as packaging host cells for
30 HIV include 293 human embryonic kidney cells (293, Graham,
F.L. et al., J. Gen Virol. 36: 59, 1977), BOSC23 (Pear et
al., Proc. Natl. Acad. Sci. 90, 8392, 1993), tsa54 and
tsa201 cell lines (Heinzel et al., J.Virol. 62,

5 3738,1988), for HBV HepG2 (Galle and Theilmann, L. Arzheim.-Forsch Drug Res. (1990) 40, 1380-1382). (Huh, Ueda, K et al. Virology *1989) 169, 213-216). A "target host cell" refers to a cell to be infected by resistance test vector viral particles produced by the resistance
10 test vector host cell in which expression or inhibition of the indicator gene takes place. Preferred host cells for use as target host cells include human T cell leukemia cell lines including Jurkat (ATCC T1B-152), H9 (ATCC HTB-176), CEM (ATCC CCL-119), HUT78 (ATCC T1B-161), and
15 derivatives thereof.

This invention is illustrated in the Experimental Details section which follows. These sections are set forth to aid in an understanding of the invention but are not
20 intended to, and should not be construed to, limit in any way the invention as set forth in the claims which follow thereafter.

Experimental Details

General Materials and Methods

25 Most of the techniques used to construct vectors, and transfect and infect cells, are widely practiced in the art, and most practitioners are familiar with the standard resource materials that describe specific conditions and
30 procedures. However, for convenience, the following paragraphs may serve as a guideline.

As used herein, "replication capacity" is defined herein

5 is a measure of how well the virus replicates. This may also be referred to as viral fitness. In one embodiment, replication capacity can be measured by evaluating the ability of the virus to replicate in a single round of replication.

10 As used herein, "control resistance test vector" is defined as a resistance test vector comprising a standard viral sequence (for example, HXB2, PNL4-3) and an indicator gene.

15 As used herein, "normalizing" is defined as standardizing the amount of the expression of indicator gene measured relative to the number of viral particles giving rise to the expression of the indicator gene. For example, 20 normalization is measured by dividing the amount of luciferase activity measured by the number of viral particles measured at the time of infection.

25 "Plasmids" and "vectors" are designated by a lower case p followed by letters and/or numbers. The starting plasmids herein are either commercially available, publicly available on an unrestricted basis, or can be constructed from available plasmids in accord with published procedures. In addition, equivalent plasmids to those 30 described are known in the art and will be apparent to the ordinarily skilled artisan.

Construction of the vectors of the invention employs

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5 standard ligation and restriction techniques which are
well understood in the art (see Ausubel et al., (1987)
Current Protocols in Molecular Biology, Wiley -
Interscience or Maniatis et al., (1992) in Molecular
10 Cloning: A laboratory Manual, Cold Spring Harbor
Laboratory, N.Y.). Isolated plasmids, DNA sequences, or
synthesized oligonucleotides are cleaved, tailored, and
religated in the form desired. The sequences of all DNA
constructs incorporating synthetic DNA were confirmed by
DNA sequence analysis (Sanger et al. (1977) Proc. Natl.
15 Acad. Sci. 74, 5463-5467).

"Digestion" of DNA refers to catalytic cleavage of the DNA
with a restriction enzyme that acts only at certain
sequences, restriction sites, in the DNA. The various
20 restriction enzymes used herein are commercially available
and their reaction conditions, cofactors and other
requirements are known to the ordinarily skilled artisan.
For analytical purposes, typically 1 µg of plasmid or DNA
fragment is used with about 2 units of enzyme in about 20
25 µl of buffer solution. Alternatively, an excess of
restriction enzyme is used to insure complete digestion of
the DNA substrate. Incubation times of about one hour to
two hours at about 37°C are workable, although variations
can be tolerated. After each incubation, protein is
30 removed by extraction with phenol/chloroform and the
nucleic acid recovered from aqueous fractions by
precipitation with ethanol. If desired, size separation
of the cleaved fragments may be performed by

5 polyacrylamide gel or agarose gel electrophoresis using standard techniques. A general description of size separations is found in Methods of Enzymology 65:499-560 (1980).

10 Restriction cleaved fragments may be blunt ended by treating with the large fragment of E. coli DNA polymerase I (Klenow) in the presence of the four deoxynucleotide triphosphates (dNTPs) using incubation times of about 15 to 25 minutes at 20°C in 50 mM Tris (pH 7.6) 50 mM NaCl, 6
15 mM MgCl₂, 6 mM DTT and 5-10 mM dNTPs. The Klenow fragment fills in at 5' sticky ends but chews back protruding 3' single strands, even though the four dNTPs are present. If desired, selective repair can be performed by supplying only one of the dNTPs, or with selected dNTPs, within the
20 limitations dictated by the nature of the sticky ends. After treatment with Klenow, the mixture is extracted with phenol/chloroform and ethanol precipitated. Treatment under appropriate conditions with S1 nuclease or Bal-31 results in hydrolysis of any single-stranded portion.

25 Ligations are performed in 15-50 µl volumes under the following standard conditions and temperatures: 20 mM Tris-Cl pH 7.5, 10 mM MgCl₂, 10 mM DTT, 33 mg/ml BSA, 10 mM- 50 mM NaCl, and either 40 µM ATP, 0.01-0.02 (Weiss)
30 units T4 DNA ligase at 0°C (for "sticky end" ligation) or 1mM ATP, 0.3 - 0.6 (Weiss) units T4 DNA ligase at 14°C (for "blunt end" ligation). Intermolecular "sticky end" ligations are usually performed at 33-100 µg/ml total DNA

5 concentrations (5-100 mM total end concentration).
Intermolecular blunt end ligations (usually employing a
10-30 fold molar excess of linkers) are performed at 1 μ M
total ends concentration.

10 "Transient expression" refers to unamplified expression
within about one day to two weeks of transfection. The
optimal time for transient expression of a particular
desired heterologous gene may vary depending on several
factors including, for example, any transacting factors
15 which may be employed, translational control mechanisms
and the host cell. Transient expression occurs when the
particular plasmid that has been transfected functions,
i.e., is transcribed and translated. During this time the
plasmid DNA which has entered the cell is transferred to
20 the nucleus. The DNA is in a nonintegrated state, free
within the nucleus. Transcription of the plasmid taken up
by the cell occurs during this period. Following
transfection the plasmid DNA may become degraded or
diluted by cell division. Random integration within the
25 cell chromatin occurs.

In general, vectors containing promoters and control
sequences which are derived from species compatible with
the host cell are used with the particular host cell.
30 Promoters suitable for use with prokaryotic hosts
illustratively include the beta-lactamase and lactose
promoter systems, alkaline phosphatase, the tryptophan
(trp) promoter system and hybrid promoters such as tac

5 promoter. However, other functional bacterial promoters
are suitable. In addition to prokaryotes, eukaryotic
microbes such as yeast cultures may also be used.
Saccharomyces cerevisiae, or common baker's yeast is the
most commonly used eukaryotic microorganism, although a
10 number of other strains are commonly available. Promoters
controlling transcription from vectors in mammalian host
cells may be obtained from various sources, for example,
the genomes of viruses such as: polyoma, simian virus 40
(SV40), adenovirus, retroviruses, hepatitis B virus and
15 preferably cytomegalovirus, or from heterologous mammalian
promoters, e.g. β -actin promoter. The early and late
promoters of the SV 40 virus are conveniently obtained as
an SV40 restriction fragment that also contains the SV40
viral origin of replication. The immediate early promoter
20 of the human cytomegalovirus is conveniently obtained as a
HindIII E restriction fragment. Of course, promoters from
the host cell or related species also are useful herein.

The vectors used herein may contain a selection gene, also
25 termed a selectable marker. A selection gene encodes a
protein, necessary for the survival or growth of a host
cell transformed with the vector. Examples of suitable
selectable markers for mammalian cells include the
dihydrofolate reductase gene (DHFR), the ornithine
30 decarboxylase gene, the multi-drug resistance gene (mdr),
the adenosine deaminase gene, and the glutamine synthase
gene. When such selectable markers are successfully
transferred into a mammalian host cell, the transformed

5 mammalian host cell can survive if placed under selective
pressure. There are two widely used distinct categories
of selective regimes. The first category is based on a
cell's metabolism and the use of a mutant cell line which
lacks the ability to grow independent of a supplemented
10 media. The second category is referred to as dominant
selection which refers to a selection scheme used in any
cell type and does not require the use of a mutant cell
line. These schemes typically use a drug to arrest growth
of a host cell. Those cells which have a novel gene would
15 express a protein conveying drug resistance and would
survive the selection. Examples of such dominant
selection use the drugs neomycin (Southern and Berg (1982)
J. Molec. Appl. Genet. 1, 327), mycophenolic acid
(Mulligan and Berg (1980) Science 209, 1422), or
20 hygromycin (Sugden et al. (1985) Mol. Cell. Biol. 5,
410-413). The three examples given above employ bacterial
genes under eukaryotic control to convey resistance to the
appropriate drug neomycin (G418 or gentamicin), xgpt
(mycophenolic acid) or hygromycin, respectively.

25 "Transfection" means introducing DNA into a host cell so
that the DNA is expressed, whether functionally expressed
or otherwise; the DNA may also replicate either as an
extrachromosomal element or by chromosomal integration.
30 Unless otherwise provided, the method used herein for
transfection of the host cells is the calcium phosphate
co-precipitation method of Graham and van der Eb (1973)
Virology 52, 456-457. Alternative methods for

5 transfection are electroporation, the DEAE-dextran method, lipofection and biolistics (Kriegler (1990) Gene Transfer and Expression: A Laboratory Manual, Stockton Press).

10 Host cells may be transfected with the expression vectors of the present invention and cultured in conventional nutrient media modified as is appropriate for inducing promoters, selecting transformants or amplifying genes. Host cells are cultured in F12:DMEM (Gibco) 50:50 with added glutamine. The culture conditions, such as
15 temperature, pH and the like, are those previously used with the host cell selected for expression, and will be apparent to the ordinarily skilled artisan.

20 The following examples merely illustrate the best mode now known for practicing the invention, but should not be construed to limit the invention. All publications and patent applications cited in this specification are herein incorporated by reference in their entirety as if each individual publication or patent application were
25 specifically and individually indicated to be incorporated by reference.

EXAMPLE 1

30 Phenotypic Drug Susceptibility and Resistance Test Using Resistance Test Vectors

Phenotypic drug susceptibility and resistance tests are carried out using the means and methods described in US Patent Number 5,837,464 (International Publication Number

5 WO 97/27319) which is hereby incorporated by reference.

10 In these experiments patient-derived segment(s) corresponding to the HIV protease and reverse transcriptase coding regions were either patient-derived segments amplified by the reverse transcription-polymerase chain reaction method (RT-PCR) using viral RNA isolated from viral particles present in the serum of HIV-infected individuals or were mutants of wild type HIV-1 made by site directed mutagenesis of a parental clone of resistance test vector DNA. Isolation of viral RNA was performed using standard procedures (e.g. RNeasy Total RNA Isolation System, Promega, Madison WI or RNeasy, Tel-Test, Friendswood, TX). The RT-PCR protocol was divided into two steps. A retroviral reverse transcriptase [e.g. Moloney MuLV reverse transcriptase (Roche Molecular Systems, Inc., Branchburg, NJ), or avian myeloblastosis virus (AMV) reverse transcriptase, (Boehringer Mannheim, Indianapolis, IN)] was used to copy viral RNA into cDNA. The cDNA was then amplified using a thermostable DNA polymerase [e.g. Taq (Roche Molecular Systems, Inc., Branchburg, NJ), Tth (Roche Molecular Systems, Inc., Branchburg, NJ), PrimeZyme (isolated from *Thermus brockianus*, Biometra, Gottingen, Germany)] or a combination of thermostable polymerases as described for the performance of "long PCR" (Barnes, W.M., (1994) Proc. Natl. Acad. Sci, USA 91, 2216-2220) [e.g. Expand High Fidelity PCR System (Taq + Pwo), (Boehringer Mannheim, Indianapolis, IN) OR GeneAmp XL PCR kit (Tth + Vent),

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5 (Roche Molecular Systems, Inc., Branchburg, NJ)].

PCR6 (Table 5, #1) is used for reverse transcription of viral RNA into cDNA. The primers, ApaI primer (PDSApa, Table 5, #2) and AgeI primer (PDSAge, Table 5, #3) used to
10 amplify the "test" patient-derived segments contained sequences resulting in ApaI and AgeI recognition sites being introduced into both ends of the PCR product, respectively.

Resistance test vectors incorporating the "test"
15 patient-derived segments were constructed as described in US Patent Number 5,837,464 (International Publication Number WO 97/27319) (see Fig. 1) using an amplified DNA product of 1.5 kB prepared by RT-PCR using viral RNA as a template and oligonucleotides PCR6 (#1), PDSApa (#2) and
20 PDSAge (#3) as primers, followed by digestion with ApaI and AgeI or the isoschizomer PnaI. To ensure that the plasmid DNA corresponding to the resultant resistance test vector comprises a representative sample of the HIV viral quasi-species present in the serum of a given patient,
25 many (>100) independent E. coli transformants obtained in the construction of a given resistance test vector were pooled and used for the preparation of plasmid DNA.

A packaging expression vector encoding an amphotrophic
30 MuLV 4070A env gene product enables production in a resistance test vector host cell of resistance test vector viral particles which can efficiently infect human target cells. Resistance test vectors encoding all HIV genes

5 with the exception of env were used to transfect a
packaging host cell (once transfected the host cell is
referred to as a resistance test vector host cell). The
packaging expression vector which encodes the amphotrophic
MuLV 4070A env gene product is used with the resistance
10 test vector to enable production in the resistance test
vector host cell of infectious pseudotyped resistance test
vector viral particles.

Resistance tests performed with resistance test vectors
15 were carried out using packaging host and target host
cells consisting of the human embryonic kidney cell line
293 (Cell Culture Facility, UC San Francisco, SF, CA) or
the Jurkat leukemic T-cell line (Arthur Weiss, UC San
Francisco, SF, CA).

20 Resistance tests were carried out with resistance test
vectors using two host cell types. Resistance test vector
viral particles were produced by a first host cell (the
resistance test vector host cell) that was prepared by
transfecting a packaging host cell with the resistance
25 test vector and the packaging expression vector. The
resistance test vector viral particles were then used to
infect a second host cell (the target host cell) in which
the expression of the indicator gene is measured (see Fig.
30 2).

The resistance test vectors containing a functional
luciferase gene cassette were constructed and host cells

5 were transfected with the resistance test vector DNA. The
resistant test vectors contained patient-derived reverse
transcriptase and protease DNA sequences that encode
proteins which were either susceptible or resistant to the
antiretroviral agents, such as nucleoside reverse
10 transcriptase inhibitors, non-nucleoside reverse
transcriptase inhibitors and protease inhibitors. The
resistance test vector viral particles produced by
transfecting the resistance test vector DNA into host
cells, either in the presence or absence of protease
15 inhibitors, were used to infect target host cells grown
either in the absence of NRTI or NNRTI or in the presence
of increasing concentrations of the drug. Luciferase
activity in infected target host cells in the presence of
drug was compared to the luciferase activity in infected
20 target host cells in the absence of drug. Drug resistance
was measured as the concentration of drug required to
inhibit by 50% the luciferase activity detected in the
absence of drug (inhibitory concentration 50%, IC₅₀).
The IC₅₀ values were determined by plotting percent drug
25 inhibition vs. log₁₀ drug concentration.

Host cells were seeded in 10-cm-diameter dishes and were
transfected one day after plating with resistance test
vector plasmid DNA and the envelope expression vector.
30 Transfections were performed using a calcium-phosphate
co-precipitation procedure. The cell culture media
containing the DNA precipitate was replaced with fresh
medium, from one to 24 hours, after transfection. Cell

5 culture media containing resistance test vector viral
particles was harvested one to four days after
transfection and was passed through a 0.45-mm filter
before being stored at -80°C. HIV capsid protein (p24)
10 levels in the harvested cell culture media were determined
by an EIA method as described by the manufacturer (SIAC;
Frederick, MD). Before infection, target cells (293 and
293/T) were plated in cell culture media. Control
15 infections were performed using cell culture media from
mock transfections (no DNA) or transfections containing
the resistance test vector plasmid DNA without the
envelope expression plasmid. One to three or more days
after infection the media was removed and cell lysis
20 buffer (Promega) was added to each well. Cell lysates
were assayed for luciferase activity. The inhibitory
effect of the drug was determined using the following
equation:

$$\% \text{ luciferase inhibition} = [1 - (\text{RLU}_{\text{luc}} [\text{drug}] / \text{RLU}_{\text{luc}})] \times 100$$

25 where $\text{RLU}_{\text{luc}} [\text{drug}]$ is the relative light unit of
luciferase activity in infected cells in the presence of
drug and RLU_{luc} is the Relative Light Unit of luciferase
activity in infected cells in the absence of drug. IC₅₀
30 values were obtained from the sigmoidal curves that were
generated from the data by plotting the percent inhibition
of luciferase activity vs. the $\log_{10}$ drug concentration.
Examples of drug inhibition curves are shown in (Fig. 3).

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EXAMPLE 2

**An in vitro Assay Using Resistance Test Vectors And Site
Directed Mutants To Correlate Phenotypes And Genotypes
Associated With HIV Drug Susceptibility And Resistance**

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Phenotypic susceptibility analysis of patient HIV samples
Resistance test vectors are constructed as described in
example 1. Resistance test vectors, or clones derived from
the resistance test vector pools, are tested in a
phenotypic assay to determine accurately and
quantitatively the level of susceptibility to a panel of
anti-retroviral drugs. This panel of anti-retroviral
drugs may comprise members of the classes known as
nucleoside-analog reverse transcriptase inhibitors
(NRTIs), non-nucleoside reverse transcriptase inhibitors
(NNRTIs), and protease inhibitors (PRIs). The panel of
drugs can be expanded as new drugs or new drug targets
become available. An IC₅₀ is determined for each
resistance test vector pool for each drug tested. The
pattern of susceptibility to all of the drugs tested is
examined and compared to known patterns of susceptibility.

A patient sample can be further examined for genotypic
changes correlated with the pattern of susceptibility
observed.

Genotypic analysis of patient HIV samples

30

Resistance test vector DNAs, either pools or clones, are
analyzed by any of the genotyping methods described in
Example 1. In one embodiment of the invention, patient
HIV sample sequences are determined using viral RNA

5 purification, RT/PCR and ABI chain terminator automated
sequencing. The sequence that is determined is compared
to control sequences present in the database or is
compared to a sample from the patient prior to initiation
of therapy, if available. The genotype is examined for
10 sequences that are different from the control or
pre-treatment sequence and correlated to the observed
phenotype.

**Phenotypic susceptibility analysis of site directed
15 mutants**

Genotypic changes that are observed to correlate with
changes in phenotypic patterns of drug susceptibility are
evaluated by construction of resistance test vectors
containing the specific mutation on a defined, wild-type
20 (drug susceptible) genetic background. Mutations may be
incorporated alone and/or in combination with other
mutations that are thought to modulate the susceptibility
of HIV to a certain drug or class of drugs. Mutations are
introduced into the resistance test vector through any of
25 the widely known methods for site-directed mutagenesis.
In one embodiment of this invention the mega-primer PCR
method for site-directed mutagenesis is used. A
resistance test vector containing the specific mutation or
group of mutations are then tested using the phenotypic
30 susceptibility assay described above and the
susceptibility profile is compared to that of a
genetically defined wild-type (drug susceptible)
resistance test vector which lacks the specific mutations.

5 Observed changes in the pattern of phenotypic susceptibility to the antiretroviral drugs tested are attributed to the specific mutations introduced into the resistance test vector.

10 **EXAMPLE 3**

Using Resistance Test Vectors To Correlate Genotypes And Phenotypes Associated With Changes in PRI Drug Susceptibility in HIV.

Phenotypic analysis of Patient 0732

15 A resistance test vector was constructed as described in example 1 from a patient sample designated as 0732. This patient had been previously treated with nelfinavir. Isolation of viral RNA and RT/PCR was used to generate a patient derived segment that comprised viral sequences
20 coding for all of PR and aa 1 - 313 of RT. The patient derived segment was inserted into an indicator gene viral vector to generate a resistance test vector designated RTV-0732. RTV-0732 was tested using a phenotypic susceptibility assay to determine accurately and
25 quantitatively the level of susceptibility to a panel of anti-retroviral drugs. This panel of anti-retroviral drugs comprised members of the classes known as NRTIs (AZT, 3TC, d4T, ddI, ddC, and abacavir), NNRTIs (delavirdine, nevirapine and efavirenz), and PRIs
30 (indinavir, nelfinavir, ritonavir, saquinavir and amprenavir). An IC50 was determined for each drug tested. Susceptibility of the patient virus to each drug was examined and compared to known patterns of susceptibility.

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5 A pattern of susceptibility to the PRIs was observed for
patient sample RTV-0732 in which there was a decrease in
both nelfinavir and indinavir susceptibility (increased
resistance) and an increase in amprenavir susceptibility
(see Fig. 4 and Table 1). Patient sample 0732 was examined
10 further for genotypic changes associated with the pattern
of susceptibility.

Determination of genotype of patient 0732

RTV-0732 DNA was analyzed by ABI chain terminator
15 automated sequencing. The nucleotide sequence was
compared to the consensus sequence of a wild type clade B
HIV-1 (HIV Sequence Database Los Alamos, NM). The
nucleotide sequence was examined for sequences that are
different from the control sequence. PR mutations were
20 noted at positions K14R, I15V, K20T, E35D, M36I, R41K,
I62V, L63Q and N88S. K14R, I15V, E35D, R41K and I62V are
naturally occurring polymorphisms in HIV-1 PR and are not
associated with reduced susceptibility to any drug. M36I
has previously been described to be associated with
25 resistance to ritonavir and nelfinavir (Shihazi, 1998).
N88S has previously been described to be associated with
resistance to nelfinavir (Patick AAC, 42: 2637 (1998) and
an investigational PRI, SC55389A (Smidt, 1997).

Phenotypic analysis of Patient 627

30 A resistance test vector was constructed as described in
example 1 from a patient sample designated as 627. This
patient had been treated with indinavir. Isolation of

5 viral RNA and RT/PCR was used to generate a patient
derived segment that comprised viral sequences coding for
all of PR and aa 1 - 313 of RT. The patient derived
segment was inserted into an indicator gene viral vector
to generate a resistance test vector designated RTV-627.
10 RTV-627 was tested using a phenotypic susceptibility assay
to determine accurately and quantitatively the level of
susceptibility to a panel of anti-retroviral drugs. This
panel of anti-retroviral drugs comprised members of the
classes known as NRTIs (AZT, 3TC, d4T, ddI, ddC, and
15 abacavir), NNRTIs (delavirdine, nevirapine and efavirenz),
and PRIs (indinavir, nelfinavir, ritonavir, saquinavir and
amprenavir). An IC50 was determined for each drug tested.
Susceptibility of the patient virus to each drug was
examined and compared to known patterns of susceptibility.
20 A pattern of susceptibility to the PRIs was observed for
patient sample RTV-627 in which there was a decrease in
indinavir and nelfinavir susceptibility (increased
resistance) and an increase in amprenavir and saquinavir
susceptibility. Patient sample 627 was examined further
25 for genotypic changes associated with the pattern of
susceptibility.

Determination of genotype of patient 627

RTV-627 DNA was analyzed by ABI chain terminator automated
30 sequencing. The nucleotide sequence was compared to the
consensus sequence of a wild type clade B HIV-1 (HIV
Sequence Database Los Alamos, NM). The nucleotide
sequence was examined for sequences that are different

5 from the control sequence. PR mutations were noted at
positions 13I/V, E35D, M46L, L63P, I64V, I73V and N88S.
I13V, E35D and I64V are naturally occurring polymorphisms
in HIV-1 PR and are not associated with reduced
susceptibility to any drug. M46L has previously been
10 described to be associated with resistance to indinavir
and amprenavir. L63P has previously been described to be
associated with resistance to indinavir and nelfinavir.
N88S has previously been described to be associated with
resistance to nelfinavir (Patick, 1998) and an
15 investigational PRI, SC55389A (Smidt, 1997).

Phenotypic analysis of Patient 1208

A resistance test vector was constructed as described in
example 1 from a patient sample designated as 1208. This
20 patient had been previously treated with nelfinavir.
Isolation of viral RNA and RT/PCR was used to generate a
patient derived segment that comprised viral sequences
coding for all of PR and aa 1 - 313 of RT. The patient
derived segment was inserted into an indicator gene viral
25 vector to generate a resistance test vector designated
RTV-1208. RTV-1208 was tested using a phenotypic
susceptibility assay to determine accurately and
quantitatively the level of susceptibility to a panel of
anti-retroviral drugs. This panel of anti-retroviral drugs
30 comprised members of the classes known as NRTIs (AZT, 3TC,
d4T, ddI, ddC, and abacavir), NNRTIs (delavirdine,
nevirapine and efavirenz), and PRIs (indinavir,
nelfinavir, ritonavir, saquinavir and amprenavir). An IC50

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5 was determined for each drug tested. Susceptibility of
the patient virus to each drug was examined and compared
to known patterns of susceptibility. A pattern of
susceptibility to the PRIs was observed for patient sample
RTV-1208 in which there was a decrease in indinavir and
10 nelfinavir susceptibility (increased resistance) and an
increase in amprenavir susceptibility. Patient sample
1208 was examined further for genotypic changes associated
with the pattern of susceptibility.

15 **Determination of genotype of patient 1208**

RTV-1208 DNA was analyzed by ABI chain terminator
automated sequencing. The nucleotide sequence was
compared to the consensus sequence of a wild type clade B
HIV-1 (HIV Sequence Database Los Alamos, NM). The
20 nucleotide sequence was examined for sequences that are
different from the control sequence. PR mutations were
noted at positions I62V, L63P, V77I, and N88S. I62V is a
naturally occurring polymorphism in HIV-1 PR and is not
associated with reduced susceptibility to any drug. L63P
25 has previously been described to be associated with
resistance to indinavir and nelfinavir. V77I has
previously been described to be associated with resistance
to nelfinavir. N88S has previously been described to be
associated with resistance to nelfinavir (Patick, 1998)
30 and an investigational PRI, SC55389A (Smidt, 1997).

Phenotypic analysis of Patient 360

A resistance test vector was constructed as described in example 1 from a patient sample designated as 360. This patient had been previously treated with indinavir. Isolation of viral RNA and RT/PCR was used to generate a patient derived segment that comprised viral sequences coding for all of PR and aa 1 - 313 of RT. The patient derived segment was inserted into an indicator gene viral vector to generate a resistance test vector designated RTV-360. RTV-360 was tested using a phenotypic susceptibility assay to determine accurately and quantitatively the level of susceptibility to a panel of anti-retroviral drugs. This panel of anti-retroviral drugs comprised members of the classes known as NRTIs (AZT, 3TC, d4T, ddI, ddC, and abacavir), NNRTIs (delavirdine, nevirapine and efavirenz), and PRIs (indinavir, nelfinavir, ritonavir, saquinavir and amprenavir). An IC50 was determined for each drug tested. Susceptibility of the patient virus to each drug was examined and compared to known patterns of susceptibility. A pattern of susceptibility to the PRIs was observed for patient sample RTV-360 in which there was a decrease in indinavir and nelfinavir susceptibility (increased resistance) and an increase in amprenavir susceptibility. Patient sample 360 was examined further for genotypic changes associated with the pattern of susceptibility.

Determination of genotype of patient 360

RTV-360 DNA was analyzed by ABI chain terminator automated

5 sequencing. The nucleotide sequence was compared to the
consensus sequence of a wild type clade B HIV-1 (HIV
Sequence Database Los Alamos, NM). The nucleotide
sequence was examined for sequences that are different
10 from the control sequence. PR mutations were noted at
positions I13V, K20M, M36V, N37A, M46I, I62V, L63P, N88S,
and I93L. I13V, N37A and I62V are naturally occurring
polymorphisms in HIV-1 PR and are not associated with
reduced susceptibility to any drug. K20M has previously
15 been described to be associated with resistance to
indinavir. M46I has previously been described to be
associated with resistance to indinavir, ritonavir,
nelfinavir and amprenavir. L63P has previously been
described to be associated with resistance to indinavir
and nelfinavir. N88S has previously been described to be
20 associated with resistance to nelfinavir (Patick, 1998)
and an investigational PRI, SC55389A (Smidt, 1997).

Phenotypic analysis of Patient 0910

25 A resistance test vector was constructed as described in
example 1 from a patient sample designated as 0910. This
patient had been previously treated with nelfinavir.
Isolation of viral RNA and RT/PCR was used to generate a
patient derived segment that comprised viral sequences
coding for all of PR and aa 1 - 313 of RT. The patient
30 derived segment was inserted into an indicator gene viral
vector to generate a resistance test vector designated
RTV-0910. RTV-0910 was tested using a phenotypic
susceptibility assay to determine accurately and

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5 quantitatively the level of susceptibility to a panel of
anti-retroviral drugs. This panel of anti-retroviral drugs
comprised members of the classes known as NRTIs (AZT, 3TC,
d4T, ddI, ddC, and abacavir), NNRTIs (delavirdine,
nevirapine and efavirenz), and PRIs (indinavir,
10 nelfinavir, ritonavir, saquinavir and amprenavir). An IC50
was determined for each drug tested. Susceptibility of
the patient virus to each drug was examined and compared
to known patterns of susceptibility. A pattern of
susceptibility to the PRIs was observed for patient sample
15 RTV-0910 in which there was a decrease in indinavir and
nelfinavir susceptibility (increased resistance) and an
increase in amprenavir susceptibility. Patient sample
0910 was examined further for genotypic changes associated
with the pattern of susceptibility.

20 **Determination of genotype of patient 0910**

RTV-0910 DNA was analyzed by ABI chain terminator
automated sequencing. The nucleotide sequence was
compared to the consensus sequence of a wild type clade B
25 HIV-1 (HIV Sequence Database Los Alamos, NM). The
nucleotide sequence was examined for sequences that are
different from the control sequence. PR mutations were
noted at positions M46I, L63P, V77I, N88S and I93I/L.
I13V, K14R, N37D and I193L are naturally occurring
30 polymorphism in HIV-1 PR and is not associated with
reduced susceptibility to any drug. V77I has previously
been described to be associated with resistance to
nelfinavir. M46I has previously been described to be

5. associated with resistance to indinavir, ritonavir,
nelfinavir and amprenavir. L63P has previously been
described to be associated with resistance to indinavir
and nelfinavir. N88S has previously been described to be
associated with resistance to nelfinavir (Patick, 1998)
10 and an investigational PRI, SC55389A (Smidt, 1997).

Phenotypic analysis of Patient 3542

A resistance test vector was constructed as described in
example 1 from a patient sample designated as 3542. This
15 patient had been treated with indinavir. Isolation of
viral RNA and RT/PCR was used to generate a patient
derived segment that comprised viral sequences coding for
all of PR and aa 1 - 313 of RT. The patient derived
segment was inserted into an indicator gene viral vector
20 to generate a resistance test vector designated RTV-3542.
RTV-3542 was tested using a phenotypic susceptibility
assay to determine accurately and quantitatively the level
of susceptibility to a panel of anti-retroviral drugs.
This panel of anti-retroviral drugs comprised members of
25 the classes known as NRTIs (AZT, 3TC, d4T, ddI, ddC, and
abacavir), NNRTIs (delavirdine, nevirapine and efavirenz),
and PRIs (indinavir, nelfinavir, ritonavir, saquinavir and
amprenavir). An IC50 was determined for each drug tested.
Susceptibility of the patient virus to each drug was
30 examined and compared to known patterns of susceptibility.
A pattern of susceptibility to the PRIs was observed for
patient sample RTV-3542 in which there was a decrease in
indinavir, nelfinavir and ritonavir susceptibility

5 (increased resistance) and an increase in amprenavir susceptibility. Patient sample 3542 was examined further for genotypic changes associated with the pattern of susceptibility.

10 Determination of genotype of patient 3542

RTV-3542 DNA was analyzed by ABI chain terminator automated sequencing. The nucleotide sequence was compared to the consensus sequence of a wild type clade B HIV-1 (HIV Sequence Database Los Alamos, NM). The
15 nucleotide sequence was examined for sequences that are different from the control sequence. PR mutations were noted at positions I13V, K14R, N37D, M46I, L63P, N88S and I93L. K14R and N37A/D are naturally occurring polymorphisms in HIV-1 PR and are not associated with
20 reduced susceptibility to any drug. M46I has previously been described to be associated with resistance to indinavir, ritonavir, nelfinavir and amprenavir. L63P has previously been described to be associated with resistance to indinavir and nelfinavir. N88S has previously been
25 described to be associated with resistance to nelfinavir (Patick, 1998) and an investigational PRI, SC55389A (Smidt, 1997).

Phenotypic analysis of Patient 3654

30 A resistance test vector was constructed as described in example 1 from a patient sample designated as 3654. This patient had been previously treated with ritonavir. Isolation of viral RNA and RT/PCR was used to generate a

5 patient derived segment that comprised viral sequences
coding for all of PR and aa 1 - 313 of RT. The patient
derived segment was inserted into an indicator gene viral
vector to generate a resistance test vector designated
RTV-3654. RTV-3654 was tested using a phenotypic
10 susceptibility assay to determine accurately and
quantitatively the level of susceptibility to a panel of
anti-retroviral drugs. This panel of anti-retroviral drugs
comprised members of the classes known as NRTIs (AZT, 3TC,
d4T, ddI, ddC, and abacavir), NNRTIs (delavirdine,
15 nevirapine and efavirenz), and PRIs (indinavir,
nelfinavir, ritonavir, saquinavir and amprenavir). An IC50
was determined for each drug tested. Susceptibility of
the patient virus to each drug was examined and compared
to known patterns of susceptibility. A pattern of
20 susceptibility to the PRIs was observed for patient sample
RTV-3654 in which there was a decrease in indinavir and
nelfinavir susceptibility (increased resistance) and an
increase in amprenavir susceptibility. Patient sample
3654 was examined further for genotypic changes associated
25 with the pattern of susceptibility.

Determination of genotype of patient 3654

RTV-3654 DNA was analyzed by ABI chain terminator
automated sequencing. The nucleotide sequence was
30 compared to the consensus sequence of a wild type clade B
HIV-1 (HIV Sequence Database Los Alamos, NM). The
nucleotide sequence was examined for sequences that are
different from the control sequence. PR mutations were

5 noted at positions I13V, R41K, M46I, L63P, V77I, N88S and
I93L. I13V, R41K and I93L are naturally occurring
polymorphism in HIV-1 PR and is not associated with
reduced susceptibility to any drug. M46I has previously
10 been described to be associated with resistance to
indinavir, ritonavir, nelfinavir and amprenavir. L63P has
previously been described to be associated with resistance
to indinavir and nelfinavir. V77I has previously been
described to be associated with resistance to nelfinavir.
N88S has previously been described to be associated with
15 resistance to an investigational PRI, SC55389A (Smidt,
1997).

EXAMPLE 4

20 Using Site Directed Mutants To Correlate Genotypes And Phenotypes Associated With Changes in PRI Drug Susceptibility in HIV.

Site directed mutagenesis

Resistance test vectors were constructed containing the
N88S mutation alone and in combination with other
25 substitutions in PR (L63P, V77I and M46L) known to
modulate the HIV susceptibility to PRIs. Mutations were
introduced into the resistance test vector using the
mega-primer PCR method for site-directed mutagenesis.
(Sakar G and Sommar SS (1994) Biotechniques 8(4),
30 404-407). First, a resistance test vector was constructed
that harbors a unique RsrII restriction site 590 bp
downstream of the ApaI restriction site. The 590 bp ApaI
- RsrII fragment thus contains the entire protease region.

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5 This site was introduced by site-specific
oligonucleotide-directed mutagenesis using primer #4. All
subsequent mutants were constructed by fragment-exchange
of the wild-type ApaI - RsrII fragment in the parent
vector with the equivalent fragment carrying the
10 respective mutations.

A resistance test vector containing the N88S mutation
(N88S-RTV) was tested using the phenotypic susceptibility
assay described above and the results were compared to
15 that of a genetically defined resistance test vector that
was wild type at position 88. The pattern of phenotypic
susceptibility to the PRIs in the N88S-RTV was altered as
compared to wild type. In the context of an otherwise
wild type background (i.e. N88S mutation alone) the
20 N88S-RTV was more susceptible to both amprenavir and
ritonavir and slightly less susceptible to nelfinavir
compared to the wild type control RTV (see Table 2).

A resistance test vector containing the N88S mutation
25 along with the L63P mutation (L63P-N88S-RTV) was tested
using the phenotypic susceptibility assay described above
and the results were compared to that of a genetically
defined resistance test vector that was wild type at
positions 63 and 88. The L63P-N88S-RTV showed decreased
30 susceptibility to both indinavir and nelfinavir and an
increase in the susceptibility to amprenavir compared the
wild-type control RTV (see Table 2). Thus it appears that
the introduction of a second mutation, L63P, in addition

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5 to N88S, results in a reduction in susceptibility to
nelfinavir and indinavir while the increased
susceptibility to amprenavir is maintained.

10 A resistance test vector containing the N88S mutation
along with the L63P mutation and the V77I mutation
(L63P-V77I-N88S-RTV) was tested using the phenotypic
susceptibility assay described above and the results were
compared to that of a genetically defined resistance test
vector that was wild type at positions 63 and 77 and 88.
15 The RTV containing mutations at these positions,
L63P-V77I-N88S-RTV, showed a decrease in susceptibility to
both indinavir and nelfinavir and an increase in the
susceptibility to amprenavir compared to the wild-type
control RTV (see Fig. 5 and Table 2). Thus it appears
20 that the introduction of a third mutation, V77I, in
addition to L63P and N88S, results in a reduction in
susceptibility to nelfinavir and indinavir while the
increased susceptibility to amprenavir is maintained.

25 The N88S mutation was also introduced into an RTV
containing additional mutations at positions L63P and M46L
(M46L + L63P + N88S). The RTV containing mutations at
these positions, M46L-L63P-N88S-RTV showed a decrease in
susceptibility to nelfinavir and a slight decrease in
30 susceptibility to indinavir and an increase in the
susceptibility to amprenavir compared to the wild-type
control RTV (see Fig. 5 and Table 2). Thus it appears
that the introduction of a third mutation, M46L, in

5 addition to L63P and N88S, results in a reduction in susceptibility to nelfinavir and indinavir while the increased susceptibility to amprenavir is maintained.

10 A resistance test vector containing the N88S mutation along with the M46L mutation, the L63P mutation, and the V77I mutation (M46L-L63P-V77I-N88S-RTV) was tested using the phenotypic susceptibility assay described above and the results were compared to that of a genetically defined resistance test vector that was wild type at positions 46,
15 63, 77 and 88. The RTV containing mutations at these four positions, M46L-L63P-V77I-N88S-RTV showed a decrease in susceptibility to nelfinavir and indinavir and an increase in the susceptibility to amprenavir compared to the wild-type control RTV (see Fig. 5 and Table 2). Thus it
20 appears that the introduction of a fourth mutation, V77I, in addition to L63P, M46L and N88S results in a reduction in susceptibility to nelfinavir and indinavir while the increased susceptibility to amprenavir is maintained.

25 A resistance test vector containing the L63P mutation (L63P-RTV) was tested using the phenotypic susceptibility assay described above and the results were compared to that of a genetically defined resistance test vector that was wild type at position 63. The pattern of phenotypic susceptibility to the PRIs in the L63P-RTV was similar to
30 wild type with no significant changes in susceptibility to the PRIs observed.

The L63P mutation was also introduced into an RTV

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5 containing an additional mutation at position V77I. The L63P-V77I-RTV showed a slight decrease in susceptibility to nelfinavir compared to the wild-type control RTV (see Fig. 5 and Table 2).

10 **EXAMPLE 5**

**Predicting Response to Protease Inhibitors by
Characterization of Amino Acid 88 of HIV-1 Protease.**

15 In one embodiment of this invention, changes in the amino acid at position 88 of the protease protein of HIV-1 is evaluated using the following method comprising: (i) collecting a biological sample from an HIV-1 infected subject; (ii) evaluating whether the biological sample contains nucleic acid encoding HIV-1 protease having an
20 asparagine to serine mutation at codon 88 (N88S); and (iii) determining susceptibility to protease inhibitors (PRI).

25 The biological sample comprises whole blood, blood components including peripheral mononuclear cells (PBMC), serum, plasma (prepared using various anticoagulants such as EDTA, acid citrate-dextrose, heparin), tissue biopsies, cerebral spinal fluid (CSF), or other cell, tissue or body fluids. In another embodiment, the HIV-1 nucleic acid
30 (genomic RNA) or reverse transcriptase protein can be isolated directly from the biological sample or after purification of virus particles from the biological sample. Evaluating whether the amino acid at position 88

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5 of the HIV-1 protease is mutated to serine, can be
performed using various methods, such as direct
characterization of the viral nucleic acid encoding
protease or direct characterization of the protease
protein itself. Defining the amino acid at position 88 of
10 protease can be performed by direct characterization of
the protease protein by conventional or novel amino acid
sequencing methodologies, epitope recognition by
antibodies or other specific binding proteins or
compounds. Alternatively, the amino acid at position 88
15 of the HIV-1 protease protein can be defined by
characterizing amplified copies of HIV-1 nucleic acid
encoding the protease protein. Amplification of the HIV-1
nucleic acid can be performed using a variety of
methodologies including reverse transcription-polymerase
20 chain reaction (RT-PCR), NASBA, SDA, RCR, or 3SR. The
nucleic acid sequence encoding HIV protease at codon 88
can be determined by direct nucleic acid sequencing using
various primer extension-chain termination (Sanger, ABI/PE
and Visible Genetics) or chain cleavage (Maxam and
25 Gilbert) methodologies or more recently developed
sequencing methods such as matrix assisted laser
desorption-ionization time of flight (MALDI-TOF) or mass
spectrometry (Sequenom, Gene Trace Systems).
Alternatively, the nucleic acid sequence encoding amino
30 acid position 88 can be evaluated using a variety of probe
hybridization methodologies, such as genechip
hybridization sequencing (Affymetrix), line probe assay
(LiPA; Murex), and differential hybridization (Chiron).

5 In a preferred embodiment of this invention, evaluation of
protease inhibitor susceptibility and of whether amino
acid position 88 of HIV-1 protease was wild type or serine
was carried out using a phenotypic susceptibility assay or
10 genotypic assay, respectively, using resistance test
vector DNA prepared from the biological sample. In one
embodiment, the plasma sample was collected, viral RNA was
purified and an RT-PCR methodology was used to amplify a
patient derived segment encoding the HIV-1 protease and
reverse transcriptase regions. The amplified patient
15 derived segments were then incorporated, via DNA ligation
and bacterial transformation, into an indicator gene viral
vector thereby generating a resistance test vector.
Resistance test vector DNA was isolated from the bacterial
culture and the phenotypic susceptibility assay was
20 carried out as described in Example 1. The results of the
phenotypic susceptibility assay with a patient sample
having an N88S mutation in PR is shown in Figure 4. The
nucleic acid (DNA) sequence of the patient derived HIV-1
protease and reverse transcriptase regions from patient
25 sample 0732 was determined using a fluorescence detection
chain termination cycle sequencing methodology (ABI/PE).
The method was used to determine a consensus nucleic acid
sequence representing the combination of sequences of the
mixture of HIV-1 variants existing in the subject sample
30 (representing the quasispecies), and to determine the
nucleic acid sequences of individual variants.

Phenotypic and genotypic correlation of mutations at amino

5 **acid 88 of HIV-1 Protease.**

10 Phenotypic susceptibility profiles of patient samples and
site directed mutants showed that amprenavir
susceptibility correlated with the presence of the N88S
15 mutation in HIV-1 protease. Phenotypic susceptibility
profiles of patient samples and site directed mutants
showed that a significant increase in amprenavir
susceptibility (decreased resistance) correlated with a
mutation in the nucleic acid sequence encoding the amino
15 acid serine (S) at position 88 of HIV-1 protease.

20 Phenotypic susceptibility profiles of patient samples and
site directed mutants showed reduction in amprenavir
susceptibility (decreased resistance) and a decrease in
susceptibility to nelfinavir and indinavir with the amino
acid serine at position 88 when the PR mutations at
positions 63, 77 or 46 were also present (L63P, V77I, or
M46L).

25

EXAMPLE 6

**Using Resistance test vectors and site directed mutants to
correlate genotypes associated with alterations in PRI
susceptibility with viral fitness.**

30

Luciferase activity measured in the absence of drug for
the seven resistance test vectors constructed from the
patient viruses containing the N88S PR mutation ranged

5 from 0.7 to 16% of control (Table 3). Although these
viruses also contain multiple mutations in reverse
transcriptase, which could also contribute to a reduction
in viral fitness, the data suggest that viruses containing
10 the N88S mutation are less fit than wild type. To confirm
this observation, the luciferase expression level for the
site-directed mutant resistance test vectors was also
examined.

15 Viruses containing N88S as the only substitution produced
only 1.0% of the luciferase activity in the absence of
drug (Table 4). This reduction was substantially
alleviated by the addition of the L63P substitution
(20.7%) or by addition of the combinations of L63P/V77I
(29.3%) or M46L/L63P (28.0%). The L63P or L63P/V77I
20 mutants had equivalent or increased relative luciferase
activity compared to wild type (163.9 and 75.6%,
respectively).

25 When the K20T substitution was added to the N88S
background, either alone or in combination with L63P, only
background levels of luciferase activity was detected.
Sequence analysis confirmed the absence of additional
mutations, which might render the vector inactive. Thus
the combination of the K20T and N88S substitutions
30 correlates with a severe defect in fitness.

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5

EXAMPLE 7

**Predicting Response to Protease Inhibitors by
Characterization of Amino Acid 82 of HIV-1
Protease.**

10 In one embodiment of this invention, changes in the amino
acid at position 82 of the protease protein of HIV-1 are
evaluated using the following method comprising: (i)
collecting a biological sample from an HIV-1 infected
subject; (ii) evaluating whether the biological sample
15 contains nucleic acid encoding HIV-1 protease having a
valine to alanine (V82A), phenylalanine (V82F), serine
(V82S), or threonine (V82T) substitution at codon 82; and
(iii) determining susceptibility to protease inhibitors
(PRI).

20

The biological sample comprises whole blood, blood
components including peripheral mononuclear cells (PBMC),
serum, plasma (prepared using various anticoagulants such
as EDTA, acid citrate-dextrose, heparin), tissue biopsies,
25 cerebral spinal fluid (CSF), or other cell, tissue or body
fluids. In another embodiment, the HIV-1 nucleic acid
(genomic RNA) or reverse transcriptase protein can be
isolated directly from the biological sample or after
purification of virus particles from the biological
30 sample. Evaluating whether the amino acid at position 82
of the HIV-1 protease is mutated to alanine,
phenylalanine, serine, or threonine, can be performed
using various methods, such as direct characterization of

5 the viral nucleic acid encoding protease or direct
characterization of the protease protein itself. Defining
the amino acid at position 82 of protease can be performed
by direct characterization of the protease protein by
conventional or novel amino acid sequencing methodologies,
10 epitope recognition by antibodies or other specific
binding proteins or compounds. Alternatively, the amino
acid at position 82 of the HIV-1 protease protein can be
defined by characterizing amplified copies of HIV-1
nucleic acid encoding the protease protein. Amplification
15 of the HIV-1 nucleic acid can be performed using a variety
of methodologies including reverse
transcription-polymerase chain reaction (RT-PCR), NASBA,
SDA, RCR, or 3SR. The nucleic acid sequence encoding HIV
protease at codon 82 can be determined by direct nucleic
20 acid sequencing using various primer extension-chain
termination (Sanger, ABI/PE and Visible Genetics) or chain
cleavage (Maxam and Gilbert) methodologies or more
recently developed sequencing methods such as matrix
assisted laser desorption-ionization time of flight
25 (MALDI-TOF) or mass spectrometry (Sequenom, Gene Trace
Systems). Alternatively, the nucleic acid sequence
encoding amino acid position 82 can be evaluated using a
variety of probe hybridization methodologies, such as
genechip hybridization sequencing (Affymetrix), line probe
30 assay (LiPA; Murex), and differential hybridization
(Chiron).

5 In a preferred embodiment of this invention, evaluation of
protease inhibitor susceptibility and of whether amino
acid position 82 of HIV-1 protease was wild type or
alanine, phenylalanine, serine, or threonine, was carried
10 out using a phenotypic susceptibility assay or genotypic
assay, respectively, using resistance test vector DNA
prepared from the biological sample. In one embodiment,
the plasma sample was collected, viral RNA was purified
and an RT-PCR methodology was used to amplify a patient
15 derived segment encoding the HIV-1 protease and reverse
transcriptase regions. The amplified patient derived
segments were then incorporated, via DNA ligation and
bacterial transformation, into an indicator gene viral
vector thereby generating a resistance test vector.
20 Resistance test vector DNA was isolated from the bacterial
culture and the phenotypic susceptibility assay was
carried out and analyzed as described in Example 1.

The nucleic acid (DNA) sequence of the patient derived
HIV-1 protease and reverse transcriptase regions was
25 determined using a fluorescence detection chain
termination cycle sequencing methodology (ABI/PE). The
method was used to determine a consensus nucleic acid
sequence representing the combination of sequences of the
mixture of HIV-1 variants existing in the subject sample
30 (representing the quasispecies), and to determine the
nucleic acid sequences of individual variants. Genotypes
are analyzed as lists of amino acid differences between
virus in the patient sample and a reference laboratory

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5 strain of HIV-1, NL4-3. Genotypes and corresponding
phenotypes (fold-change in IC50 values) are entered in a
relational database linking these two results with patient
information. Large datasets can then be assembled from
10 patient virus samples sharing particular characteristics,
such as the presence of any given mutation, or combination
of mutations or reduced susceptibility to any drug or
combination of drugs.

15 **(a) Protease inhibitor susceptibility of viruses
containing mutations at amino acid 82 of HIV-1 Protease.**

Phenotypic susceptibility profiles of 75 patient virus
samples which contained a mutation at position 82 (V82A,
F, S, or T), but no other primary mutations, were
20 analyzed. According to most published guidelines, such
viruses are expected to be resistant to ritonavir,
nelfinavir, indinavir, and saquinavir. However, 8%, 20%,
23%, and 73% of these samples were phenotypically
susceptible to these four protease inhibitors,
25 respectively (see Table 6). Thus, particularly for
indinavir and saquinavir, there was poor correlation
between the presence of mutations at position 82 and drug
susceptibility.

30 **(b) Indinavir susceptibility of viruses containing
combinations of mutations at amino acid 82 and one
secondary mutation in HIV-1 Protease.**

Indinavir resistance in viruses containing mutations at

5 position 82 was evaluated with respect to the presence of
other specific mutations. Decreased indinavir
susceptibility (fold-change in IC_{50} greater than 2.5) in
10 viruses containing V82A, F, S, or T but no other primary
mutations was correlated with the presence of mutations at
secondary positions. Reduced indinavir susceptibility was
observed in 20 samples containing mutations at both
positions 24 and 82 (100%) and in 27 samples with both 71
and 82 (100%) (See Table 7). The combination of mutations
15 at position 82 with mutations at other positions (e.g. 54,
46, 10, and 63) also significantly increased the
proportion of samples that had reduced indinavir
susceptibility (Table 7).

20 **(c) Saquinavir susceptibility of viruses containing
combinations of mutations at amino acid 82 and one
secondary mutation in HIV-1 Protease.**

Saquinavir resistance in viruses containing mutations at
position 82 was evaluated with respect to the presence of
other specific mutations. Decreased saquinavir
25 susceptibility (fold-change in IC_{50} greater than 2.5) in
viruses containing V82A, F, S, or T but no other primary
mutations was correlated with the presence of mutations at
secondary positions. Reduced saquinavir susceptibility was
observed in 4 of 5 samples containing mutations at both
30 positions 20 and 82 (80%) and in 8 of 11 samples with both
36 and 82 (73%) (See Table 8). The combination of
mutations at position 82 with mutations at other positions
(e.g. 24, 71, 54, and 10) also significantly increased the

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5 proportion of samples that had reduced saquinavir susceptibility (Table 8).

10 **(d) Indinavir susceptibility of viruses containing combinations of mutations at amino acid 82 and many secondary mutations in HIV-1 Protease.**

Indinavir resistance in viruses containing mutations at position 82 was evaluated with respect to the presence of a defined number of other mutations. Decreased indinavir susceptibility (fold-change in IC_{50} greater than 2.5) in
15 viruses containing V82A, F, S, or T but no other primary mutations was correlated with the number of mutations at secondary positions. Reduced indinavir susceptibility was observed in 100% of samples with V82A, F, S, or T and at least 6 other secondary mutations (See Table 9). The
20 proportion of samples that had reduced indinavir susceptibility increased significantly in samples with V82A, F, S, or T combined with 3 to 5 other secondary mutations (Table 9).

25 **(e) Saquinavir susceptibility of viruses containing combinations of mutations at amino acid 82 and many secondary mutations in HIV-1 Protease.**

Saquinavir resistance in viruses containing mutations at position 82 was evaluated with respect to the presence of
30 a defined number of other mutations. Decreased saquinavir susceptibility (fold-change in IC_{50} greater than 2.5) in viruses containing V82A, F, S, or T but no other primary mutations was correlated with the number of mutations at

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5 secondary positions. Reduced saquinavir susceptibility
was observed in 60 to 76% of samples with V82A, F, S, or T . .
and at least 5 other secondary mutations (See Table 9).
The proportion of samples that had reduced saquinivir . .
susceptibility increased significantly in samples with
10 V82A, F, S, or T combined with 3 or 4 other secondary
mutations (Table 9).

EXAMPLE 8

Predicting Response to Protease Inhibitors by 15 Characterization of Amino Acid 90 of HIV-1 Protease.

In one embodiment of this invention, changes in the amino
acid at position 90 of the protease protein of HIV-1 are
20 evaluated using the following method comprising: (i)
collecting a biological sample from an HIV-1 infected
subject; (ii) evaluating whether the biological sample
contains nucleic acid encoding HIV-1 protease having a
leucine to methionine (L90M) substitution at codon 90; and
25 (iii) determining susceptibility to protease inhibitors
(PRI).

The biological sample comprises whole blood, blood
components including peripheral mononuclear cells (PBMC),
30 serum, plasma (prepared using various anticoagulants such
as EDTA, acid citrate-dextrose, heparin), tissue biopsies,
cerebral spinal fluid (CSF), or other cell, tissue or body
fluids. In another embodiment, the HIV-1 nucleic acid

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5 (genomic RNA) or reverse transcriptase protein can be
isolated directly from the biological sample or after
purification of virus particles from the biological
sample. Evaluating whether the amino acid at position 90
of the HIV-1 protease is mutated to methionine, can be
10 performed using various methods, such as direct
characterization of the viral nucleic acid encoding
protease or direct characterization of the protease
protein itself. Defining the amino acid at position 90 of
protease can be performed by direct characterization of
15 the protease protein by conventional or novel amino acid
sequencing methodologies, epitope recognition by
antibodies or other specific binding proteins or
compounds. Alternatively, the amino acid at position 90
of the HIV-1 protease protein can be defined by
20 characterizing amplified copies of HIV-1 nucleic acid
encoding the protease protein. Amplification of the HIV-1
nucleic acid can be performed using a variety of
methodologies including reverse transcription-polymerase
chain reaction (RT-PCR), NASBA, SDA, RCR, or 3SR. The
25 nucleic acid sequence encoding HIV protease at codon 90
can be determined by direct nucleic acid sequencing using
various primer extension-chain termination (Sanger, ABI/PE
and Visible Genetics) or chain cleavage (Maxam and
Gilbert) methodologies or more recently developed
30 sequencing methods such as matrix assisted laser
desorption-ionization time of flight (MALDI-TOF) or mass
spectrometry (Sequenom, Gene Trace Systems).
Alternatively, the nucleic acid sequence encoding amino

5 acid position 90 can be evaluated using a variety of probe hybridization methodologies, such as genechip hybridization sequencing (Affymetrix), line probe assay (LiPA; Murex), and differential hybridization (Chiron).

10 In a preferred embodiment of this invention, evaluation of protease inhibitor susceptibility and of whether amino acid position 90 of HIV-1 protease was wild type or methionine, was carried out using a phenotypic susceptibility assay or genotypic assay, respectively,
15 using resistance test vector DNA prepared from the biological sample. In one embodiment, the plasma sample was collected, viral RNA was purified and an RT-PCR methodology was used to amplify a patient derived segment encoding the HIV-1 protease and reverse transcriptase regions. The amplified patient derived segments were then
20 incorporated, via DNA ligation and bacterial transformation, into an indicator gene viral vector thereby generating a resistance test vector. Resistance test vector DNA was isolated from the bacterial culture and the phenotypic susceptibility assay was carried out
25 and analyzed as described in Example 1.

The nucleic acid (DNA) sequence of the patient derived HIV-1 protease and reverse transcriptase regions was
30 determined using a fluorescence detection chain termination cycle sequencing methodology (ABI/PE). The method was used to determine a consensus nucleic acid sequence representing the combination of sequences of the

5 mixture of HIV-1 variants existing in the subject sample
(representing the quasispecies), and to determine the
nucleic acid sequences of individual variants. Genotypes
are analyzed as lists of amino acid differences between
virus in the patient sample and a reference laboratory
10 strain of HIV-1, NL4-3. Genotypes and corresponding
phenotypes (fold-change in IC50 values) are entered in a
relational database linking these two results with patient
information. Large datasets can then be assembled from
patient virus samples sharing particular characteristics,
15 such as the presence of any given mutation, or combination
of mutants, or reduced susceptibility to any drug or
combination of drugs.

20 *(a) Protease inhibitor susceptibility of viruses
containing mutations at amino acid 90 of HIV-1 Protease.*

Phenotypic susceptibility profiles of 58 patient virus
samples which contained a mutation at position 90 (L90M),
but no other primary mutations, were analyzed. According
25 to most published guidelines, such viruses are expected to
be resistant to ritonavir, nelfinavir, indinavir, and
saquinavir. However, 28%, 9%, 31%, and 47% of these
samples were phenotypically susceptible to these four
protease inhibitors, respectively (see Table 6). Thus,
30 particularly for indinavir and saquinavir, there was poor
correlation between the presence of mutations at position
90 and drug susceptibility.

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5 **(b) Indinavir susceptibility of viruses containing combinations of mutations at amino acid 90 and one secondary mutation in HIV-1 Protease.**

Indinavir resistance in viruses containing mutations at position 90 was evaluated with respect to the presence of other specific mutations. Decreased indinavir susceptibility (fold-change in IC_{50} greater than 2.5) in viruses containing L90M but no other primary mutations was correlated with the presence of mutations at secondary positions. Reduced indinavir susceptibility was observed in 17 of 19 samples containing mutations at both positions 73 and 90 (89%) and in 16 of 18 samples with both 71 and 90 (89%) (See Table 10). The combination of mutations at position 90 with mutation at position 46 also significantly increased the proportion of samples that had reduced indinavir susceptibility (Table 10).

20 **(c) Saquinavir susceptibility of viruses containing combinations of mutations at amino acid 90 and one secondary mutation in HIV-1 Protease.**

25 Saquinavir resistance in viruses containing mutations at position 90 was evaluated with respect to the presence of other specific mutations. Decreased saquinavir susceptibility (fold-change in IC_{50} greater than 2.5) in viruses containing L90M but no other primary mutations was correlated with the presence of mutations at secondary positions. Reduced saquinavir susceptibility was observed in 15 of 19 samples containing mutations at both positions 73 and 90 (79%) and in 14 of 18 samples with both 71 and

5 90 (78%) (See Table 11). The combination of mutations at position 90 with mutations at other positions (e.g. 77 and 10) also significantly increased the proportion of samples that had reduced saquinavir susceptibility (Table 1).

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(d) Indinavir susceptibility of viruses containing combinations of mutations at amino acid 90 and many secondary mutations in HIV-1 Protease.

15 Indinavir resistance in viruses containing mutations at position 90 was evaluated with respect to the presence of a defined number of other mutations. Decreased indinavir susceptibility (fold-change in IC_{50} greater than 2.5) in
20 viruses containing L90M but no other primary mutations was correlated with the number of mutations at secondary positions. Reduced indinavir susceptibility was observed in 100% of samples with L90M and at least 5 other secondary mutations had (See Table 12). The proportion of
25 samples that had reduced indinavir susceptibility increased significantly in samples with L90M combined with 3 or 4 other secondary mutations (Table 12).

30 **(e) Saquinavir susceptibility of viruses containing combinations of mutations at amino acid 90 and many secondary mutations in HIV-1 Protease.**

Saquinavir resistance in viruses containing mutations at position 90 was evaluated with respect to the presence of

5 a defined number of other mutations. Decreased saquinavir
susceptibility (fold-change in IC_{50} greater than 2.5) in
viruses containing L90M but no other primary mutations was
correlated with the number of mutations at secondary
positions. Reduced saquinavir susceptibility was observed
10 in 100% of samples with L90M and at least 5 other
secondary mutations (See Table 12). The proportion of
samples that had reduced saquinivir susceptibility
increased significantly in samples with L90M combined with
3 or 4 other secondary mutations (Table 12).

EXAMPLE 9

Predicting Response to Protease Inhibitors by Characterization of Amino Acids 82 and 90 of HIV-1 Protease.

20 In one embodiment of this invention, changes in the amino
acid at position 82 and 90 of the protease protein of
HIV-1 are evaluated using the following method comprising:
(i) collecting a biological sample from an HIV-1 infected
25 subject; (ii) evaluating whether the biological sample
contains nucleic acid encoding HIV-1 protease having a
valine to alanine (V82A), phenylalanine (V82F), serine
(V82S), or threonine (V82T) substitution at codon 82 or a
leucine to methionine at position 90 (L90M); and (iii)
30 determining susceptibility to protease inhibitors (PRI).

The biological sample comprises whole blood, blood
components including peripheral mononuclear cells (PBMC),

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5 serum, plasma (prepared using various anticoagulants such
as EDTA, acid citrate-dextrose, heparin), tissue biopsies,
cerebral spinal fluid (CSF), or other cell, tissue or body
fluids. In another embodiment, the HIV-1 nucleic acid
(genomic RNA) or reverse transcriptase protein can be
10 isolated directly from the biological sample or after
purification of virus particles from the biological
sample. Evaluating whether the amino acid at position 82
of the HIV-1 protease is mutated to alanine,
phenylalanine, serine, or threonine or at position 90 to
15 methionine, can be performed using various methods, such
as direct characterization of the viral nucleic acid
encoding protease or direct characterization of the
protease protein itself. Defining the amino acid at
positions 82 and 90 of protease can be performed by direct
20 characterization of the protease protein by conventional
or novel amino acid sequencing methodologies, epitope
recognition by antibodies or other specific binding
proteins or compounds. Alternatively, the amino acid at
positions 82 and 90 of the HIV-1 protease protein can be
25 defined by characterizing amplified copies of HIV-1
nucleic acid encoding the protease protein. Amplification
of the HIV-1 nucleic acid can be performed using a variety
of methodologies including reverse
transcription-polymerase chain reaction (RT-PCR), NASBA,
30 SDA, RCR, or 3SR. The nucleic acid sequence encoding HIV
protease at codons 82 and 90 can be determined by direct
nucleic acid sequencing using various primer
extension-chain termination (Sanger, ABI/PE and Visible

5 Genetics) or chain cleavage (Maxam and Gilbert) methodologies or more recently developed sequencing methods such as matrix assisted laser desorption-ionization time of flight (MALDI-TOF) or mass spectrometry (Sequenom, Gene Trace Systems).

10 Alternatively, the nucleic acid sequence encoding amino acid positions 82 and 90 can be evaluated using a variety of probe hybridization methodologies, such as genechip hybridization sequencing (Affymetrix), line probe assay (LiPA; Murex), and differential hybridization (Chiron).

15 In a preferred embodiment of this invention, evaluation of protease inhibitor susceptibility and of whether amino acid positions 82 and 90 of HIV-1 protease was wild type or alanine, phenylalanine, serine, or threonine in the case of position 82 and methionine at position 90, was carried out using a phenotypic susceptibility assay or genotypic assay, respectively, using resistance test vector DNA prepared from the biological sample. In one embodiment, plasma sample was collected, viral RNA was purified and an RT-PCR methodology was used to amplify a patient derived segment encoding the HIV-1 protease and reverse transcriptase regions. The amplified patient derived segments were then incorporated, via DNA ligation and bacterial transformation, into an indicator gene viral vector thereby generating a resistance test vector. Resistance test vector DNA was isolated from the bacterial culture and the phenotypic susceptibility assay was carried out and analyzed as described in Example 1.

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The nucleic acid (DNA) sequence of the patient derived HIV-1 protease and reverse transcriptase regions was determined using a fluorescence detection chain termination cycle sequencing methodology (ABI/PE). The method was used to determine a consensus nucleic acid sequence representing the combination of sequences of the mixture of HIV-1 variants existing in the subject sample (representing the quasispecies), and to determine the nucleic acid sequences of individual variants. Genotypes are analyzed as lists of amino acid differences between virus in the patient sample and a reference laboratory strain of HIV-1, NL4-3. Genotypes and corresponding phenotypes (fold-change in IC50 values) are entered in a relational database linking these two results with patient information. Large datasets can then be assembled from patient virus samples sharing particular characteristics, such as the presence of any given mutation or reduced susceptibility to any drug or combination of drugs.

Protease inhibitor susceptibility of viruses containing mutations at amino acids 82 and 90 of HIV-1 Protease.

Phenotypic susceptibility profiles of 33 patient virus samples which contained mutations at positions 82 (V82A, F, S, or T) and 90 (L90M), but no other primary mutations, were analyzed. According to most published guidelines, such viruses are expected to be resistant to ritonavir, nelfinavir, indinavir, and saquinavir. However, 9% and 21% of these samples were phenotypically susceptible to

5 indinavir and saquinavir, respectively (see Table 6).
Thus, particularly for saquinavir, there was poor
correlation between the presence of mutations at positions
82 and 90 and drug susceptibility.

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EXAMPLE 10

Measuring Replication Fitness Using Resistance Test 15 Vectors

A means and method is provided for accurately measuring
and reproducing the replication fitness of HIV-1. This
method for measuring replication fitness is applicable to
20 other viruses, including, but not limited to
hepadnaviruses (human hepatitis B virus), flaviviruses
(human hepatitis C virus) and herpesviruses (human
cytomegalovirus). This example further provides a means
and method for measuring the replication fitness of HIV-1
25 that exhibits reduced drug susceptibility to reverse
transcriptase inhibitors and protease inhibitors. This
method can be used for measuring replication fitness for
other classes of inhibitors of HIV-1 replication,
including, but not limited to integration, virus assembly,
30 and virus attachment and entry.

Replication fitness tests are carried out using the means

5 and methods for phenotypic drug susceptibility and resistance tests described in US Patent Number 5,837,464 (International Publication Number WO 97/27319) which is hereby incorporated by reference.

10 In these experiments patient-derived segment(s) corresponding to the HIV protease and reverse transcriptase coding regions were either patient-derived segments amplified by the reverse transcription-polymerase chain reaction method (RT-PCR) using viral RNA isolated
15 from viral particles present in the serum of HIV-infected individuals or were mutants of wild type HIV-1 made by site directed mutagenesis of a parental clone of resistance test vector DNA. Resistance test vectors are also referred to as "fitness test vectors" when used to
20 evaluate replication fitness. Isolation of viral RNA was performed using standard procedures (e.g. RNeasy Total RNA Isolation System, Promega, Madison WI or RNeasy, Tel-Test, Friendswood, TX). The RT-PCR protocol was divided into two steps. A retroviral reverse
25 transcriptase [e.g. Moloney MuLV reverse transcriptase (Roche Molecular Systems, Inc., Branchburg, NJ), or avian myeloblastosis virus (AMV) reverse transcriptase, (Boehringer Mannheim, Indianapolis, IN)] was used to copy viral RNA into cDNA. The cDNA was then amplified using a
30 thermostable DNA polymerase [e.g. Taq (Roche Molecular Systems, Inc., Branchburg, NJ), Tth (Roche Molecular Systems, Inc., Branchburg, NJ), PrimeZyme (isolated from

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5 Thermus brockianus, Biometra, Gottingen, Germany)] or a
combination of thermostable polymerases as described for
the performance of "long PCR" (Barnes, W.M., (1994) Proc.
Natl. Acad. Sci, USA 91, 2216-2220) [e.g. Expand High
Fidelity PCR System (Taq + Pwo), (Boehringer Mannheim.
10 Indianapolis, IN) OR GeneAmp XL PCR kit (Tth + Vent),
(Roche Molecular Systems, Inc., Branchburg, NJ)].

PCR6 (Table 5, #1) is used for reverse transcription of
viral RNA into cDNA. The primers, ApaI primer (PDSApa,
15 Table 5, #2) and AgeI primer (PDSAge, Table 5, #3) used to
amplify the "test" patient-derived segments contained
sequences resulting in ApaI and AgeI recognition sites
being introduced into both ends of the PCR product,
respectively.

20 Fitness test vectors incorporating the "test"
patient-derived segments were constructed as described in
US Patent Number 5,837,464 (International Publication
25 Number WO 97/27319) (see Fig. 1) using an amplified DNA
product of 1.5 kB prepared by RT-PCR using viral RNA as a
template and oligonucleotides PCR6 (#1), PDSApa (#2) and
PDSAge (#3) as primers, followed by digestion with ApaI
and AgeI or the isoschizomer PinAI. To ensure that the
30 plasmid DNA corresponding to the resultant fitness test
vector comprises a representative sample of the HIV viral
quasi-species present in the serum of a given patient,

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5 many (>100) independent E. coli transformants obtained in
the construction of a given fitness test vector were
pooled and used for the preparation of plasmid DNA.

10 A packaging expression vector encoding an amphotrophic
MuLV 4070A env gene product enables production in a
fitness test vector host cell of fitness test vector viral
particles which can efficiently infect human target cells.
Fitness test vectors encoding all HIV genes with the
exception of env were used to transfect a packaging host
15 cell (once transfected the host cell is referred to as a
fitness test vector host cell). The packaging expression
vector which encodes the amphotrophic MuLV 4070A env gene
product is used with the resistance test vector to enable
production in the fitness test vector host cell of
20 infectious pseudotyped fitness test vector viral
particles.

Fitness tests performed with fitness test vectors were
carried out using packaging host and target host cells
25 consisting of the human embryonic kidney cell line 293
(Cell Culture Facility, UC San Francisco, SF, CA)..

Fitness tests were carried out with fitness test vectors
using two host cell types. Fitness test vector viral
30 particles were produced by a first host cell (the fitness
test vector host cell) that was prepared by transfecting a
packaging host cell with the fitness test vector and the

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5 packaging expression vector. The fitness test vector viral particles were then used to infect a second host cell (the target host cell) in which the expression of the indicator gene is measured (see Fig. A).

10 The fitness test vectors containing a functional luciferase gene cassette were constructed and host cells were transfected with the fitness test vector DNA. The fitness test vectors contained patient-derived reverse transcriptase and protease DNA sequences that encode
15 proteins which were either susceptible or resistant to the antiretroviral agents, such as nucleoside reverse transcriptase inhibitors, non-nucleoside reverse transcriptase inhibitors and protease inhibitors._

20 The amount of luciferase activity detected in the infected cells is used as a direct measure of "infectivity", "replication capacity" or "fitness", i.e. the ability of the virus to complete a single round of replication. Relative fitness is assessed by comparing the amount of
25 luciferase activity produced by patient derived viruses to the amount of luciferase activity produced by a well-characterized reference virus (wildtype) derived from a molecular clone of HIV-1, for example NL4-3 or HXB2. Fitness measurements are expressed as a percent of the
30 reference, for example 25%, 50%, 75%, 100% or 125% of reference (Figure B, C).

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5 Host cells were seeded in 10-cm-diameter dishes and were
transfected one day after plating with fitness test vector
plasmid DNA and the envelope expression vector.
Transfections were performed using a calcium-phosphate
co-precipitation procedure. The cell culture media
10 containing the DNA precipitate was replaced with fresh
medium, from one to 24 hours, after transfection. Cell
culture media containing fitness test vector viral
particles was harvested one to four days after
transfection and was passed through a 0.45-mm filter
15 before being stored at -80°C. HIV capsid protein (p24)
levels in the harvested cell culture media were determined
by an EIA method as described by the manufacturer (SIAC;
Frederick, MD). Before infection, target cells (293 and
293/T) were plated in cell culture media. Control
20 infections were performed using cell culture media from
mock transfections (no DNA) or transfections containing
the fitness test vector plasmid DNA without the envelope
expression plasmid. One to three or more days after
infection the media was removed and cell lysis buffer
25 (Promega) was added to each well. Cell lysates were
assayed for luciferase activity. Alternatively, cells
were lysed and luciferase was measured by adding Steady-
Glo (Promega) reagent directly to each well without
aspirating the culture media from the well.

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Example 11

Measuring Replication Fitness of Viruses with Deficiencies in Reverse Transcriptase Activity

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A means and method is provided for identifying mutations in reverse transcriptase that alter replication fitness. A means and method is provided for identifying mutations that alter replication fitness and can be used to identify mutations associated with other aspects of HIV-1 replication, including, but not limited to integration, virus assembly, and virus attachment and entry. This example also provides a means and method for quantifying the affect that specific mutations reverse transcriptase have on replication fitness. A means and method for quantifying the affect that specfic protease and reverse transcriptase mutations have on replication fitness to mutations in other viral genes involved in HIV-1 replication, including, but not limited to the gag, pol, and envelope genes is also provided.

Fitness test vectors were constructed as described in example 10. Fitness test vectors derived from patient samples or clones derived from the fitness test vector pools, or fitness test vectors were engineered by site directed mutagenesis to contain specific mutations, and were tested in a fitness assay to determine accurately and quantitatively the relative fitness compared to a well-characterized reference standard. A patient sample was

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5 examined for increased or decreased reverse transcriptase activity and correlated with the relative fitness observed (Figure C).

Reverse transcriptase activity of patient HIV samples

Reverse transcriptase activity can be measured by any
10 number of widely used assay procedures, including but not limited to homopolymeric extension using (e.g., oligo dT:poly rC) or real time PCR based on molecular beacons (reference Kramer) or 5' exonuclease activity (Lie and Petropoulos, 1996). In one embodiment, virion associated
15 reverse transcriptase activity was measured using a quantitative PCR assay that detects the 5' exonuclease activity associated with thermo-stable DNA polymerases (Figure C). In one embodiment of the invention, the fitness of the patient virus was compared to a reference
20 virus to determine the relative fitness compared to "wildtype" viruses that have not been exposed to reverse transcriptase inhibitor drugs. In another embodiment, the fitness of the patient virus was compared to viruses collected from the same patient at different timepoints,
25 for example prior to initiating therapy, before or after changes in drug treatment, or before or after changes in virologic (RNA copy number), immunologic (CD4 T-cells), or clinical (opportunistic infection) markers of disease progression.

30 **Genotypic analysis of patient HIV samples**

Fitness test vector DNAs, either pools or clones, are

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5 analyzed by any of the genotyping methods described in
Example 1. In one embodiment of the invention, patient
HIV sample sequences were determined using viral RNA
purification, RT/PCR and ABI chain terminator automated
sequencing. The sequence was determined and compared to
10 reference sequences present in the database or compared to
a sample from the patient prior to initiation of therapy.
The genotype was examined for sequences that are different
from the reference or pre-treatment sequence and
correlated to the observed fitness.

15 **Fitness analysis of site directed mutants**

Genotypic changes that are observed to correlate with
changes in fitness were evaluated by construction of
20 fitness vectors containing the specific mutation on a
defined, wild-type (drug susceptible) genetic background.
Mutations may be incorporated alone and/or in combination
with other mutations that are thought to modulate the
fitness of a virus. Mutations were introduced into the
25 fitness test vector through any of the widely known
methods for site-directed mutagenesis. In one embodiment
of this invention the mega-primer PCR method for
site-directed mutagenesis is used. A fitness test vector
containing the specific mutation or group of mutations
30 were then tested using the fitness assay described in
Example 10 and the fitness was compared to that of a
genetically defined wild-type (drug susceptible) fitness

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5 test vector which lacks the specific mutations. Observed
changes in fitness are attributed to the specific
mutations introduced into the resistance test vector. In
several related embodiments of the invention, fitness test
vectors containing site directed mutations in reverse
10 transcriptase that result in amino acid substitutions at
position 190 (G190A, G190S, G190C, G190E, G190V, G190T)
and that display different amounts of reverse
transcriptase activity were constructed and tested for
fitness (Figure D). The fitness results were correlated
15 with specific reverse transcriptase amino acid
substitutions and fitness.

Example 12

Measuring Replication Fitness of Viruses with 20 Deficiencies in Protease Activity

A means and method for identifying mutations in protease
that alter replication fitness is provided.

25 This example provides the means and methods for
identifying mutations that alter replication fitness for
various components of HIV-1 replication, including, but
not limited to integration, virus assembly, and virus
attachment and entry. This example also provides a means
and method for quantifying the affect that specific
30 mutations in protease or reverse transcriptase have on
replication fitness. This method can be used for

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5 quantifying the effect that specific protease mutations
have on replication fitness and can be used to quantify
the effect of other mutations in other viral genes
involved in HIV-1 replication, including, but not limited
to the gag, pol, and envelope genes.

10 Fitness test vectors were constructed as described in
example 10. Fitness test vectors derived from patient
samples or clones derived from the fitness test vector
pools, or fitness test vectors engineered by site directed
15 mutagenesis to contain specific mutations, were tested in
a fitness assay to determine accurately and quantitatively
the relative fitness compared to a well-characterized
reference standard. A patient sample was examined further
for increased or decreased protease activity correlated
20 with the relative fitness observed (Figure C).

Protease activity of patient HIV samples

Protease activity can be measured by any number of widely
used assay procedures, including but not limited to in
25 vitro reactions that measure protease cleavage activity
(reference Erickson). In one embodiment, protease
cleavage of the gag polyprotein (p55) was measured by
Western blot analysis using an anti-capsid (p24) antibody
(Figure C). In one embodiment of the invention, the
30 fitness of the patient virus was compared to a reference
virus to determine the relative fitness compared to
"wildtype" viruses that have not been exposed to protease

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5 inhibitor drugs. In another embodiment, the fitness of
the patient virus was compared to viruses collected from
the same patient at different timepoints, for example
prior to initiating therapy, before or after changes in
10 drug treatment, or before or after changes in virologic
(RNA copy number), immunologic (CD4 T-cells), or clinical
(opportunistic infection) markers of disease progression.

Genotypic analysis of patient HIV samples

15 Fitness test vector DNAs, either pools or clones, are
analyzed by any of the genotyping methods described in
Example 1. In one embodiment of the invention, patient
HIV sample sequences were determined using viral RNA
purification, RT/PCR and ABI chain terminator automated
sequencing. The sequence was determined and compared to
20 reference sequences present in the database or compared to
a sample from the patient prior to initiation of therapy,
if available. The genotype was examined for sequences
that are different from the reference or pre-treatment
sequence and correlated to the observed fitness.

Fitness analysis of site directed mutants

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30 Genotypic changes that are observed to correlate with
changes in fitness are evaluated by construction of
fitness vectors containing the specific mutation on a
defined, wild-type (drug susceptible) genetic background.
Mutations may be incorporated alone and/or in combination

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5 with other mutations that are thought to modulate the
fitness of a virus. Mutations are introduced into the
fitness test vector through any of the widely known
10 methods for site-directed mutagenesis. In one embodiment
of this invention the mega-primer PCR method for
site-directed mutagenesis is used. A fitness test vector
containing the specific mutation or group of mutations are
then tested using the fitness assay described in Example
10 and the fitness is compared to that of a genetically
defined wild-type (drug susceptible) fitness test vector
15 which lacks the specific mutations. Observed changes in
fitness are attributed to the specific mutations
introduced into the fitness test vector. In several
related embodiments of the invention, fitness test vectors
containing site directed mutations in reverse protease
20 that result in amino acid substitutions at positions 30,
63, 77, 90 (list from Figure E) and that display different
amounts of protease activity are constructed and tested
for fitness (Figure E). The fitness results enable the
correlation between specific protease amino acid
25 substitutions and changes in viral fitness.

Example 13

Measuring Replication Fitness and Drug Susceptibility in a Large Patient Population

30 This example describes the high incidence of patient
samples with reduced replication fitness. This example

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5 also describes the general correlation between reduced
drug susceptibility and reduced replication fitness. This
example further describes the occurrence of viruses with
reduced fitness in patients receiving protease inhibitor
and/or reverse transcriptase inhibitor treatment. This
10 example further describes the incidence of patient samples
with reduced replication fitness in which the reduction in
fitness is due to altered protease processing of the gag
polyprotein (p55). This example further describes the
incidence of protease mutations in patient samples that
15 exhibit low, moderate or normal (wildtype) replication
fitness. This example further describes protease mutations
that are frequently observed, either alone or in
combination, in viruses that exhibit reduced replication
capacity. This example also describes the incidence of
20 patient samples with reduced replication fitness in which
the reduction in fitness is due to altered reverse
transcriptase activity. This example describes the
occurrence of viruses with reduced replication fitness in
patients failing antiretroviral drug treatment.

25 Fitness/resistance test vectors were constructed as described
in example 10. Fitness and drug susceptibility was measured
in 134 random patient samples that were received for routing
phenotypic testing by the ViroLogic Clinical Reference
30 Laboratory. Fitness assays were performed as described in
Example 10. Drug susceptibility testing and genotyping of the
protease region was performed as described in Example 1.

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- 5 Reverse transcriptase activity was measured as described in Example 11. Protease processing was measured as described in Example 12.

Drug susceptibility of patient viruses

- 10 Reduced drug susceptibility was observed for a majority of the patient virus samples (Table A). 66 percent of the viruses exhibited large (define as >10X of the reference) reductions in susceptibility to one or more NRTI drugs. 52 percent of the viruses exhibited large reductions in susceptibility to
15 one or more NNRTI drugs. 45 percent of the viruses exhibited large reductions in susceptibility to one or more PRI drugs.

Fitness of patient viruses

- Reduced replication fitness was observed for a majority of the
20 patient virus samples (Table A). Forty one percent of the viruses exhibited large reductions in replication fitness (<25% of the reference). Another 45% had moderate reductions (between 25-75% of the reference) in replication fitness. A minority of the patient samples (14%) displayed replication
25 fitness that approached or exceeded "wildtype" levels (>75% of the reference). Viruses with reduced drug susceptibility, were much more likely to display reduced replication fitness (Figures F, G, H, and I).

30 Protease Mutations in patient viruses

Greater than 10 mutations in protease were observed in a majority of the patient virus samples (Table A). Viruses with

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5 reduced fitness were much more likely to contain 10 or more
protease mutations (Figure I). Sixty two percent of the
viruses that exhibited large reductions in replication fitness
($<25\%$ of the reference) contained 10 or more protease
10 reductions (between 25-75% of the reference) in fitness
contained 10 or more protease mutations. Only 5% of the
viruses that displayed replication fitness that approached or
exceeded "wildtype" levels ($>75\%$ of the reference) contained
10 or more protease mutations (Table A). Certain protease
15 mutations either alone (D30N) or in combination (L90M plus
K20T, or M46I, or 73, or N88D) were observed at high
incidences in viruses with reduced fitness (Figures I and J).

Protease processing of patient viruses

20 Reduced protease processing of the p55 gag polyprotein was
observed in a majority of the patient virus samples (Table A).
Viruses with reduced fitness were much more likely to display
reduced protease processing; defined as having detectable
amounts of the p41 intermediate cleavage product (Figures F, I
25 and K). Seventy one percent of the viruses that exhibited
large reductions in replication fitness ($<25\%$ of the
reference) displayed reduced protease processing. Eighteen
percent of the viruses with moderate fitness reductions
(between 25-75% of the reference) displayed reduced protease
30 processing. Only 10% of the viruses that displayed
replication fitness that approached or exceeded "wildtype"
levels ($>75\%$ of the reference) exhibited reduced protease
processing (Table A). Certain protease mutations (D30N,

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- 5 M46I/L, G48V, I54L/A/S/T/V, and I84V) were observed at high incidences in viruses with reduced protease processing of the p55 gag polyprotein (Figure L).

Reverse transcriptase of patient viruses

- 10 Reduced reverse transcriptase activity processing was observed in a minority of the patient virus samples (Table A). Viruses with reduced fitness were much more likely to display reduced reverse transcriptase activity. Fourteen percent of the viruses that exhibited large reductions in replication fitness
15 (<25% of the reference) displayed reduced reverse transcriptase activity. Only 2% of the viruses with moderate fitness reductions (between 25-75% of the reference) displayed reduced reverse transcriptase activity. None of the viruses that displayed replication fitness that approached or exceeded
20 "wildtype" levels (>75% of the reference) exhibited reduced reverse transcriptase activity.

Example 14

Measuring Replication Fitness to Guide Treatment Decisions

- 25 A means and method for using replication fitness measurements to guide the treatment of HIV-1 is provided. This example further provides a means and method for using replication fitness measurements to guide the treatment of patients
30 failing antiretroviral drug treatment. This example further provides the means and methods for using replication fitness measurements to guide the treatment of patients newly infected with HIV-1.

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Guiding treatment of patients with multi-drug resistant virus:

Fitness/resistance test vectors were constructed as described in example 10. Fitness and drug susceptibility were measured on serial longitudinal samples collected weekly for 12 weeks from 18 patients. These patients were considered failing a protease inhibitor (typically indinavir) containing regimen and had incomplete suppression of virus replication based on routine viral load testing ($>2,500$ copies/mL). Phenotypic drug susceptibility testing indicated that these patient viruses were multi-drug resistant. Each patient agreed to interrupt therapy for a period of at least 12 weeks. Phenotypic drug susceptibility assays were performed as described in Example 1 on serial samples collected just prior to interrupting therapy and weekly during the period of interruption. Fitness assays were performed as described in Example 10 on serial samples collected just prior to interrupting therapy and weekly during the period of interruption. Protease processing was measured as described in Example 12.

25

Of the 18 patients that interrupted therapy, 16 patients had resistant viruses that regained susceptibility to antiretroviral drugs during the period of treatment interruption. The phenotypic test results of a representative patient are shown in Figure M. Typically, susceptibility returned to all drug classes simultaneously, consistent with the re-emergence of a minor population of drug sensitive virus. In the representative example shown in Figure M, drug

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5 sensitivity was abruptly restored between weeks 9 and 10. Genotypic analysis (DNA sequence of protease and reverse transcriptase) are also consistent with the re-emergence of a drug sensitive virus. These data show the loss of most or all drug resistance mutation simultaneously (data not shown). The data are not consistent with random back mutations. Back mutations would predict that restored susceptibility to drugs would occur unevenly for different drug classes and/or within a drugs within the same class.

15 Generally, the re-emergence of the drug susceptible virus was also accompanied by a simultaneous increase in replication fitness. This relationship is clearly evident for the representative virus (Figure N). Several other examples with less frequent timepoints are shown in Figure O. Virus from patients that did not revert to drug susceptibility after interruption generally did not exhibit an increase in replication fitness, nor did viruses from patients that did not interrupt treatment (Figures O). The data indicate that the drug sensitive virus that re-emerged after treatment interruption is able to replicate better than the drug resistant virus that was present before treatment was interrupted. The re-emergence of drug susceptible virus in this group of patients was also accompanied by an increase in viral load and a decrease in DC4 T-cells, indicators of disease progression. Thus, fitness information can be used to guide treatment of patients that harbor multi-drug resistant virus and are considering treatment interruption. If the patient virus is drug resistant but has low replication

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5 capacity, the patient and the physician should consider
continuing drug treatment to prevent the re-emergence of a
drug sensitive virus with higher replication capacity and
greater pathogenecity. Alternatively, if the patient virus is
10 drug resistant and has high replication capacity, the patient
and the physician may consider interrupting treatment to spare
the patient from the harmful and unpleasant side effects of
antiretroviral drugs that are not providing clinical benefit.

15 Furthermore, physicians may choose to perform routine
replication fitness assays for patients that have multi-drug
resistant virus. This assay could be used to monitor the
replication fitness of patient viruses when complete
suppression of virus replication is not possible due to multi-
20 drug resistance. The assay would be used to guide treatment
decisions that prevent the drug resistant virus with low
replication fitness from increasing its replication fitness.
In this way, physicians may prolong the usefulness of
antiretroviral drugs despite the presence of drug resistant
25 virus in the patient.

Guiding treatment of newly infected patients:

30 Patients that maintain high virus loads (setpoint) after acute
infection are more likely to exhibit accelerated disease
progression. Therefore, it is advantageous for this class of
patient to initiate antiretroviral drug treatment as soon as
possible after diagnosis with HIV-1 infection. In conjunction

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5 with viral load, fitness measurements of viruses in newly
 infected patients may provide a useful measurement to identify
 those individuals that will develop elevated setpoints after
 primary infection and consequently are likely to exhibit
 accelerated disease progression. Fitness measurements may
 10 guide the decision to treat immediately after diagnosis or a
 some later time point.

Table 1: PRI susceptibility of selected patient samples.
 Viruses displaying increased susceptibility to amprenavir
 15 (5-fold or greater) were genotyped and found to contain the
 N88S mutation in PR. Samples were listed in order of
 decreasing amprenavir susceptibility.

Table 1

Sample ID	Prior PRI Experience	Fold Change vs. Reference					PR Mutations
		SQV	IDV	RTV	NFV	AMP	
0732	NFV	0.73	2.11	1.72	8.92	0.08	K14R, I15V, K20T, E35D, M36I, R41K, I62V, L63Q, N88S
627	IDV	0.26	6.16	1.50	21.06	0.09	I13I/V, E35D, M46L, L63P, I64V, I73V, N88S
1208	NFV	1.55	3.15	1.22	11.06	0.10	I62V, L63P, V77I, N88S
360	IDV	1.88	6.31	1.49	29.95	0.15	I13V, K20M, M36V, N37A, M46I, I62V, L63P, N88S, I93L
0910	NFV	1.41	5.47	1.85	16.76	0.16	M46I, L63P, V77I, N88S, I93I/L
3542	IDV	1.28	7.61	3.36	24.67	0.16	I13V, K14R, N37D, M46I, L63P, N88S, I93L
3654		1.80	7.56	1.95	18.61	0.20	I13V, R41K, M46I, L63P, V77I, N88S, I93L

Fold Change Limits: **>2.5** **<0.4**

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- 5 Table 2: PRI susceptibility of site-directed mutants in PR. Mutations were introduced into the drug sensitive reference resistance test vector and the susceptibility to PRIs was determined.

Table 2

Site-Directed Mutations	Fold Change vs. reference				
	SQV	IDV	RTV	NFV	AMP
L63P	1.04	1.12	1.27	1.43	1.06
L63P, V77I	1.24	1.72	1.73	2.49	0.91
N88S	0.47	1.56	0.36	2.39	0.04
L63P, N88S	1.44	2.56	0.77	5.10	0.11
L63P, V77I, N88S	1.24	3.09	1.39	12.89	0.08
M46L, L63P, N88S	1.15	2.30	0.85	8.18	0.12
M46L, L63P, V77I, N88S	1.45	2.97	1.33	12.24	0.14

FOLD CHANGE LIMITS: <0.4 >2.5

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Table 3: Relative luciferase activity levels for patient sample virus-derived resistance test vector pools. The luciferase activity (relative light units, RLU) measured in the absence of drug for the patient sample was compared to that of the drug sensitive reference control from the same assay run, and expressed as a percentage of control. These values are from one assay each. All the samples that contain the N88S mutations in PR were found to have reduced luciferase activity compared to control.

15

Table 3

Sample ID PR Mutations		Relative Luciferase Activity (% of control)
0732	K14R, I15V, K20T, E35D, M36I, R41K, I62V, L63Q, N88S	8.5
627	I13I/V, E35D, M46L, L63P, I64V, I73V, N88S	0.7
1208	I62V, L63P, V77I, N88S	14.2
360	I13V, K20M, M36V, N37A, M46I, I62V, L63P, N88S, I93L	2.2
0910	M46I, L63P, V77I, N88S, I93I/L	16.0
3542	I13V, K14R, N37D, M46I, L63P, N88S, I93L	4.6
3654	I13V, R41K, M46I, L63P, V77I, N88S, I93L	12.8

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Table 4: Relative luciferase activity levels for resistance test vectors containing site-directed mutations. The luciferase activity (relative light units, RLU) measured in the absence of drug for the mutant was compared to that of the drug sensitive reference control from the same assay run, and expressed as a percentage of control. These values are from one to five assays each, and each value was obtained using an independent clone for mutants which were tested multiple times. All the constructs that contain the N88S mutations in PR were found to have reduced luciferase activity compared to control. All the constructs with the K20T mutation were essentially inactive in the assay.

Table 4

Site-Directed Mutations	Average Luciferase Activity	
	(% of control)	number of clones tested
L63P	163.9	1
L63P, V77I	75.6	1
N88S	1.0	3
L63P, N88S	20.7	2
L63P, V77I, N88S	29.3	2
M46L, L63P, N88S	28.0	2
M46L, L63P, V77I, N88S	53.2	5
K20T, N88S	<0.01	5
K20T, L63P, N88S	<0.01	1

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5 Table 5: Oligonucleotide primers used for PCR amplification
and for generating site-directed mutants:

Table 5.

Primer name:			
#1: PCR6	5'	CCAATTRYTGATATTTCTCATGNTCHTCTTGGG	3' (35-mer)
#2: PDS/Apa	5'	CATGTTGCAGGGCCCCTAGGAAAAGGGCTGTTGGAAATGTG	3' (42-mer)
#3: PDS/Age	5'	CACTCCATGTACCGGTTCTTTTAGAATYTCYCTG	3' (34-mer)
#4: RsrII	5'	ACTTTCGGACCGTCCATTCCTGGCTTTAATTTTACTGGTACAG	3' (43-mer)
#5: K20T	5'	GGGGGGCAATTAACGGAAGCTCTATTAG	3' (28-mer)
#6: M46L	5'	GATGGAAACCAAATTGATAGGGGGAATTG	3' (30-mer)
#7: L63P	5'	GTATGATCAGATACCCATAGAAATCTGC	3' (28-mer)
#8: N88S	5'	CTGAGTCAACAGACTTCTTCCAATTATG	3' (28-mer)

R = A or G

Y = C or T

N = A, C, G, or T

H = A, C, or T

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5 Table 6. PRI Susceptibility (Fold Change <2.5) of Viruses with
Mutations at 82 and/or 90

Percent of viruses with indicated primary mutation(s) which are drug sensitive (fold change in IC50 < 2.5)			
drug	V82A/F/S/T	L90M	V82A/F/S/T and L90M
RTV	8.0	27.6	3.0
NFV	20.0	8.6	3.0
IDV	22.7	31.0	9.1
AMP	53.3	65.5	33.3
SQV	73.3	46.6	21.2

15 Table 7. Correlation Between 82A/F/S/T, Secondary Mutations,
and IDV Susceptibility.

position	n	% FC > 2.5	chi square p
24	20	100%	<0.005
71	27	100%	<0.0001
54	38	95%	<0.0001
46	35	89%	<0.01
10	47	83%	<0.05
63	72	79%	<0.05
82	75	77%	

25 all virus with V82A/F/S/T and no other primary mutations.

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5 Table 8. Correlation Between 82A/F/S/T, Secondary Mutations,
and SQV Susceptibility.

position	n	% FC > 2.5	chi square p
20	5	80%	<0.001
36	11	73%	<0.001
10 24	20	65%	<0.0001
71	27	52%	<0.0001
54	38	47%	<0.0001
10	47	40%	<0.001
15 82	75	27%	

all virus

20 Table 9. Association Between SQV and IDV Susceptibility,
V82A/F/S/T, and Number of Resistance Associated Mutations

Number of secondary mutations	Number of samples	% with IDV FC > 2.5	% with SQV FC > 2.5
25 1	75	77	27
2	67	82	30
3	51	88	39
4	38	95	50
30 5	25	96	60
6	17	100	76
7	5	100	60

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Table 10. Correlation Between L90M, Secondary Mutations, and IDV Susceptibility.

	position	n	% FC > 2.5	chi square p
	73	19	89%	<0.01
10	71	18	89%	<0.001
	46	25	88%	<0.05
	90	58	69%	

15

all viruses with L90M and

Table 11. Correlation Between L90M, Secondary Mutations, and SQV Susceptibility.

	position	n	% FC > 2.5	chi square p
	73	19	79%	<0.01
20	71	18	78%	<0.001
	77	25	76%	<0.05
	10	34	65%	<0.05
	90	58	55%	

25

all virses

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5 Table 12. Association Between SQV and IDV Susceptibility, L90M, and Number of Resistance Associated Mutations.

	Number of secondary mutations	Number of samples	% with IDV FC > 2.5	% with SQV FC > 2.5
10	0	58	69	53
	1	57	70	47
	2	56	70	48
	3	41	80	68
	4	31	87	77
15	5	14	100	100
	6	6	100	100

TABLE A
**Summary of Replication Capacity (RC) and
Enzyme Function Results**

	LOW RC (<25% of Ref.*)	MEDIUM RC (26-75% of Ref.)	HIGH RC (>75% of Ref.)
% of Total Tested	41% (55)	45% (59)	14% (19)
PR Processing Defects (%p41>10%)	71% (39)	24% (14)	10% (2)
Impaired RT Activity (<25% of reference)	14% (7)	2% (1)	0%
>10 mutations in Protease	62% (34)	22% (13)	5% (1)
>10X reduced susceptibility to NFV	63% (35)	32% (19)	16% (3)

*Reference virus: NL4-3

What is claimed is:

1. A method for assessing the effectiveness of protease antiretroviral therapy of an HIV-infected patient comprising evaluating whether a plasma sample from said HIV-infected patient contains a nucleic acid encoding HIV protease having a mutation at codon 88, wherein the presence of said nucleic acid is correlated with increased susceptibility of said HIV to amprenavir.
2. The method of claim 1, wherein said mutation at codon 88 codes for a serine (S).
3. The method of claim 1, wherein said HIV-infected patient is being treated with an antiretroviral agent.
4. A method of assessing the effectiveness of protease antiretroviral therapy of an HIV-infected patient comprising evaluating whether a plasma sample from said HIV-infected patient contains a nucleic acid encoding HIV protease having a mutation at codon 88 and an additional mutation at codons 63 or 77, or a combination thereof, wherein the presence of said mutations is correlated with decreased susceptibility of said HIV to nelfinavir and indinavir and increased susceptibility of said HIV to amprenavir.
5. The method of claim 4, wherein said mutation at codon 63 encodes proline (P) or glutamine (Q) and said mutation at codon 77 encodes isoleucine (I).
6. The method of claim 4, wherein said HIV-infected patient is being treated with an antiretroviral agent.
7. A method of assessing the effectiveness of protease antiretroviral therapy of an HIV-infected patient comprising evaluating whether a plasma sample from said HIV-infected patient contains a nucleic acid encoding HIV protease having a mutation at codon 88 and an additional mutations at codon 63, 77 or 46, or a combination thereof, wherein the presence of said mutations is correlated with decreased susceptibility of said HIV to nelfinavir and indinavir and increased susceptibility of said HIV to amprenavir.

8. The method of claim 7, wherein said mutation at codon 63 encodes proline (P) or glutamine (Q), said mutation at codon 77 encodes isoleucine (I), and said mutation at codon 46 encodes leucine (L) or isoleucine (I).
9. The method of claim 7, wherein said HIV-infected patient is being treated with an antiretroviral agent.
10. A method of assessing the effectiveness of protease antiretroviral therapy of an HIV-infected patient comprising: evaluating whether a plasma sample from said HIV-infected patient contains a nucleic acid encoding HIV protease having a mutation at codon 88 and an additional mutation at codons 63, 77, 46, 10, 20, or 36, or a combination thereof, wherein the presence of said mutations is correlated with decreased susceptibility to nelfinavir and indinavir and increased susceptibility to amprenavir.
11. The method of claim 10, wherein said mutation at codon 63 encodes proline (P) or glutamine (Q), said mutation at codon 77 encodes isoleucine (I), said mutation at codon 46 encodes leucine (L) or isoleucine (I), said mutation at codon 10 encodes isoleucine (I) or phenylalanine (F), said mutation at 20 encodes threonine (T), methionine (M), or arginine (R), and said mutation at codon 36 encodes isoleucine (I) or valine (V).
12. The method of claim 10, wherein said HIV-infected patient is being treated with an antiretroviral agent.
13. A method for assessing the effectiveness of a candidate HIV antiretroviral compound, said method comprising:
 - (a) culturing a host cell in the presence of said candidate HIV antiretroviral compound, wherein said host cell comprises a test vector comprising (i) a nucleic acid segment encoding HIV protease having a mutation at codon 88 and (ii) an indicator gene, wherein expression of said indicator gene depends upon the activity of said HIV protease;
 - (b) measuring the amount of expression of said indicator gene in said host cell from step (a); and

- (c) comparing the amount of expression of said indicator gene as measured in step (b) with an amount of expression of said indicator gene measured in said host cell of step (a) cultured in the absence of said candidate HIV antiretroviral compound, wherein the difference between the amount of expression of said indicator gene measured in step (c) relative to that measured in step (b) correlates with the effectiveness of said candidate HIV antiretroviral compound, thereby assessing the effectiveness of said candidate HIV antiretroviral compound.
14. The method of Claim 13, wherein said nucleic acid segment encoding HIV protease further comprises a mutation at codons 63 or 77, or a combination thereof.
15. The method of Claim 13, wherein said nucleic acid segment encoding HIV protease further comprises a mutation at codons 63, 77, or 46, or a combination thereof.
16. The method of Claim 13, wherein said nucleic acid segment encoding HIV protease further comprises a mutation at codons 63, 77, 46, 10, 20, or 36, or a combination thereof.
17. A test vector comprising a nucleic acid segment encoding HIV protease having a mutation at codon 88 and an indicator gene, wherein expression of said indicator gene depends upon the activity of said HIV protease.
18. The test vector of claim 17, wherein said nucleic acid segment encoding HIV protease further comprises a mutation at codons 63 or 77, or a combination thereof.
19. The test vector of claim 17 wherein said nucleic acid segment encoding HIV protease further comprises a mutation at codons 63, 77, or 46, or a combination thereof.
20. The test vector of claim 17, wherein said nucleic acid segment encoding HIV protease further comprises a mutation at codons 63, 77, 46, 10, 20, or 36, or a combination thereof.
21. A method for evaluating the viral fitness of an HIV from an HIV-infected patient, said method comprising:

- (a) culturing a host cell comprising a resistance test vector comprising a patient-derived segment from a patient's virus and an indicator gene;
 - (b) measuring the amount of activity of said indicator gene in said host cell; and
 - (c) comparing said amount of activity of said indicator gene measured in step (c) with an amount of activity of said indicator gene measured when steps (a) and (b) are carried out for a reference control, wherein a reduction in said amount of activity of said indicator gene measured in step (c) as compared to step (b) indicates a reduction in viral fitness.
22. A method of assessing the effectiveness of ritonavir, nelfinavir, indinavir, saquinavir and amprenavir antiretroviral therapy of an HIV-infected patient comprising evaluating whether a plasma sample from said HIV-infected patient contains a nucleic acid encoding HIV protease having a mutation at codon 82 and one or more additional mutations at secondary positions, wherein the presence of said mutations is correlated with changes in susceptibility of said HIV to ritonavir, nelfinavir, indinavir, saquinavir and amprenavir.
23. The method of claim 22, wherein said mutation at codon 82 encodes alanine (A), phenylalanine (F), serine (S), or threonine (T).
24. The method of claim 22, wherein said HIV-infected patient is being treated with an antiretroviral agent.
25. The method of claim 22, wherein said mutations in secondary positions comprise a mutation at codon 24 of HIV protease.
26. The method of claim 25, wherein said mutation at codon 24 encodes isoleucine (I).
27. The method of claim 25, wherein said HIV-infected patient is being treated with an antiretroviral agent.
28. A method of assessing the effectiveness of protease antiretroviral therapy of an HIV-infected patient comprising evaluating whether a plasma sample from said HIV-infected patient contains a nucleic acid encoding HIV protease having a mutation at codon 82 and an additional mutation at codon 71, wherein said mutation at codon 71 encodes an amino

acid that is selected from the group consisting of threonine (T), leucine (L), and isoleucine (I), and wherein the presence of said mutations is correlated with decreased susceptibility to indinavir.

29. The method of claim 28, wherein said HIV-infected patient is being treated with an antiretroviral agent.
30. A method of assessing the effectiveness of protease antiretroviral therapy of an HIV-infected patient comprising evaluating whether a plasma sample from said HIV-infected patient contains a nucleic acid encoding HIV protease having a mutation at codon 82 and an additional mutation at a codon selected from the group consisting of codon 54, 46, 10, and 63; or a combination thereof, wherein said mutation at codon 54 encodes an amino acid that is selected from the group consisting of alanine (A), leucine (L) and threonine (T); said mutation at codon 46 encodes valine (V); said mutation at codon 10 encodes an amino acid that is selected from the group consisting of valine (V) and phenylalanine (F); and said mutation at codon 63 encodes an amino acid that is selected from the group consisting of alanine (A), serine (S), threonine (T), glutamine (Q), cysteine (C), and valine (V); and wherein the presence of said mutations is correlated with decreased susceptibility to indinavir.
31. The method of claim 30, wherein said HIV-infected patient is being treated with an antiretroviral agent.
32. A method of assessing the effectiveness of protease antiretroviral therapy of an HIV-infected patient comprising evaluating whether a plasma sample from said HIV-infected patient contains a nucleic acid encoding HIV protease having a mutation at codon 82 and a mutation at codon 20, wherein the presence of said mutations is correlates with decreased susceptibility to saquinavir.
33. The method of claim 32, wherein said mutation at codon 20 encodes an amino acid that is selected from the group consisting of methionine (M), threonine (T), isoleucine (I), and arginine (R).

34. The method of claim 32, wherein said HIV-infected patient is being treated with an antiretroviral agent.
35. A method of assessing the effectiveness of protease antiretroviral therapy of an HIV-infected patient comprising evaluating whether a plasma sample from said HIV-infected patient contains a nucleic acid encoding HIV protease having a mutation at codon 82 and a mutation at codon 36, wherein the presence of said mutations is correlated with decreased susceptibility to saquinavir.
36. The method of claim 35, wherein said mutation at codon 36 encodes an amino acid that is selected from the group consisting of isoleucine (I), leucine (L), and valine (V).
37. The method of claim 35, wherein said HIV-infected patient is being treated with an antiretroviral agent.
38. A method of assessing the effectiveness of protease antiretroviral therapy of an HIV-infected patient comprising evaluating whether a plasma sample from said HIV-infected patient contains a nucleic acid encoding HIV protease having a mutation at codon 82 and an additional mutation at codons 24, 71, 54, or 10, or a combination thereof, wherein the presence of said mutations is correlated with decreased susceptibility to saquinavir.
39. The method of claim 38, wherein said mutation at codon 24 encodes an isoleucine (I), said mutation at codon 71 encodes an amino acid that is selected from the group consisting of threonine (T), valine (V), leucine (L), and isoleucine (I), said mutation at codon 54 encodes an amino acid that is selected from the group consisting of valine (V), alanine (A), leucine (L), and threonine (T), and said mutation at codon 10 encodes an amino acid that is selected from the group consisting of isoleucine (I), valine (V), phenylalanine (F), and arginine (R).
40. The method of claim 38, wherein said HIV-infected patient is being treated with an antiretroviral agent.
41. A method of assessing the effectiveness of protease antiretroviral therapy of an HIV-infected patient comprising evaluating whether a plasma sample from said HIV-infected

patient contains a nucleic acid encoding HIV protease having a mutation at codon 82 and one or more additional mutations at secondary positions wherein the presence of said mutations is correlated with decreased susceptibility to indinavir and saquinavir.

42. The method of claim 41, wherein said nucleic acid encoding HIV protease comprises at least 3 additional mutations at secondary positions.
43. A method of assessing the effectiveness of protease antiretroviral therapy of an HIV-infected patient comprising evaluating whether a plasma sample from said HIV-infected patient contains a nucleic acid encoding HIV protease having a mutation at codon 90 and one or more secondary mutations, wherein the presence of said mutations is correlated with changes in susceptibility of said HIV to ritonavir, nelfinavir, indinavir, saquinavir and amprenavir.
44. The method of claim 43, wherein said mutation at codon 90 encodes methionine.
45. The method of claim 43, wherein said HIV-infected patient is being treated with an antiretroviral agent.
46. A method of assessing the effectiveness of protease antiretroviral therapy of an HIV-infected patient comprising evaluating whether a plasma sample from said HIV-infected patient contains a nucleic acid encoding HIV protease having a mutation at codon 90 and an additional mutation at codon 73, wherein the presence of said mutations is correlated with decreased susceptibility of said HIV to indinavir.
47. The method of claim 46, wherein said mutation at codon 73 encodes an amino acid that is selected from the group consisting of serine (S), threonine (T), and cysteine (C).
48. The method of claim 46, wherein said HIV-infected patient is being treated with an antiretroviral agent.
49. A method of assessing the effectiveness of protease antiretroviral therapy of an HIV-infected patient comprising evaluating whether a plasma sample from said HIV-infected patient contains a nucleic acid encoding HIV protease having a mutation at codon 90 and an additional mutation at codon 71, wherein said mutation at codon 71 encodes an amino

acid that is selected from the group consisting of threonine (T), leucine (L), and isoleucine (I), and wherein the presence of said mutations is correlated with decreased susceptibility of said HIV to indinavir.

50. The method of claim 49, wherein said HIV-infected patient is being treated with an antiretroviral agent.
51. A method of assessing the effectiveness of protease antiretroviral therapy of an HIV-infected patient comprising evaluating whether a plasma sample from said HIV-infected patient contains a nucleic acid encoding HIV protease having a mutation at codon 90 and an additional mutation at codon 46, wherein said mutation at codon 46 encodes valine (V), and wherein the presence of said mutations is correlated with decreased susceptibility of said HIV to indinavir.
52. The method of claim 51, wherein said HIV-infected patient is being treated with an antiretroviral agent.
53. A method of assessing the effectiveness of protease antiretroviral therapy of an HIV-infected patient comprising evaluating whether a plasma sample from said HIV-infected patient contains a nucleic acid encoding HIV protease having a mutation at codon 90 and an additional mutation at codon 73, wherein the presence of said mutations is correlated with decreased susceptibility of said HIV to saquinavir.
54. The method of claim 53, wherein said mutation at codon 73 encodes an amino acid that is selected from the group consisting of serine (S), threonine (T), and cysteine (C).
55. The method of claim 53, wherein said HIV-infected patient is being treated with an antiretroviral agent.
56. A method of assessing the effectiveness of protease antiretroviral therapy of an HIV-infected patient comprising evaluating whether a plasma sample from said HIV-infected patient contains a nucleic acid encoding HIV protease having a mutation at codon 90 and an additional mutation at codon 71, wherein the presence of said mutations is correlated with decreased susceptibility of said HIV to saquinavir.

57. The method of claim 56, wherein said mutation at codon 71 encodes an amino acid that is selected from the group consisting of a threonine (T), valine (V), leucine (L), and isoleucine (I).
58. The method of claim 56, wherein said HIV-infected patient is being treated with an antiretroviral agent.
59. A method of assessing the effectiveness of protease antiretroviral therapy of an HIV-infected patient comprising evaluating whether a plasma sample from said HIV-infected patient contains a nucleic acid encoding HIV protease having a mutation at codon 90 and additional mutations at codons 77 and 10, wherein the presence of said mutations is correlated with decreased susceptibility of said HIV to saquinavir.
60. The method of claim 59, wherein said mutation at codon 77 encodes an amino acid that is selected from the group consisting of isoleucine (I) and threonine (T) and said mutation at codon 10 encodes an amino acid that is selected from the group consisting of isoleucine (I), valine (V), phenylalanine (F), and arginine (R).
61. The method of claim 59, wherein said HIV-infected patient is being treated with an antiretroviral agent.
62. A method of assessing the effectiveness of protease antiretroviral therapy of an HIV-infected patient comprising evaluating whether a plasma sample from said HIV-infected patient contains a nucleic acid encoding HIV protease having a mutation at codon 90 and one or more additional mutations at secondary positions; wherein the presence of said mutations is correlated with decreased susceptibility of said HIV to indinavir and saquinavir.
63. The method of claim 62, wherein said nucleic acid encoding HIV protease comprises at least 3 additional mutations at secondary positions.
64. A method of assessing the effectiveness of protease antiretroviral therapy of an HIV-infected patient comprising evaluating whether a plasma sample from said HIV-infected patient contains a nucleic acid encoding HIV protease having a mutation at codon 82 and

- 90 and one or more additional secondary mutations, wherein the presence of said mutations is correlated with changes in susceptibility of said HIV to ritonavir, nelfinavir, indinavir, saquinavir and amprenavir.
65. The method of claim 64, wherein said mutation at codon 82 encodes an amino acid that is selected from the group consisting of alanine (A), phenylalanine (F), serine (S), and threonine (T) and said mutation at codon 90 encodes a methionine (M).
66. The method of claim 64, wherein said HIV-infected patient is being treated with an antiretroviral agent.
67. A method for assessing the effectiveness of a candidate HIV antiretroviral compound, said method comprising:
- (a) culturing a host cell in the presence of said candidate HIV antiretroviral compound, wherein said host cell comprises a test vector comprising (i) a nucleic acid segment encoding HIV protease having a mutation at codon 82 and (ii) an indicator gene, wherein expression of said indicator gene depends upon the activity of said HIV protease;
 - (b) measuring the amount of expression of said indicator gene in said host cell from step (a); and
 - (c) comparing the amount of expression of said indicator gene as measured in step (b) with an amount of expression of said indicator gene measured in said host cell of step (a) cultured in the absence of said candidate HIV antiretroviral compound, wherein the difference between the amount of expression of said indicator gene measured in step (c) relative to that measured in step (b) correlates with the effectiveness of said candidate HIV antiretroviral compound, thereby assessing the effectiveness of said candidate HIV antiretroviral compound.
68. A method for assessing the effectiveness of a candidate HIV antiretroviral compound, said method comprising:
- (a) culturing a host cell in the presence of said candidate HIV antiretroviral compound, wherein said host cell comprises a test vector comprising (i) a nucleic acid segment encoding HIV protease having a mutation at codon 82 and a

secondary mutation(s) at codons 20, 24, 71, 54 or 10, or a combination thereof, and (ii) an indicator gene, wherein expression of said indicator gene depends upon the activity of said HIV protease;

- (b) measuring the amount of expression of said indicator gene in said host cell from step (a); and
- (c) comparing the amount of expression of said indicator gene as measured in step (b) with an amount of expression of said indicator gene measured in said host cell of step (a) cultured in the absence of said candidate HIV antiretroviral compound, wherein the difference between the amount of expression of said indicator gene measured in step (c) relative to that measured in step (b) correlates with the effectiveness of said candidate HIV antiretroviral compound, thereby assessing the effectiveness of said candidate HIV antiretroviral compound.

69. A method for assessing the effectiveness of a candidate HIV antiretroviral compound, said method comprising:

- (a) culturing a host cell in the presence of said candidate HIV antiretroviral compound, wherein said host cell comprises a test vector comprising (i) a nucleic acid segment encoding HIV protease having a mutation at codon 90 and one or more additional mutations at secondary positions and (ii) an indicator gene, wherein expression of said indicator gene depends upon the activity of said HIV protease;
- (b) measuring the amount of expression of said indicator gene in said host cell from step (a); and
- (c) comparing the amount of expression of said indicator gene as measured in step (b) with an amount of expression of said indicator gene measured in said host cell of step (a) cultured in the absence of said candidate HIV antiretroviral compound, wherein the difference between the amount of expression of said indicator gene measured in step (c) relative to that measured in step (b) correlates with the effectiveness of said candidate HIV antiretroviral compound, thereby assessing the effectiveness of said candidate HIV antiretroviral compound.

70. A method for assessing the effectiveness of a candidate HIV antiretroviral compound, said method comprising:
- (a) culturing a host cell in the presence of said candidate HIV antiretroviral compound, wherein said host cell comprises a test vector comprising (i) a nucleic acid segment encoding HIV protease having a mutation at codon 90 and a secondary mutation(s) at codons 73, 71, 10 or 46, or a combination thereof, and (ii) an indicator gene, wherein expression of said indicator gene depends upon the activity of said HIV protease;
 - (b) measuring the amount of expression of said indicator gene in said host cell from step (a); and
 - (c) comparing the amount of expression of said indicator gene as measured in step (b) with an amount of expression of said indicator gene measured in said host cell of step (a) cultured in the absence of said candidate HIV antiretroviral compound, wherein the difference between the amount of expression of said indicator gene measured in step (c) relative to that measured in step (b) correlates with the effectiveness of said candidate HIV antiretroviral compound, thereby assessing the effectiveness of said candidate HIV antiretroviral compound.
71. A method for assessing the effectiveness of a candidate HIV antiretroviral compound, said method comprising:
- (a) culturing a host cell in the presence of said candidate HIV antiretroviral compound, wherein said host cell comprises a test vector comprising (i) a nucleic acid segment encoding HIV protease having a mutation at 82 and 90 and one or more additional mutations at secondary positions and (ii) an indicator gene, wherein expression of said indicator gene depends upon the activity of said HIV protease;
 - (b) measuring the amount of expression of said indicator gene in said host cell from step (a); and
 - (c) comparing the amount of expression of said indicator gene as measured in step (b) with an amount of expression of said indicator gene measured in said host cell of step (a) cultured in the absence of said candidate HIV antiretroviral compound, wherein the difference between the amount of expression of said indicator gene

measured in step (c) relative to that measured in step (b) correlates with the effectiveness of said candidate HIV antiretroviral compound, thereby assessing the effectiveness of said candidate HIV antiretroviral compound.

72. A test vector comprising a nucleic acid segment encoding HIV protease having a mutation at codon 82 and an indicator gene, wherein expression of said indicator gene depends upon the activity of said HIV protease.
73. The resistance test vector of claim 72, wherein said nucleic acid segment encoding HIV protease further comprises at least one secondary mutation at a codon selected from the group consisting of 20, 24, 71, 54, 10 and a combination thereof.
74. A test vector comprising a nucleic acid segment encoding HIV protease having a mutation at codon 90 and an indicator gene, wherein expression of said indicator gene depends upon the activity of said HIV protease.
75. The resistance test vector of claim 74, wherein nucleic acid segment encoding HIV protease further comprises at least one secondary mutation at a codon selected from the group consisting of 73, 71, 46, 10 and a combination thereof.
76. A method for determining replication capacity of an HIV from an HIV-infected patient, said method comprising:
 - (a) culturing a host cell comprising a test vector that comprises a patient-derived segment and an indicator gene,
 - (b) measuring the amount of expression of said indicator gene in said host cell, wherein said amount of expression of said indicator gene depends upon the activity of a gene encoded by said patient-derived segment;
 - (c) comparing said amount of expression of said indicator gene from (c) with an amount of the expression of said indicator gene measured when steps (a) through (c) are performed using a control test vector, wherein the replication capacity of said HIV relative to control HIV is determined from said comparison.